GAZİ UNIVERSITY

PHYS156

PHYSICS LABORATORY

MANUAL

ANKARA 2019

CONTENTS

INTRODUCTION

AIR TABLE:

The air table experiment setup consists mainly of the following elements:

- **a.** Air Desk,
- **b.** Discs,
- **c.** Arc chronometer,
- **d.** Air pump.

The air table consists of a thick glass plate placed into the metal frame, having screwed legs to provide adjustable height for the inclination. In the experimental setup, the compressed air coming from the air pump passes through the distributor plastic hose and reaches the discs. The discs are connected to the arc chronometer with the help of conductive chains passing through the plastic hoses. The airbag formed between the disc and the table surface allows the discs to move without friction. The conductive carbon paper and the trace paper to record the test data are placed between the table surface and discs. The arc chronometer generates a timed tuned signal to provide a spark at the bottom of the disc. Due to the impact generated by the sparks, the trajectory of the disc is obtained on the back of the trace paper. As a result of the time-dependent positions of the discs during the motion, the experimental data can graphically be obtained.

AIR TABLE OPERATION:

1. The test paper (trace paper) is placed properly without adhering onto the carbon paper.

2. The arc pedal is placed in a position so that it can be easily operated. The operation of the air pump provides discs to move in the air table. The arc pedal is pressed to determine the position of the moving discs during their motion. If only one of the discs is to be used in the experiment, the other disc is left in a suitable corner of the table so that it remains on top of the carbon paper.

3. To determine whether the air table is in a horizontal position, the discs are placed in the center of the table and the air pump is switched on. If the air table is horizontal position, the discs remain still in the center of the air table. However, the air table is inclined if the discs move when the air pump is turned on. In this case, the air table is adjusted horizontal position by using the screws of the table legs.

4. Place both discs on top of the trace paper, open the air pump, push the discs lightly and press the arc pedal. When the discs reach the edge of the table, the arc pedal is released and the traces of sparks of the discs appear on the rear side of the trace paper. The same procedure can be repeated by changing the frequency of the arc chronometer.

GRAPHIC and GRAPHIC DRAWING:

Because of its practical and easy understanding, the results of the experiments are usually given graphically. The following rules must be applied in the graphic drawing:

1. Write the name and date of the graph.

2. Remark what the axes correspond to and what their units are.

3. Place the text and numbers easily readable.

4. Select the unit lengths in the graph so that the drawn graph covers the entire paper. The graphical axes should be scaled appropriately within themselves.

5. Mark the data as a dot on the graph and circle these dots.

I. Importance of Graphs

Physical expressions are obtained in two ways as theoretical and experimental. In the theoretical method, assumptions are made and the suitability of the expected results is investigated. Unless they are proved by experimentation, they are not considered as a law of physics. In experimental method, laws or relations are based on experimental results. Even if these are not obtained theoretically, their accuracy is certain.

II. Benefits of Graphs

According to the data obtained experimentally, the physical meaning of the graph is called the *graphical analysis*. The key benefits of a graph analysis are as follows:

- The graph shows whether a correlation exists between the measured quantities. It is not possible to see this directly from the data table.
- If there is a relation between the measured quantities, the mathematical relation between them is derived with the help of the graph.
- Even if there is no relation between the variables, the graphs can be used to obtain the non-measured values of the variables.

III. Graphic Drawing

In order to obtain the expected benefits from the graph, the following points should be taken into account in the graphical drawing. If this is not done, there may be an incorrect relation from the graph or the graph may not be analyzed properly. The following are the main rules for graph drawing:

1. Selection and Marking of Coordinate Axes

The free variable is placed on the horizontal axis and the bound variable is placed on the vertical axis. The name of the variables and the units are written in parentheses.

2. Scale Selection

One unit (1 cm) length is referred to as the *scale* (or function scale) in horizontal and vertical axis. Scale selection is arbitrary. The following rules must be applied in the selection of the starting point of the scale and the variables.

a. In the scale, the integer values of the measured quantity should be shown, the fractional parts after the integer should not be shown. If this rule is not applied, it is difficult to mark the data and read the value from the graph.

b. If the data consists of very large or very small numbers, these are written in the form of to order of ten and the scale selection is made thereafter. In graph paper, exponential multiplier is written in parentheses together with the unit.

c. Depending on the data, the scale units of the *x* and *y* axes may not be equal.

d. The zero values of free and bound variables can be found at the origin or, in general, the zero value of one or both variables may be absent from the origin.

e. The values on the *x* and *y* axis should not be intersected with dashed lines when drawing graphics.

3. Marking Data

The locations of the data are obtained on the related axes and their intersection are marked by one of the symbols in Figure 1 (The first symbol is preferred). *Measured values should never be written on the coordinates*. If multiple graphs are drawn on the same graph paper, a separate symbol must be used for each curve.

⊙ △ ⊡ + ×

Figure 1. Shapes used to mark data in graphical drawing.

4. Curve Drawing

The dots marked on the axes form a curve (trajectory). The word of "curve" is used to mean both straight line and curved line. The laws of physics and their relations are in the form of simple equations. Since the data may contain errors, all points may not be on the curve. The probability of errors being positive and negative is equal. Therefore, the curve must be drawn in as many points as possible and centered on the points. (The drawn curve does not have to pass through all data points. Note that there must be an equal number of dots above and below the drawn curve.) Figure 2 shows how to draw the curve for some examples.

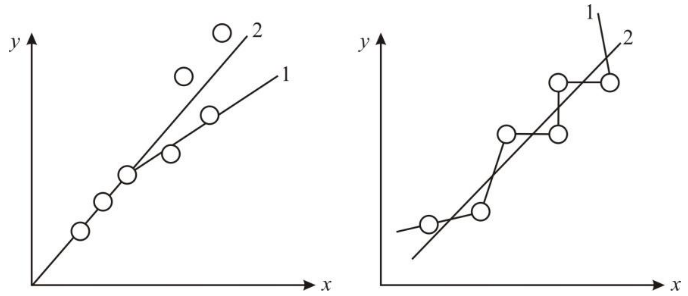


Figure 2. Curve Drawing in Graph. (1) wrong drawing; (2) shows the correct drawing.

PHYS156 PHYSICS LABORATORY APPLICATION RULES

Preliminary Study: Students should have prior knowledge about the experiment. They also need to make the preliminary work required to write a report.

Preliminary Exam: It is a theoretical examination which is a prerequisite for starting the experiment in order to determine whether the student is ready for the experiment in relation to the experiments. The exam is evaluated over 100. Students who take less than 30 points are not taken into the experiment. These students participate in the make-up experiments. Following the completion of the experiments, average preliminary exam grade will be announced.

Report: The report to be written at the end of each experiment is a study that integrates the experiment. The report should be prepared and delivered within the lesson hour, or it should be delivered at the beginning of the lesson the following week, if the time is not sufficient. Reports that are not submitted on time are not taken into account and their grade is considered to be zero. Reports are evaluated over 100. After completion of the experiments, the average of the report grade of all experiments is announced.

Absence Status: According to Article 13/1 of Gazi University Associate Degree and Undergraduate Education and Examination Regulation which is published in the Official Gazette No. 30171 dated 05.09.2017, students are obliged to attend at least 80% of the lessons, consists entirely of practical course hour, for each semester. This student cannot participate in subsequent experiments. The maximum number of experiments a student can absent is 2. The students coming to the class before the end of the pre-test will be taken into the experiment. These students are not given extra time for the preliminary examination.

Make-up experiment: If the student gets less than 30 or cannot come to the experiment, he / she will participate in the make-up experiment. The maximum number of make-up experiments a student can attend is two. Students who have more than two make-up experiments are considered as absent. In these experiments, preliminary exams and reports are evaluated over 70 points. These experiments are made at the end of all experiments, and the student who cannot succeed in the preliminary examination carried out in these experiments cannot make the make-up experiment again.

Midterm Exam: This exam is a theoretical and common exam. In the exam, the student is given an experiment data as a generally and his / her knowledge about the experiment is tested. The midterm exam is evaluated over 100.

Midterm Exam Mark: Mid-term exam grade, preliminary exam grade mark average and report mark average are collected and the resulting value is divided by three. This mark is "Midterm Exam Mark".

Final Exam: Final exam is a theoretical and common exam which is done at the end of the semester. In the exam, the student is given an experiment data as a generally and his / her knowledge about the experiment is tested. The midterm exam is evaluated over 100.

Final Grade: The final grade is the sum of 60% of the midterm and 40% of the final exam.

List of materials for laboratory course:

Laboratory Manual, Graph Paper, Report Papers, Trace Paper, Calculator, Ruler, Eraser, Pen/pencil

EXPERIMENT-1

STRAIGHT LINE MOTION WITH CONSTANT VELOCITY

AIM OF THE EXPERIMENT:

To examine how displacement changes with time in uniform linear motion.

THEORY:

An object moving at a constant velocity in a straight line makes a uniform linear motion. The object takes equal paths at equal time intervals and the velocity doesn't change with time. Taking $x_i = 0$ in straight line motion ($a_x = 0$), the expression of the displacement as the function of the velocity and time can be obtained as

$$x_f = x_i + v_i t + \frac{1}{2} a_x t^2 \rightarrow x = vt$$

The positon-time (*x*-*t*) graph and the velocity-time (*v*-*t*) graph are shown in Figure 1 (a) and (b), respectively. The slope of the *x*-*t* graph gives the velocity of the object.

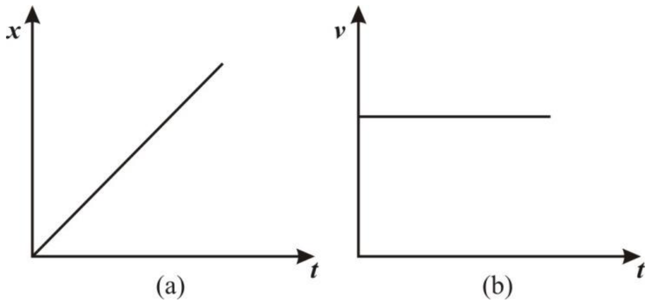


Figure 1. Time-dependent variation of (a) the position, (b) the velocity.

