MEASUREMENTS – ACCELERATION DUE TO GRAVITY

Purpose

a. To illustrate the uncertainty of a measurement in the laboratory and to illustrate the methods of estimating the best values of the measured quantity and its reliability.

b. To determine the acceleration due to gravity *g*.

Theory

Part 1

It is not possible to perform an absolute measurement. There are three causes of uncertainty or error of measurements: human, instrumental, and statistical. The human uncertainty depends on the skills of the person performing the measurement. The instrumental uncertainty usually equals the smallest value which can be measured with the instrument as described by the scale of the instrument. For greater accuracy, a more precise instrument could be used. The statistical uncertainty includes all other uncontrolled factors.

To illustrate the uncertainty in this lab, we will measure a physical quantity a number of times. For N measurements, $x_1, x_2, x_3 \ldots\ldots x_N$, the average, or mean ($x_{avg}$) of these measurements can be used for the best estimate value and calculated as

$$x_{avg} = \frac{x_1 + x_2 + x_3 + \ldots\ldots + x_N}{N} \; . \qquad (1)$$

The standard deviation (σ) of the measurements can be used for the uncertainty in the results and calculated as

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x_{avg})^2}{N-1}} \; . \qquad (2)$$

The experimental measurement can be expressed in the form of Best Estimate ± Uncertainty as

$$x = x_{avg} \pm \sigma \; . \qquad (3)$$

We will make the measurement of *time* of fall for a free falling ball in this part of the experiment.

Part 2

In the second part of the lab, we will use the time measured to determine the acceleration due to gravity. It is not too difficult to observe that a falling body falls faster and faster as it descends: it accelerates. Under certain conditions (mainly when the resistance of air is not strong) this acceleration is constant and the same for all bodies – heavy or light. The value of this acceleration due to gravity is designated as *g*. One of the purposes of this experiment is to determine *g*.

You might have already learned in lecture that a body released from rest and falling with acceleration *g*, will fall a distance *d* in time *t*, where

$$d = \frac{1}{2} g t^2. \quad (4)$$

From this equation, we have

$$g = \frac{2d}{t^2}. \quad (5)$$

Hence, by measuring the time *t* it takes an object to fall a distance *d*, we can determine *g* from this equation.

It is evident from Eq. (5) that the units of g must be those of Length/[Time]^2. If we use centimeter for the measurement of length, the units of *g* will be cm/s^2 in our experiment.

Apparatus

Electronic free-fall timer equipment, two-meter stick, support stand, two steel balls of different masses.

Description of Apparatus

In this experiment, we will measure the time of fall (*t*) of a metal ball for a specified height (*d*) by using the electronic free-fall timer equipment as shown in Figure 1. It consists of a ball-release system and receptor connected by a digital timer circuit. The receptor pad is normally placed on the floor. A metal ball is clamped into the release mechanism and held directly over a receptor pad, as shown in the Figure 1. The distance of the fall, i.e., the distance from the initial position of the ball to the receptor pad can be varied by adjusting the release mechanism support clamp on the stand. The release plate is loaded by pressing inward on the metal pin, thereby bending the plate and compressing the spring. The release plate is held in place by tightening the thumbscrew. The ball is released by loosening the thumbscrew. As soon as the ball is released, it starts the digital timer. The timer will be on until the ball hits the receptor pad on the floor. The impact of the ball on the receptor pad stops the timer, which then displays the time of fall to three decimal places (one thousandth of a second).

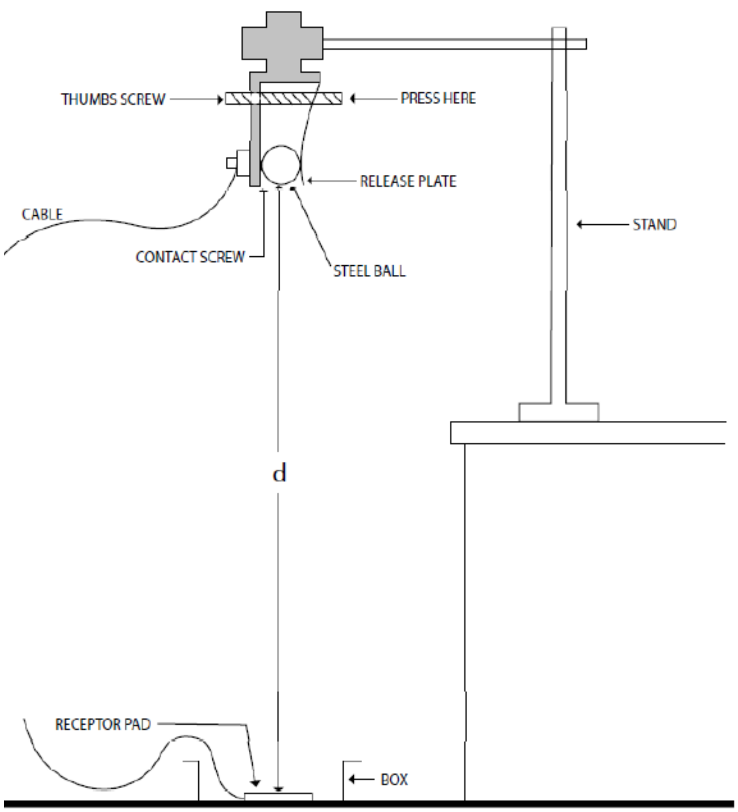

Figure 1: Experimental set up.

