PHYS 101

Lab Manual

2007 Edition

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PREFACE

This manual contains laboratory experiments for "General Physics I" (Physics 101). These experiments have been designed to acquaint freshman students with the fundamentals of apparatus manipulation, physical measurements, data recording and analysis aimed at verifying known laws.

It is hoped that comments and suggestions from both students and instructors will help bring up new experiments and improve existing ones.

Physics Department
Dhahran
2003

LABORATORY POLICY

Supplies

Students must bring the supplies they need, such as laboratory note book (graph notebook), pencils, ruler, eraser and calculator, as none of these items will be provided to them in the lab. NO food or drinks allowed in the lab.

Attendance

1. Attending the lab session is compulsory.

2. If and when the total number of unexcused absences reaches three (3) or unexcused and/or excused absences reaches five (5), a grade of "DN" will be assigned for the course.

3. A student absent from a lab session and who submits an official excuse will be allowed to make up the associated experiment, if possible. The case of a student who has no official excuse will be dealt with at the discretion of the instructor.

4. A student cannot make up a lab with another section without a written request to that effect from his own lab instructor.

Lab Grade

. The lab work comprises 20% of the total score for the course. The final lab grade will be calculated according to the prevailing policy.

2. The lab grade will be based on reports, final lab exam and quizzes, the latter at the discretion of the instructor. The final lab exam is compulsory, and it may either be written or practical or both, at the discretion of the instructor.

Preparation, Lab work, etc.....

1. Students should read the write-up of each experiment before coming to the lab.

2. All experiments have been designed so that they can be completed within the allotted time of 3 hours.

3. Students should arrive in time for their lab. Late arrival will be dealt with at the discretion of the instructor.

4. A student found in possession of an old lab report during a lab session will get a zero for that lab irrespective of whether he used that lab report or not.

5. Students are required to leave the equipment in a proper state after they finish an experiment. Electrical appliances, if used, should be switched off and disconnected.

THE SKILLS YOU SHOULD LEARN FROM DOING EXPERIMENTS

You are doing labs to demonstrate and/or verify the laws of physics. In addition, we hope that you will acquire some skills which will remain with you well after you have finished with the general physics courses and will be helpful in your future careers. For this reason your instructor will constantly emphasise on these skills. In particular, the lab final exam will test if you have learnt some of these skills.

There are four types of skills which we hope you will acquire:

1. Experimental Skills.

- Record all measurements taken. Repetitive measurements should be tabulated.
- Know that every measurement is subject to uncertainty ("error"). Know how to estimate error in each measurement and thus be able to identify the major sources of errors.
- Emphasise units and significant figures.
- Be familiar with measuring instruments used in the experiments and to choose the appropriate scale for more precise readings.
- Know how to follow experimental procedures.

2. Graphical Skills.

- How to linearise the equation so as to plot a straight line graph. How to find the slope/intercepts from the graph and relate them to the linearised equation.
- Use of proper scales in plotting graphs. Label the axes. Show units.

3. Analytical Skills.

- To infer relationships, if any, between sets of data.
- Draw conclusions from experimental results and compare with theory.

4. Common Sense Skills.

- Check your result to see if it makes sense. You should be able to judge whether a measured/calculated value is reasonable or not. Example: a calculated value of g of, say, 1000 m/s^2 is not reasonable; likely you have made a mistake in the calculations and/or units. So do not just blindly write down the result given by your calculator!

WRITING YOUR LAB REPORT

Your instructor will guide you on how to write a lab report. Here we give an outline of what a typical lab report should contain, mention briefly the concept of uncertainty (error) of measurements and finally give a sample report.

1. Lab Report

Lab reports generally have the following sub-headings: Objective(s), Theory, Data, Data Analysis and Conclusion.

The **Objective** of the lab is always given with each experiment; you only need to copy it in your report.

In **Theory** you should write down the important formulae and define the symbols used; draw a simple clear line drawing where necessary; and show how you will manipulate the formula to perform the analysis e.g. drawing a straight-line graph. Your instructor will guide you in the first few experiments.

In **Data** you record all measurements taken. Repetitive measurements should be put in a tabular form. In most cases the tables are given in the manual write-up of the experiment. Single measurements are recorded, only one measurement per line. In all cases, measurements are recorded to the appropriate number of significant digits consistent with the precision of the apparatus used.

In most experiments we shall analyse the data by plotting a straight-line graph and finding its slope and intercept. In **Data Analysis**[1], therefore, refer to the formula in Theory, which you said you are going to use to plot the graph. After the graph is plotted, do all calculations in this section, including finding the slope of the graph, as directed in the manual. If needed, you may also discuss your results here. Do not do any calculations on the graph.

In most experiments we try to measure a quantity, for example the acceleration due to gravity. In **Conclusion** you should therefore quote the final result of the quantity measured, e.g. the acceleration due to gravity, to the appropriate number of significant figures.
Exercises should be done after the writing of the Conclusion.

2. Percent Difference and Percent Uncertainty (Error)

Very often we ask you to calculate the **percent difference** between the value of the quantity you have measured, called the experimental (your) value and the accepted value. For example, the accepted value of g is 9.8 m/s^2 but your experimental value is say 9.2 m/s^2. The percent difference is then calculated as follows:

$$\text{Percent difference} = \frac{|\text{experimental value} - \text{accepted value}|}{\text{accepted value}} \times 100\%$$

$$= \frac{|9.2 - 9.8|}{9.8} \times 100\% = 6.1\ \%.$$

[1] **Students should work independently (that is, each by himself) to do the data analysis and the rest of the write-up of the report.**

You should quote the percent difference to 2 significant figures; however, if it is less than 1%, then give it to 1 significant figure (i.e. 1 decimal place). We all know that every measurement has some uncertainty depending on the apparatus used. You should develop the good habit of estimating the percent uncertainty of your measurements. For example if you are measuring a range of 200 cm to the nearest cm, your percent uncertainty (error) is (1/200)x100% = 0.5 %. On the other hand, if you measure a height of 5.0 cm to the nearest mm, your error is (0.1/5.0)x100% = 2%. The larger the percent uncertainty of a measured quantity, the larger will be its contribution to the uncertainty of the final result. In Physics 101 lab, we do not go into the details of how the uncertainties (errors) of measured quantities affect the final result. However, the general rule is that **the final result can not be more accurate (low percent error) than the least accurate (large percent error) measurement.** Therefore you should use this idea of percent uncertainty of your measurements to get an idea of the minimum error expected in your final result. **This will determine how many significant figures you should quote for the final result.**

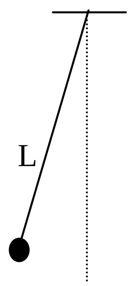
3. Sample Lab Report

In this experiment a student is asked to find the acceleration due to gravity using the simple pendulum method. His report would go something like this:

Objective

To measure the acceleration due to gravity using the simple pendulum method.

Theory



The period T of a simple pendulum of length L is given by

$$T = 2\pi\sqrt{(L/g)} \quad \ldots\ldots\ldots.. \quad (1)$$

where L is the length of the pendulum, and g is the acceleration due to gravity.
From equation 1, we get

$$T^2 = (4\pi^2/g)\,L \quad \ldots\ldots\ldots\ldots \quad (2)$$

A graph of T^2 versus L will be a straight line with slope = $4\pi^2/g$. From the slope we calculate the acceleration due to gravity.

Data

The length L of the pendulum is the distance from the point of support to the centre of mass of the bob. For a given length L of the pendulum, the time t for 20 oscillations was measured three times and the period T calculated. The data is shown in the table.

L (cm)	t_1 (s)	t_2 (s)	t_3 (s)	t_{av} (s)	T = t_{av}/20 (s)	T^2 (s^2)
120.1	44.4	44.6	44.2	44.40	2.22	4.93
102.2	40.5	40.8	40.5	40.60	2.03	4.12
80.2	36.2	35.6	35.9	35.90	1.80	3.24
60.4	31.6	31.3	31.4	31.43	1.57	2.46
40.0	25.3	25.6	25.5	25.47	1.27	1.61

Data Analysis

A graph of T^2 versus L is plotted as shown in Fig. 1. From equation (2),

$$\text{the slope of the graph} = 4\pi^2 / g .$$

From the graph,

$$\text{slope} = (4.48 - 0.0)\ s^2 / (110.0 - 0.0)\ cm$$
$$= 0.0407\ s^2/cm.$$

Hence, $4\pi^2 / g = 0.0407\ s^2/cm$,

and $g = 969\ cm/s^2 = 9.69\ m/s^2$.

Taking the accepted value of g as 9.80 m/s^2, the percent difference is

$$= \left| \frac{9.69 - 9.80}{9.80} \right| \times 100\% = 1.1\ \%.$$

L is measured accurately to about 0.1 cm, but because of the uncertainty in the exact position of the centre of mass of the bob it is probably accurate to 0.3 cm. Hence the largest % error in L is about (0.3 / 40)x100% ~ 1 %. The stop watch could measure t to 0.1 s, but because of the uncertainty of starting and stopping the watch (reaction time) the largest error in t is about (0.5 / 25.5) x 100% ~ 2 %. Hence the percent difference in g calculated above is within the expected error. Therefore, the value of g obtained is reasonable.

Since the largest error estimated above is ~ 2 %, then 2% of 9.69 = 0.2 . Hence g should be quoted to only one decimal place, that is g = 9.7 m/s^2.

Conclusion

The acceleration due to gravity was measured to be 9.7 m/s^2.

Exercises:

.

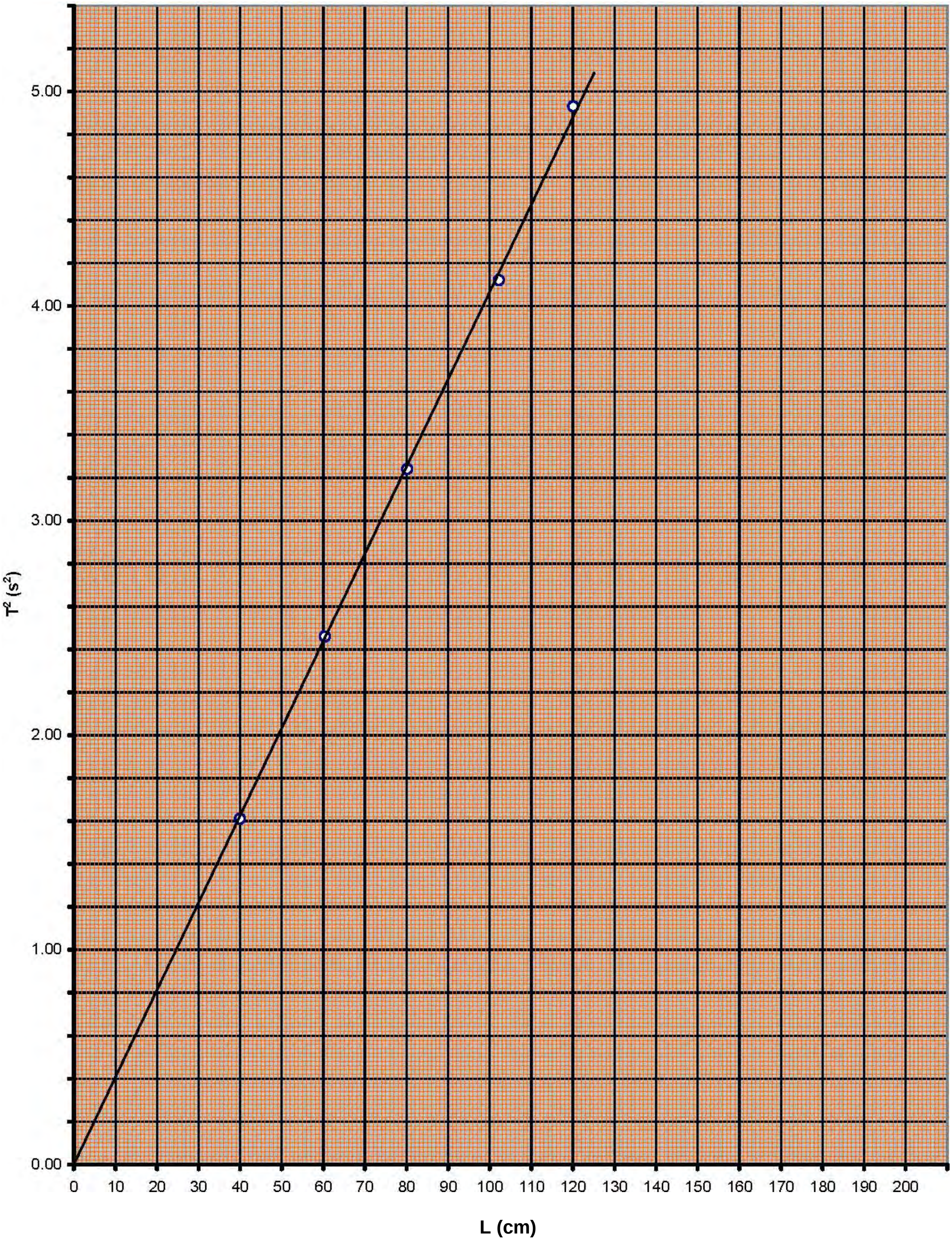
NOTE:

You should distinguish between **precision** and **accuracy**.

- **Precision** is a measure of how closely a set of individual measurements (of the same quantity) agree with one another. High precision implies a small spread of individual measurements about the mean.
- **Accuracy** is a measure of how closely a measured value agrees with the true value. High accuracy in a measurement means that there is a small amount of error.

Precision is determined by the apparatus used whereas accuracy is determined by how (carefully) the actual measurement is carried out. For example, in the above experiment, L is measured with a meter rule, which can give a precision of 1 mm. However, the student may not have measured the distance L accurately, and so the actual error may be larger.

Figure 1. Graph



GRAPHING

Objectives

To learn to quickly and accurately plot a graph; how to use graphical techniques to represent and analyze laboratory data.

Background

In PHYS 101-102 lab the student is often asked to plot a graph from the data he has gathered. Usually this graph is also the tool used to analyze the data. It is thus important for the student to have a good idea how to go about plotting a graph, and how a graph may be used to analyze data, particularly when the data satisfy a non-linear relation.

Steps in Plotting a Graph

1. What Is to Be Plotted?

When a student is told to plot, say, *S* versus *t*, it is important that he understands that this means: *S* is the *dependent* variable, plotted on the "*y*" or vertical axis; *t* is the *independent* variable, plotted on the "*x*" or horizontal axis. This is a *convention* (agreement) which should be memorized.

2. Choice of Scale

The *scale* for a variable is the number of centimeters of length of the graph paper given to a unit of the variable being plotted. For example, one might allow 1 cm for each 10 seconds of time. Note that in general the scales along the *x* and *y* axes may be different.

Two things need careful consideration before choosing the scales for a graph, the ranges of the variables, and convenience in plotting:

a) Range of the variable-Suppose a student has some data for a variable *S* which ranges from 5 cm to 125 cm. He then should choose a scale which allows him to plot *S* values from zero to values somewhat greater than 125 cm.

Notice in this case that, unless told to do so by the instructor, he does not choose to *suppress the zero* and start the *S* scale from 5 cm. The reason is that later he may need to use the graph to find values *extrapolated* (continued) to the origin. Also, he allows space on the graph for values somewhat greater than the largest value in the data set (in our example, 125 cm). He does this because later some more data, with larger values, may be acquired, or he might need to extrapolate the graph to larger values.

Finally, the scale should be chosen to most nearly use the whole of the graph paper. Just because a simple choice (say, 1 cm to 1 second of time) makes a graph easy to plot, this should not be done if it results in a tiny graph "hiding" in a corner of the sheet of paper! Besides not looking "nice", such a graph is also inaccurate when used to analyze the data.

b) Convenience in plotting-It turns out that scales of 1,2, 5 and 10 (and multiples of 10 of these) per centimeter are easiest to use; a scale of 4 per centimeter is somewhat more difficult but can be used. Scales of 3, 6, 7, 9, etc. per centimeter are *very* difficult to plot and read and should be avoided.
In choosing scales it sometimes helps to turn the paper so that the "x-axis" is either the long or short dimension of the paper.

3. Label the Axes

The vertical and horizontal axes of the graph paper should carry labels indicating the quantities plotted, with units. In our previous example the label on the y-axis would be: *S*(cm). Some instructors also ask students to put a *legend* on the graph: Plot of *S* versus *t*.

4. Circle Your Data Points

Each data point should have a neat circle drawn around it. If more than one experimental trial is used then circles, triangles, squares, etc. may be used to distinguish these and a legend added: trial 1; trial 2; etc. (See Figure 1.)

5. Drawing a Straight Line through the Data Points

When the data fall on a straight line (or are expected theoretically to do so), a ruler may be used to draw a straight line through the points. Observe the following rules: the line is drawn to match the data trend, and for data with some "scatter" balance some points above and below the line. Points which fall far outside the general data trend should be double-checked for correct plotting, then, if found correctly plotted, ignored in drawing the line. Extrapolations to larger or smaller values, thus outside of the range of the data set, should be indicated by making the line "dashed" not solid. (See Figure 1 as an example.)

Graphical Analysis

For data sets (x, y) obeying a linear relation $y = mx + b$, we can use a graph of the data to determine the values of m and b. On the graph these are found to be:

b: y-intercept of the graph (value of y when $x = 0$.)
m: slope of the graph = $\frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$. (See Figure 1.)

Note that in finding the slope we should choose the points (x_1, y_1), (x_2, y_2) relatively far apart for accuracy. These values should not be chosen to correspond to data points even if they appear to lie on the straight line.

Data sets which do not follow a linear relation may often be "forced" to do so for analysis purposes. For example, suppose we have a set of data, which we believe obeys: $S = \frac{1}{2}at^2$.
We can verify that the relation is satisfied by plotting S versus t^2. If this relation holds, the resulting graph will be a straight line with intercept zero. The slope of the graph in this case then gives us the constant $a/2$.

Exercises

1. *The data set given in Table 1 is expected to obey a **linear relation*** $\mathbf{v} = v_0 + a\mathbf{t}$. You are asked to choose a good set of scales for the data, make a careful and accurate graph of **v** versus **t** and analyze the graph to obtain its slope and y-intercept. These may then be used to obtain acceleration, a, and initial velocity, v_0. Pay careful attention to the rules of graphing outlined above. In particular, before plotting decide which variable goes on the *y*-axis, and which goes on the *x*-axis.

