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Ministry of Education

Islamic University in Madinah

Department of Physics

المملكة العربية السعودية

وزارة التعليم

الجامعة الإسلامية بالمدينة المنورة

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PHYS 3101 LABORATORY MANUAL

January 2020

Physics Department

Faculty of Science

Islamic University in Madinah

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Safety Instructions

Carefully read and follow the following laboratory Safety Instructions:

1. Before you come to the laboratory, read your assigned laboratory experiment, be prepared to perform it and pay attention to any related safety instructions.
2. Dress appropriately to avoid any possible safety hazard. Ware a closed-toed shoes to avoid exposing the top of the foot to heated or heavy items that may injure the feet if spilled or dropped.
3. Use suitable personal protective equipment. For example, you need to ware safety goggles when working with sources of heat, or laser experiments.
4. Never eat, drink, smoke, chew gum or put anything into your mouth in the laboratory.
5. Do not use cell phones inside laboratory unless given the permission from the laboratory instructor.
6. Do not enter the laboratory except under the supervision of an instructor.
7. You are not permitted to enter the laboratory storage areas.
8. Students with special medical issues should seek medical consultation about potential risks associated with their participation in a science laboratory.
9. In case of injury or any type of accidents immediately notify your instructor for help.
10. Prior to laboratory work, you should get familiarized with the location and correct use of safety equipment. These may include fire alarm, fire extinguisher, and fire blanket.
11. Do not block the work area and aisles with your personal items.
12. Do not perform any experiment that is not part of the syllabus or authorized by the instructor.
13. Never use equipment or supplies unless getting acquainted with their use and safety precautions.
14. Do not distract your classmates while they are conducting their experiments.
15. Before leaving the laboratory, check your work space to ensure that you do not leave personal items in the laboratory.
16. Clean up your work area to ensure that you leave it the way you found it when coming to the lab.

Reference:

1. General Physics Laboratory Safety Guidelines, Universal Physics Laboratory Agreement for Georgia State University, http://physics.gmu.edu/~jcressma/Phys244/LabSafety.pdf.
2. Physics 136-1: General Physics Lab, Laboratory Manual – Mechanics, Northwestern University, Version 1.1b, USA, June 21, 2019.

Experiment 1: Measurement of Uncertainty and Errors

All measurements contain error. An experiment is truly incomplete without an evaluation of the amount of error in the results. In this lesson, you will learn to use some common tools for analyzing experimental uncertainties. The methods you will learn here are sufficient for many applications.

Types and Sources of Experimental Errors

Experimental errors arise for many sources and can be grouped in three categories:

- **personal:** from personal bias or carelessness in reading an instrument (e.g., parallax), in recording observations, or in mathematical calculations.

- **systematic:** associated with particular measurement techniques

  - improper calibration of measuring instrument

  - is the —same error each time. This means that the error can be corrected if the experimenter is clever enough to discover the error.

- **random error:** unknown and unpredictable variations

- fluctuations in temperature or line voltage
- mechanical vibrations of the experimental setup
- unbiased estimates of measurement readings
- is a —different error each time. This means that the error cannot be corrected by the experimenter after the data has been collected.

Significant Digits

It is important that measurements, results from calculations, etc. be expressed with the appropriate amount of digits. A real-life example concerns the average weight of an adult. If someone expressed this value as 75.234353556 kg., that would not make much sense. If it were expressed as 75 kg, that would make more sense, since typical scales found in bathrooms and gymnasia measure to the nearest kilogram. Similarly, when you present your results for a given experiment, the figures should contain no more digits than necessary.

- exact factors have no error (e.g., e, π)
- all measured numbers have some error or uncertainty

  - this error must be calculated or estimated and recorded with every final expression in a laboratory report

  - the degree of error depends on the quality and fineness of the scale of the measuring device

- use all of the significant figures on a measuring device. For example, if a measuring device is accurate to 3 significant digits, use all of the digits in your answer. If the measured value is 2.30 kg, then the zero is a significant digit and so should be recorded.
- keep only a reasonable number of significant digits

- e.g., 136.467 + 12.3 = 148.8 units

- e.g., 2.3456 ± 0.4345634523 units → 2.3 ± 0.4 units

- NOTE: hand-held calculators give answers that generally have a false amount of precision.