PRELIMINARY STUDY: *Answer the following questions.*

1. Describe the average and instantaneous velocity. Write the mathematical expressions of them.

2. Describe the uniform linear motion.

3. Explain why the air table isn't inclined in this experiment?

EXPERIMENTAL PROCEDURE:

1. Make the air table horizontal.

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom right corner of the trace paper and keep it motionless there for the duration of the experiment. Place the other disc on the top of the paper.

4. Before pressing the arc pedal, make a few attempts to keep the disc moving at a constant speed.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

5. After the sufficient attempts, turn on the arc chronometer. Accelerate the disc by pressing the arc pedal and the air pedal at the same time. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 2.

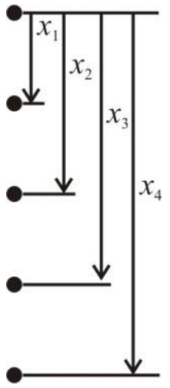


Figure 2. Sample trace paper

6. Record the frequency (f) of the arc chronometer. The time between two consecutive points on trace paper (A) is obtained as

f=…

A =1/f =.....

7. Set the starting point of the motion on the trace paper. Measure the distance of each point from the starting point (x_1, x_2, x_3, ...) with the ruler and write it down in the table (see Figure 2).

8. Calculate the elapsed time (t) for each point and write it down in the table: For the first point $1\times A$, for the second point $2\times A$ …

x (…)	**t (...)**
x_1=	$t_1=1\times A=$
x_2=	$t_2=2\times A=$
x_3=	$t_3=3\times A=$
x_4=	$t_4=4\times A=$
x_5=	$t_5=5\times A=$
x_6=	$t_6=6\times A=$
x_7=	$t_7=7\times A=$
x_8=	$t_8=8\times A=$
x_9=	$t_9=9\times A=$
x_{10}=	$t_{10}=10\times A=$

9. Using the table, draw the x-t graph, what kind of curve do you obtain? Interpret your result.

10. Is there a relationship between the slope of the curve and the speed of the disc? If available, use the graph to calculate the speed of the disc.

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-2

MOTION WITH CONSTANT ACCELERATION

AIM OF THE EXPERIMENT:

To examine how displacement changes with time in a motion with constant acceleration.

THEORY:

If a constant external force is applied to the object, the body moves with a constant acceleration. The speed of an object increases equally in equal time intervals, and the displacement (x) of the objects is given by $x_f = x_i + v_i t + \frac{1}{2}at^2$. In the case of releasing from rest and the origin, the displacement becomes

$$x = \frac{1}{2}at^2$$

Also, the velocity (v) of the objects is given by $v_f = v_i + at$. In the case of releasing from rest and the origin, the velocity becomes

$$v = at$$

Here, *a* and *t* is the acceleration and time, respectively. The *x*-*t* graph, the *v*-*t* graph and the *a*-*t* graph are shown in Figures 1 (a), (b) and (c), respectively. The slope of the *v*-*t* graph gives the acceleration of the object. At the same time, the slope of the x-t^2 graph equals the half the acceleration of the object.

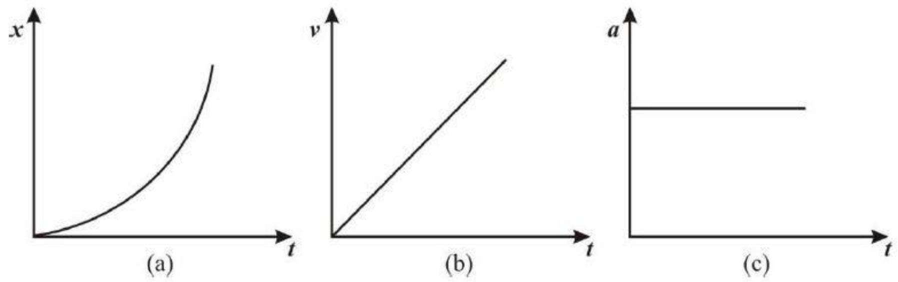


Figure 1. The time dependence of (a) displacement, (b) velocity, and (c) acceleration in motion with constant acceleration.

The motion of an object on an inclined plane with angle θ can be given as an example of motion with constant acceleration (Figure 2). The forces acting on the object are shown in Figure 2.

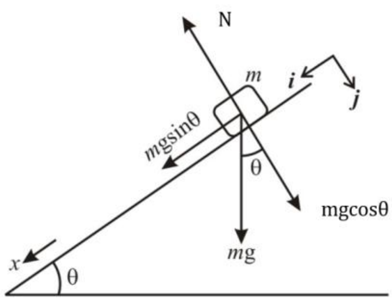


Figure 2. Inclined plane

In the x-direction, the force $\vec{F}_x = mgsin\theta\hat{\imath}$ acts and the body moves in the x-direction with *constant acceleration* due to this force. Since the magnitude of the action and reaction forces are equal and opposite, there is no motion in the y-direction. The acceleration of motion can be calculated from Newton's second law:

$$F = ma \rightarrow a = F/m = F_x/m = mgsin\theta/m = gsin\theta$$

In other words, the acceleration of the moving object on the inclined plane is constant. The acceleration of the object is the product of the gravitational acceleration and the sine angle of the inclination angle. In this case, the displacement is

$$x = \frac{1}{2}at^2 = \frac{1}{2}gsin\theta t^2$$

for an object that released from rest from the origin.

PRELIMINARY STUDY: *Answer the following questions.*

1. What is a motion with constant acceleration?

2. Write and explain the Newton Laws of Motion in order.

EXPERIMENTAL PROCEDURE:

1. Make the air table horizontal. Then make the table inclined with θ angle raising one of the legs of the table using a block. Measure a and b lengths to determine the angle θ. For θ_1

$$sin\theta_1 = \frac{b-a}{L} \rightarrow \theta_1 = arcsin\left(\frac{b-a}{L}\right) \rightarrow \theta_1 =$$

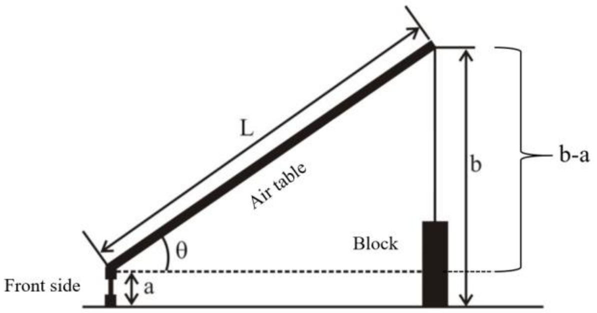


Figure 3. Determination of the inclination angle of air table

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom right corner of the trace paper and keep it motionless there for the duration of the experiment.

4. Place the other disc on the top of the paper. Before pressing the arc pedal, make a few attempts to keep the disc moving at a constant speed.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

5. After the sufficient attempts, turn on the arc chronometer. Release the disc from rest by pressing the arc pedal and the air pedal at the same time. Raise the trace paper and make it checked by the advisor if you have obtained a pattern as shown in Figure 4.

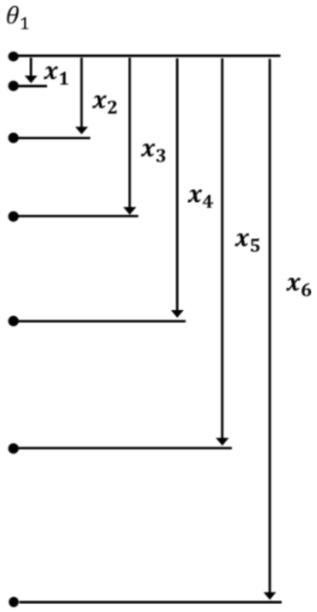


Figure 4. Sample trace paper (for θ_1 angle)

6. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=...

A =1/*f* =...

7. Set the starting point of the motion the track paper. Measure the distance of each point from the starting point (x_1, x_2, x_3, ...) with the ruler and write it down in the table (see Figure 4).

8. Calculate the elapsed time (*t*) for each point and write it down in the table: For the first point *1×A,* for the second point *2×A …*

$\boldsymbol{\theta_1} =$		
***x* (…)**	***t* (...)**	***t*² (…)**
x_1=	t_1 =1×A=	t_1^2 =
x_2=	t_2 =2×A=	t_2^2 =
x_3=	t_3 =3×A=	t_3^2 =
x_4=	t_4 =4×A=	t_4^2 =
x_5=	t_5 =5×A=	t_5^2 =
x_6=	t_6 =6×A=	t_6^2 =
x_7=	t_7 =7×A=	t_7^2 =
x_8=	t_8 =8×A=	t_8^2 =
x_9=	t_9 =9×A=	t_9^2 =
x_{10}=	t_{10} =10×A=	t_{10}^2 =

9. Repeat the steps **7** and **8** for two different angles (using blocks of different lengths). Find θ_2 and θ_3:

$$sin\theta_2 = \frac{b_2 - a_2}{L} \rightarrow \theta_2 = arcsin\left(\frac{b_2 - a_2}{L}\right) \rightarrow \theta_2 =$$

$$sin\theta_3 = \frac{b_3 - a_3}{L} \rightarrow \theta_3 = arcsin\left(\frac{b_3 - a_3}{L}\right) \rightarrow \theta_3 =$$

Create the following tables.