TABLE 1

t (s)	5.0	10.0	15.0	20.0	25.0	30.0	35.0
v (m/s)	10.6	14.3	17.8	21.2	24.1	27.7	31.1

2. *The data set given in Table 2 is expected to obey a non-linear relation* $\mathbf{x} = 1/2\ a\ \mathbf{t}^2$. You are asked to plot **x** versus $\mathbf{t}^2$ such as to obtain a straight line graph. Choose a good set of scales for the data, make a careful and accurate graph, and analyze the graph to obtain the value of the acceleration, a, from the slope.

TABLE 2

t (s)	0.2	0.4	0.6	0.8	1.0	1.2
x (m)	0.03	0.12	0.27	0.51	0.77	1.14
$\mathbf{t^2}$ $\mathbf{(s^2)}$						

3. In each of the following experiments, the data set (presented by bold letters) obeys a non-linear relation.

Simple Pendulum: $\mathbf{T} = 2\pi\ (\mathbf{L}/g)^{1/2}$

Perfect Gas Law: $\mathbf{P} = nRT / \mathbf{V}$

Stefan's Law: $\mathbf{P} = \sigma\ (\mathbf{T}^4 + T_0^4)$

e/m Experiment: $e/m = 2\mathbf{V} / (B^2\ \mathbf{r}^2)$

Standing Waves: $\mathbf{n}^2 = (4L^2f^2\mu) / (\mathbf{m}g)$

In the above expressions, all the parameters other than the data may be treated as constants.

Suggest how to plot the data, in each of the above experiments, to obtain a **straight line graph**. In each case, state what the slope of the graph would represent, and also the y-intercept, if any.

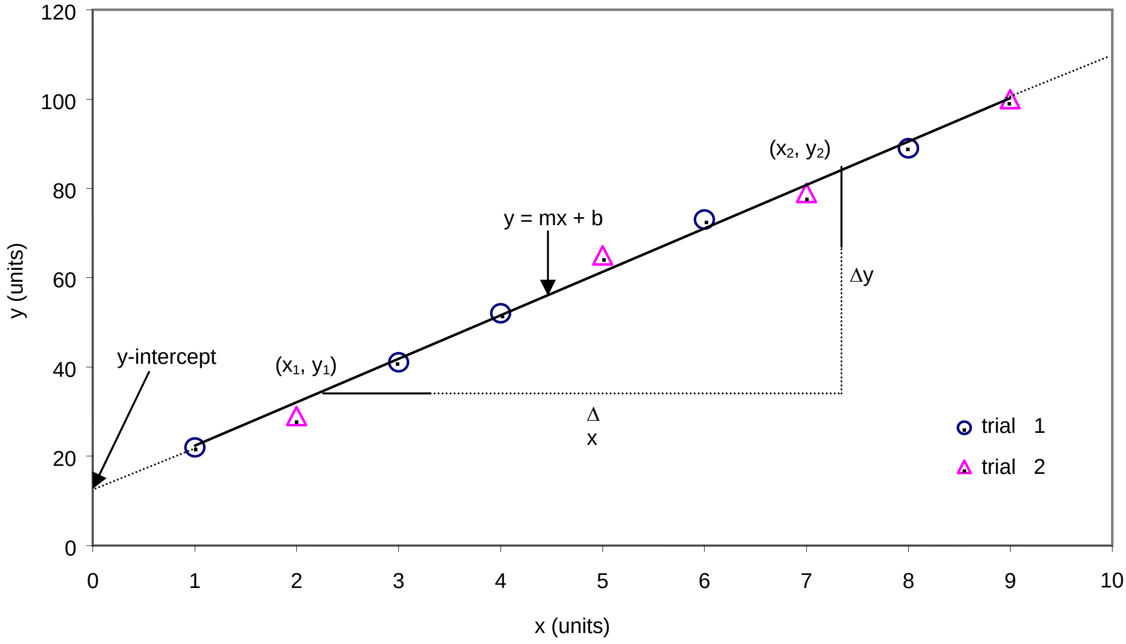


Figure 1. Graphing

AN EMPIRICAL LAW

Objectives

To find the empirical relation between T and d for a ring, where T is the period of oscillation and d is the average diameter.

The Experiment

In this experiment you will be provided with metal rings of different diameters (**d**). Each of these rings has a notch in it. You are asked to measure the time taken by each of the rings to complete one swing. The data collected has the diameter of the ring as the independent variable, and the time for one period as the dependent variable. The empirical law we seek relates these two variables.

Background

Any motion that repeats itself in equal intervals of time is called periodic motion. Periodic motion is often called harmonic motion, oscillatory motion, or vibratory motion. The only requirement for such a motion is that the body moves back and forth over the **same path**. That is the motion of the body repeats itself over and over again. The time taken by the body to **start repeating** its motion is defined as the period. This is often denoted by T.

In the current experiment, we hang a ring, pull it aside through a **small angle**, and release it. You will observe that the metal ring will swing periodically around an axis perpendicular to its plane. As you will discover, the period is short. Then, a direct measurement of T will lead to a large relative error. Why? To get around this difficulty, the time taken for 10 swings is measured. Then T can be obtained from such a measurement.

Theory

The period of oscillation of a ring is proportional to the diameter of the ring raised to some power (exponent)*, that is

$$T \propto d^m \qquad (1)$$

This may be written in equation form as

$$T = k\, d^m \qquad (2)$$

where k is a constant and the power "m" is unknown.

Your task is to find k and m. The graph of log(T) versus log(d) shall be a straight line and can be verified by taking the logarithm of both sides of Eq. (2).

$$\log(T) = \log(k) + m \log(d) \qquad (3)$$

* After studying harmonic motion, you will be able to derive the exact relation between T and d.

Procedure

1. Hang a ring from the knife edge support at the notch in the ring.
2. Set the ring vibrating by rotating it through a **small angle**.
3. Measure the time taken for 10 swings. Find the period **T.** Enter all the measurements in a Table (such as given below).
4. Measure the average diameter, d, of the ring and enter this in the Table.
5. Repeat steps 1 through 4 for the other rings except the smallest one.

Data and Analysis

Table 1

Ring #	d (cm)	Time for 10 oscillations, t(s)	Time Period T = t / 10 (s)	log (d)	log (T)
1					
2					
3					
4					

Plot a graph of log(T) versus log(d) for the data you have collected. (Log T scale should start from -0.8 in order to get the intercept.) From the slope and intercept find m and k and write the empirical formula for the period T of a ring of diameter d.

Exercises

(1) Use the smallest ring and measure its diameter. Use the empirical law to predict its period.

(2) Test your prediction by experiment, i.e. measure its period and compare it with the predicted value.

(3) State the major source of error in this experiment.

(4) Suppose, in an experiment, the potential difference, **V**, across a discharging capacitor is measured as a function of time, **t**. The relation between V and t is given by

$$\mathbf{V} = V_0 \exp(-\mathbf{t}/RC)$$

where V_0, R and C are constants. Suggest how the data (**t,V**) could be used to obtain a straight line graph.

UNIFORMLY ACCELERATED MOTION

Objectives

To measure the acceleration due to gravity, g.

Theory

The distance, *x*, traveled in time *t* by an object moving in a straight line with constant acceleration *a* is given by:

$$x = v_o\, t + 1/2\, a\, t^2 \qquad (1)$$

Here v_o is the initial speed of the object at time $t = 0$. For convenience we choose the initial value of the distance to satisfy $x_o = 0$.

In the experiment we will release a glider of mass *m* from rest on an air track inclined at an angle θ (See Figure 1). The "lubrication" provided by the air flowing to the air track and under the glider provides nearly frictionless motion, so to a very good approximation we may neglect the effects of friction. Thus the object is accelerated only by gravity and hence its acceleration satisfies

$$a = g \sin\theta \qquad (2)$$

where g = acceleration due to gravity = 9.80 m/s^2. (Prove this to yourself by drawing a free-body diagram for the glider.) Note that the acceleration *a* is independent of the mass of the object.

We will experimentally check the validity of equations (1) and (2) by fixing two "light forks" along the air track at various fixed distances *x* apart, then use the forks and an electronic timer to very accurately measure the time taken to travel the distance *x*. The method works as follows: when the glider passes the first fork, it interrupts a light beam and starts the timer; when the glider passes the second fork, it again interrupts a light beam but now stops the timer. The timer then displays the time taken to travel the distance *x* between the forks.

Procedure

1. Level your air track as follows: turn on the blower, then adjust the elevation screw at the air intake end of the track until the glider either remains stationary at the mid-point of the track or moves slowly back and forth about this point; leave this setting fixed for the duration of the experiment. Next, use the necessary block(s) under the intake end screw to raise that end of the air track an amount *h* (whose value will be assigned by the instructor).

Your instructor will also assign you an initial length value (which may be different for different students.) Fix the first light fork (photogate #1) this distance from the higher end of the air track.

IMPORTANT: Do not change this setting for the rest of the experiment

2. Now fix the second, lower light fork (photogate #2) a convenient distance, say, 25 cm from the upper light fork. Use a meter stick to accurately measure the distance between the two light forks. This is your first value of *x, that is x = 25 cm.*

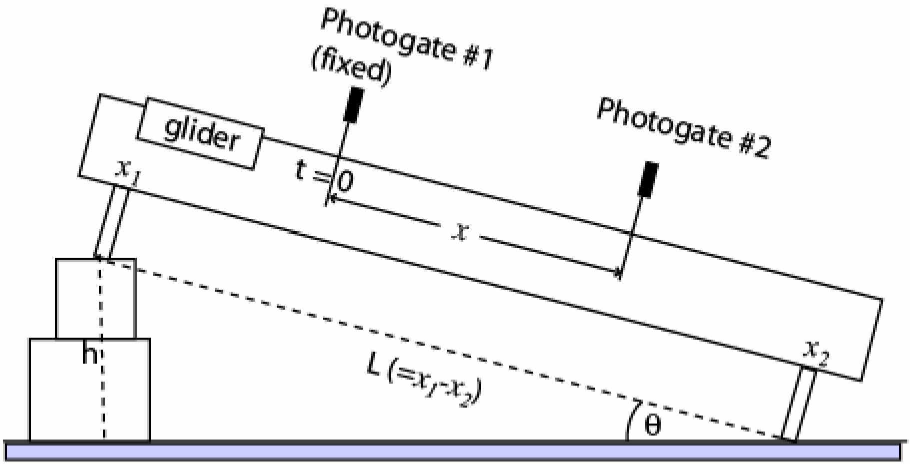


Figure 1. Uniformly Accelerated Motion

3. Check that the timer is set to "ms" (that is millisecond) and properly reset to zero. Start the air blower for the air track while holding the glider gently at the top of the air track. Release the glider; observe the timer start when the glider passes the first light fork, then stop as it passes the second light fork. Repeat the measurement several times (remember to zero the timer after each reading), entering your results in a table, and then average the resulting times.

4. Repeat step 2, *varying only the position of the lower light fork, such that x = 50 cm, 75 cm, 100 cm, 125 cm, and 150 cm.* For each of these settings repeat step 3 to obtain a set of values of *x* and *t*.

Table 1

x (m)						
Time t_1, t_2, and t_3 (s)						
Average time t (s)						

5. Using the x, t data, plot a straight line graph. Note that Equation (1) is not linear in *t*. However, data sets which do not follow a linear relation may often be "forced" to do so for analysis purposes (as you have studied in your first lab., that is on "Graphing"). Use the straight line graph to obtain the experimental value for *a*.

6. Measure the track dimension L between the leveling screws and, using this value together with the value of h, calculate $\sin\theta = \frac{h}{L}$. Substitute this vaue of $\sin\theta$ and, your experimental value for *a* in equation (2) to find your experimental value for *g*. Calculate the percentage difference between your value of *g* and the accepted value, 9.80 m/s^2.

7. Is this difference "reasonable", say, approximately 5% or less?

8. List the major sources of error in this experiment.

OPTIONAL Your instructor may ask you to load the glider with an additional mass, *M*, then take a few points and check the prediction of equation (2) that the acceleration is independent of the mass of the glider.

Exercise

Explain why it is important to keep "the setting of the first light fork" fixed. Hint: how are we choosing our initial conditions?

FREELY FALLING BODY I

Objectives

To measure the acceleration due to gravity, g.

Theory

Your instructor will review the derivation given in your text which shows that the downward vertical displacement *y* of a mass *m* starting from rest in the Earth's gravitational field satisfies the relation

$$y = \frac{1}{2} g t^2 \qquad (1)$$

where *t* is the time of fall and *g* = acceleration due to gravity = 9.80 m/s^2.

We will experimentally check the validity of equation (1) by repeatedly dropping a steel ball and accurately measuring the time it takes to cover a fixed distance y.

Procedure

1. Examine the apparatus as set up in the lab; a sketch of it is also shown in Figure 1. Initially a steel ball is suspended from an electromagnet. When you tap the key it starts the timer, at the same time power to the electromagnet is interrupted so that the ball falls. After falling a distance *y* the ball strikes a contact plate which stops the counter, which then displays the time of fall, *t*.

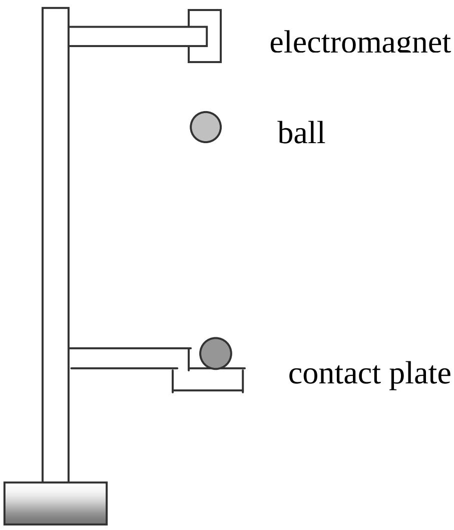


Figure 1. Freely Falling Body

2. We will do the experiment by leaving the contact plate fixed in place and moving the holding magnet to give various distances of fall. Note that the ball is not a point mass but

has a diameter of 1.6 cm so this must be taken into account in determining the height of fall.

3. Adjust the position of the electromagnet so that the height of fall is approximately 0.7 m. Measure the distance setting accurately and after correcting this for the ball diameter, record this as your first value of y in the table shown below. Check that the timer is set to "ms" (1 ms = 10^{-3} s) and properly reset to zero. Tap the key, observe the timer begin running then stop as the ball strikes the contact plate. The value displayed on the counter is the time *t* taken for the ball to fall the distance y. Repeat the measurement two more times, entering your results in the table, and then average the resulting times.

4. Vary the height over a range of values, as shown in the table, each time repeating the procedure in step 3. Record the actual values of y used in the experiment; the values given in the table are for guidance only.

y (m)	t_1(s)	t_2 (s)	t_3 (s)	t = t_{av} (s)	t^2 (s^2)
0.7					
0.6					
0.5					
0.4					
0.3					
0.2					

Data Analysis

1. Plot a graph of y vs t^2. Calculate the slope of the graph, and from the slope find the value of g.

2. Compare your experimental value of *g* to the standard value, 9.80 m/s^2. What is the percentage difference between these?

3. Given the accurate distance and timing measurements done in this experiment we might expect the difference calculated in step 2 to be no more than about 5%; how does your result compare with this view?

4. What is the major source of error in this experiment?

Questions

Q. Calculate the final velocity of the ball just before it hits the contact plate for the data set containing the largest value of y.

FREELY FALLING BODY II

Objectives

To measure the acceleration due to gravity, g.

Theory

An object is said to be in free fall if it has an acceleration downward and equals to the acceleration due to gravity, g. Near the Earth's surface the magnitude of g is approximately constant if one neglects air resistance. Your instructor will review the derivation given in your textbook for a body moving with a constant acceleration in a straight line, of which free fall is an example. For such a freely falling body, at time t the position y of the body is given by $y = v_o t + \frac{1}{2}gt^2$. Then in time t_1 the body will fall a distance y_1, given by

$$y_1 = v_o t_1 + \frac{1}{2}gt_1^2 \qquad (1)$$

and after time t_2

$$y_2 = v_o t_2 + \frac{1}{2}gt_2^2 \qquad (2)$$

After some mathematical manipulation it follows that

$$y_2 - y_1 = v_o(t_2 - t_1) + \frac{1}{2}g(t_2 - t_1)(t_2 + t_1) \qquad (3)$$

or

$$\Delta y = v_o \Delta t + g\Delta t\left(\frac{t_2 + t_1}{2}\right) \qquad (4)$$

Dividing by Δt we get

$$\frac{\Delta y}{\Delta t} = v_o + gt' \qquad (5)$$

Note that $\frac{\Delta y}{\Delta t} = v_{av}$ = average velocity over the time interval Δt. For uniformly accelerated motion, $v_{av} = v$ (instantaneous velocity) at the midpoint of the time interval, i.e. at $t = t' = \left(\frac{t_2 + t_1}{2}\right)$. Hence we can rewrite equation (5) as

$$\frac{\Delta y}{\Delta t} = v = v_o + gt \qquad (6)$$

where we have dropped the prime on t.

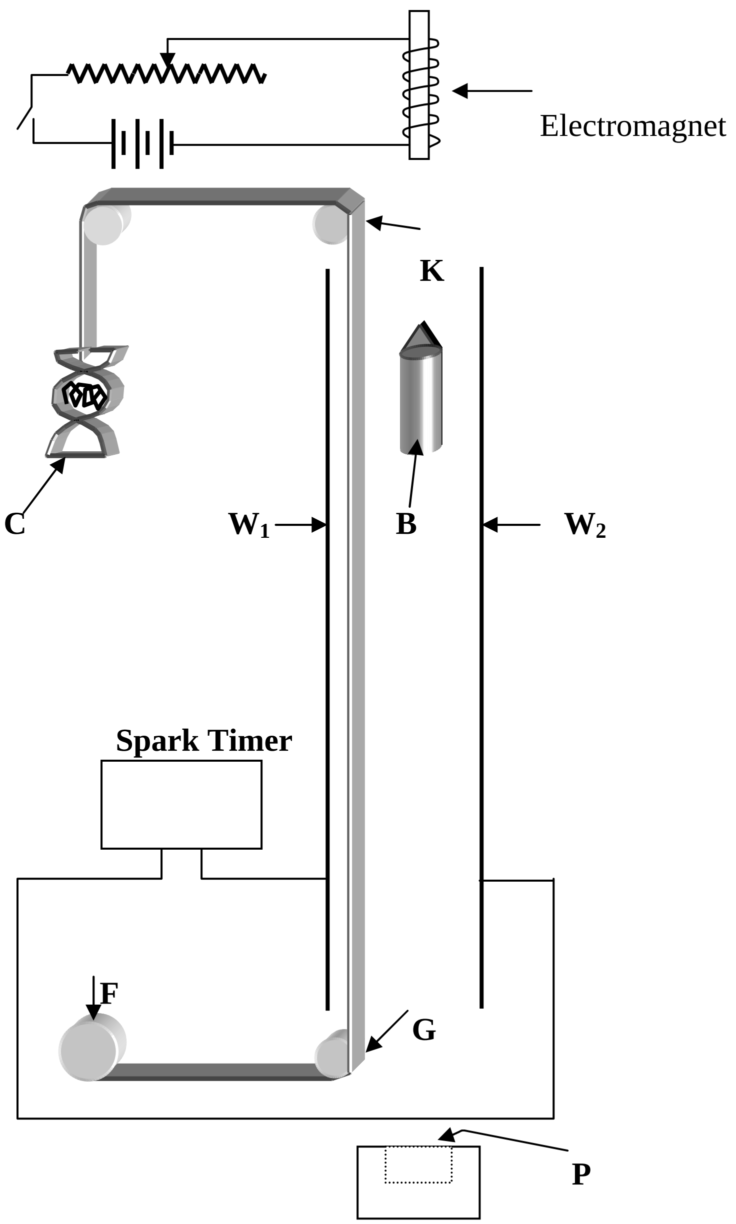


Figure 1. Schematic diagram of the free fall apparatus.