Round these values correctly; again as a rule, the final answer should have no more significant digits than the data from which it was derived.

READING ERROR (DIRECT MEASUREMENTS):

use half of the smallest division

(e.g. in case of a meter stick with millimeter divisions, the reading error is 0.5 mm),

- Scientists make a lot of measurements. They measure the masses, lengths, times, speeds, temperatures, volumes, etc.

- When they report a number as a measurement the number of digits and the number of decimal places tell you how exact the measurement is

  - For example: 121 is less exact than 121.5
  - The difference between these two numbers is that a more precise tool was used to measure the 121.5.
  - The total number of digits and the number of decimal points tell you how precise a tool was used to make the measurement.

- Reporting measurements:

There are 3 parts to a measurement:

1. The measurement
2. The uncertainty
3. The unit

The result of the measurement of a quantity x should be presented as

$x \pm \Delta x$ (Unit)

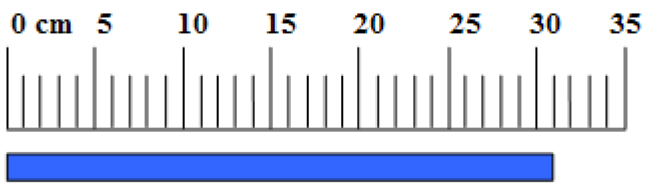
where x is the directly measured value (or average value) and Δx is the uncertainty of the measurement.

Example: 5.2 ± 0.5 cm

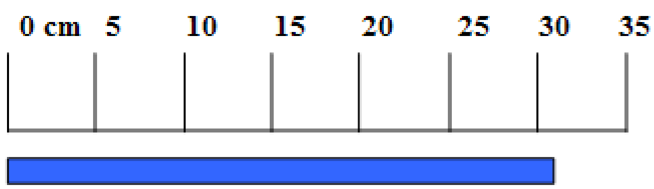
Which means you are reasonably sure the actual length is somewhere between 4.7 and 5.7

- No measurement should be written without all three parts.

- The last digit in your measurement should be an estimate



In the above, you would report the length of the bar as 31.0 ± 0.5 cm (assuming the big marks are centimeters). The bar appears to line up with the 31st mark and you know it is more than ½ way from the 30 mark and less than ½ way from the 32nd mark. So you can be reasonably sure the actual length of the bar is between 30.5 and 31.5 cm.



In the above, you would report the length of the bar as 31 ± 2 cm. You know the bar is longer than 30 cm and the last digit is your best guess. You are reasonably sure the actual bar length is between 30 and 33 cm.

- The uncertainty is half (1/2) the amount between the smallest hash marks. Notice in the above 2 examples that this is the case.
- Some uncertainties are determined by the manufacturer. (e.g. electronic balances, probes)

PROPOGATION OF ERROR (INDIRECT MEASUREMENTS)

In the majority of experiments the quantity of interest is not measured directly, but must be calculated from other quantities. Such measurements are called INDIRECT. For example, the volume of a sphere calculated from the measurement of its radius, or the density of the sphere's material calculated from the ratio of the mass and volume of the sphere.

As seen above, the quantities measured directly are not exact but have errors associated with them.

What is now the uncertainty associated with an indirect measurement?
In order to calculate the uncertainty of an indirect measured quantity we need first to calculate the uncertainties of the directly measured quantities involved, and then apply the appropriate formula for propagation of errors.
These formulas depend on how the indirect measurement quantity depends on the direct measured quantities. The three rules you need for this lab are:

Rule 1: If two or more **direct measured** quantities are being **added or subtracted to yield an indirect measured quantity *y***:
$y = x_1 + x_2 + \cdots$ or $y = x_1 - x_2 - \cdots$
then

$$\Delta y = \sqrt{(\Delta x_1)^2 + (\Delta x_2)^2 + \cdots} \qquad \text{Eq.(1)}$$

where $\Delta x_1, \Delta x_2$, etc. are the uncertainties of the direct measured quantities x_1, x_2 etc and Δy is the uncertainty of the indirect measured quantity *y*.