$\boldsymbol{\theta_2} =$		
***x* (…)**	***t* (…)**	***t*² (…)**
x_1=	t_1=1×A=	$t_1^2 =$
x_2=	t_2=2×A=	$t_2^2 =$
x_3=	t_3=3×A=	$t_3^2 =$
x_4=	t_4=4×A=	$t_4^2 =$
x_5=	t_5=5×A=	$t_5^2 =$
x_6=	t_6=6×A=	$t_6^2 =$
x_7=	t_7=7×A=	$t_7^2 =$
x_8=	t_8=8×A=	$t_8^2 =$
x_9=	t_9=9×A=	$t_9^2 =$
x_{10}=	t_{10}=10×A=	$t_{10}^2 =$

$\boldsymbol{\theta_3} =$		
***x* (…)**	***t* (…)**	***t*² (…)**
x_1=	t_1=1×A=	$t_1^2 =$
x_2=	t_2=2×A=	$t_2^2 =$
x_3=	t_3=3×A=	$t_3^2 =$
x_4=	t_4=4×A=	$t_4^2 =$
x_5=	t_5=5×A=	$t_5^2 =$
x_6=	t_6=6×A=	$t_6^2 =$
x_7=	t_7=7×A=	$t_7^2 =$
x_8=	t_8=8×A=	$t_8^2 =$
x_9=	t_9=9×A=	$t_9^2 =$
x_{10}=	t_{10}=10×A=	$t_{10}^2 =$

10. Using the tables, draw the *x-t* graphs, what kind of curves do you obtain? Interpret your results.

11. Using the tables, draw the *x*- t^2 graphs. Calculate the acceleration of the disc by taking the slope of the graph (*slope = a /2*) and write it in the table below.

12. Calculate the values of acceleration theoretically using the $a = gsin\theta$ equation and write in the table below.

θ (°)	$a_{experimental}$ (…)	$a_{theoretical}$ (…)
$\boldsymbol{\theta_1} =$		
$\boldsymbol{\theta_2} =$		
$\boldsymbol{\theta_3} =$		

13. How does the acceleration of the system change with the θ angle? Please explain.

14. Compare the theoretical acceleration values and experimental acceleration values. Are these values equal? If not, explain briefly why.

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-3

MOTION IN THE TWO DIMENSIONS-PROJECTILE MOTION

AIM OF THE EXPERIMENT:

To examine projectile motion and in order to understand some concepts such as maximum height, horizontal range, flight time.

THEORY:

When an object is launched at its initial velocity v_0 (at *t=0*) it moves so as to draw a parabolic trajectory (Figure 1). The *projectile motion* is one of the best examples of motions in two-dimensions. In a projectile motion when an object is moving at a constant speed along the *x*-axis, at the same time it makes a motion with constant acceleration along the *y*-axis. In other words, the velocity of the object on the *x*-axis, v_{0x}, remains constant during the motion, while the *y*-component of the velocity in the *y*-axis, v_{0y}, changes over time with the effect of gravity. The object slows down to the peak due to gravity and the *y*-component of its velocity becomes zero, then the *y*-component of the velocity begins to rise again.

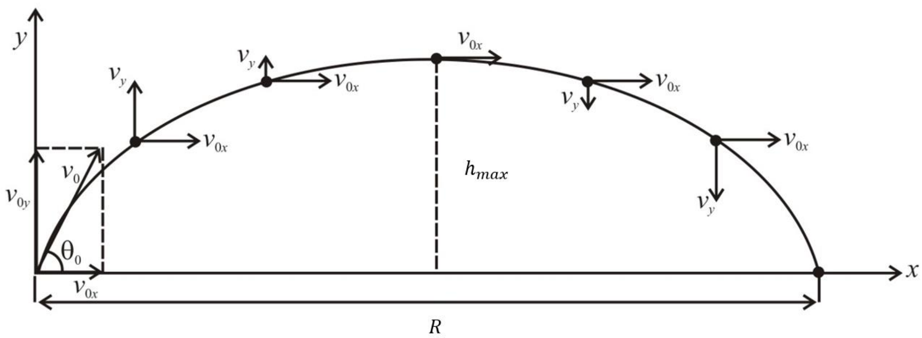


Figure 1. Projectile motion

The components of the initial velocity of the object are important for the kinematics of the projectile motion and are as follows:

$$v_{0x} = v_0 cos\theta_0$$

$$v_{0y} = v_0 sin\theta_0$$

During the motion the components of the velocity are as follows:

$$\vec{v}_x = \vec{v}_{0x} = \frac{dx}{dt} = v_0 cos\theta_0 \hat{\imath}$$

$$\vec{v}_y = \frac{dy}{dt} = (v_0 sin\theta_0 - gt)\hat{\jmath}$$

Taking the integral of these equations gives us displacements along the *x*- and *y*-axes:

$$x = v_0 cos\theta_0 \, t$$

$$y = v_0 sin\theta_0 \, t - \frac{1}{2} g t^2$$

If the time term (t) is eliminated between these two equations, $t = x/(v_0 cos\theta_0)$, *trajectory equation* is obtained as

$$y = tan\theta_0 x - \frac{g}{2(v_0 cos\theta_0)^2} x^2$$

This equation defines a parabola. Thus projectile motion is named as parabolic motion. However, the maximum height at which an object may rise is as follow:

$$h_{max} = \frac{(v_{0y})^2}{2g} = \frac{(v_0 sin\theta_0)^2}{2g}$$

The time reaching the maximum height is equal to the landing time from the maximum height and the sum of the two gives the flight time of the object:

$$t_{rising} = t_{landing} = \frac{v_{0y}}{g} = \frac{v_0 sin\theta_0}{g}$$

$$t_{flight} = 2t_{landing} = \frac{2v_0 sin\theta_0}{g}$$

Since the velocity of the object and its flight time are known, the distance of the object to the horizontal (range) can be calculated:

$$R = v_{0x} t_{flight} = v_0 cos\theta_0 \frac{v_0 sin\theta_0}{g} = \frac{{v_0}^2 (2sin\theta_0 cos\theta_0)}{g} = \frac{{v_0}^2 sin(2\theta_0)}{g}$$

Important: *In the calculations related to the experiment, it will be taken $g sin\varphi$ in place of g in the above equations due to the inclination (φ) of the air table. θ_0 angle and φ angle should not be confused with each other.*

PRELIMINARY STUDY: *Answer the following questions.*

1. Explain the components of the projectile motion?

EXPERIMENTAL PROCEDURE:

1. Make the air table inclined with angle φ. Then calculate the angle φ.

$\varphi =$

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom right corner of the trace paper and keep it motionless there for the duration of the experiment. Place the other disc in the left corner of the paper and launch it at an angle θ_0 with an initial speed v_o. Before pressing the arc pedal, make a few attempts.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

4. After the sufficient attempts, turn on the arc chronometer. Launch the disc from the left corner by pressing the arc pedal and the air pedal at the same time. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 2.

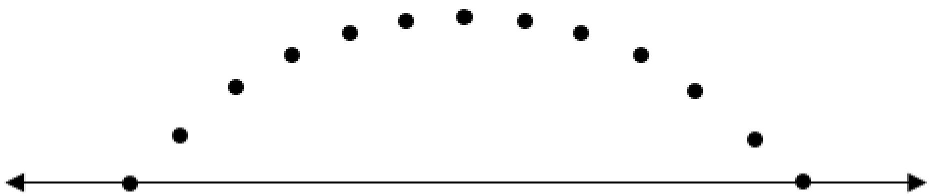


Figure 2. Sample trace paper for a projectile motion

5. As in Figure 3, make the necessary drawings and measurements on the trace pattern you have obtained.

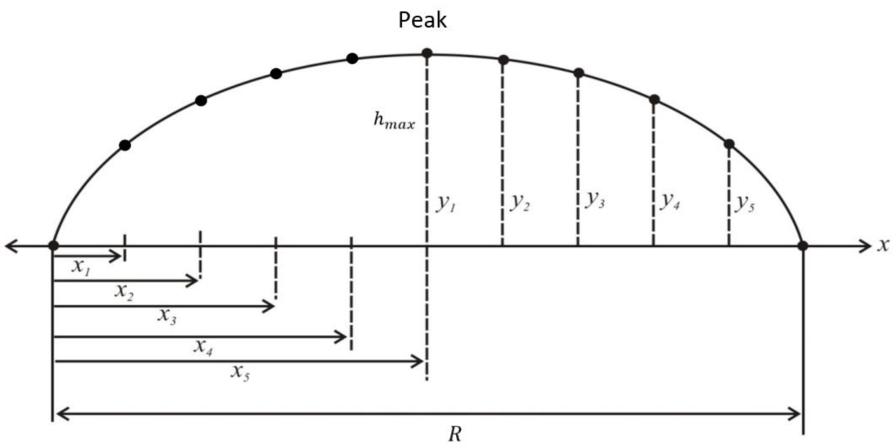


Figure 3. Drawings on the trace paper

6. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=...

A =1/f =...

7. Count how many intervals exist until the disc reaches the peak of the trajectory and multiply this value by *A* to calculate the rising time of the disc.

t_{rising} =…

8. Count how many intervals consist during landing and multiply this value by *A* to calculate the landing time of the disc.

$t_{landing}$ =…

9. Are the rising and the landing times equal each other? Calculate the total flight time of the disc.

t_{flight}=…

10. Calculate the *y*-component of the initial velocity.

$$t_{rising} = \frac{v_{0y}}{gsin\varphi} \rightarrow v_{0y} = gsin\varphi \times t_{rising} = \cdots$$

11. Measure the horizontal component of the displacement between first two point.

$x_1 = \cdots$

12. Calculate the *x*-component of the initial velocity dividing x_1 by *A*.

$$v_x = v_{0x} = \frac{x_1}{A} = \cdots$$

Also, measure the horizontal component of the displacement between the starting point and the trajectory peak and write it down in the table. Plot the *x*-*t* graph and interpret the result.