Procedure

A body is allowed to fall freely and its positions at the ends of successive equal time intervals are recorded on a wax-coated paper tape by means of electric sparks. The falling body falls between wires W_1 and W_2 into the dashpot P as shown in Figure 1.

1. With the body B temporarily removed, pull the end of the coated paper strip from its holder F through the opening G at the lower end of the apparatus, thence upward over wire W_1, and back through opening K. The coated side (light) of the paper must be facing outward. Attach the weight clip C to the end of the paper to keep it stretched tight.

2. Set the frequency f on the timer at 60 Hz, that is the number of sparks per second are equal to 60.

3. Suspend the body from the electromagnet M, and get it to be motionless.

4. Start the spark timer. The spark now jumps from the outer wire W2 through the body to the electromagnet and ground support (a spark will not jump to inner wire W1 until the body has been released from the electromagnet).

DO NOT TOUCH THE WIRES OF THE FREE APPARATUS WHILE THE SPARK TIMER IS OPPERATIONAL.

5. Release the body, let it fall in the dashpot P, stop the spark timer, and examine the paper tape. If the spark spots are missing or very faint, shift the tape to the left or right and repeat the procedure.

A. Analyzing the tape.

Skipping a first few spots at the beginning, select a spot, say the 5th spot, and call it reference spot i=0. Pick alternate spots and label them i =1, i = 2, ... i =10, as shown in Figure 2.

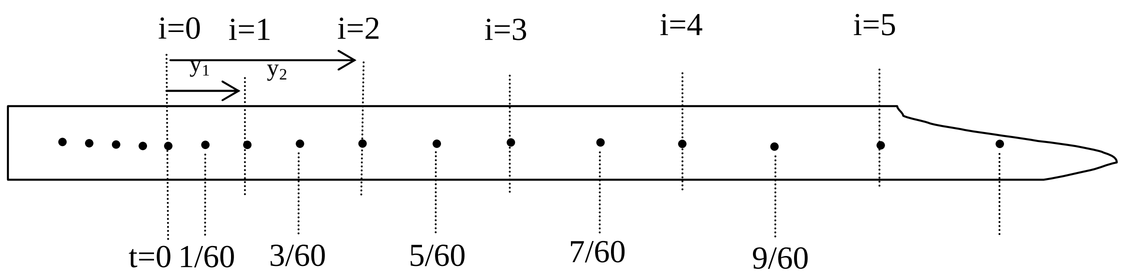


Figure 2.

Place the numbers on your tape and read of the values of y_1, y_2, y_3, ... y_{10}, which are the positions of the points relative to the reference point i=0 and record your values in a table as shown below. Note that Δt is set at (2/60) s.

Point i	y_i (cm)	$\Delta y = y_{i+1}-y_i$	$v = \frac{\Delta y}{\Delta t} = \frac{\Delta y}{(2/60)}$	t (s)
0	0			
		$y_1 - 0$		1/60
1	y_1			
		$y_2 - y_1$		3/60
2	y_2			
		$y_3 - y_2$		5/60
3	y_3			
		$y_4 - y_3$		7/60
4	y_4			
		$y_5 - y_4$		9/60
5	y_5			
		$y_6 - y_5$		11/60
6	y_6			
		$y_7 - y_6$		13/60
7	y_7			
		$y_8 - y_7$		15/60
8	y_8			
		$y_9 - y_8$		17/60
9	y_9			
		$y_{10} - y_9$		19/60
10	y_{10}			

B. Data Analysis

1. Use the data from the table and plot a graph of v against t.
2. Calculate the slope of the graph, and thus g, the acceleration due to gravity.
3. Calculate the percentage difference between your value of g and the accepted value of 9.8 m/s^2.
4. Explain any difference you find in 3.
5. What is the major source of error in this experiment?

THE SPRING

Objectives

(a) To measure the spring constant of a spring.

(b) Study the conservation of mechanical energy in a spring-mass system.

Theory

Hooke's law describes the relationship between the restoring force *F* and the displacement, *x*, of a spring from equilibrium, for small displacements:

$$F = -kx \qquad (1)$$

Here *k* is the *spring constant*, with units N/m.

If we start with a massless spring hanging as in Figure 1a, and add a mass *m* to it, it will extend to a distance x_o (see Figure 1b), where the value of x_o is determined by the requirement that the restoring force of the spring balances the weight of the mass:

$$k\, x_0 = m\, g \qquad (2)$$

Here *g* = the acceleration due to gravity = 9.80 m/s^2. In this lab we will use Equation (2) to make measurements on a spring to determine its value of *k*.

Now suppose we lift the spring and hold it so that its displacement is now x_1 as in Figure 1c. (Remember: all displacements are measured from the no-mass-loaded position of the spring, i.e. natural length of the spring.) If we now release the mass, it will fall until coming to rest at a displacement x_2 (see Figure 1d), then rebound. Since the spring and mass are momentarily at rest at both x_1 and x_2 (that is kinetic energy of the system is zero, both at x_1 and x_2), the energy of the system then just consists of gravitational plus spring potential energies. Thus assuming conservation of energy we have:

$$\frac{1}{2}k\,x_1^2 - m\,g\,(x_1 + d) = \frac{1}{2}k\,x_2^2 - m\,g\,(x_2 + d) \qquad (3)$$

where *d* is the distance of the center of mass of the mass below the end of the spring. We may rearrange this equation so that it reads:

$$m\,g\,(x_2 - x_1) = \frac{1}{2}k\,(x_2^2 - x_1^2) \qquad (4)$$

This equation just says that the decrease in gravitational potential energy between points 1 and 2 is equal to the increase in spring potential energy between those two points.

After making a series of static measurements to measure *k*, we will then make some dynamic measurements to check the validity of Equation (4).

Measurement of spring constant

1. Place a series of masses (m = 50 g, 100 g, 150 g, 200 g, 250 g, and 300 g) on a spring as set up in the lab, recording the value of the masses and their corresponding displacements (x_0). Note that the mass, m, includes the mass of the hanger. Be careful not to place too much mass on the spring, thus possibly exceeding the spring's elastic limit; a "stop" will usually be provided to prevent this from happening. Tabulate your data.

Table 1:

Mass, m (kg)						
Extension, x_0 (m)						

2. Use Equation (2) to plot a graph of x_0 vs. m. Then use the slope of this graph to obtain the value of *k* for your spring.

Conservation of energy

1. Next choose one of the masses in the mid-range of the data you have just taken. If the corresponding value of its displacement is x_o, then raise the mass so that its displacement is now $x_1 \approx \frac{x_o}{2}$. Release the mass and determine the value of x_2, the displacement at the lowest point of the motion. Repeat the measurements *three times* and get the average value of x_2. Record the mass value, and the values of x_1 and x_2. Next vary the value of x_1 somewhat from your initial measurement and repeat the measurements. Change to another mass value and make another set of measurements as before.

2. Now set up a table, with entries corresponding to your chosen values of *m*, and the values of x_1 and x_2 which resulted; also provide entries for the calculated values of the left and right hand sides of Equation (4), that is, the quantities $m\,g\,(x_2 - x_1)$ and $\frac{1}{2}k\,(x_2^2 - x_1^2)$. Note that you will need to use the value of *k* obtained in the first part of this experiment. Calculate the percentage difference between the two energy values.

Table 2:

m (kg)	x_1 (m)	x_2 (m)	LHS = $mg(x_2 - x_1)$ (J)	RHS = $0.5k(x_2^2 - x_1^2)$ (J)	% difference ={|RHS-LHS| / RHS}*100

3. As mentioned we expect the gravitational potential energy change to equal the spring potential energy change. Is the percentage difference between these quantities "reasonable", say, less than 10% so we may decide that this idea is correct? Discuss your findings. List the major sources of error.

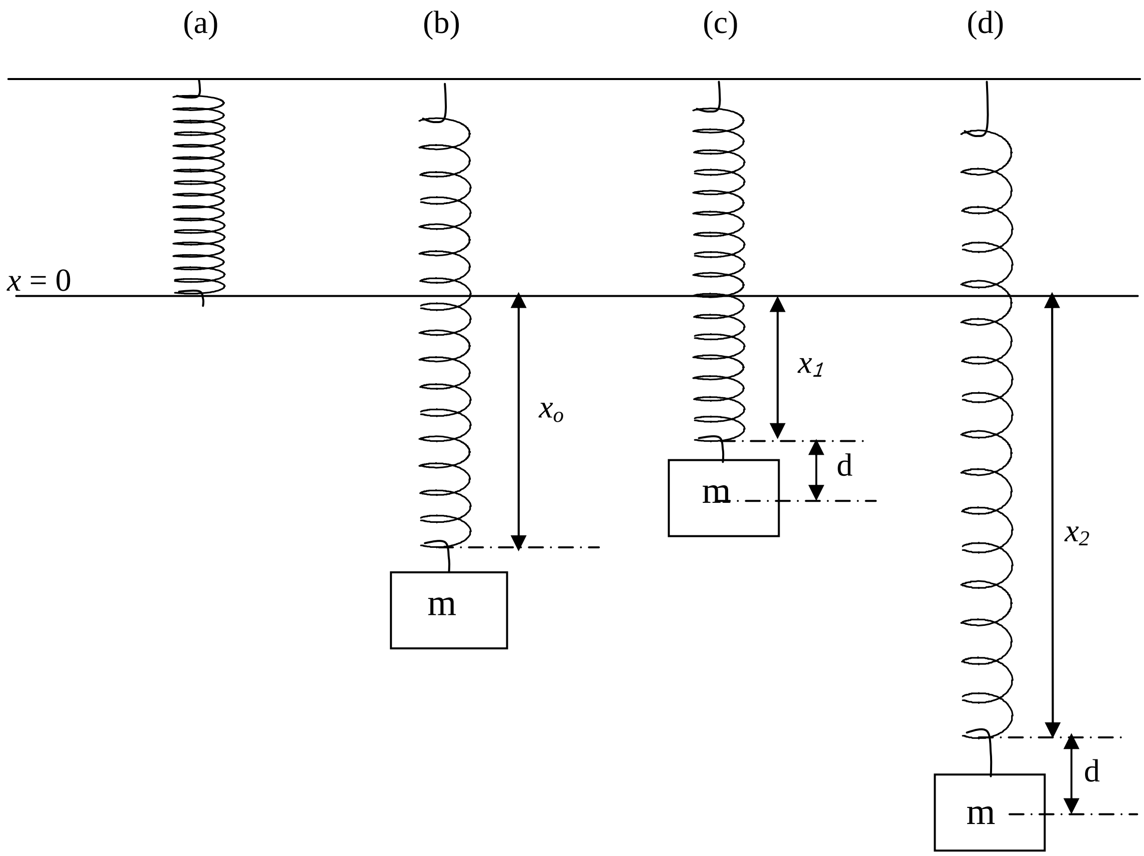


Figure 1. The Spring

COLLISIONS IN ONE DIMENSION

Objectives

To study ***elastic*** and ***inelastic*** collisions on a linear air track and to compare the observed results with those predicted by theory.

Theory

If friction may be neglected, then in the collision of two masses m_1 and m_2 in one dimension the total linear momentum of the system is conserved:

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} \quad (1)$$

Here v_{1i}, v_{2i} and v_{1f}, v_{2f} define the initial and final velocities, respectively, of the two masses.

If the collision is ***elastic*** (the masses bounce off one another with no loss of energy) then the total kinetic energy of the system before and after the collision is also conserved:

$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2 \quad (2)$$

However, certain collisions may not be very "bouncy" or elastic so that some kinetic energy is "lost" (appearing as another form of energy in heating up the colliding bodies); such a collision is called ***inelastic*** and for this kind of collision, equation (2) does *not* hold. The extreme case of an inelastic collision is one in which the two bodies stick together and move as one body after the collision; such a collision is called ***perfectly inelastic***.

In this experiment we will make observations on an air track of an elastic collision and a perfectly inelastic collision.

Procedure

Elastic collision

You are provided with two gliders of *equal mass* on an air track. Level your air track as follows: turn on the blower, then adjust the elevation screw at the air intake end of the track until one of the glider either remains stationary at the mid-point of the track or moves slowly back and forth about this point**.** Leave this setting fixed for the duration of the experiment. Next, launch one of the gliders from the end of the track using the rubber-band launcher provided (see Figure 1).

Observe what happens before and after the collision. Repeat the experiment several times to make sure you get a consistent picture for this case.

Assuming an ***elastic*** collision, you should find that v_{2f} is equal to v_{1i} and $v_{1f} = 0$. Use equations (1) and (2), with $m_1 = m_2 = m$ and $v_{1i} = v$ and $v_{2i} = 0$ (initial conditions) and prove that $v_{1f} = 0$ and $v_{2f} = v$ as observed.

Perfectly inelastic collision

WARNING: DO NOT TOUCH THE WIRE WHEN THE SPARKING IS ON.

1. Next choose one of the previously used gliders and the third one provided. For the ***perfectly inelastic*** collision these will need to be fitted with sticky tape (or possibly Velcro), which will be provided. We will follow the same procedure as in step 1 of the elastic collision experiment, *except*: 1) in this case when the gliders collide, they will stick together and move off together; 2) we will time the motions before and after using a tape and spark timer.

2. Mount a tape along the edge of the air track. Set the more massive glider at the center of the track and launch the less massive glider towards it, pushing the button to start the spark timing *only after you have launched the glider*. (Your instructor will demonstrate the procedure.)

3. Observe the two gliders collide, stick together and move off together; *stop the sparking as the two reach the other end of the track*. Inspect the tape and mark each end of it respectively, "start" and "finish".

Data and Analysis

1. Unmount the tape and have a look at it. Near the beginning, as the glider is launched, the points will be irregularly separated as the glider accelerates. After a short distance the spark points become regular and equally spaced, indicating that the glider is moving with constant velocity. Again, when the gliders collide there will be a region of irregular motion, followed by a stretch of equally spaced spark points, indicating a constant (and different) velocity after the collision.

2. The spark points are generated at equal time intervals. For example, when the spark timer is set at a frequency of 10 Hz, the sparking is occurring 10 times per second; the time interval between spark points is then 0.1 sec. Find the velocity of the glider(s) before and after collision by measuring the length of, say, 10 spark intervals. This is Δx. The time Δt to cover this distance is then 10 x 0.1 s = 1.0 s. The velocity is then given by $\frac{\Delta x}{\Delta t}$.

3. Record your data and calculate the total linear momentum and kinetic energy before and after the collision, and the percent difference. Present your data analysis as follows;

$v_i = \Delta x_i/\Delta t_i =$ (m/s)

$v_f = \Delta x_f/\Delta t_f =$

$m_1 =$ (kg)

$m_2 =$

Total linear momentum before the collision, $p_i = m_1 v_i =$ (kg m/s)

Total linear momentum after the collision, $p_f = (m_1+m_2) v_f =$

The percent difference in linear momentum, $\Delta p = \frac{|\ p_f - p_i\ |}{p_i}$ x100% =

Total kinetic energy before the collision, $K_i = 1/2\ m_1 v_i^2$ = (J)

Total kinetic energy after the collision , $K_f = 1/2\ (m_1+m_2)\ v_f^2$ =

The percent difference in kinetic energy, $\Delta K = \frac{|\ K_f - K_i\ |}{K_i}$ x100% =

4. Since this is an ***inelastic*** collision, we expect that momentum is conserved so that its values before and after the collision will be approximately the same, to within, say, an estimated 10% experimental error. On the other hand the kinetic energy values should be quite clearly different, well outside an approximate 10% error estimate. Do your obsevations agree with this picture? Discuss your findings.

5. What is the major source of error in this experiment?

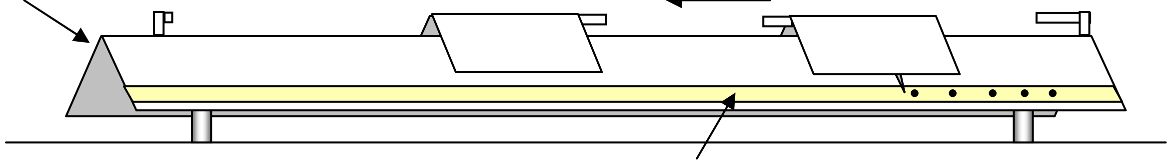


Figure 1. Elastic and Inelastic Collisions

Questions:

When measuring the velocities before and after the collision it is better to take more than one spartk interval to get an average value, and also it reduces the fractional error in the length measurement. However it is not advisable to make measurements far from where the collision occurred, explain why this is so.

TWO-DIMENSIONAL ELASTIC COLLISION

Objectives

To test conservation of momentum and kinetic energy in a two-dimensional, two-body *elastic* collision.

Theory

Consider a collision between two bodies of the same mass, *m*, in the case that one of them is initially at rest. If friction may be neglected, then in the collision the total linear momentum of the system is conserved:

$$m\,\mathbf{v} = m\,\mathbf{v_1} + m\,\mathbf{v_2} \qquad (1a)$$

Here $\mathbf{v}$, and $\mathbf{v_1}$, $\mathbf{v_2}$ define the initial and the two final velocities, respectively, of the masses. We may divide Equation (1a) through by the mass, *m*:

$$\mathbf{v} = \mathbf{v_1} + \mathbf{v_2} \qquad (1b)$$

This equation says that the three vectors, $\mathbf{v}$, $\mathbf{v_1}$ and $\mathbf{v_2}$ form a *triangle* if momentum is conserved. Now assume the collision is *elastic* (the masses bounce off one another with no loss of energy) so that the total kinetic energy of the system before and after the collision is also conserved:

$$\frac{1}{2} m\, v^2 = \frac{1}{2} m\, v_1^2 + \frac{1}{2} m\, v_2^2 \qquad (2a)$$

Dividing through by $\frac{1}{2}m$ we get:

$$v^2 = v_1^2 + v_2^2 \qquad (2b)$$

This is just the Pythagorian theorem, which implies that not only do the three vectors form a triangle if momentum is conserved, but that it is a *right* triangle if energy is also conserved.