Procedure

For this experiment, the instructor will assign a different distance d = 40, 45, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180 cm to each group.

Part 1

You are given two different balls, one is heavier than another. Start with the larger, heavier ball.

1. Place the ball in the release mechanism. The release plate is loaded by pressing inward on the metal pin, thereby bending the plate and compressing the spring. The release plate is held in place by tightening the thumbscrew. The ball should be held in place between the contact screw and the hole in the release plate. The spring pressure should be ***just sufficient*** to hold the ball in place – too much pressure will delay the release of the ball from the mechanism.
2. Make sure the receptor plate is aligned directly under the ball in the box provided. For the timer to operate properly, the point of impact must be close to the center of the pad.
3. Carefully adjust the distance d assigned to your group by the instructor. Use the **two-meter ruler** to set the distance. The distance d (see Figure) is the distance from the bottom of the ball to the top of the receptor pad.
4. Reset the timer to zero.
5. Activate the timer by ***gently*** loosening the thumbscrew so that the steel ball falls.
6. For the distance d assigned to your group by the instructor, perform the measurement of time t of fall in seconds (s) for ***twenty trials***. Record your measurements in Table 1.
7. From the data in the table 1, calculate t_{avg} and σ using equations (1) and (2) respectively. You need to calculate these for Part 2 of this lab.
8. Repeat the measurement of time t using another steel ball which is lighter and smaller for ***5 trials only***. As the difference in diameter of the two balls is small, you may assume that the distance d of fall is the same as before. Put these values of time in Table 3. Calculate the average time of these 5 trials. According to the law of falling bodies, the time of fall is independent of the weight of the object. Compare your result with that obtained previously for the heavier ball. Do your results agree with the law?

Part 2

In this part you will not be performing additional measurements but will use the results obtained by other groups with different values of d. **The instructor will put on the board the values of d and t_{avg} obtained for the heavier ball by each group, as in Table 4.**

9. Copy the results of t_{avg} for different d obtained by each group into Table 4. Use the data for further computation and analysis.

Computations

From the data in the table 1, calculate t_{avg} and σ using Equations (1) and (2) respectively. Express the measurement result in the form Best Estimate ± Uncertainty.

From the data you have in table 1, complete the Table 2. If you look carefully at the data in Table 1, you might have noticed that the time of fall for the same height is not always the same, and the same time of fall might be observed in several trials. The first column in table 2 is the different values of time you measured and second column is the number of times it occurred (frequency, f). Now using the derived data in Table 2, plot a graph of Number of occurrence (f) along the y-axis and time along the x-axis.

Does your graph look like a Gaussian distribution?

In table 4, complete the column for $t_{avg}^{\ 2}$. Determine g for each distance d.

Do these results show that g is independent of the distance d?

Determine the average g_{avg} and the standard deviation σ. The experimental value of the acceleration due to gravity g_{expt} is then

$$g_{\exp} = g_{avg} \pm \sigma.$$

The acceleration of gravity in New York City is 980 cm/s^2. Determine the percent error of the average value g_{avg} using the following formula,

$$\%\ error = \frac{x - x_{std}}{x_{std}} \times 100.$$

Plot the data of Table 4 with the values of d on the y-axis and t_{avg}^{2} on the x-axis. Draw a straight line that best fits these points and determine its slope. From equation (4) since we are plotting d versus t^2, (comparing with a linear equation y = mx + c), the slope (m in the linear equation) of the line should be g/2. Thus you can also obtain an estimated experimental value of acceleration due to gravity, g_{expt} from the graph as,

$$g_{\exp} = 2 \times slope.$$

Calculate the percent error of the value of g_{expt} as obtained from the graph.

Questions:

1. The manufacturer of the free-fall timer claims that the timer is accurate to 1%. Are your results consistent with the manufacturer's claim?
2. What do you think are the sources of error in your experiment?

Data Sheet

Date experiment performed:

Name of the group members:

Distance, d =

Table 1. For heavier ball

Trial #	Time, t (sec)

Table 2.

Time, t (sec)	Number of occurrence (f)

Average time, t_{avg} =

Standard deviation, σ =

Experimental value of free-fall time from the distance, d = cm is

$$t = t_{avg} \pm \sigma =$$

Table 3. For lighter ball. Distance d = cm

Trial #	Time, t (sec)

Average time, t_{avg} =

Table 4

Distance, d *(cm)*	*Time, t_{avg}* *(s)*	(Time)^2, t_{avg}^2 (s^2)	*Acceleration, g* *(cm/s^2)*
40			
45			
50			
60			
70			
80			
90			
100			
120			
140			
160			
180			

Average acceleration, g_{avg} =

Standard deviation σ =

Experimental value, $g_{expt} = g_{avg} \pm \sigma$ = (cm/s^2)

Percent error =

From graph

Slope from the graph of d vs t_{avg}^2) = (cm/s^2)

Experimental value $g_{expt} = 2 \times slope$ = (cm/s^2)

Percent error =