***x* (…)**	***t* (…)**
x_1=	$t_1=1\times A=$
x_2=	$t_2=2\times A=$
x_3=	$t_3=3\times A=$
x_4=	$t_4=4\times A=$
x_5=	$t_5=5\times A=$
x_6=	$t_6=6\times A=$
x_7=	$t_7=7\times A=$

13. Calculate the launching angle and the initial velocity.

$$\tan\theta_0 = \frac{v_{0y}}{v_{0x}} \rightarrow \theta_0 = \ ...$$

$$v_0 = \sqrt{{v_{0x}}^2 + {v_{0y}}^2} = \ ...$$

14. Calculate the maximum height and range of the object. Compare these values to the ones you measured from the paper.

	Calculated	Measured
$h_{max} = \frac{(v_0 sin\theta_0)^2}{2gsin\,\varphi}$		
$R = \frac{{v_0}^2 sin(2\theta_0)}{gsin\varphi}$		

15. Choose a point on the trajectory. Determine the *(x,y)* coordinates and the time value of this point.

$(x, y) = \cdots$

$t\ = \cdots$

Calculate the value of *y* substituting the value of *x* into the trajectory equation.

$$y = tan\theta_0 x - \frac{gsin\varphi}{2(v_0 cos\theta_0)^2}x^2 = \cdots$$

Calculate the value of *t* substituting the value of *y* into the displacement equation.

$$y\ = v_0 sin\theta_0\, t - \frac{1}{2}gsin\varphi t^2 = \cdots$$

Compare the measured value of *y* with the calculated value of *y*.

16. Measure the *y* distances for the landing part of the motion (See Figure 3) and fill the table.

			y (...)				t^2 (…)
y_1=		y_1- y_1=		t_1=1×A=		t_1^2 =	
y_2=		y_1- y_2=		t_2=2×A=		t_2^2 =	
y_3=		y_1- y_3=		t_3=3×A=		t_3^2 =	
y_4=		y_1- y_4=		t_4=4×A=		t_4^2 =	
y_5=		y_1- y_5=		t_5=5×A=		t_5^2 =	
y_6=		y_1- y_6=		t_6=6×A=		t_6^2 =	
y_7=		y_1- y_7=		t_7=7×A=		t_7^2 =	

17. Plot y-t^2 graph using the table, interpret the results.

18. Calculate the acceleration of the disc by taking the slope of the y-t^2 graph (slope=a/2) and compare with $a = gsin\varphi$.

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-4
CONSERVATION OF THE MECHANICAL ENERGY

AIM OF THE EXPERIMENT:

To examine the conservation of mechanical energy.

THEORY:

The mechanical energy of the system is conserved if all the existing forces are conservative in other words, if there is no nonconservative forces such as friction force in any physical system. Mechanical energy is defined as the sum of kinetic and potential energies.

$$E = U + K$$

The mechanic energy at any moment of motion remain constant. The kinetic energy during the motion can be transformed into potential energy or potential energy can be transformed into kinetic energy.

$$\Delta E = E_s - E_i = 0 \rightarrow E_i = E_s$$

Potential energy is the energy that an object has due to its position. For example, if the object is elevated from the Earth's surface to a point height *h*, it gains potential energy. The gained energy is given as

$$U = mgh$$

Kinetic energy is the energy which arises from the motion of an object. That is, if the object has a velocity, it also has kinetic energy expressed as follows

$$K = \frac{1}{2}mv^2$$

Where *m* and *v* are the mass and the velocity of the object, respectively.

PRELIMINARY STUDY: *Answer the following questions.*

1. Explain the conservation of the mechanical energy?

2. Explain the conservative and nonconservative forces, and give examples.

EXPERIMENTAL PROCEDURE:

1. Make the air table horizontal.

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom right corner of the trace paper and keep it motionless there for the duration of the experiment. Attach the mass to the end of a 70-80-cm-long rope with a ring. Then, attach the ring on the end of the rope to the disc.

4. Pass the rope to the pulley and let the mass hang downward.

5. Press the air pedal. You will see that the disc is activated with the effect of mass.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

6. After the sufficient attempts, turn on the arc chronometer. Release the disc from rest by pressing the arc pedal and the air pedal at the same time. Raise the trace paper and consult your advisor whether you have obtained a pattern.

7. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=…

A =1/f =...

8. Similar to the previous experiment on the motion with constant acceleration, fill in the following table using the traces you have obtained.

***x* (…)**	***t* (...)**	***t*² (….)**
x_1=	t_1 =1×A=	t_1^2 =
x_2=	t_2 =2×A=	t_2^2 =
x_3=	t_3 =3×A=	t_3^2 =
x_4=	t_4 =4×A=	t_4^2 =
x_5=	t_5 =5×A=	t_5^2 =
x_6=	t_6 =6×A=	t_6^2 =
x_7=	t_7 =7×A=	t_7^2 =
x_8=	t_8 =8×A=	t_8^2 =
x_9=	t_9 =9×A=	t_9^2 =
x_{10}=	t_{10} =10×A=	t_{10}^2 =

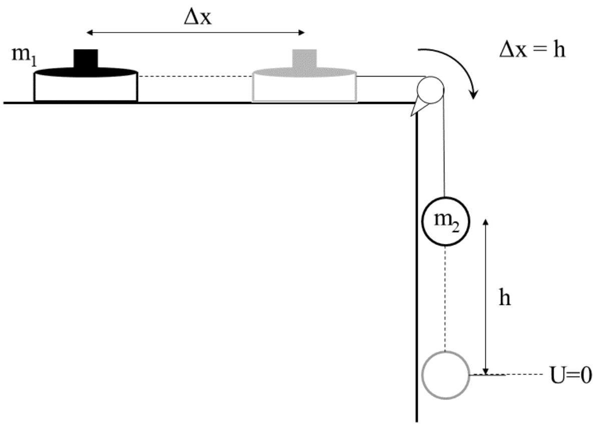


Figure 1. Experimental setup.

9. Using the table, draw the graph x-t^2. Calculate the acceleration of the disc by taking the slope of the graph from slope = a/2.

$a_{disc} =$

10. Find final velocity (v_f) of the disc using timeless speed formula.

$v_f^2 - v_i^2 = 2a(x_f - x_i)$

x_i is the point where the traces begin, and x_f is the position of the point where it ends. Assuming that the disc starts from the rest, that is, v_i = 0 and x_i=0. Then the quantity x_f-x_i will be the distance between the initial and final trace.

$v_f = \cdots$

$\Delta x = (x_f - x_i) = \cdots$

11. The disc ($m_{disc} = m_1$) and the mass attached to the disc ($m_{mass} = m_2$) are shown in Figure 1. Note that the path taken by the disc on the air table is equal to the decrease in height of the mass attached to the disc.

$m_1 = m_{disc} = \cdots$

$m_2 = m_{mass} = \cdots$

12. Since the mechanical energy must remain constant, the kinetic energy that the disc gains must be equal to the potential energy lost by the mass attached to the disc. Check if the initial mechanical energy equals the final mechanical energy $E_i = E_f$. If not, what could be the reason?

$m_2 gh = \frac{1}{2} m_1 v_f^2 + \frac{1}{2} m_2 v_f^2 \rightarrow \cdots$

13. If there is friction in the system, the friction coefficient (μ) is calculated as follows:

If Newton's Second Law applies to mass m_1:

$$\sum F_y = m_1 a_y \rightarrow N - m_1 g = 0 \rightarrow N = m_1 g$$

Then,

$$E_f - E_i = -f_s \Delta x \rightarrow \left[\frac{1}{2} m_1 v_f^2 + \frac{1}{2} m_2 v_s^2\right] - m_2 gh = -\mu N \Delta x$$

$$\rightarrow \frac{1}{2}(m_1 + m_2) v_f^2 - m_2 gh = -\mu m_1 g \Delta x \rightarrow \mu = \frac{m_2 gh - \frac{1}{2}(m_1 + m_2) v_f^2}{m_1 g \Delta x}$$

Find the coefficient of friction using this equation

$\mu = \cdots$

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-5

CIRCULAR MOTION WITH CONSTANT ACCELERATION

AIM OF THE EXPERIMENT:

To have information about circular motion, tangential acceleration and angular acceleration.

THEORY:

The simplest rotating motion about a fixed axis is a circular motion with constant acceleration. It can be examined in analogous to the linear motion with constant acceleration. However, some changes must be done: angular velocity (w) instead of linear velocity, angular displacement (θ) instead of linear displacement, and angular acceleration (α) are used instead of linear acceleration. For an object with constant angular acceleration, the angular velocity is

$$w_f = w_i + \alpha t$$

and the angular displacement is

$$\theta_f = \theta_i + w_i t + \frac{1}{2}\alpha t^2$$

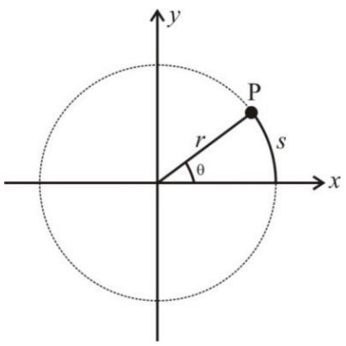


Figure 1. Arc length

For an object rotating in a circular orbit, the arc length s (Figure 1) is given by

$$s = r\theta$$

If the radius is constant, it is remembered that the velocity is the first derivative of displacement, the following relation exists between tangential velocity (v_t) and angular velocity:

$$\frac{ds}{dt} = r\frac{d\theta}{dt} \rightarrow v_t = rw$$

If it is recalled that acceleration is also the first derivative of velocity, a relationship between tangential acceleration and angular acceleration can be established by this relation:

$$\frac{dv_t}{dt} = r\frac{dw}{dt} \rightarrow a_t = r\alpha$$

PRELIMINARY STUDY: *Answer the following questions.*

1. What is a uniform circular motion?

2. What is circular motion with constant acceleration?

EXPERIMENTAL PROCEDURE:

1. Make the air table horizontal.

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom right corner of the trace paper and keep it motionless there for the duration of the experiment.