In this experiment we will verify conservation of momentum (Eq. 1b), and kinetic energy (Eq. 2b) in the case of a *two dimensional elastic* collision.

Background

1. In the experiment a projectile ball rolls down an incline. At the bottom of the incline its motion becomes horizontal, after which it strikes a target ball at rest. (Figure 1.) It is important to note that at the time of collision the centers of both balls are at the same height. The collision takes place in a plane parallel to the floor, and both balls leave their supports (just after the collision) with horizontal velocities.

   Both balls then fall to the floor, *taking the same time to do so*. (Why is this so?). The vectors drawn from the point directly under the point of collision, to the point where each

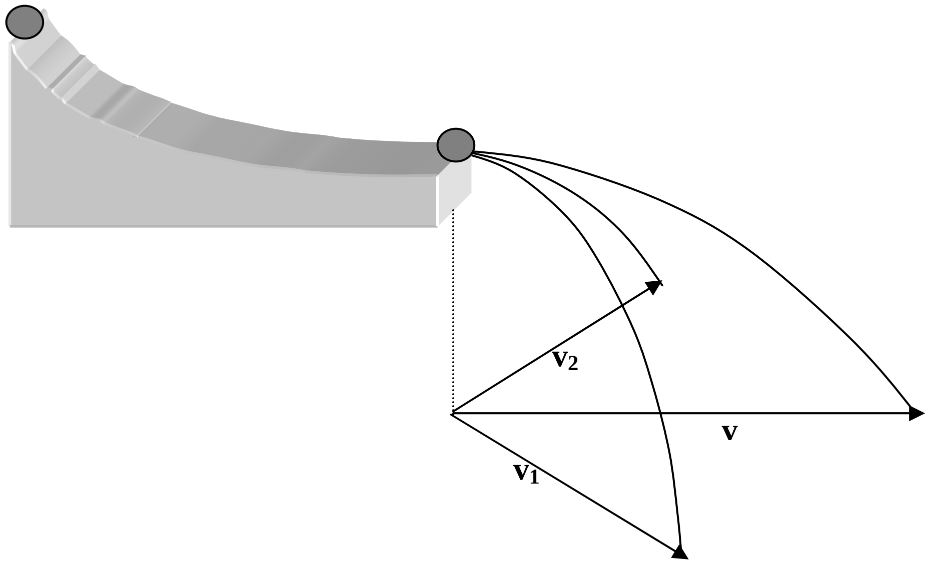


Figure 1. Two Body Collision

ball strikes the floor, is proportional to the respective velocity of each ball. Let $\mathbf{v}_1$ and $\mathbf{v}_2$ be the velocities of the two balls after the collision. Hence we would expect these vectors to be at *right angles* (as in Figure 2) to each other, if the theoretical analysis given above is true.

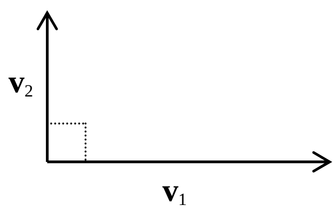


Figure 2

2. Furthermore, if we move the target ball out of the way and repeat the experiment, the vector from the point directly under the collision point to the point where the projectile ball lands will be proportional to the initial velocity **v** of the projectile. According to the theoretical analysis we made, the three vectors we find this way should make a *closed triangle* as in Figure 3.

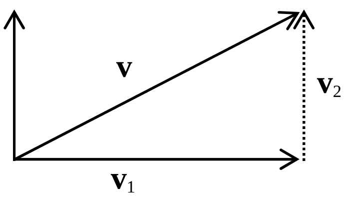


Figure 3

3. We will check these two statements by measurements recorded on a piece of carbon paper placed on the floor.

Procedure

1. Place the carbon paper you are given on the floor beneath the apparatus. Mark the point directly below the collision point. Now, with the target ball out of the way, roll the projectile ball down the incline from a fixed height, and note where it strikes the paper. Repeat this procedure 5 times to get an average measurement. This is done by taking the average of the lengths and half the angular spread to represent the magnitude and direction of the vector, respectively (see Figure 4). The dashed vector represent the average measurement.

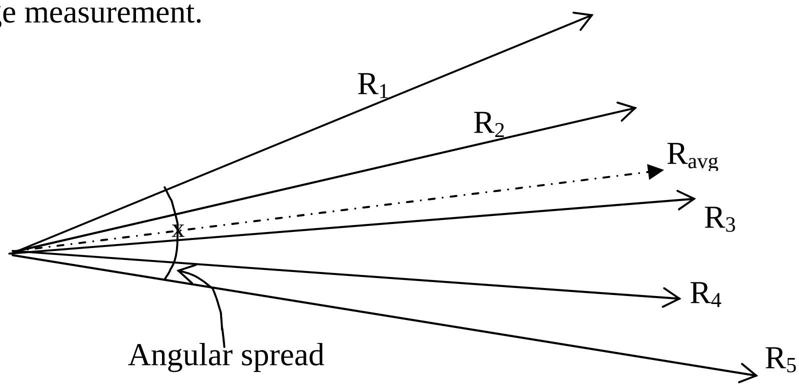


Figure 4

2. Now set up the target ball so that there will be an *off-center* collision when you next roll the projectile ball down the incline. Roll the projectile down from the same height as before, and note where the two balls strike the paper. Again, repeat the procedure 5 times to get an average measurement, as shown in step 1.

3. Remove the paper from the floor and draw in the three vectors, which are proportional to the three velocities $\mathbf{v}$, $\mathbf{v}_1$ and $\mathbf{v}_2$.

4. Does the "initial velocity" vector form a closed triangle with the other vectors? If the triangle is not exactly closed, is it reasonably close to being closed? In other words, do you feel justified in concluding that momentum is conserved in the experiment? Discuss.

5. Measure the angle between the "velocity" vectors of the balls after the collision. Is this angle consistent with a value of 90 degrees, say, $\pm$ 10^o? Do you feel justified in concluding that energy is conserved in the experiment? Discuss.

6. List the expected sources of errors.

<u>Exercise:</u>

Show that the speed of a ball rolling horizontally off a table (as in this experiment) is proportional to the range.

PROJECTILE MOTION AND THE BALLISTIC PENDULUM

Objective

To measure and compare the momentum and kinetic energy before and after an inelastic collision.

Theory

This is a two-parts experiment. In the first part we study projectile motion. In the second part we study the ballistic pendulum.

1. Projectile motion

A ball is fired horizontally from a spring-loaded gun (see Figure 1).

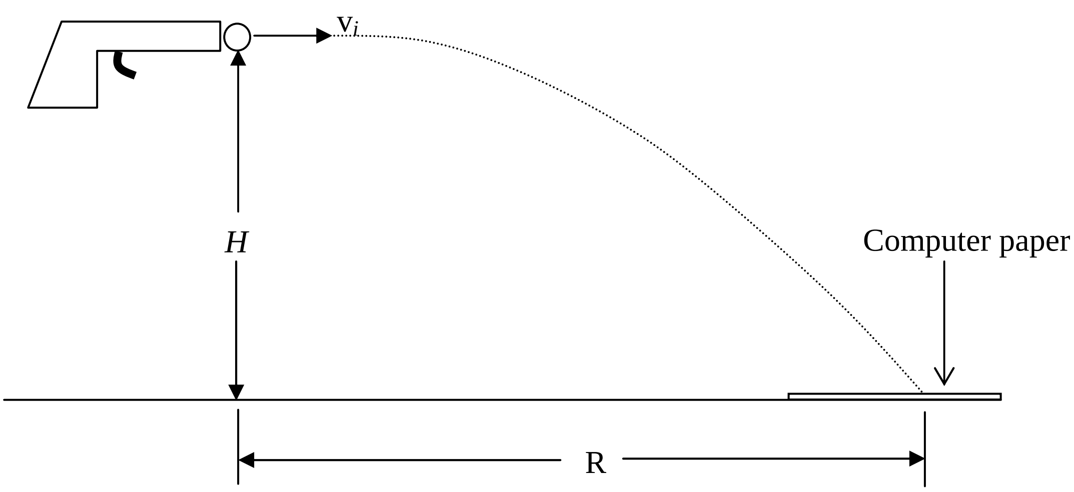


Figure 1.

By measuring the initial height of the ball, *H*, and its range, R, the initial speed, v_i, of the ball can be determined using equation 1.

$$v_i = R\sqrt{g/2H} \quad (1)$$

where g is the acceleration due to gravity, 9.80 m/s^2.

Once v_i is determined, the initial momentum, p_i and kinetic energy, K_i of the ball can be calculated by:

$$p_i = m\, v_i \quad (2)$$

$$K_i = \frac{1}{2} m\, v_i^2 \quad (3)$$

where m is the mass of the ball.

2. Ballistic pendulum

We will now study a *perfectly inelastic collision* between a moving ball and a pendulum (the ballistic pendulum). Since the pendulum is initially at rest, the initial momentum and initial kinetic energy of the system (ball + pendulum) are given by equations (2) and (3). Let us now calculate the momentum and kinetic energy of the system after the collision.

The pendulum apparatus is now placed in front of the ball. When the gun is fired, the ball is caught in a socket in the pendulum as shown in Figure 2. Then the pendulum and ball combination swings upward and is caught by a rachet arrangement at its highest point. By measuring the height *h* that the center of mass of the pendulum plus ball rises, the speed v_f of the center of mass immediately after the collision can be calculated using equation 4.

$$\mathrm{v}_f = \sqrt{2gh} \tag{4}$$

The momentum and kinetic energy of the ball and pendulum system after the collision can be calculated by:

$$p_f = (m + M)\mathrm{v}_f \tag{5}$$

$$K_f = (1/2)(m + M)\mathrm{v}_f^{\,2} \tag{6}$$

where M is the mass of the pendulum.

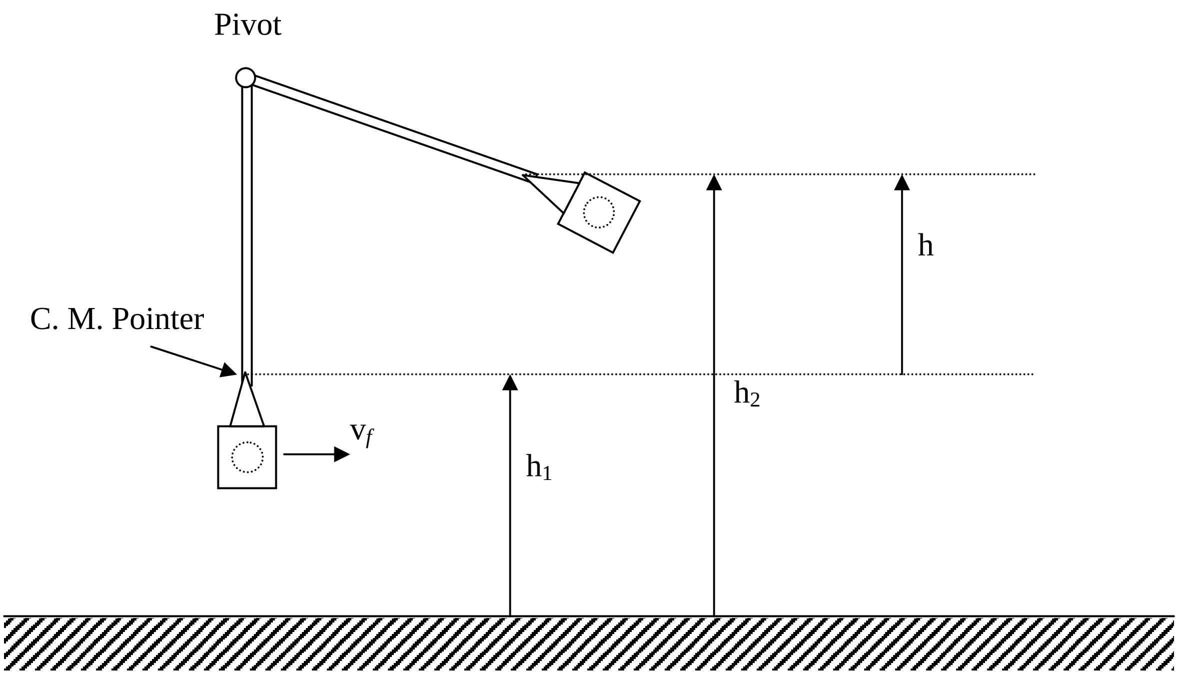


Figure 2.

Thus the experiment allows the determination of the values of the momentum and kinetic energy of the system before and after the collision. Since the collision is *perfectly inelastic*, it is expected that the momentum will be conserved, and that the kinetic energy will not be conserved. By comparing the measured values, this prediction can be confirmed experimentally. It is assumed that frictional losses in the pivot and rachet arrangement are negligible.

Procedure

1. Projectile motion

(i) Place the ball onto the shaft at the front of the gun. Fire the gun and note approximately where the ball hits the floor. Your are provided with computer paper backed by a carbon paper; place it at this point on the floor and tape it down.

(ii) Fire the gun ten times. The carbon paper marks the paper part at the point where the ball lands. Measure and record the values of R.

(iii) Measure and record the value of *H*.

2. Ballistic pendulum

(i) With the pendulum back in place hanging vertically, measure and record the distance h_1, from the base of the apparatus to the tip of the c.m. pointer on the pendulum.

(ii) Fire the ball five times into the socket. Each time you fire the gun measure the corresponding value of h_2. In this experiment we need the values of $h = h_2 – h_1$. Calculate and record the five values of h.

(iii) Finally, measure and record the masses of the ball, m, and the pendulum, M, using the balance provided. Because it would be necessary to take the apparatus apart to measure the mass of the pendulum used, sample pendulums (two types) are provided in the lab for you to use instead.

Data Analysis

1. Record the value of H. Calculate R_{av} from the ten values of the range that you found. Using this average value, your value of *H*, and equation (1), calculate v_i.

2. Record the five values of h you found and calculate the average h_{av}.. Using this average value and equation (4), find v_f.

3. Record the values of m and M. Using equations (2), (3), (5), (6) and your values of v_i, v_f , m, and M, calculate the values of the momentum and kinetic energy in the initial and final states of the system.

5. Calculate the percentage change, Δp, in the momentum of the system between initial and final states as follows:

$$\Delta p = \frac{p_f - p_i}{p_i} \text{x}100$$

6. Calculate the percentage change, ΔK , in the kinetic energy of the system between initial and final states as follows:

$$\Delta K = \frac{K_f - K_i}{K_i} \text{x}100$$

Conclusion

Depending on your measurements, a complete error analysis would show that the values of the momentum and kinetic energy measured in this experiment are accurate to about 5%. Thus, if two values of, say, the initial and final values of the momentum differ only by an amount in this range, then we can state, to the experimental accuracy, that momentum is conserved. Otherwise we must conclude that the measured quantity is not conserved.

Q1. Based on your value of Δp can you conclude that momentum is conserved? Explain.

Q2. Based on your value of ΔK can you conclude that kinetic energy is conserved? Explain also why ΔK is negative?

Q3. Identify the major sources of error.

Exercise:

Prove equation 1 and 4

MOMENT OF INERTIA I

Objective

To measure the moment of inertia of several symmetrical rigid bodies and compare with theory.

Theory

In studying the rotational motion of rigid bodies, it is found that a quantity called the *moment of inertia* plays a role similar to mass in translational motion. Unlike mass, which is a quantity intrinsic to a given body, the moment of inertia depends upon the shape of the object, the axis of rotation and the choice of the origin of the coordinate system. Quite often the origin is taken somewhere on the axis of rotation.

In this experiment we will be rolling various bodies down an incline, so we are interested in the moment of inertia about the symmetry axis of the body, passing through the center of mass, denoted I_c. The Table below gives values of I_c for various common bodies. (The calculations leading to these results will be found in your textbook and discussed by your instructor.) All of these moments of inertia can be written $I_c = \beta\, Mr^2$, where M is the total mass of the body and r is its radius, so only the value of the constant β needs to be given.

Moments of Inertia of Various Bodies,

$$I_c = \beta\, Mr^2$$

Type of Body	β
Solid sphere	2/5
Hoop	1
Disk	1/2
Composite body ("unknown")	?

Assume now that one of these bodies *rolls without slipping* down an incline of height *h* (see Figure 1). It can be shown that its translational velocity, v_c, at the base of the plane satisfies:

$$v_c = \sqrt{\frac{2gh}{1+\frac{I_c}{Mr^2}}} = \sqrt{\frac{2gh}{1+\beta}} \qquad (1)$$

where g is the acceleration due to gravity = 9.80 m/s^2.

The apparatus we will use is set on a table whose surface is at a height H above the floor. If we allow the body to *roll* down the incline, then fall to the floor, it will strike the floor at a distance R measured from the edge of the table (see Figure 1). Since motion in the horizontal direction is uniform, R satisfies the relation R = v_c t, where t is the time for the body to fall from the table to the floor. A short calculation shows that R is given by:

$$R = \frac{R_o}{\sqrt{1+\beta}} \qquad (2)$$

where R_o is the range for a *point mass* ($I_c = 0$) which is found to be $2\sqrt{hH}$.

Procedure and Data Analysis

1. Measure h, H and calculate the range for a point mass value $R_o = 2\sqrt{hH}$.

2. Starting from rest, allow the various bodies you are given to roll down the incline. Use the carbon paper provided to measure the range R for each body. Record your results as shown in the Table below. Since the quantity in the denominator of equation (2) is always greater than 1 for other than a point mass, R will always be less than R_o. Do your measurements confirm this observation?

Body	R_1	R_2	R_3	$R=R_{avg}$
hoop				
disk				
sphere				
Composite body				

3. Solve equation (2) for β in terms of R/R_o . Use your experimental values of R and the value of R_o obtained from step 1 to find the experimental value of β for the bodies listed in Table 1. Calculate the percentage difference between the true and the experimental value of β. Tabulate your results as shown in the Table below.

Body	β_{true}	$(R/Ro)_{exp.}$	β_{exp}	% difference
hoop	1			
disk	1/2			
sphere	2/5			
Composite body	______			______

4. The composite body you have used serves as a test of your experimental skills. Each composite body has been numbered; be sure to record the number on the unknown together with your measured value of β so when grading your report the instructor can judge how carefully you have done this experiment.