Rule 2: If two **direct measured** quantities are being **multiplied or divided:**
$y = x_1 x_2$ *or* $y = x_1/x_2$
Then

$$\frac{\Delta y}{y} \approx \sqrt{\left(\frac{\Delta x_1}{x_1}\right)^2 + \left(\frac{\Delta x_2}{x_2}\right)^2} \qquad \text{Eq. (2)}$$

$\frac{\Delta x}{x}$ is called relative error

Rule 3: Multiplying or dividing by a pure (whole) number:

We multiply or divide the uncertainty by that number.
$y = cx$ or $z = x/c$
Then
$$\Delta y = c\Delta x\,, \Delta z = \Delta x/c \qquad \text{Eq. (3)}$$
Where *c* is constant
Eg. 4.95 ± 0.05 x 10 = 49.5 ±0.5

References:
1. Lab manual, part 1 For PHY 166 and 168 students, Department of Physics and Astronomy, HERBERT LEHMAN COLLEGE, 2018.
2. Physics 150 Laboratory Manual, HWS Physics Department, Hobart & William Smith Colleges, 2015.

EXPERIMENT 1: Experimental Errors and Uncertainty

Name: __________________________________ID: ________________________

Instructor: ____

Section: ____________________________Date:____________________________

Lab. Partners: ____

As a simple exercise to learn how to find the direct reading error and how it propagates, you will be doing the following:

- Take a paper of certain size, say A4.
- Measure the dimensions of the paper (length and width) using a typical ruler. Make sure to record the reading error of the ruler which would be the same for the length and width.
- Calculate the circumference, C of the paper : $C = 2(L + W)$
- Calculate the error in C using the Equations 1 and 3.
- Calculate the area, A of the paper: $A = L \times w$
- Calculate the error in A using the Equation 2.
- Repeat these steps for another paper type, call it paper X.

Uncertainty in length, $\Delta L =$........... Uncertainty in width ΔW= ....

	Length, L (cm)	Width, W (cm)	Circumference, C (cm)	ΔC (cm)	Area, A (cm^2)	ΔA (cm^2)
Paper A4						
Paper X						

Show your calculations in the next page

Calculations:

EXPERIMENT 2: Graph Plotting

Purpose: To practice data plotting and data analysis.

Frequently, a graph is the clearest way to represent the relationship between the quantities of interest. A graph indicates a relation between two quantities, x and y, *when other variables or parameters have fixed values.*

Components of a graph

You need to consider the following components to make your graph accurate and readable.

- ✓ **Title:** A title should be given to the whole graph. The title of the graph is written at the top of the graph. The title should be clear, descriptive, and self-explanatory.
- ✓ **Axes:** Take the independent variable as the abscissa (x-axis) and the dependent variable as the ordinate (y-axis) (unless you are instructed otherwise)
- ✓ **Labels:** Label each axis to identify the variable being plotted and the units being used. Mark prominent divisions on each axis with appropriate numbers.
- ✓ **Scale:** Choose a convenient scale for each axis so that the plotted points will occupy a substantial part of the graph paper (eg. 1, 2, 5, 10, *etc.*, units per scale division), but do not choose a scale which is difficult to plot and read, such as 3 or 3/4 units to a square. Graphs should usually be at least half a page in size.
- ✓ **Points**: Identify plotted points with appropriate symbols, such as crosses or empty circles.
- ✓ **Fitting**: If the experimental data is theoretically a straight line, draw the best straight line through the points with a straight edge. There are mathematical techniques for determining which straight line best fits the data, but for the purposes of this lab it will be sufficient if you simply make a rough estimate visually. The line should be drawn with about as many points above it as below it, and with the `aboves' and `belows' distributed at random along the line. (For example, not all points should be above the line at one end and below at the other end).