4. Attach the disc to the edge of the air table with a rope (Figure 2).

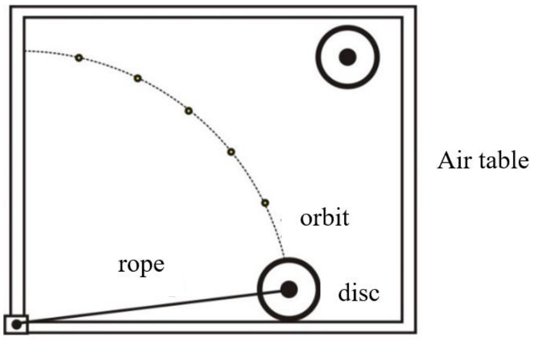


Figure 2. Experimental setup

5. Press the air pedal. Move the disc in circular orbit by giving an initial speed. The disc will make a quarter turn. Make sure the rope remains taut during the motion.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

6. After the sufficient attempts, turn on the arc chronometer. Move the disc in circular orbit by giving an initial speed by pressing the arc pedal and the air pedal at the same time. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 3.

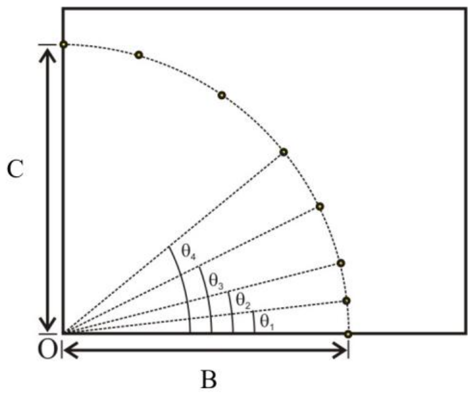


Figure 3. Trace paper

7. Mark *O*, *B* and *C* as shown in Figure 3. Measure the lengths *B* and *C*. If *B* = C, the disc is circular. If not take the measurement again.

$B = \cdots$

$C = \cdots$

8. Record the frequency (f) of the arc chronometer. Time between two consecutive points on trace paper (A) is obtained as

f=...

$A = 1/f =$...

9. Measure the angular displacements (θ) for each point and calculate the elapsed time (t), write it down in the table (1 radian=57.295°).

θ (°)	**θ (radian)**	***t* (…)**	***t*²(…)**
θ_1=		$t_1 = 1 \times A =$	
θ_2=		$t_2 = 2 \times A =$	
θ_3=		$t_3 = 3 \times A =$	
θ_4=		$t_4 = 4 \times A =$	
θ_5=		$t_5 = 5 \times A =$	
θ_6=		$t_6 = 6 \times A =$	
θ_7=		$t_7 = 7 \times A$	
θ_8=		$t_8 = 8 \times A =$	

10. Using the table, draw the graph θ-t^2, what kind of curve do you obtain? Interpret your result.

11. Calculate the angular acceleration (α) of the disc by taking the slope of the graph.

$Angular\ acceleration = \alpha = 2 \times slope =...$

12. The distances B and C measured above give the radius of motion. Calculate the tangential acceleration of the disc.

$a_t = \alpha \times B =...$

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-6
ELASTIC AND INELASTIC COLLISIONS

AIM OF THE EXPERIMENT:

To examine the conservation of linear momentum and conservation of kinetic energy in elastic and inelastic collisions in an isolated system.

THEORY:

The collision is called an elastic collision if momentum and kinetic energy of a system are conserved in the collision of two objects in an isolated system. Assume two objects with masses m_1 and m_2 are doing an elastic collision, and the velocities of the two masses before the collision are $\vec{v}_1$ and $\vec{v}_2$, respectively, and the velocities after the collision are $\vec{u}_1$ and $\vec{u}_2$, respectively. The conservation of linear momentum is given by

$$\vec{P}_{before} = \vec{P}_{after}$$

$$\sum \vec{P}_i = \sum \vec{P}_f \;\rightarrow \underbrace{m_1\vec{v}_1 + m_2\vec{v}_2}_{before\ collision} = \underbrace{m_1\vec{u}_1 + m_2\vec{u}_2}_{after\ collision}$$

The conservation of kinetic energy is

$$\sum K_i = \sum K_f \rightarrow \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$$

At the same time, the center of mass of the two objects moves with constant velocity $\vec{V}$. The velocity of the center of mass is written by

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{u}_1 + m_2\vec{u}_2 = (m_1 + m_2)\vec{V}$$

$$\vec{V} = (m_1\vec{v}_1 + m_2\vec{v}_2)/(m_1 + m_2) = (m_1\vec{u}_1 + m_2\vec{u}_2)/(m_1 + m_2)$$

If the masses of the two bodies are equal (if $m_1 = m_2$), the expressions for the conservation of momentum, the conservation of kinetic energy and the velocity of the center of mass are given as follows:

$$\vec{v}_1 + \vec{v}_2 = \vec{u}_1 + \vec{u}_2$$

$$v_1^2 + v_2^2 = u_1^2 + u_2^2$$

$$\vec{V} = (\vec{v}_1 + \vec{v}_2)/2 = (\vec{u}_1 + \vec{u}_2)/2$$

While the momentum is conserved in inelastic collisions, the kinetic energy is not conserved. In other words, a loss in kinetic energy occurs in such collisions. After the collision, the total kinetic energy is less than the total kinetic energy before the collision. The total kinetic energy K_i before the collision and the total kinetic energy K_f after the collision can be represented as

$$K_i > K_f$$

The difference in kinetic energy $(K_i - K_f)$ is transformed into heat energy or other energy forms, and can be defined the flexibility of collisions. The coefficient of elasticity for a collision is given as follow:

$$e = \left(K_i - K_f\right)/K_i$$

PRELIMINARY STUDY: *Answer the following questions.*

1. What is the difference between elastic and inelastic collision?

2. What is the mass center?

3. How is the combination of two vectors found?

EXPERIMENTAL PROCEDURE:

A. Elastic Collision

1. Make the air table horizontal.

2. Place the trace paper on the air table.

3. Place one of the discs in the bottom left and the other in the bottom right corner.

4. Press the air pedal. Accelerate the discs to ensure collision.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

5. After the sufficient attempts, turn on the arc chronometer. Move the discs by pressing the arc pedal and the air pedal at the same time.

6. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 1.

7. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=...

$A = 1/f =$...

8. Measure the velocities in each trajectory by the ruler and divide by the elapsed time (*A* value) to find the velocities before and after the collision (Figure 1). [Velocities before the collision: $\vec{v}_1$ and $\vec{v}_2$, velocities after the collision: $\vec{u}_1$ and $\vec{u}_2$]

$$v_1 = \frac{\dots.}{A} =$$

$$v_2 = \frac{\dots.}{A} =$$

$$u_1 = \frac{\dots.}{A} =$$

$$u_2 = \frac{\dots.}{A} =$$

9. Extend the trajectories so that their extensions will intersect as shown in Figure 1 and carry each velocity vectors along its orientation starting from the intersection points so that their length does not change. Find the resultant velocities $\vec{v}_1 + \vec{v}_2$ and $\vec{u}_1 + \vec{u}_2$ in vector form.

$R = |\vec{v}_1 + \vec{v}_2\ | = \dots..$

$R' = |\vec{u}_1 + \vec{u}_2\ | = \dots.$

$|\vec{v}_1 + \vec{v}_2\ | = |\vec{u}_1 + \vec{u}_2\ |$ Is equality ensured? Discuss your result.

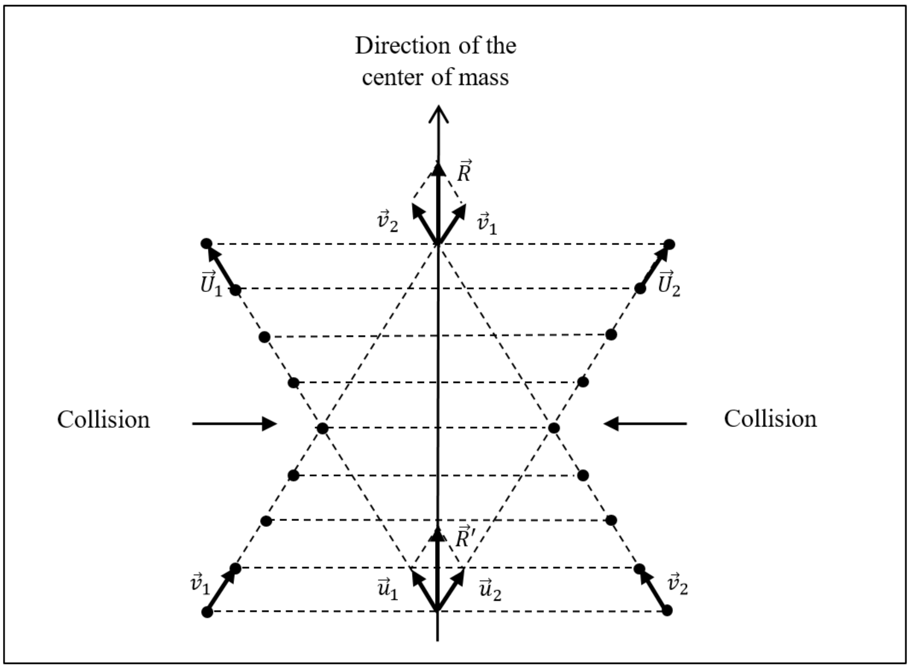


Figure 1. Sum of the velocity vectors $\vec{R} = \vec{v}_1 + \vec{v}_2$ before collision, and sum of the velocity vectors $\vec{R}' = \vec{u}_1 + \vec{u}_2$ after collision in an elastic collision.

10. On the trace paper, connect the points horizontally as shown in Figure 1 and determine the exact midpoints between these points. Combine these points to obtain the center of mass.

11. Measure the vertical distance between two consecutive lines in the region before and after the collision and divide by the time (A) to find the velocity of the center of mass before and after the collision. If the measured values are compatible, discuss your results.