5. List the sources of error in the experiment and write a brief conclusion.

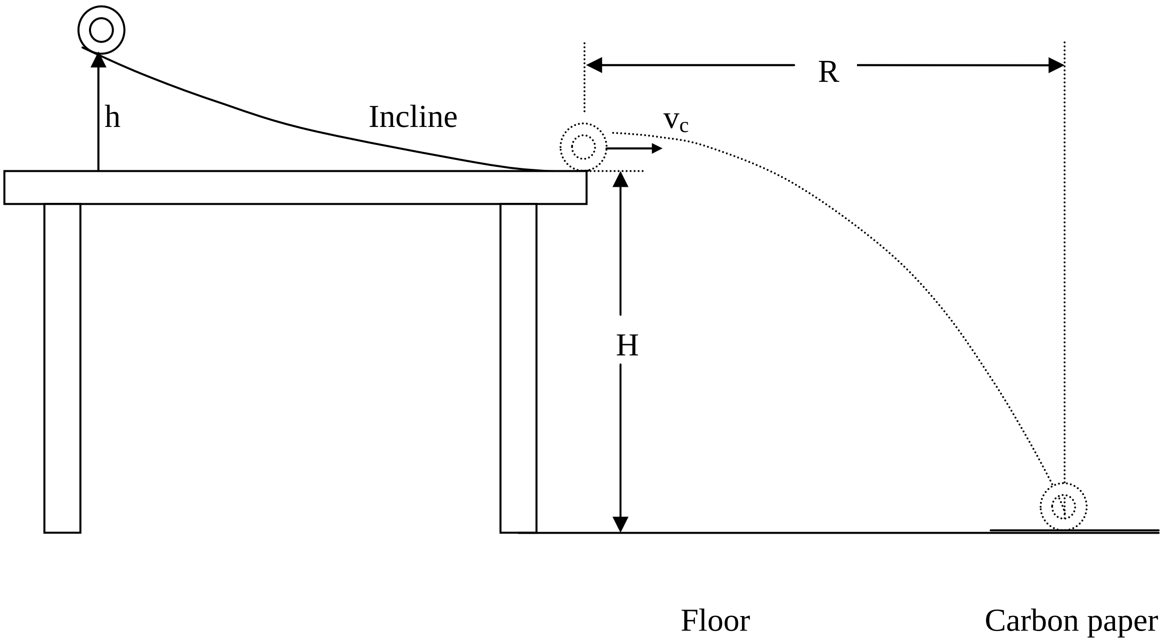


Figure 1. Moment of Inertia

MOMENT OF INERTIA II

Objective

To determine moments of inertia of different rigid bodies.

Theory

In studying the dynamics of rotational motion of rigid bodies one has to define a quantity which is known as "Moment of Inertia". This quantity plays the same role in rotational motion as that of the mass in translational motion.

The moment of inertia I of a point mass m located at a distance r from a fixed axis of rotation is defined as:

$$I = m r^2 \qquad (1)$$

A rigid body can be thought of as a collection of a large number of point masses (m_i) rigidly fixed together. Thus the total moment of inertia of a rigid body (I_B) about a fixed axis of rotation is the sum of the moments of inertia of its point masses about the same axis. In other words

$$I_B = \sum_i m_i r_i^2 \qquad (2)$$

where r_i is the distance of the point mass m_i from the axis of rotation (see Figure 1).

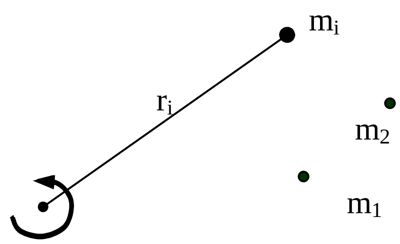


Figure 1

For a body that is not composed of discrete point masses but is instead a continuous distribution of matter, Equation (2) becomes

$$I_B = \int r^2 dm \qquad (3)$$

where dm is an infinitesimal element of mass at a distance r from the axis of rotation. (see Figure 2).

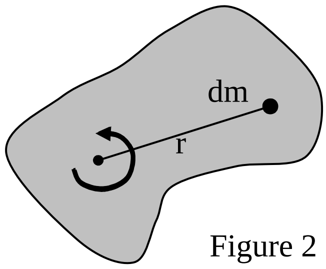


Figure 2

Experimentally, moments of inertia of rigid bodies can be determined by applying the dynamical relations for rotational motion. The apparatus to be used for this purpose consists of a disk of radius R, which can rotate about a fixed vertical axis through its center (see Figure 3). A mass m is attached to a string wrapped around the periphery of the disk. If enough weight (mg) is used and the system is released from rest, the mass m moves downward with an acceleration a while the disk rotates about its axis with an angular acceleration α. The equations of motion of this dynamical system are:

$$m g - T = ma \qquad (4),$$

where T is the tension in the string.

Ignoring friction,

$$T\,R \;=\; I\alpha \;=\; I\,\frac{a}{R} \qquad (5)$$

where I is the moment of inertia of the disk about a vertical axis through its center.

Solving Equations (4) and (5) for I, one gets

$$I \;=\; mR^2\,(\frac{g}{a} - 1) \qquad (6)$$

Since *a* is constant, *a* can be calculated from

$$a = 2\,y\,/\,t^2 \qquad (7)$$

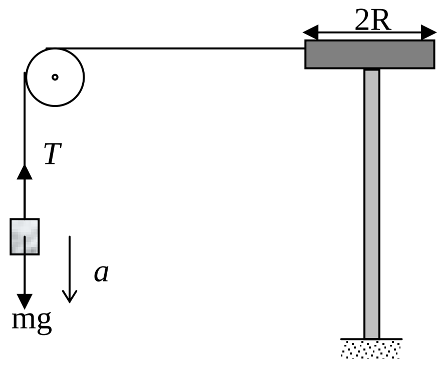


Figure 3

Now, if a rigid body is placed on the top of the disk such that their centers of mass coincide, the measured moment of inertia of the system is the sum of moments of inertia of both the disk and the rigid body.

For the purpose of this experiment, rigid bodies in the form of rods, plates and dumbbells are provided. (Information regarding their masses and dimensions are also provided in the laboratory). Every student is expected to complete measurements and calculations of moments of inertia of three different rigid bodies.

Procedure

Note: When placing any of the rigid bodies on the disk, be sure that their mass-centers coincide.

The general procedure for determining the moment of inertia of a given system (i.e. disk or disk + a rigid body) is to determine the acceleration of the descending mass m (see Equation 6). The acceleration *a* may be determined in the following way:

1. Wind the string around the periphery of the disk. Keep the system at rest in this position.

2. Attach a mass m to the free end of the string. Note that the value of m depends on the particular system whose moment of inertia is to be determined. For the disk alone use m = 10 g and for other rigid bodies use m = 50 g.

3. Release the system (from rest) and measure the time it takes the mass m to travel a fixed distance y. Repeat time measurements for the same distance y two more times and find the average time. Now you should be able to determine the acceleration, *a*, for any specific system. It is convenient to keep y constant.

   Note that steps 1 through 3 will be done four times, each time for one specific system whose moment of inertial is to be determined.

4. Measure and record the radius R of the disk and the distance y in step 3.

Data and Analysis

1. Make a table as shown below to record your data and results. Calculate *a* and I using Equations (7) and (6), respectively.

R =
y =

Object	m	t_1	t_2	t_3	$t = t_{av}$	a	I
Disk Disk+ Dumbbell Disk + Rod Disk + Plate							

2. From the above table determine the following:

(a) The moment of inertia of the steel rod, I_R = I (disk + one steel rod) – I (disk).

(b) The moment of inertia of the plate, I_P = I (disk + one plate) – I (disk).

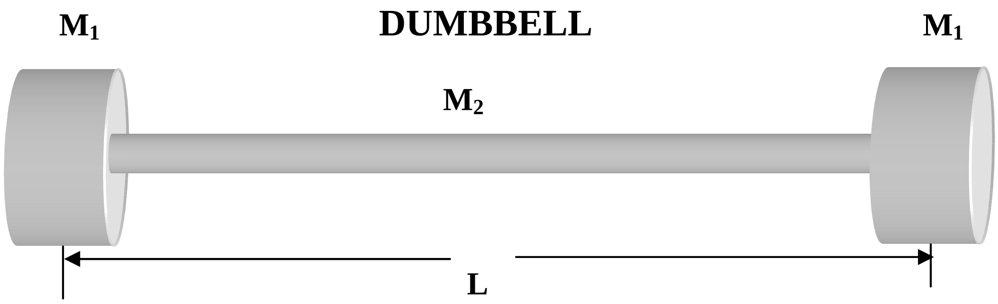
(c) The moment of inertia of a dumbbell, I_D = I (disk + one dumbbell) – I (disk). (Choose one dumbbell, small or large).

3. The values of I_R, I_P and I_D you have just determined are experimental values. Figure 4 contains formulae that are required to calculate the moments of inertia about the center of mass of the objects you have used in this experiment. The formulae are derived using Equation (3). Use these formulae and the information provided about the objects to calculate I_R, I_P and I_D.

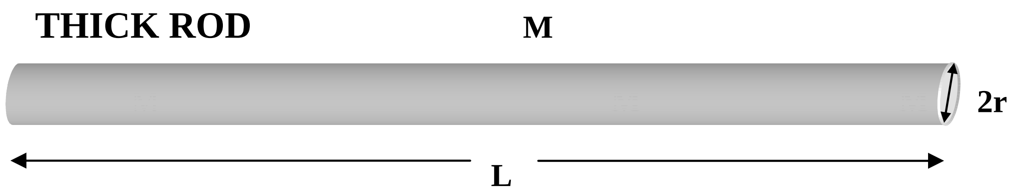
4. Record your results, with correct units, as shown below:

Object	I_{exp}	$I_{formula}$	% difference
Rod Plate Dumbbell			

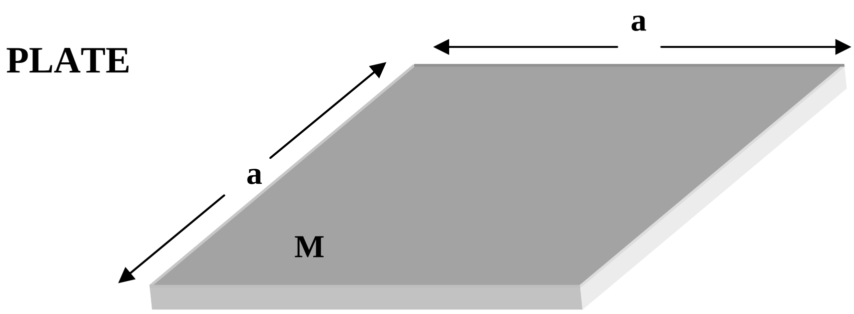
5. List sources of error.



$$I_D = 2M_1\left(\frac{L}{2}\right)^2 + M_2\left(\frac{L^2}{12}\right)$$



$$I_R = M\left(\frac{r^2}{4} + \frac{L^2}{12}\right)$$



$$I_P = \frac{Ma^2}{6}$$

Figure 4

MAXWELL WHEEL

Objective

To test conservation of energy in a system with gravitational, translational and rotational energies and to explore the effect of friction.

Theory

A wheel is suspended by two cords wrapped on its axis (see Figure 1). After being released from rest, it unrolls from its cords and moves downward in the gravitational field. As time increases, more and more of the initial gravitational potential energy (U_g) of the system is converted to translational (K_T) and rotational (K_R) kinetic energies.

The total energy E = ($U_g + K_T + K_R$) of the system is conserved if friction is negligible. This implies that:

$$\Delta E = \Delta U_g + \Delta K_T + \Delta K_R = 0 \qquad \text{(1a)}$$

If the mass of the system is *m* and its moment of inertia about the axis of rotation is I_c, then Equation (1a) becomes:

$$\Delta E = -mgs + \frac{1}{2}m\text{v}^2 + \frac{1}{2}I_c\omega^2 \qquad \text{(1b)}$$

where g = acceleration due to gravity = 9.80 m/s^2, s is the vertical distance traveled in time t, v is the translational velocity and ω the angular velocity at that time. It can be shown that the translational acceleration a of such a system is constant if one neglects the effects of friction. Therefore, from $s = (½)(\text{v}_0 + \text{v})\,t$, and the initial velocity $\text{v}_0 = 0$,

$$\text{v} = \frac{2s}{t} \quad \text{and} \quad a = \frac{\text{v}}{t} = \frac{2s}{t^2} \qquad \text{(2)}$$

Furthermore, $\omega = \frac{\text{v}}{r}$, where r is the wheel's spindle radius.

Using these relations Equation (1b) may then be rewritten in the simple form:

$$\Delta E = -mgs + 2m\left(\frac{s}{t}\right)^2 + 2\frac{I_c}{r^2}\left(\frac{s}{t}\right)^2 \qquad \text{(3)}$$

It follows that each component of the energy change, ΔU_g, ΔK_T, and ΔK_R may be evaluated if s and t are measured.

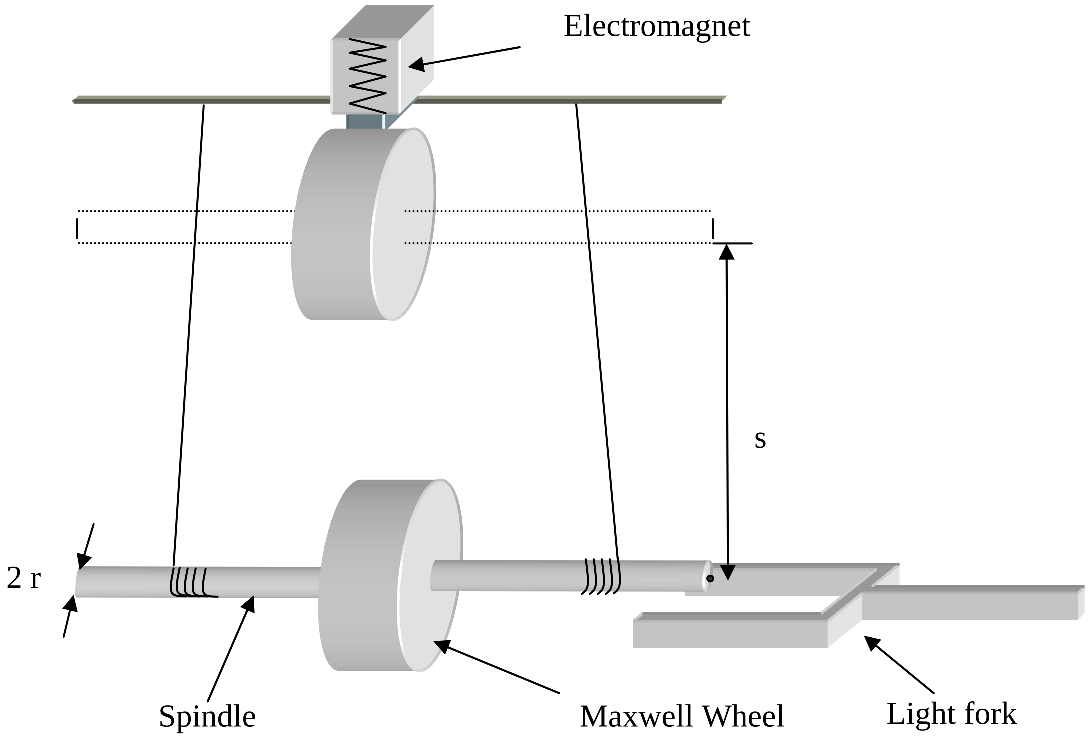


Figure 1

Procedure

1. Carefully roll up the wheel on its cords until one of the metal tabs on its rim contacts the electromagnet which will hold it in place. **Be sure that the cord winding runs inward**, so that the wheel will drop smoothly. If at any time the wheel begins to wobble and move erratically, you must gently catch it and do a proper job of rewinding.

2. Check that the timer is set to “ms” (milli seconds) and properly reset to zero. Adjust the height of the light fork to a particular value of *s*. When you tap the key, the power to the electromagnet will be interrupted, the wheel will begin to travel downward, and the timer begins running. At the level of the light fork the light beam will be cut, stopping the counter. The value displayed on the counter is the value of *t* belonging to your first value of *s*. Repeat the measurement two more times, enter your results in a table as shown below, and then average the resulting times.

3. Repeat steps 1 and 2 for four other values of *s*.

Data and Analysis

Take m = 0.476 kg, and I_c = 10.0 x 10^{-4} kg m^2. Record the value of r: r = …………mm.

1. Prepare a table with your data as shown below. Give a sample calculation for ΔE.

s	t_1 (ms)	t_2 (ms)	t_3 (ms)	t_{av} (s)	ΔE	0.05 mgs	a

2. Since the wheel began its motion from rest and we are assuming friction may be neglected, one would expect ΔE = 0 for all values of s. Take as a rough estimate the expected error in energy measurements as 5% of the gravitational potential energy. That is, the uncertainty in ΔE is then approximately equal to 0.05 mgs. To within this experimental uncertainty, can you conclude that mechanical energy is conserved?

3. Is the acceleration a of the system constant within the experimental uncertainties of approximately 5%? To answer this question calculate the average acceleration and calculate the percent difference between either your largest a or your smallest a and a_{av}.

4. List major sources of errors.

SIMPLE PENDULUM I

Objective

To investigate the fundamental physical properties of a simple pendulum.

Background

A simple pendulum consists of a point mass suspended by a weightless string, as shown in Figure 1. The diagram also shows the forces acting on the body.

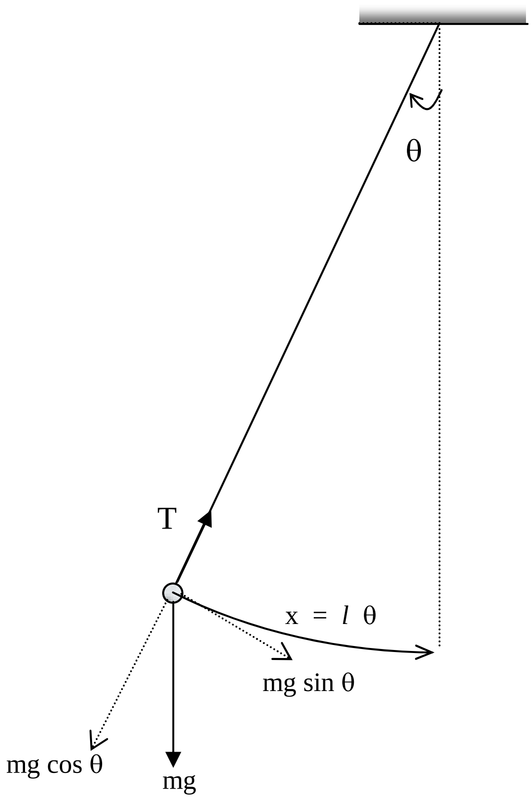


Figure 1

The restoring force on the particle, tending to return it to the equilibrium position, is

$$F = -mg\sin\theta \qquad (1)$$

where θ is the angular displacement from equilibrium. Provided that θ is small, we can write

$$\sin\theta \cong \theta \qquad (2)$$

where θ is in radians. Then the motion is nearly one-dimensional along the x-axis, where $x = l\theta$.