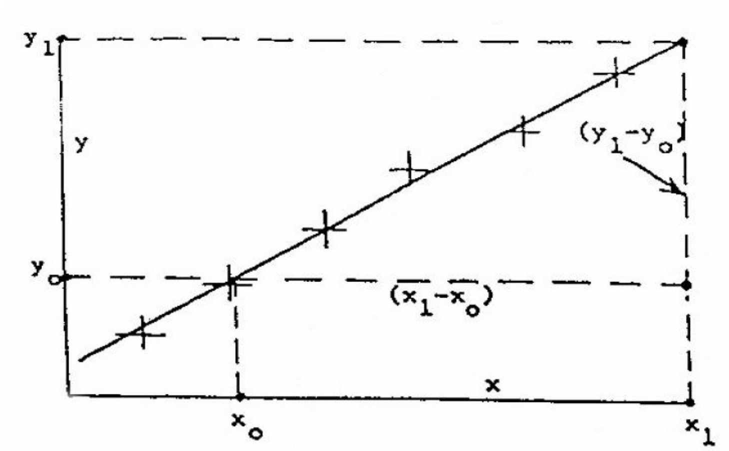
Straight line Analysis

Often there will be a theory concerning the relationship of the two plotted variables. A linear relationship can be demonstrated if the data points fall along a single straight line.

The general form of a straight line equation is

$$y = mx + b$$

Where *m* is the slope and *b* is the y-intercept.



THE SLOPE

In plotting linear relationships, you frequently will be asked to find the slope of the line you have fitted to the data (this slope usually has a physical meaning). The slope is given by :

$$slope = \frac{\Delta y}{\Delta x} = \frac{(y_2 - y_1)}{(x_2 - x_1)}$$

To calculate an accurate slope, read a point on the line near each end of the line. Do not use data points unless they are on the fitted line!!!! That is, choose widely separated points only on the line for the calculation of a slope.

INTERCEPTS

The x-intercept of a line is that point on the abscissa, or x-axis, at which a line crosses that axis. The y-intercept is defined in the same manner.

References:

1. Physics 150 Laboratory Manual, HWS Physics Department, Hobart & William Smith Colleges, 2015.
2. Laboratory Exercises for Physics 101 Department of Physics and Astronomy of Hunter College of the City University of New York. Edited and revised by The anne Schiros, January 2001.

EXPERIMENT 2: Graph Plotting

Name: ________________________________ID: ______________________

Instructor: ____

Section: __________________________Date:__________________________

Lab. Partners: ____

GRAPHING EXERCISE

You need to graph the following two sets of data and have them checked by your instructor.

1. The following data was collected on the position of a car as a function of time, as detected by a police radar detector:

time (min)	position (km)
0.00	2.51
0.67	3.33
1.17	6.43
1.80	7.58
2.37	8.83
3.05	12.18
3.59	12.65
4.18	13

a. Make a graph of the above data.

b. Determine the slope and y-intercept of the above curve. What is the physical significance of the slope?

2. The data set given in Table 2 is expected to obey the relation $x = \frac{1}{2}at^2$.

a. Calculate t^2 for each value of t in the table and record it in the table.

b. Plot the relation between x and t^2, and from your analysis of the graph find the acceleration a.

t (s)	0.2	0.4	0.6	0.8	1	1.2
x (m)	0.03	0.12	0.27	0.51	0.77	1.14
t^2 (s^2)						

3. The relation between the time of swing or period, T, of a pendulum and its length L is given by

$$T = 2\pi\sqrt{L/g}\ \text{, where g is a constant.}$$

The value of L and T obtained from an experiment are:

L(cm) :	24	49	74	105	150
T(sec) :	1.02	1.45	1.80	2.07	2.48

(a) Determine g by the following way. Substitute each pair of the values for L and T into the above formula to obtain a value for g, then find the mean $\bar{g}$.