$\vec{V}_{KM} = \cdots$

$\vec{V}'_{KM} = \cdots$

12. Find the total kinetic energies before and after the collision and discuss your results.

$K_i = \cdots$

$K_f = \cdots$

B. Inelastic Collision

13. Wrap the adhesive strips around the discs in such a way that the adhesive part is inside.

14. Press the air pedal. Accelerate the discs to ensure collision. Repeat this step until the collisions are correct.

WARNING! **<u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>**

15. After the sufficient attempts, turn on the arc chronometer. Move the discs by pressing the arc pedal and the air pedal at the same time.

16. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 1.

17. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=...

A =1/*f* =...

18. Measure the velocities in each trajectory by the ruler and divide by the elapsed time (*A* value) to find the velocities before ($\vec{v}_1$ and $\vec{v}_2$) and after ($\vec{u}_1$ and $\vec{u}_2$) the collision (Figure 1).

$v_1 = \frac{\cdots.}{A} =$

$v_2 = \frac{\cdots.}{A} =$

$u_1 = \frac{\cdots.}{A} =$

$u_2 = \frac{\cdots.}{A} =$

19. Extend the trajectories so that their extensions will intersect as shown in Figure 1 and carry each velocity vectors along its orientation starting from the intersection points so that their length does not change. Find the resultant velocities $\vec{v}_1 + \vec{v}_2$ and $\vec{u}_1 + \vec{u}_2$ in vector form.

$R = |\vec{v}_1 + \vec{v}_2\ | = \ldots..$

$R' = |\vec{u}_1 + \vec{u}_2\ | = \ldots.$

$|\vec{v}_1 + \vec{v}_2\ | = |\vec{u}_1 + \vec{u}_2\ |$ Is equality ensured? Discuss your result.

20. On the trace paper, connect the points horizontally as shown in Figure 1 and determine the exact midpoints between these points. Combine these points to obtain the center of mass.

21. Measure the vertical distance between two consecutive lines in the region before and after the collision and divide by the time (*A*) to find the velocity of the center of mass before and after the collision. If the values you find are compatible, discuss your results.

$\vec{V}_{KM} = \cdots$

$\vec{V}'_{KM} = \cdots$

22. Find the total kinetic energies before and after the collision and discuss your results.

$K_i = \cdots$

$K_f = \cdots$

23. Calculate the elasticity coefficient for the inelastic collision.

$e = \frac{(K_i - K_f)}{K_f} = \cdots$

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-7

PERFECTLY INELASTIC COLLISION

AIM OF THE EXPERIMENT:

To examine the conservation of linear momentum and conservation of kinetic energy in perfectly inelastic collisions in an isolated system.

THEORY:

In a perfectly inelastic collision, the momentum of the system is conserved, but not kinetic energy in an isolated system, and two objects move together in a common velocity after the collision. Assume that two objects with a mass of m_1 and m_2 are doing a perfectly inelastic collision, and the system moves without rotation after the collision, the velocity of both bodies ($\vec{u}_1$ and $\vec{u}_2$) and the common velocity of the center of mass ($\vec{v}$) are the same. That is,

$$\vec{u}_1 = \vec{u}_2 = \vec{v}$$

The conservation of energy can be expressed as

$$\underbrace{m_1\vec{v}_1 + m_2\vec{v}_2}_{before\ collision} = \underbrace{(m_1 + m_2)\vec{v}}_{after\ collision}$$

where $\vec{v}_1$ and $\vec{v}_2$ are the velocities of the objects before collision. From this relation, the velocity of the center of mass is

$$\vec{v} = (m_1\vec{v}_1 + m_2\vec{v}_2)/(m_1 + m_2)$$

If the masses of the objects are equal $(m_1 = m_2)$,

$$\vec{v} = (\vec{v}_1 + \vec{v}_2)/2$$

There is always a loss of kinetic energy in perfectly inelastic collisions. So, kinetic energies are obtained as

$$\sum K_i > \sum K_f \rightarrow \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 > \frac{1}{2}(m_1 + m_2)v^2$$

If the masses of the two bodies are equal ($m_1 = m_2$),

$$v_1^2 + v_2^2 > 2v^2$$

The total kinetic energy before the collision is K_i, and the total kinetic energy after the collision is K_f. The coefficient of elasticity is given as

$$e = \frac{(K_i - K_f)}{K_i}$$

PRELIMINARY STUDY: *Answer the following questions.*

1. Give examples for a completely inelastic collision.

2. Discuss the causes of loss in kinetic energy.

EXPERIMENTAL PROCEDURE:

A. Perfectly Inelastic Collision

1. Make the air table horizontal.

2. Place the trace paper on the air table.

3. Wrap the adhesive strips around the discs in such a way that the adhesive part is outside. Place one of the discs in the bottom left and the other in the bottom right corner.

4. Press the air pedal. Accelerate the discs to ensure collision.

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

5. After the sufficient attempts, turn on the arc chronometer. Move the disc by pressing the arc pedal and the air pedal at the same time.

6. Raise the trace paper and consult your advisor whether you have obtained a pattern as shown in Figure 1.

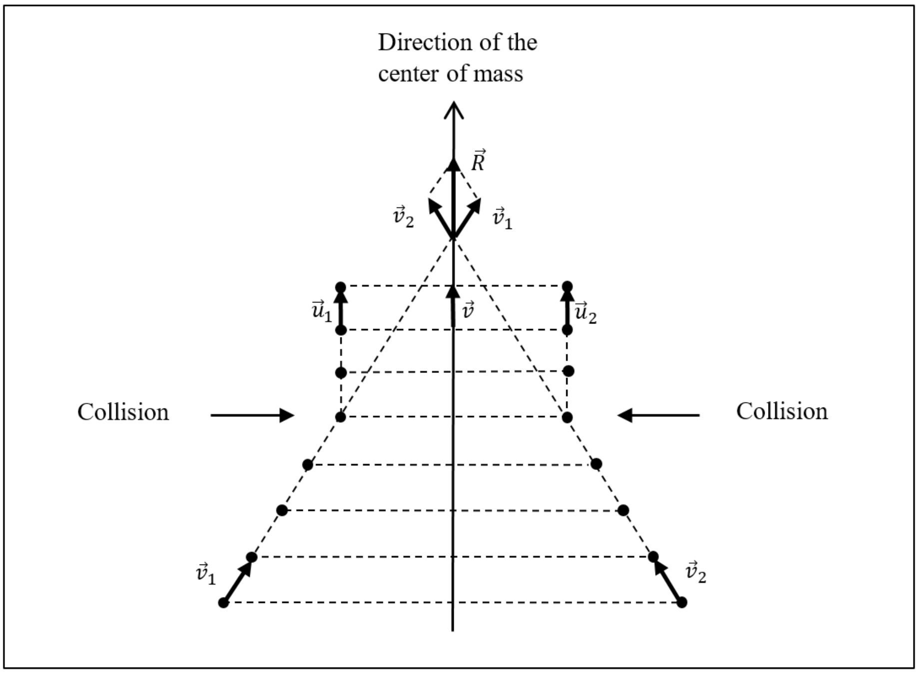


Figure 1. Sum of velocity vectors $\vec{R} = \vec{v}_1 + \vec{v}_2$ before collision, the common velocity vector $\vec{v}$ after the collision for a perfectly inelastic collision.

7. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (*A*) is obtained as

f=...

$A = 1/f$ =...

8. Measure the velocities in each trajectory by the ruler and divide by the elapsed time (*A* value) to find the velocities before ($\vec{v}_1$ and $\vec{v}_2$) and after ($\vec{v}$) the collision (Figure 1).

$v_1 = \frac{\dots.}{A} =$

$v_2 = \frac{\dots.}{A} =$

$v = \frac{\dots.}{A} =$

9. Extend the trajectories so that their extensions will intersect as shown in Figure 1 and carry each velocity vectors in its orientation starting from the intersection points so that their length does not change. Find the resultant velocities $\vec{v}_1 + \vec{v}_2$ and $\vec{u}_1 + \vec{u}_2$ in vector form.

$R = |\vec{v}_1 + \vec{v}_2\,| = \dots..$

$|\vec{v}_1 + \vec{v}_2\,| = 2|\vec{v}|$ Is equality ensured? Discuss your result.

10. Find the total kinetic energies before and after the collision. Is kinetic energy conserved?

$K_i = \cdots$

$K_f = \cdots$

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-8
SIMPLE HARMONIC MOTION

AIM OF THE EXPERIMENT:

To examine the simple harmonic motion.

THEORY:

In the case of small displacements, the force applied to the spring having a spring constant k is proportional to the displacement (x) and spring constant. This force is in the opposite direction to the displacement (Hook's Law):

$$F = -kx$$

The motion of the object under the influence of such a force is called a simple harmonic motion. Applying Newton Second Law to the simple harmonic motion, the following relation is written

$$F = ma \rightarrow -kx = m\frac{d^2x}{dt^2}$$

Solving this relation, the displacement equation for a simple harmonic motion is obtained as

$$x = A\,sin(\omega t + \delta)$$

Here, A, ω, and δ are the amplitude, angular frequency and phase angle of the motion, respectively. The time-dependent variation of displacement is shown in Figure 1 (for $\delta=0$).