Thus Newton's law, F = ma, becomes in this approximation

$$F = -mg\,\theta = -mg\,x/l = m\,d^2x/dt^2 \qquad (3)$$

or

$$d^2x/dt^2 + (g/l)\,x = 0 \qquad (4)$$

This is the standard form of the equation for a particle executing simple harmonic motion with period (time for one oscillation)

$$T = 2\pi\,(l/g)^{1/2} \qquad (5)$$

We notice that Equation (5) predicts that the period of a simple pendulum:
a) is independent of the mass of the particle.
b) depends on the square root of the length of the pendulum.
c) is independent of the amplitude of the motion.

In this experiment we will be making measurements on a real-world pendulum, in which the string is light, but not weightless, and the mass is not a point, but has some dimensions. Nevertheless, if we measure the length l from the point of suspension to the center of mass of the masses we shall hang on the string, it will turn out that the measured periods will agree very well with Equation (5).

Measurements

Part A: Fixed Length, Variable Mass

You are able to vary the mass m by attaching various bodies made of aluminum, brass, lead, and plastic to the string. Check whether the period is independent of the mass by measuring the period of oscillation, T, for each of the masses for a fixed value of l, say, l = 70 cm. The technique to measure T is as follows:

1) Displace the mass from equilibrium to a small angle, say, 10^o. (Use this same fixed value throughout the lab session, except for the last part)
2) Measure and record the time t for 10 oscillations. Repeat the measurement one more time and find the t_{av}. Then T = t_{av} / 10. (This increases the accuracy of your measurements.)

Finally, use the balance provided in the lab to measure and record the values of the masses used.

Table A

l =

Object	m	t_1	t_2	t_{av}	T
Aluminum					
Brass					
Lead					
Plastic					

Part B: Fixed Mass, Variable Length

Now use a fixed mass and vary the length l over a range of 30-200 cm, measuring the period T, as described in Part A, for each of the lengths chosen.

Table B

m =

l	t_1	t_2	t_3	t_{av}	T	$l^{1/2}$

Analysis

1. Examine your results from part A. Does your data support the statement that the period is independent of the mass?

2. Now make a plot of T vs. $l^{1/2}$ for the data obtained in part B. According to Equation (5) this should be a straight-line plot, with slope $2\pi / g^{1/2}$.

   Does your data support the statement that the period depends on the square root of the length? Explain.

3. From your graph of T vs. $l^{1/2}$, obtain the slope. Use this to obtain a value for the acceleration of gravity, g. Compare your value to the standard value, 9.80 m/s^2, by computing the percent difference.

4. List the major sources of error in this experiment.

Exercises

1. To get an idea whether the approximation $\sin\theta \cong \theta$ is valid for the angles used in this experiment, compute the percent difference between θ and sin θ for $\theta = 10^o$. (You must convert θ to radians for this comparison.) Is there much of a difference between the two values? What is the percent difference for $\theta = 40^o$? Is it a large difference?

2. Make some measurements of the period T for larger angles, using one of the l-values from Part B. Does the period decrease or increase for large-amplitude motion (compared to the small-amplitude value)? Do the small- and large-amplitude T-values differ significantly?

SIMPLE PENDULUM II

Objectives

To time the motion of a simple pendulum over half a period, testing the sinusoidal dependence of the motion's displacement on time and checking an equation for the period.

Theory

A simple pendulum consists of a point mass suspended by a weightless string, as shown in Figure 1. Your instructor will review the derivation given in your text, that for small angular displacements θ from equilibrium the corresponding linear displacement, x, of the pendulum obeys the equation

$$x = A\cos(2\pi \frac{t}{T}) \qquad (1)$$

In writing the equation this way we are making a particular choice of the phase of the pendulum's motion to be zero at $t = 0$, in keeping with the way we will carry out this experiment. Here T is the period (time for one complete oscillation) of the motion, which obeys the relation:

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad (2)$$

where L is the length of the pendulum, and g = acceleration due to gravity = 9.80 m/s^2.

In the experiment we will use a magnet to hold the mass m at some fixed initial linear displacement, A. Tapping a key will switch the magnet off momentarily, thereby releasing the mass while simultaneously starting a timer. A "light fork" is fixed at various distances, x, and as the pendulum's string sweeps through the light beam, the timer stops and displays the time t corresponding to x. A complete set of such measurements of (x, t) when plotted allows us to check the sinusoidal variation of x with t predicted by Equation (1). Furthermore, we will be able to extract the period T from this plot and compare this experimental value to that predicted by the theory given by Equation (2).

Procedure

1. Measure the length of the pendulum suspension string, L, taking this to be from the point of suspension to the center of mass of the suspended object. Note that for convenience the scale and light fork are not set at the level of the mass m, but at a distance R from the suspension point, so we will actually be measuring a displacement y whose amplitude is B. However, both y and B are simply proportional to x and A respectively, so we expect y to have the same dependence as in Equation (1).

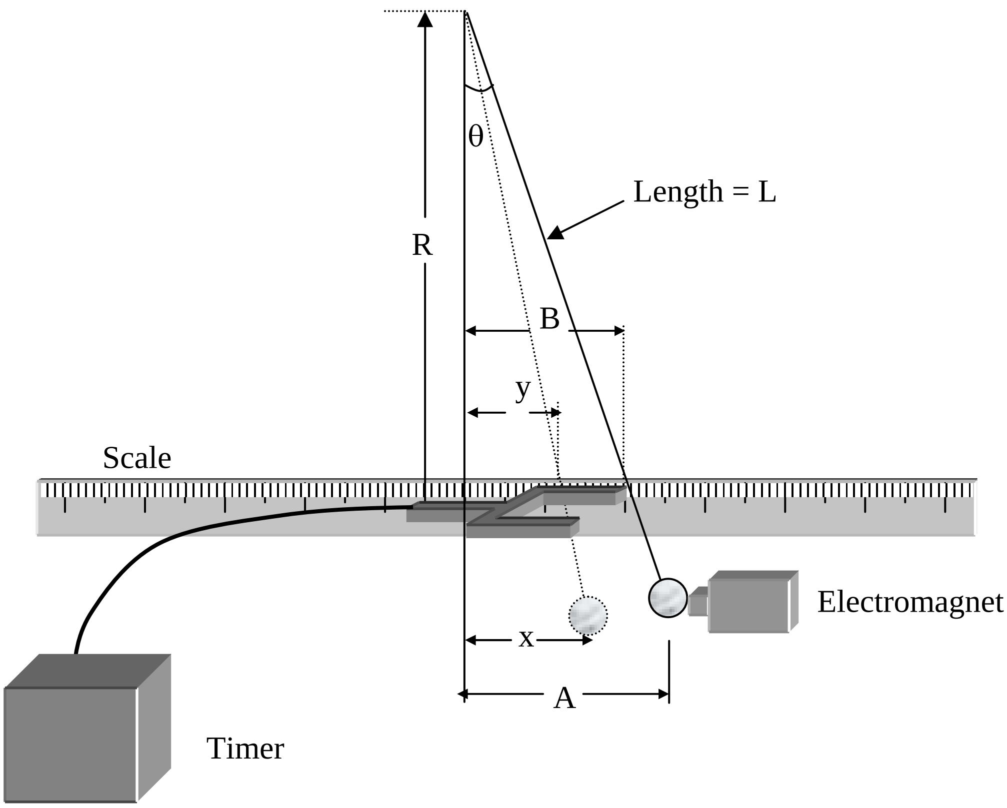


Figure 1

Measure the distance *R* for possible future reference; then with the pendulum mass held by the magnet, read off the amplitude *B* from the scale and record this value. You may have to lower the scale in order to have as large a *B*-value as possible.

2. Now fix the light fork at some point *y* from the equilibrium position of the pendulum. (The distance *y* is measured from the equilibrium position of the pendulum to a raised line the manufacturer has placed on the light fork to mark the position of the light beam). Note that the value of *y* is positive or negative depending on whether the light beam is to the right or left of the equilibrium position of the pendulum respectively.

3. Check that the timer is set to "ms" and properly reset to zero. Tap the key to release the mass; observe the timer start, then stop as the string passes through the light beam. Repeat the measurement two more times (remember to zero the timer after each reading), enter your results in a table as shown below, and then average the resulting times.

4. Repeat steps 2 and 3, *varying only the position of the light fork*, to obtain 8 values of *y* and *t*, with *y* both positive and negative, spanning the range $-B < y < +B$.

y	t_1	t_2	t_3	$t = t_{av}$
B	0	0	0	0

Data Analysis

1. Plot your values of *y* and *t*; note that by definition the value of *y* at $t = 0$ is *B*.

2. From your plot read off the time interval from the origin to the point where your curve passes through zero displacement; this is a quarter of a period, i.e., *T*/4. Multiply your result by 4 to obtain the period, *T*. Now compute the theoretical value for *T* from Equation (2).

3. Is the difference between these measured and theoretical values of *T* "reasonable", say, approximately 10% or less?

4. List the major sources of error in this experiment.

BUOYANT FORCES

Objectives

To study buoyant forces and use Archimedes' principle to determine the specific gravity of several materials.

Theory

The *density* of an object, ρ_o, is defined as the ratio of the mass of the body *m*, to its volume *V*:

$$\rho_0 \equiv \frac{m}{V} \qquad (1)$$

The units of the density (in the SI system) are obviously kg/m^3. A related quantity is the specific gravity, SG, the ratio of the density of an object to the density of water, $\rho = 1.000 \times 10^3 \, \frac{kg}{m^3}$, that is,

$$SG \equiv \frac{\rho_0}{\rho_w} \qquad (2)$$

If the body is a regular one, for example, a sphere, it is straightforward to determine its volume by measurement of its dimensions followed by a simple geometrical calculation. The density immediately follows from Equation (1) after the mass is found using a balance.

But how can one determine the density of an irregular body, for example, a bundle of wire? The answer is due to the ancient Greek philosopher, Archimedes. He discovered that if a body is immersed in a fluid, it experiences an upward, *buoyant force*, *B*, equal to the weight of the fluid displaced by the body, a physical law we now call *Archimedes' principle*. Thus if *W* is the true weight of an object in a vacuum, its *apparent* weight when submerged in a fluid will be W_a, where

$$W_a = W - B \qquad (3)$$

In this lab we will be using pure water as the experimental fluid, and test materials heavier than water so that they are totally submerged below the surface of the water. In this case the buoyant force satisfies:

$$B = \rho_w V g \qquad (4)$$

where *g* = acceleration due to gravity = 9.80 m/s^2. In other words, the buoyant force is just the mass of the displaced water, $\rho_w V$, times *g*. It is important to note that the buoyant force depends only on the *volume* of the body and *not* its mass. One final point: by definition, the weight of an object is its mass times *g*, hence

$$W = \rho_0 V g \qquad (5)$$

A small, but possibly confusing detail: laboratory balances are set up to display the *mass* of objects, not their *weight*. Hence in the following manipulations we divide by *g* so we are discussing the true mass, $m = \frac{W}{g}$, and the apparent mass, $m_a = \frac{W_a}{g}$. Then dividing Equation (5) by Equation (4), and using Equation (3) it follows that (prove this):

$$SG \equiv \frac{\rho_0}{\rho_w} = \frac{m}{m - m_a} \qquad (6)$$

This equation allows us to find the specific gravity of an object whether regular or irregular. All we need do is determine its actual mass, the apparent value of its mass when the body is immersed in water, and then apply Equation (6).

Procedure-Estimate

1. In the lab we will have available geometrically regular objects made of aluminium, brass, lead, and plastic. There will also be one irregular object. Your instructor will assign you two materials from the first four just listed whose specific gravity is to be found, and you will also determine the specific gravity of the irregular object.

2. Before using Archimedes' principle, first let us just *estimate* what will be found, for one of the objects. Choose one of the two regular objects you have been assigned and measure its true mass by hanging it from a wire attached to the balance pan. Using a ruler, measure the dimensions of the object and calculate its volume. Find its SG by using Equations (1) and (2).

<u>Procedure-Archimedes' Principle</u>

1. For the same object in item 2 above, measure its apparent mass by immersing it in the beaker of water supplied, and re-reading the balance. Then find its specific gravity using Equation (6). How does the experimental value you obtain compare to the estimate found using the previous procedure?

   Repeat your measurements for the second regular object and also the irregular object.

Object	Actual Mass (m)	Apparent Mass (m_a)	Specific Gravity (SG)
Regular 1			
Regular 2			
Irregular			

2. For the two regular objects, compare your values to the accepted values for these substances, as shown in the following table.

Substance	**SG**
Aluminium	2.7
Brass	8.4
Lead	11.3
Plastic	1.18

3. Calculate the percentage difference between your measured values of the SG and the accepted values in the table. Are the differences reasonable, say, in the 5-10% range?

4. List the major sources of error in this experiment.

CAL Lab

One of the things your instructor will ask you to do in the CAL lab is to take some of your old data and plot it again, but this time using the computer. You may then compare the manually plotted data with the one plotted using the computer. The plotting software is called EXCEL and it is already installed in the computer.

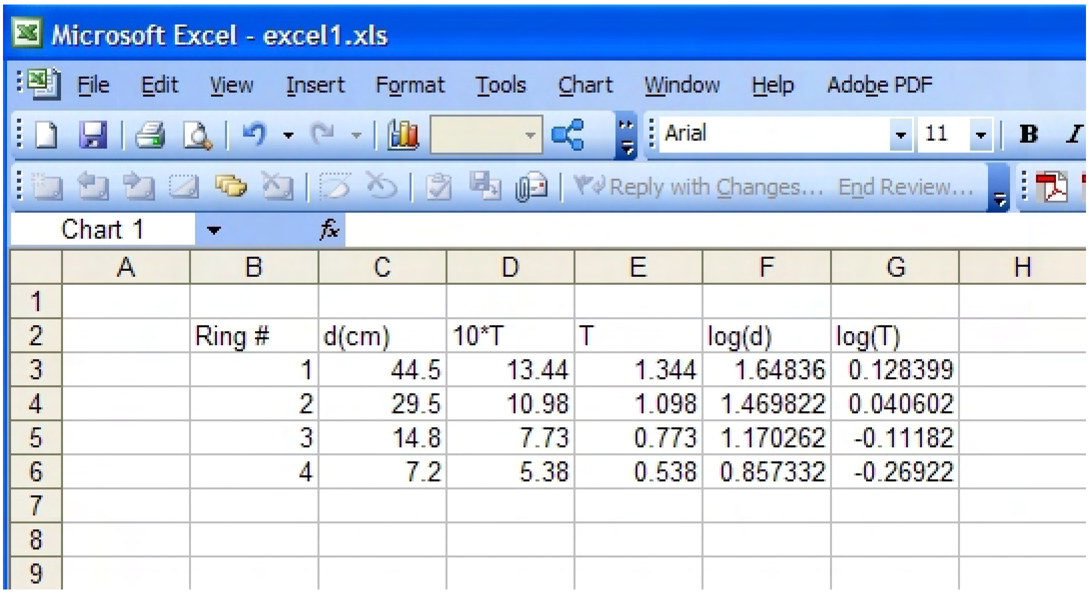
Graphing and Best Line using EXCEL

This is a step by step, quick tutorial on how to plot experimental data, draw the best line using linear regression and find the slope and y-intercept, all of these using MS-EXCEL

It is hoped that most of you would find the instruction below is clear enough. However you can go to the link http://faculty.kfupm.edu.sa/phys/mohamedk/cal_lab/ for a guide with more illustrations.

1. Enter the data

Enter the data from an experiment, say "An Empirical Law" as shown below. Fill only the first three columns as they are the raw data (measured values).



	A	B	C	D	E	F	G	H
1								
2		Ring #	d(cm)	10*T	T	log(d)	log(T)	
3		1	44.5	13.44	1.344	1.64836	0.128399	
4		2	29.5	10.98	1.098	1.469822	0.040602	
5		3	14.8	7.73	0.773	1.170262	-0.11182	
6		4	7.2	5.38	0.538	0.857332	-0.26922	
7								
8								
9								

cal1

2. Enter the formulas

Type in "=D3/10" in the cell E3. The program understands what follows the equal sign as formula. Continue typing the formulas "=LOG(C3)" and "=LOG(E3)" in cells F3 and G3 respectively.

3. Fill Down formula

Select the cells from E3 to G6 by clicking the left mouse in cell E3 and dragging it all the way to G6 keeping the mouse pressed.
With cells thus highlighted, choose from the main menu *Edit* ---> *Fill* -----> and then *Down*. This will result in corresponding formulae printed in all the cells as needed.

4. Start Chart Wizard

Select the data area for the x and y axis, F2 to G6 (this include the heading). Invoke the Chart Wizard: *Insert* ---> *Chart*...

5. Chart Type

You will now be shown with the Chat Wizard – Step 1 of 4 – Chart Type. Choose 'XY(Scatter)' from *Chart Types* and *Chart sub-type* is the top one (i.e. without connecting line). Click **Next>** button.

6. Source Data

You are now in the Chat Wizard – Step 2 of 4 – Chart Source Data. Nothing to do here. Click **Next>** button.