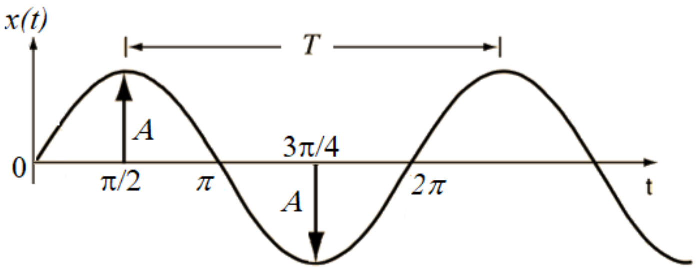


Figure 1. The time-dependent variation of displacement in simple harmonic motion

The displacement, velocity and acceleration of the object for $\delta=0$ are expressed as

$$x = A\,sin\omega t$$

$$v = \frac{dx}{dt} = \omega A\,cos\omega t$$

$$a = \frac{d^2x}{dt^2} = -\omega^2 Asin\omega t$$

Substituting x and a into equation $-kx = ma$, we get

$$-k(A\,sin\omega t) = m(-\omega^2 Asin\omega t) \rightarrow k = m\omega^2 \rightarrow w^2 = k/m \rightarrow \omega = \sqrt{k/m}$$

The period of motion is given by

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{k/m}} = 2\pi\sqrt{\frac{m}{k}}$$

PRELIMINARY STUDY: *Answer the following questions.*

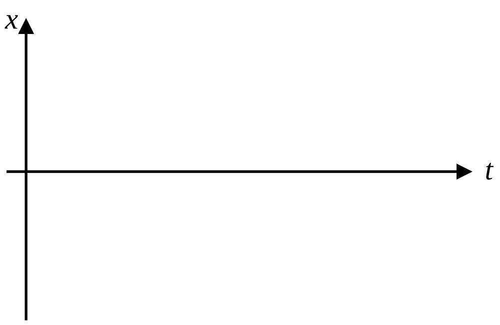
1. What is Hooke's law? Discuss where it can be applied.

2. Define the spring constant and perform the unit analysis.

3. Define the frequency and period.

4. The displacement of an object having a harmonic motion is given by $x = A\,sin\omega t$. For this object, fill in the table below to draw the *x*-*t*, *v*-*t* and *a*-*t* graphs. Note: Please note that $\omega = 2\pi/T$.

t	$x = A\,sin\omega t$	$v = \omega A\,cos(\omega t)$	$a = -\omega^2 Asin\omega t$
t= 0			
t=T/4			
t= T/2			
t= 3T/4			
t= T			



EXPERIMENTAL PROCEDURE:

A. Determination of Spring Constants

1. First of all, the spring constants of the springs used must be determined. Incline the air table with an angle φ and calculate this angle.

φ = …

WARNING! <u>During the experiment, do not touch the metal parts of the table and discs after pressing the arc pedal and holding the discs from the plastic part will prevent you from being exposed to electric current.</u>

2. Attach one end of the spring to the top of the air table. Connect one of the discs to the lower end. With the spring in equilibrium and without releasing the disc, press the arc pedal and determine the equilibrium position. Note the mass of the disc.

$m = \cdots$

3. Then, release the disc and press the arc pedal again after the spring has been stretched and the disc stopped. Measure the distance between two points on the trace paper to determine the extension of the spring.

$x \ = \cdots$

4. With the Newton equation of motion, we write $mgsin\varphi = \ kx$, so we can find the spring constant:

$k = \dfrac{mgsin\varphi}{x}$

Find the spring constant for the first spring:

$k_1 = \ ...$

5. Find the spring constant for the other spring:

$k_2 = \ ...$

B. Spring-Disc-Spring System, Simple Harmonic Motion

6. Using the springs you have, set the spring constants and one of the discs, install the assembly in Figure 2. Follow the steps below to examine simple harmonic motion. Note the mass of the disc.

$m_{disc} = \cdots$

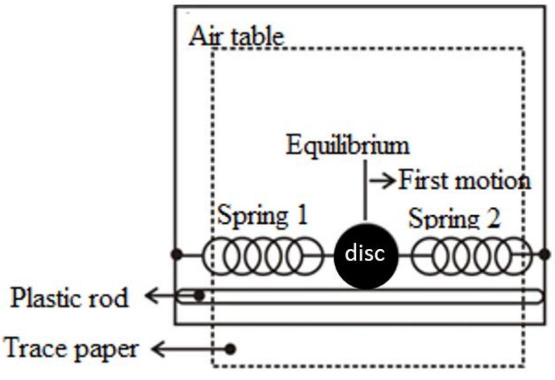


Figure 2. Experimental setup for simple harmonic motion

7. Pass the trace paper through beneath the plastic bar and remove the end of the paper from the edge of the table. Pull the disc in the direction of the spring and release it. At this time, press the arc pedal and pull the paper slowly at a constant speed. Try to obtain a trace pattern similar to that in Figure 3 (repeat this procedure until you get a good trace pattern). Make the necessary drawings on the trace pattern, insert the axes. Measure the amplitude and peak-to-peak amplitude values, record below.

$A = \cdots$

$A_{peak-to-peak} = \ \cdots$

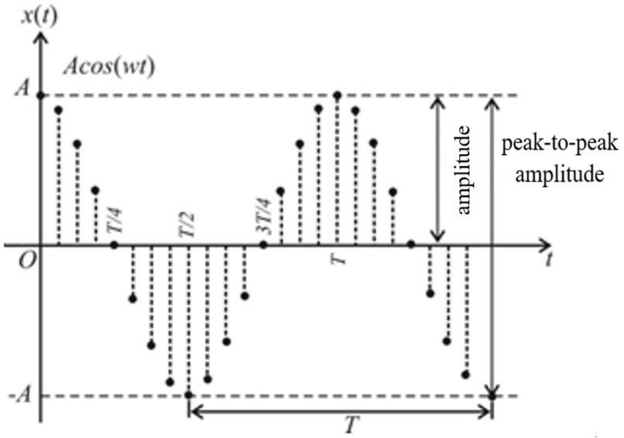


Figure 3. Sample trace paper and markings

8. Record the frequency (*f*) of the arc chronometer. Time between two consecutive points on trace paper (A') is obtained as

f=...

A' =1/f =...

9. Count the number of the intervals between two peaks, two troughs, or identical two points. Multiply this value by A' to determine the period (*T*) of the motion. Calculate the angular frequency (ω):

$T \ = \ number\ of\ intervals\ x\ A' = \ ...$

$Angular\ frequency: \omega \ = \ 2\pi/T \ = \ ...$

10. The total force acting on the disc in the spring-disc-spring system is

$F_{net} = -k_1x - k_2x = -(k_1 + k_2)x = -k_{eq}x$

The spring constant of the system must be $k_{eq} = k_1 + k_2$. With this equation, find the spring constant of the system and calculate the period:

$k_{eq} = \cdots$

$T = 2\pi\sqrt{m_{disc}/k_{eq}} = \cdots$

Compare the value of calculated period with the value you find on the trace paper (step **9**) and interpret your result.

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …

EXPERIMENT-9

DETERMINATION OF THE GRAVITATIONAL ACCELERATION

AIM OF THE EXPERIMENT:

To determine the gravitational acceleration with error analysis.

THEORY:

A. PHYSICAL MEASUREMENTS AND ERRORS

Each measurement contains some errors. The numerical found results in the experiments do not make any sense unless measurement errors are identified. For each measured result, the reliability limits of this result, that is, the error limits must be specified. For this purpose, some practical information on the determination of errors are presented below. There are two types of errors in the experiments: (*i*) Systematic Errors and (*ii*) Statistical Errors.

i) Systematic Errors:

As the name implies, they are fixed errors due to the system itself and they affect the result in the same direction. For example, if the measurement is made with a mass greater than one kilogram for the calculations of acceleration of an object in motion, the measurement results will be smaller at the same rate. In the existence of such errors, errors are unidirectional; the result is either continuously larger or smaller. Systematic errors can be resolved in the mean following ways:

1. Correcting the measurement result,
2. By removing the error in the measurement system,
3. By changing the measurement method.

ii) Statistical Errors: Due to the limited accuracy of the measurement, they are usually small and bidirectional errors resulting from instability in the measured object or measurement system. The presence of such errors can be seen by multiple repetitions of the same measurement. The measured results are different from each other and are distributed around a certain value. These errors cannot be extracted from the measurement results, but it is possible to determine approximately the extent to which the margins of error and the measured magnitude are reliable. The effect of such errors on the measurement results can be reduced by multiple repetitions of the same measurement and statistical evaluation of the results.

When a physical quantity is measured, for instance x, N times, the measurement results are $x_1, x_2, ..., x_N$. The average value of $\bar{x}$ is

$$\bar{x} = \frac{(x_1 + x_2 + x_3 + \cdots + x_N)}{N}$$

The $\bar{x}$ value is the approximate value of x. Therefore, if a quantity is measured N times, we can take the average value as a result of the measurement. The reliability of the result of measurement is found to increase proportionally to the number of measurements (N). However, we have to repeat enough tests in the experiments.

What is the error in $\bar{x}$? A general method for determination of errors is to calculate the average deviation value. For example, the deviation of x_i in any one measurement is

$$d_i = x_i - \bar{x}$$

and the average deviation of this measurement is

$$\bar{d} = (|d_1| + |d_2| + |d_3| + \cdots + |d_N|)/N$$

The arithmetic mean of the average deviation values can be taken as a statistical error. For any measurement of x, the measurement result is expressed as

$$x = \bar{x} \pm \bar{d}$$

In some cases, errors are given as an error percentage. In this case, the error percentage will be $(\bar{d}/\bar{x})$×100% in which case the measurement result for x is

$$x = \bar{x} \pm \left[(\bar{d}/\bar{x})\times 100\%\right]$$

The deviation from the average value for the N measurement can be a measure of the sensitivity of the measured value. But this deviation is not a real error. This should only be considered as an approach in the determination of statistical error.

When a large number of measurements cannot be repeated, where a systematic error is suspected, or where non-sensitive measuring instruments are used, the most appropriate way to determine measurement errors is to take the largest possible error value. For example, for the length measured by a meter with the smallest part of 1mm, the greatest possible error would be Δx =1 mm. In this case, the actual value of a measured x length will vary between x-Δx and x+Δx.

Measurements cannot be done directly. Related values are measured and the magnitude of physical quantity to be determined is calculated. In this case, the effect of error margins on measurement of different magnitudes must be determined. In such cases, we will briefly examine the methods to be used in the calculation of errors.

Suppose that the physical quantity r given by $r = f(x, y, z)$ will be calculated by the measurement of the dimensions x, y, z. If the greatest possible error in the measurement of x, y and z is Δx, Δy, Δz, respectively, the effect of these values on the change of r will be

$$\Delta r = \left|\left(\frac{\partial f}{\partial x}\right) \cdot \Delta x\right| + \left|\left(\frac{\partial f}{\partial y}\right) \cdot \Delta y\right| + \left|\left(\frac{\partial f}{\partial z}\right) \cdot \Delta z\right|$$

Here are a few examples of the implementation of the above equation.

a. Addition: $r = x + y \rightarrow \Delta r = |\Delta x| + |\Delta y| = \Delta x + \Delta y$ (RULE 1)

b. Extraction: $r = x - y \rightarrow \Delta r = |\Delta x| + |-\Delta y| = \Delta x + \Delta y$ (RULE 2)

c. Multiplication: $r = x \cdot y \rightarrow \Delta r = |y \cdot \Delta x| + |x \cdot \Delta y| = y\Delta x + x\Delta y \rightarrow \frac{\Delta r}{r} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$ (RULE 3)

d. Division: $r = x/y \rightarrow \Delta r = \frac{|y \cdot \Delta x| + |x \cdot \Delta y|}{y^2} = \frac{\Delta x}{y} + r\frac{\Delta y}{y} \rightarrow \frac{\Delta r}{r} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$ (RULE 4)

e. Exponential Function: $r = x^n \rightarrow \Delta r = nx^{n-1}\Delta x \rightarrow \frac{\Delta r}{r} = n\frac{\Delta x}{x}$ (RULE 5) (*n* any number)

f. Trigonometric Function: $r = sin(x) \rightarrow \Delta \mathrm{r} = \cos(\mathrm{x})\Delta \mathrm{x}$

B. SIMPLE PENDULUM

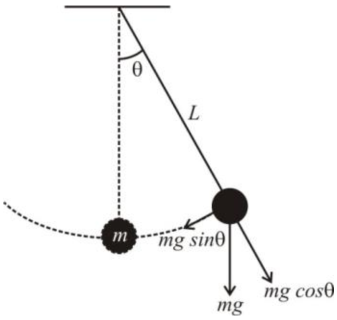


Figure 1. Simple Pendulum

A simple pendulum consists of a point mass suspended from a string or rode of negligible mass (Figure 1). During the motion of the mass, the force acting on the mass is expressed as

$$F = -mgsin\theta$$

The sign (-) indicates that the force is in the restoring character, in other words, this force tries to bring the mass to a constant equilibrium position and is in the opposite direction to the displacement. According to Newton's Second Law of Motion, the equation of motion is

$$F = ma = m\frac{d^2x}{dt^2} = -mgsin\theta$$

$$\frac{d^2x}{dt^2} + gsin\theta = 0 \rightarrow \frac{d^2\theta}{dt^2} + \frac{g}{L}sin\theta = 0$$

The equation of motion is a 2nd order non-linear differential equation and no analytical solution! However, in the case of *small displacements*, we can write $sin\theta \cong \theta$. In this case, the equation is converted into a 2nd order differential equation with constant coefficient and has the solution:

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\theta = 0 \rightarrow \theta(t) = Asin(wt + \delta), w^2 = \frac{g}{L}$$

The period of motion is

$$T = \frac{2\pi}{w} = \frac{2\pi}{\sqrt{g/L}} = 2\pi\sqrt{L/g}$$

Important Note: Please note that the solution presented here is only valid for *minor displacements* from the equilibrium position. If you oscillate your pendulum with very large angles in the experiment, these solutions will not be valid!

PRELIMINARY STUDY: *Answer the following questions.*

1. What are the errors that may occur in the measurements?

2. Write down the error types.

EXPERIMENTAL PROCEDURE:

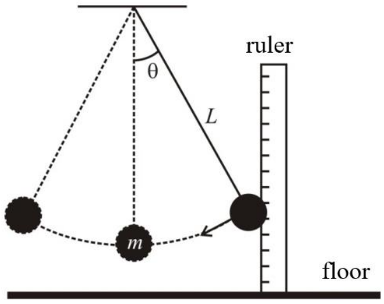


Figure 2. Experimental setup

1. Hold a plastic ruler fixed on the side of the pendulum and release the mass from a height you set on the ruler (Figure 2). Be careful not to leave at a very large angle.

2. At this time, start the chronometer and measure the time it takes for the 5 oscillations of the mass (when the mass comes to the point where it was released, it oscillates and one period of time passes). Stop the mass and measure the length of the string. Record the time and length you measured in the table below. Repeat the process 9 times again and fill in the table. Make sure that a different person has measured each time. Calculate periods by dividing the measured time by 5. Then calculate the arithmetic average of periods and lengths.

Measurement	Time for 5 oscillations, t (…)	Time for an oscillation, period, T (…)	String length, L (…)
1.	t_1=	T_1= t_1/5=	L_1=
2.	t_2=	T_2= t_2/5=	L_2=
3.	t_3=	T_3= t_3/5=	L_3=
4.	t_4=	T_4= t_4/5=	L_4=
5.	t_5=	T_5= t_5/5=	L_5=
6.	t_6=	T_6= t_6/5=	L_6=
7.	t_7=	T_7= t_7/5=	L_7=
8.	t_8=	T_8= t_8/5=	L_8=
9.	t_9=	T_9= t_9/5=	L_9=
10.	t_{10}=	T_{10}= t_{10}/5=	L_{10}=
		Total $T=T_{total}$=	*Total* $L=L_{total}$=
		$\bar{T}=T_{av}=T_{total}/10$=	$\bar{L}=L_{av}=L_{total}/10$=

3. $T = 2\pi\sqrt{\frac{L}{g}} \rightarrow g = 4\pi^2\frac{L}{T^2}$

Find the g_{av} using average value of time and period in above equation.

$$g_{av} = 4\pi^2\frac{L_{av}}{T^2{}_{av}} = \cdots$$

4. Calculate the average deviation for the periods, perform the calculations using the table below.

Measurement	Period (…)	Deviation of period, $d_i = T_i - \bar{T}$ (…)	
1.	T_1=	$d_1 = T_1 - \bar{T}$=	$\lvert d_1 \rvert$=
2.	T_2=	$d_2 = T_2 - \bar{T}$=	$\lvert d_2 \rvert$=
3.	T_3=	$d_3 = T_3 - \bar{T}$=	$\lvert d_3 \rvert$=
4.	T_4=	$d_4 = T_4 - \bar{T}$=	$\lvert d_4 \rvert$=
5.	T_5=	$d_5 = T_5 - \bar{T}$=	$\lvert d_5 \rvert$=
6.	T_6=	$d_6 = T_6 - \bar{T}$=	$\lvert d_6 \rvert$=
7.	T_7=	$d_7 = T_7 - \bar{T}$=	$\lvert d_7 \rvert$=
8.	T_8=	$d_8 = T_8 - \bar{T}$=	$\lvert d_8 \rvert$=
9.	T_9=	$d_9 = T_9 - \bar{T}$=	$\lvert d_9 \rvert$=
10.	T_{10}=	$d_{10} = T_{10} - \bar{T}$=	$\lvert d_{10} \rvert$=
			Total=
		$\Delta T = \Delta d = \bar{d}$ =*Total/10*=	

5. Calculate the average deviation for the lengths, perform your calculations on the table below.

Measurement	String length (…)	Deviation of length, $b_i = L_i - \bar{L}$ (…)	
1.	L_1=	$b_1 = L_1 - \bar{L}$=	$\lvert b_1 \rvert$=
2.	L_2=	$b_2 = L_2 - \bar{L}$=	$\lvert b_2 \rvert$=
3.	L_3=	$b_3 = L_3 - \bar{L}$=	$\lvert b_3 \rvert$=
4.	L_4=	$b_4 = L_4 - \bar{L}$=	$\lvert b_4 \rvert$=
5.	L_5=	$b_5 = L_5 - \bar{L}$=	$\lvert b_5 \rvert$=
6.	L_6=	$b_6 = L_6 - \bar{L}$=	$\lvert b_6 \rvert$=
7.	L_7=	$b_7 = L_7 - \bar{L}$=	$\lvert b_7 \rvert$=
8.	L_8=	$b_8 = L_8 - \bar{L}$=	$\lvert b_8 \rvert$=
9.	L_9=	$b_9 = L_9 - \bar{L}$=	$\lvert b_9 \rvert$=
10.	L_{10}=	$b_{10} = L_{10} - \bar{L}$=	$\lvert b_{10} \rvert$=
			Total =
		$\Delta L = \Delta b = \bar{b}$ =*Total/10*=	

6. Considering Rule 4 and Rule 5, calculate the error at the period measurement using expression $T = 2\pi\sqrt{L/g}$.

$$\frac{\Delta T}{T} = \frac{1}{2}\left(\frac{\Delta L}{L} + \frac{\Delta g}{g}\right) \rightarrow \frac{\Delta g}{g_{av}} = 2\frac{\Delta T}{T_{av}} - \frac{\Delta L}{L_{av}} \rightarrow \Delta g = g_{av}\left[2\frac{\Delta T}{T_{av}} - \frac{\Delta L}{L_{avg}}\right]$$

Calculate the error (Δg) in finding g:

$$\Delta g = g_{av}\left[2\frac{\Delta T}{T_{av}} - \frac{\Delta L}{L_{av}}\right] = \cdots$$

7. Write the gravitational acceleration:

$$g = g_{av} \pm \Delta g = \cdots$$

COMMENT:

(Interpret the experiment by establishing a relationship among theory, purpose and results.)

REFERENCES:

(Write the references you used.)

1. …

2. …

APPENDICES:

(If any trace and graph paper were used, they should be added.)

Appendix 1. …

Appendix 2. …