7. Chart Options

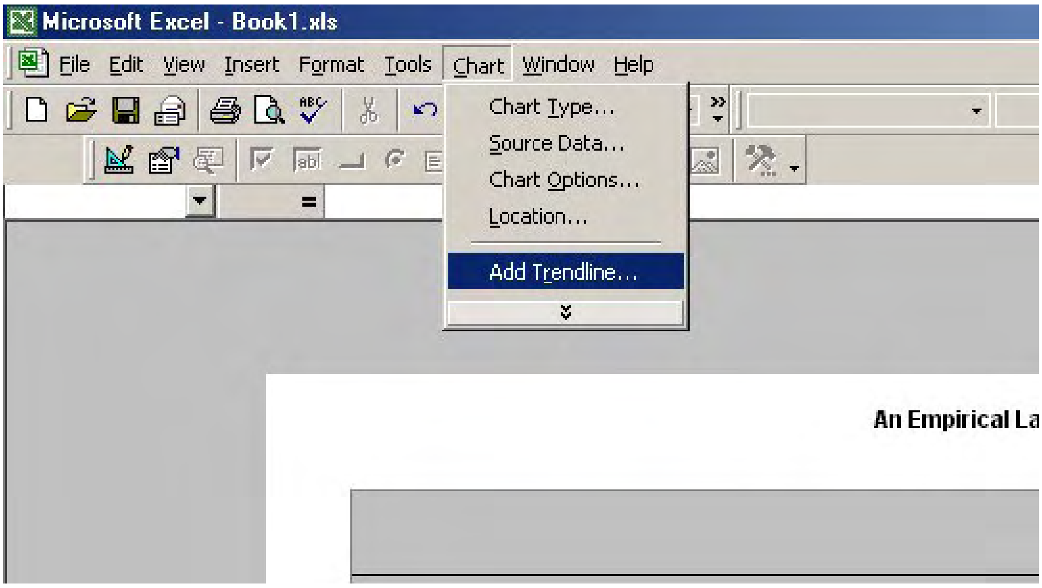
You are now in the Chat Wizard – Step 3 of 4 – Chart Option. Make changes in the three boxes *Chart title*, *Value (X) axis* and *Value (Y) axis* as you like. Then click the folder Legend. Click off the Show Legend. Click **Next>** button.

8. Chart Location

You are now in the Chat Wizard – Step 4 of 4 – Chart Location. Choose 'As new sheet' Click **Finish**. The graph will now be displayed in a new sheet.

9. Best Line

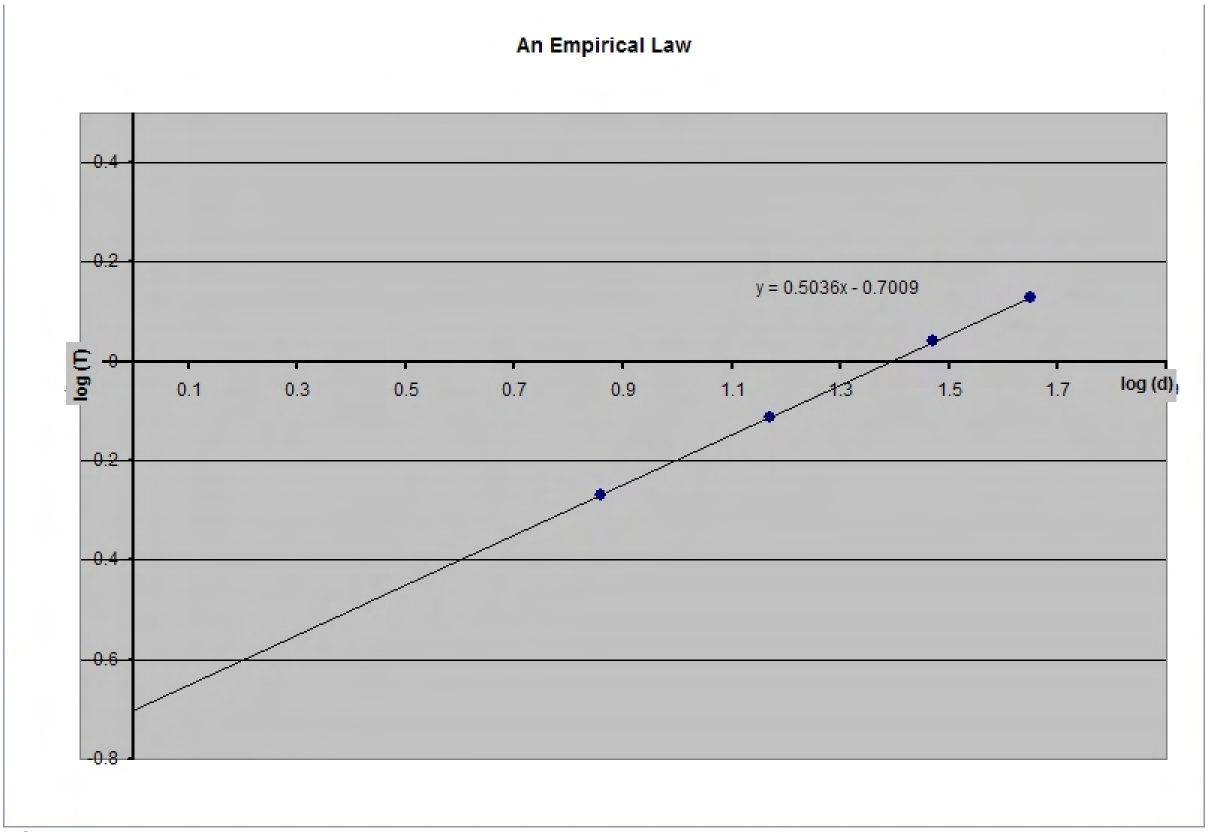
Go to the main menu of the sheet Chart1 and choose *Chart* ---> *Chart Type…*-----> and then *Add Trendline…*



cal16

10. Trendline - Type

You will be presented with the Add Trendline Box. Choose the *Trend/Regression type*: Linear, then click on the tab **Options**. Click 'Display equation on chart'. Now click **OK**, and you will have the Chart with the best line and the equation for that line displayed in it!



cal16

You can download the finished product (the *Interactive Physics* files called calIP.IP and calIP2.IP) from the following links:

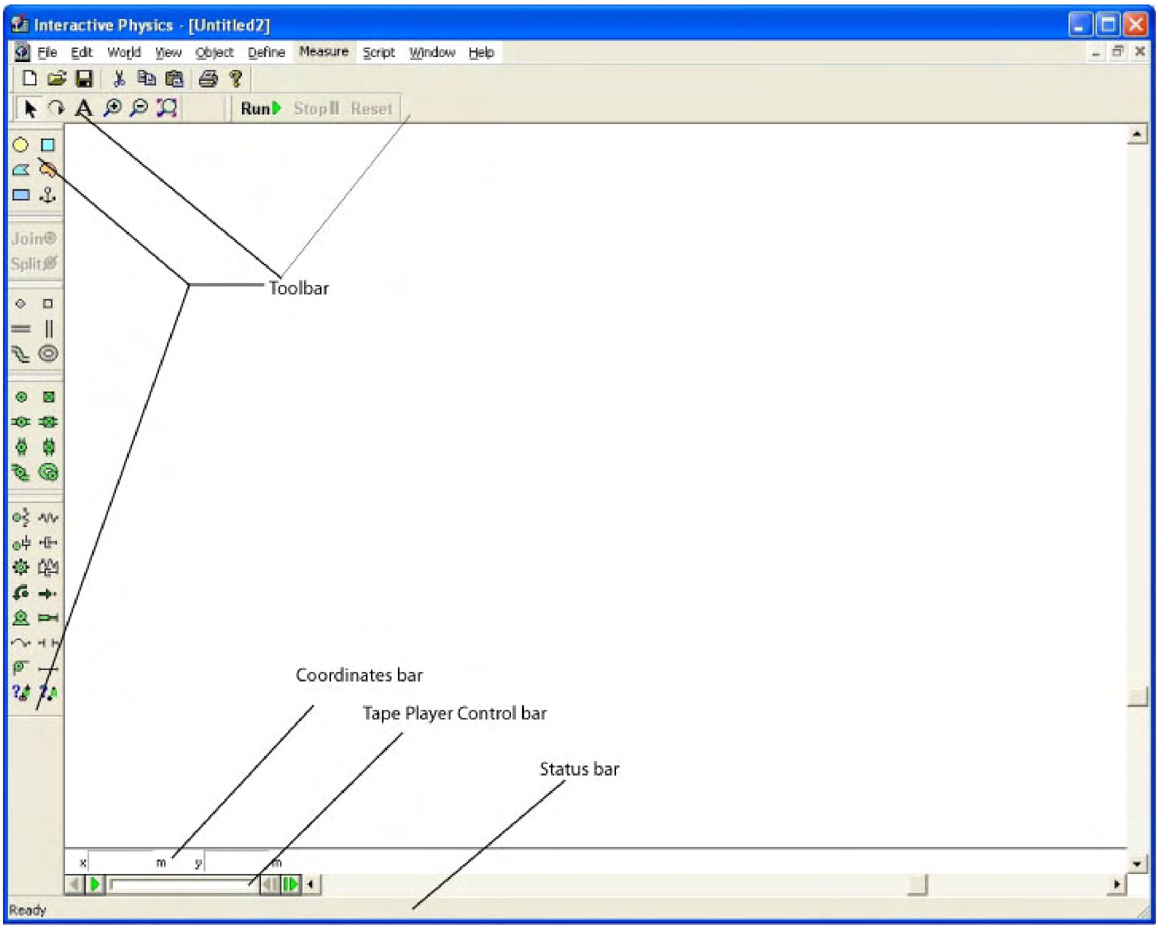
http://faculty.kfupm.edu.sa/phys/mohamedk/calIP.IP
http://faculty.kfupm.edu.sa/phys/mohamedk/calIP2.IP

Or follow the instructions that follow to create them yourself.

Interactive Physics Lab

PART A (FREELY FALLING BODY)

Open Interactive physics 2005



Note the terminology used

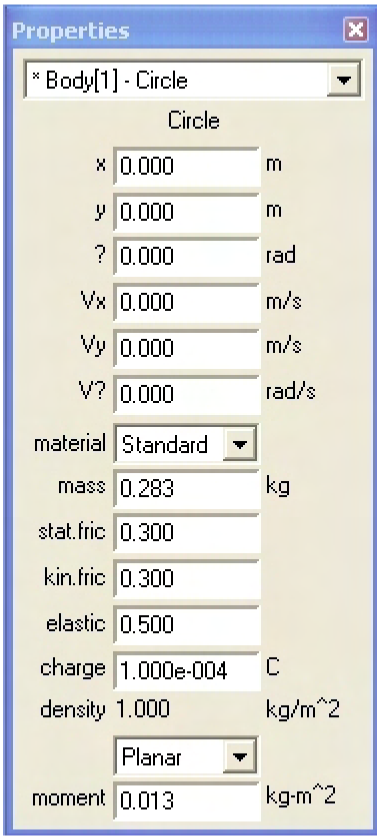
Save this file as say "calIP"

Click once (select) the "circle tool" in the "tool bar" and draw a circle in the drawing (white) area.

If the circle is selected (click once on the circle) you will observe that the coordinate bar showing the x-coordinate, y coordinate, radius (r) and angle (?) orientation of the reference line in the circle.

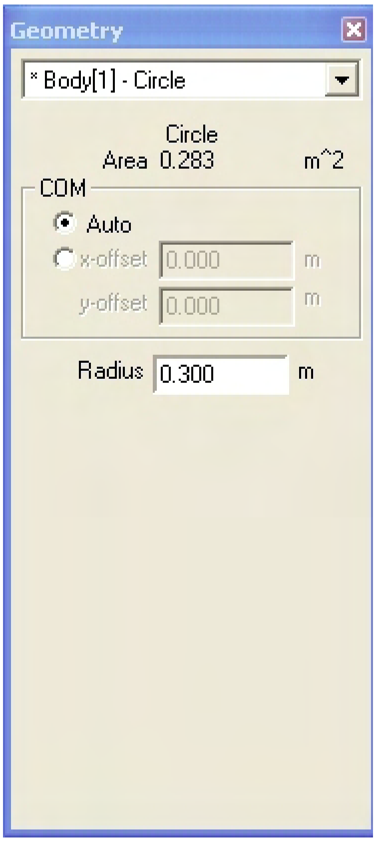
Double click on the circle (Or select the circle, pull down the menu Window → Properties. This will bring up the properties window.

Set x=0 and y= 0 for this object (Body[1])

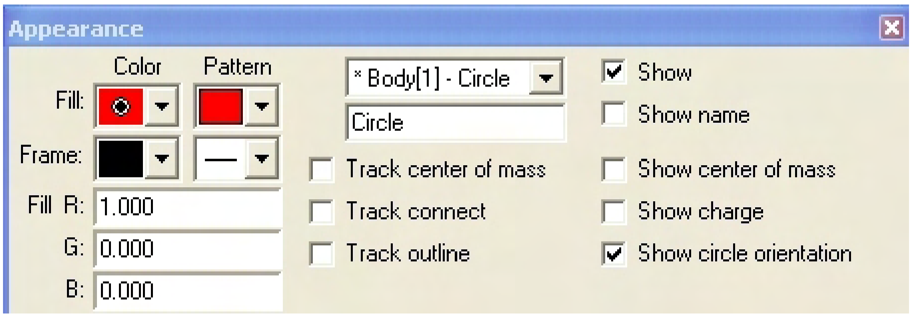


Move the vertical and horizontal scroll bars so that the circle appears approximately in the middle of the drawing region.

With the circle selected, go to menu "Window" → Geometry. You will get the geometry window opened up. Set the radius to 0.300 m.

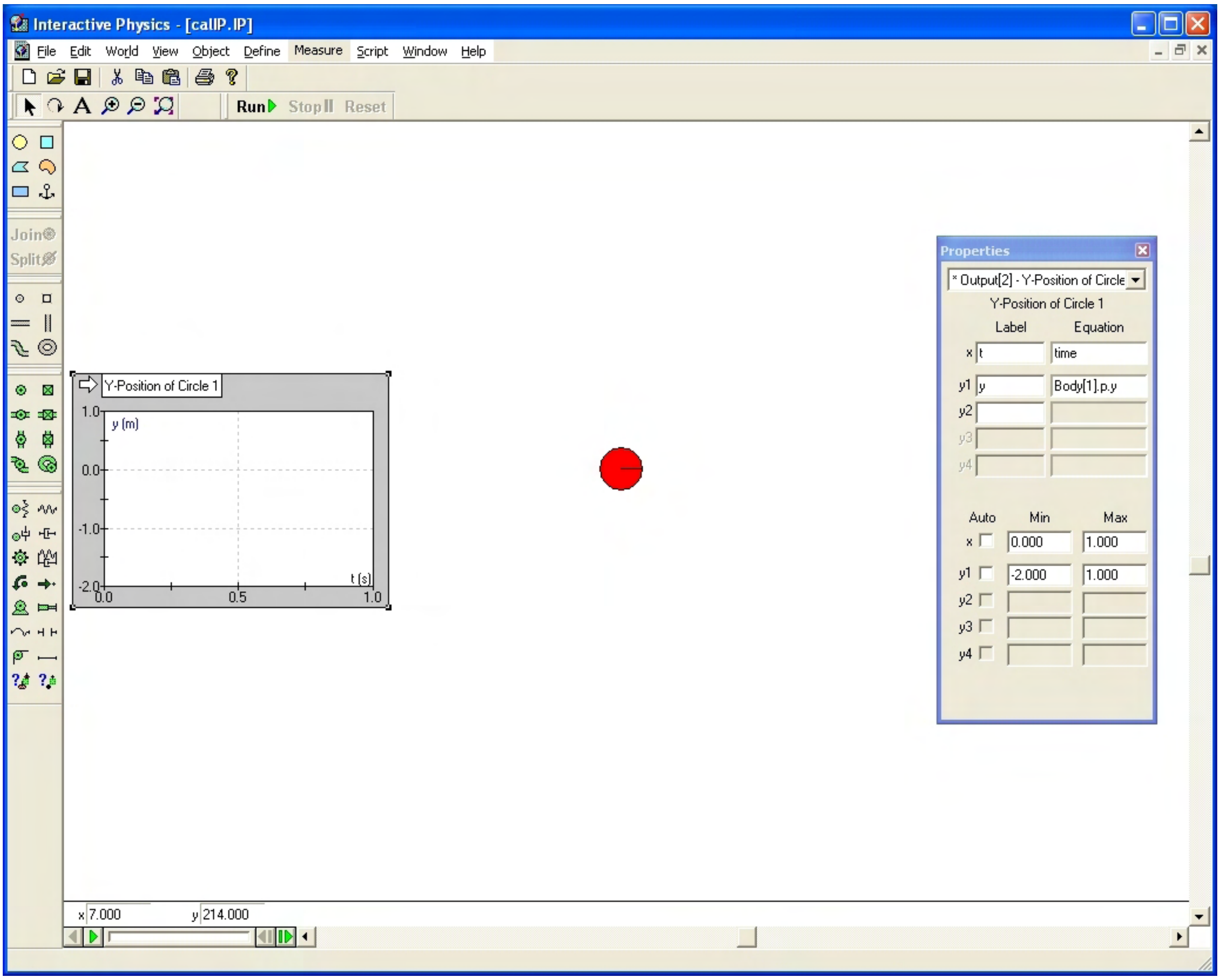


Close both the geometry and the properties window, and now open the Appearance window. Set the fill color to red. You can simply type in 1 for R, 0 for G and 0 for B.



With the object circle selected, click the menu "Measure" → Position -→ y-graph. This will bring the Graph Window "Y-position of Circle 1". Double click on the graph and it will bring you the property window for this graph object.

Unclick the tick marks under "Auto" and set the minimum and maximum values as (0, 1) for x-axis and (-2, 1) for y-axis.



Close the properties window.
Go to Menu "Measure" → Time. (To bring up the time meter you don't have to select any object). And place this "meter" somewhere at the top.

Press the "Run" button at the top (or alternatively you can use the short cut key Ctrl+R) and observe. The ball falls in the virtual environment of earth's gravity. The ball is still falling when it is out of the view at the bottom. You can stop the play at any time by clicking anywhere in the drawing area or by pressing the "Stop" button at the top. After stopping press the "Reset" button to come back to the editing mode.

For the instructors: **Explain to the student about the y versus t graph. This is not the trajectory (y versus x) of the ball but y-position versus time (y-position curve). The velocity (slope of the curve) seems to decrease steadily with time. There will be few students who won't understand the "decrease", obviously the speed (magnitude of the velocity or the magnitude of the slope) is increasing. Explain. The default positive direction of the y-axis is upward – numbers increases upward and decreased downward.**

Position Graph and Velocity Graph for red ball

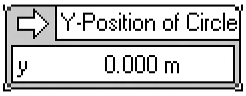
With the object circle selected, go to Menu "Measure" → Velocity → Y-graph. This will bring up the velocity curve. Double click on the velocity graph; the property window pops up. Unclick the tick marks under "Auto" and set the minimum and maximum values as (0, 1) for x-axis and (-20, 10) for y-axis. Close the properties window.

Run this model and observe. As suspected you see that the velocity is decreasing steadily (straight line), meaning the acceleration is negative and constant. Stop and Reset to return to edit mode.

Go to Menu "Define" → Vectors → and click on "Velocity. This will make the velocity vector to be displayed on the ball as it falls. Run and observe.

You can make the simulation to stop after a given time as follows: Go to Menu "World" → Pause Control → click on "new condition" and in the "Pause when" type in "time > 2.5". Run the simulation again and wait until it stops on its own at t =2.55 s.

Use the "Tape Player Control" slider to move the model frame by frame at will, forward and backward. You can stop at any time and get the time from the "time" meter. Click on the white arrow on the y-position graph, until the display changes to show just the y-coordinate.



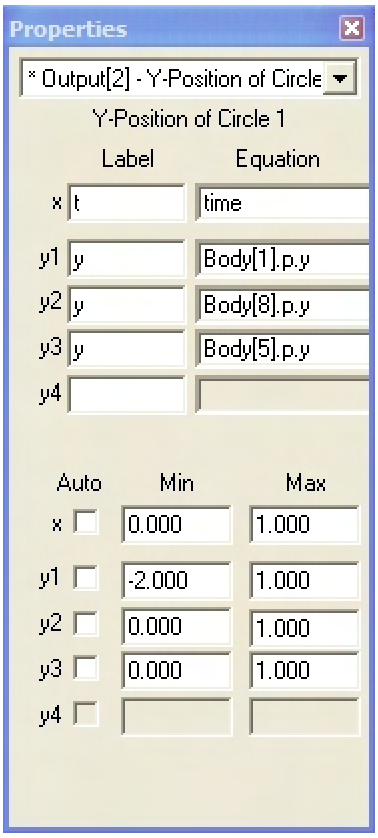
Switch it back to display the graph.

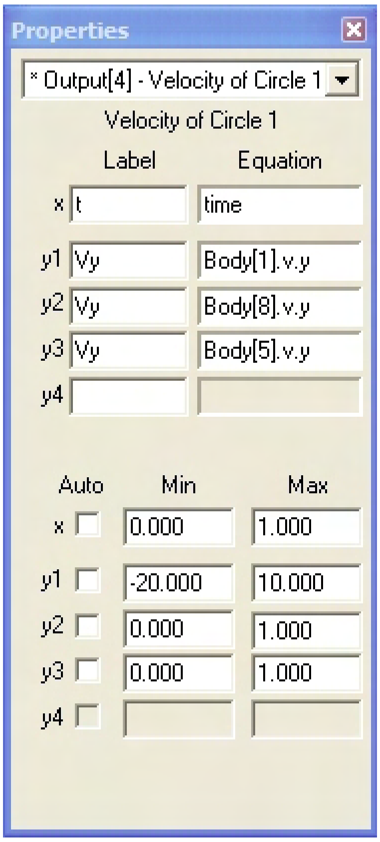
Place two more circles (one blue and other green; use the appearance window) to the left and right of this red disk. Make the coordinate of the blue circle (-2, 0) and green circle (+2, 0).

Double click on the blue circle to bring out the properties window. Set the initial y-velocity (Vy) to +4.00 m/s. From the Define menu make the velocity vector to be displayed. Do the same with the green circle but set the initial y-velocity to -4.00 m/s.

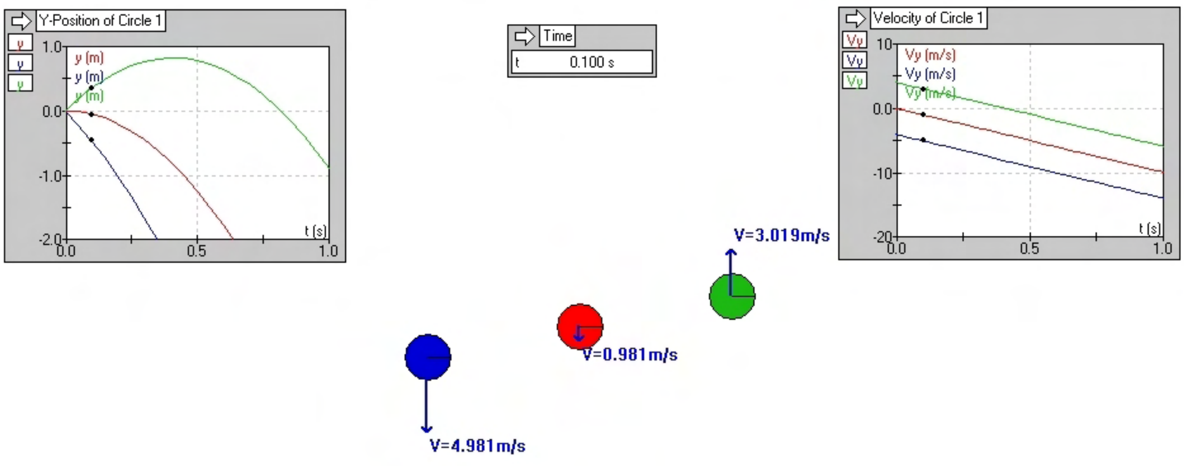
Graphs for blue and red balls as well

Double click on the y-position graph. Type "y" in the field *Label* of the row y2 and press enter; this will enable the field *Equation* in the same row (y2). Copy the text "Body[1].p.y" from the field above (in row y1) and paste it in the *Equation* field of row y2. Change it to read "Body[8].p.y" or whatever the correct name of the blue ball in your case. Type "y" in the field *Label* field of the row y3 and enter, this will enable the field *Equation* in row y3. Type "Body[5].p.y" or whatever the correct name of the red ball.
Repeat this procedure for the velocity graph, but typing Vy in the label field. At the end the property windows for the graphs should look like below:





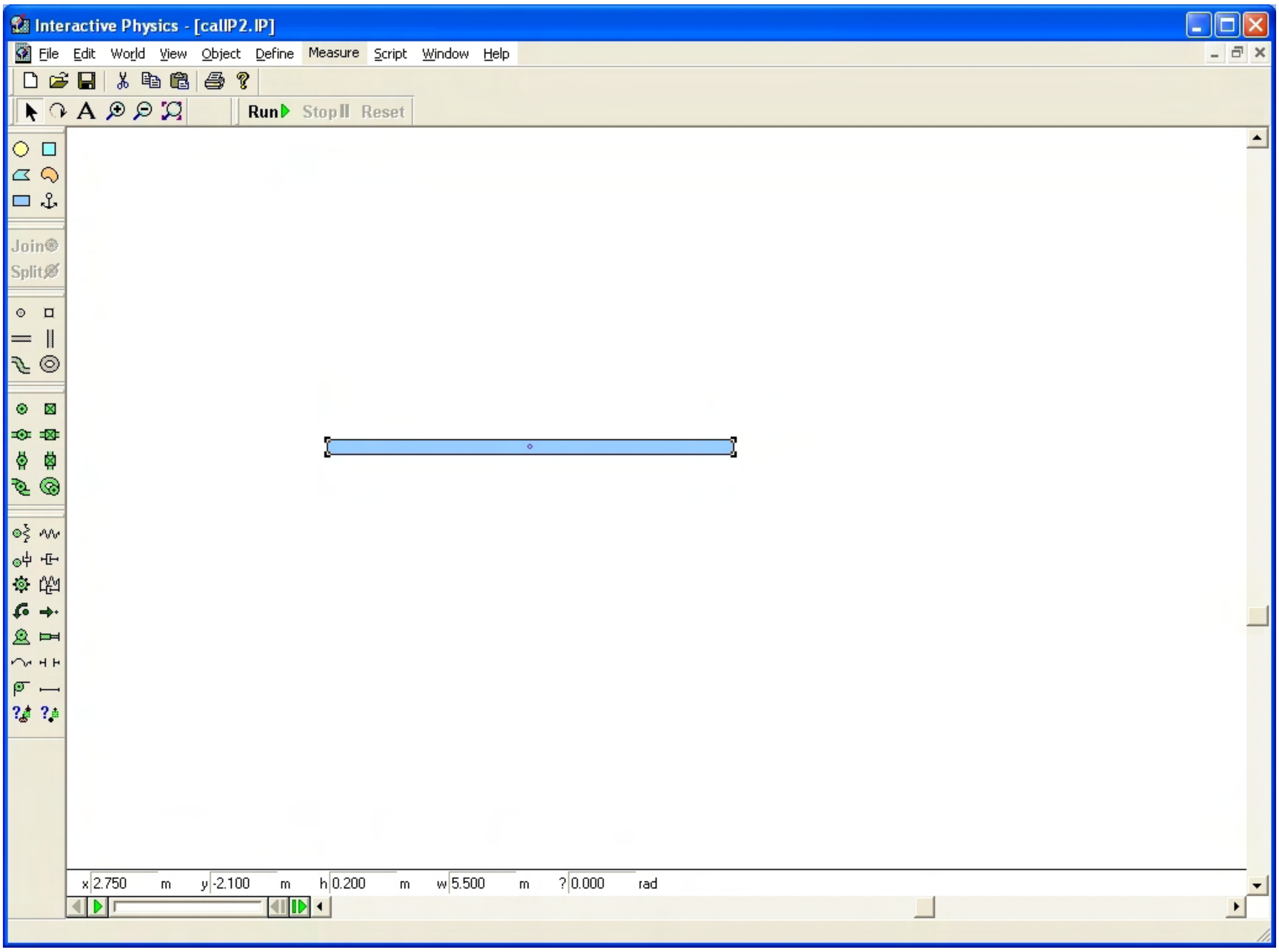
Run the simulation until it stops and reset. You will now have something like this:



For Instructors: **Direct the students' attention to the position curve of blue circle and show them that the rate of change of y-position is steadily decreasing always: on its way up, at the top and on the way down. Velocity curve on the right proves it. And whatever the initial velocity is all three balls have the same rate of change of velocity (the same negative, constant slope for the velocity curve - acceleration) throughout its journey. The acceleration of a freely falling body is the same and is downward (negative if we choose positive direction to be upward, as it is in IP) whether it is going up, down or at the top**.

PART B: (Acceleration on a smooth incline).

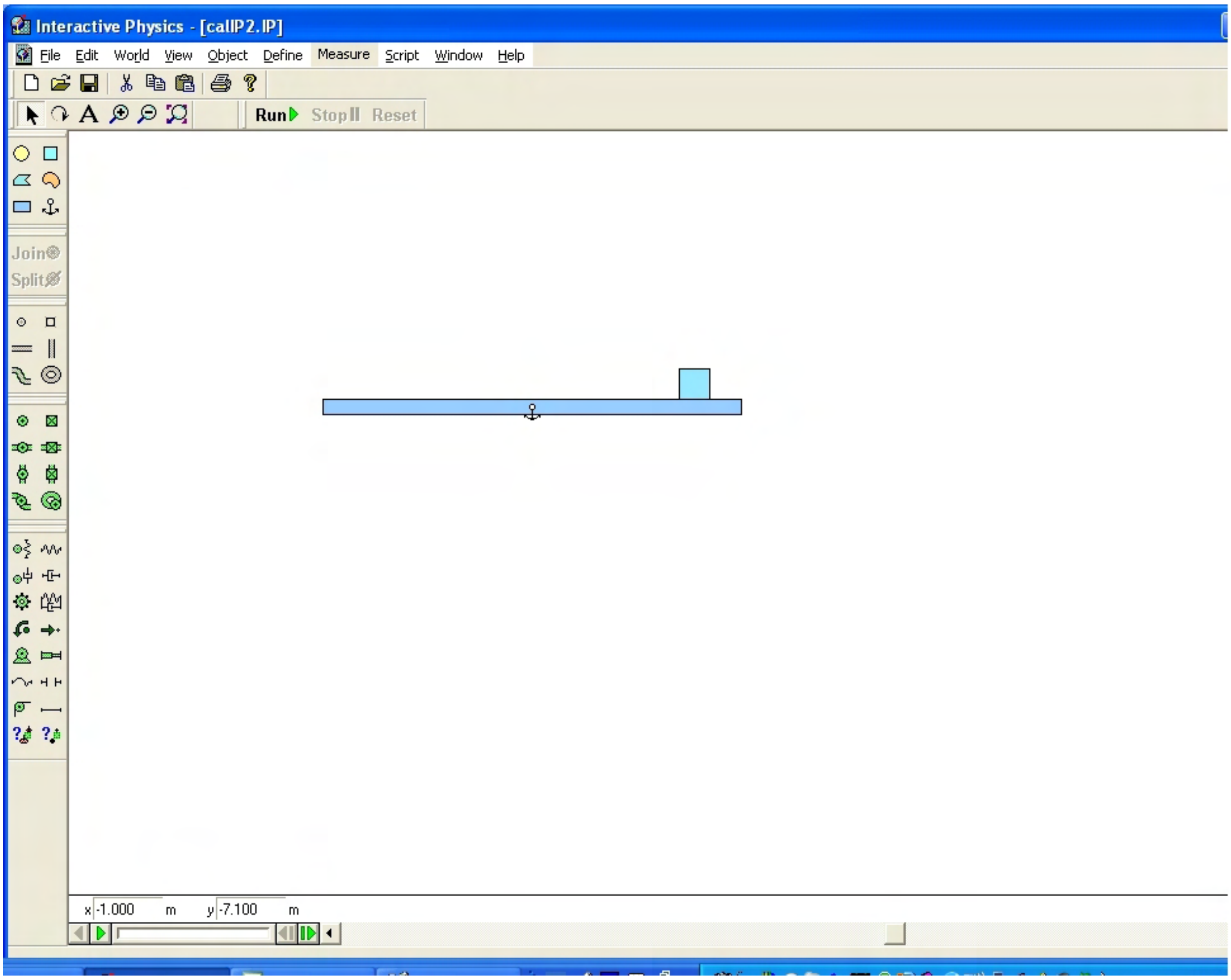
Choose the rectangle tool, and draw a rectangle in the drawing area.



Go to menu "View" and make sure that Oject Snap (and Grid Snap) are enable (ticked).

Click the anchor tool  , and click preferably on the center point of the rectangular block. The anchor tool has the effect of fixing the object to whatever is behind it, in this case the background. So when the simulation starts, the block will not fall.

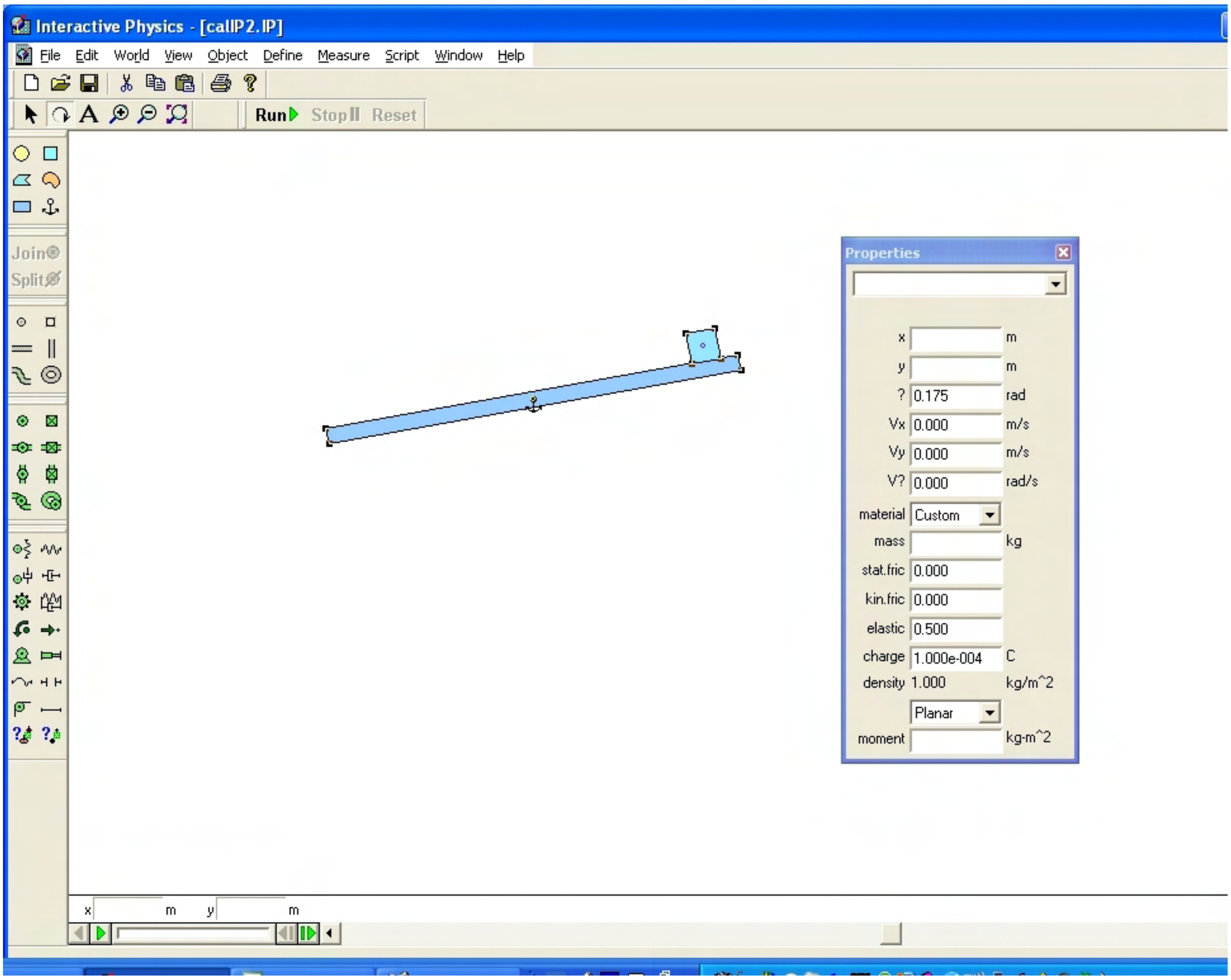
Now draw a square block using the square tool and move it to place exactly on the rectangular block somewhere on the right side. This is possible only if the "Object Snap" is ticked.



Double click on the rectangular block to bring up the properties window and make both the kinetic and static friction of the block zero. It is not necessary to make the friction of the square block to be zero, as IP will take the friction to be the friction of the one with the smaller value.

Select both the rectangle and the square together. Go to Window menu → Properties. In the properties window set both the kinetic and static friction to zero.

With both blocks still selected, click the rotate tool . Rotate by picking the center of the rectangle block by about 10 degrees (0.175 rad) counterclockwise.



Click the arrow tool. Click on an empty white space, so none of the objects is selected. Close the properties window.

Draw a marquee over the square block so only the square block is selected. Go to the menu "Measure" → Acceleration → All.

Run the simulation and record the total acceleration (|A|), which is the acceleration of the block along the rectangle block.

Repeat this with different angle of the smooth incline and each time record the acceleration.

Plot a graph of acceleration versus angle in EXCEL and see if you can figure out the relationship between them from the experimental data.