(b) Determine g from the graph of T^2 vs L.

(c) State which method you would consider to give the more accurate value of g, and why.

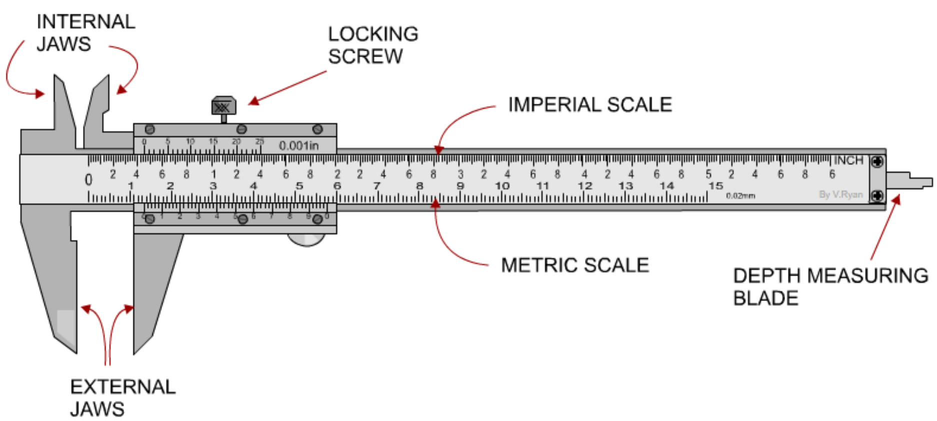
3. EXPERIMENT 3: MEASUREMENT OF DENSITY

Purpose

o Determine the mass and volume of three different objects of different metals.
o Calculate the density of each object and compare with the accepted values of the density of the metals.
o Determine the uncertainty in the value of the calculated density caused by the uncertainties in the measured mass, length, and diameter.

Apparatus

- Three solid objects of different metals (aluminum, steel)
- Vernier calipers

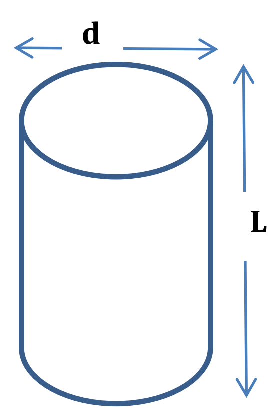


Theory

The most general definition of density is mass per unit volume. If the mass in an object is distributed uniformly throughout the object, the density ρ is defined as the total mass M divided by the total volume V of the object.

$$\rho = \frac{M}{V} \qquad (1)$$

Cylinder:



For a cylinder the volume is given by

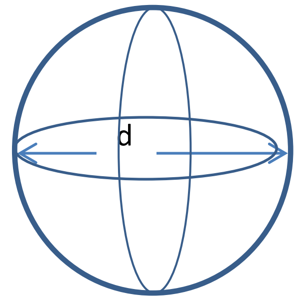
$$V = \frac{\pi d^2 L}{4}$$

Where d: is the cylinder diameter, and L is its length.

For this laboratory, the uncertainty in the density is related to the uncertainties in the mass, length, and diameter by:

$$\Delta\rho = \rho\sqrt{\left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + 4\left(\frac{\Delta d}{d}\right)^2}$$

Sphere:



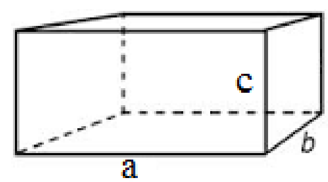
The volume of the sphere is

$$V = \frac{4}{3}\pi r^3 = \frac{\pi d^3}{6}$$

Where d is the diameter of the sphere.
The uncertainty in the density is

$$\Delta\rho = \rho\sqrt{\left(\frac{\Delta M}{M}\right)^2 + 9\left(\frac{\Delta d}{d}\right)^2}$$

Cuboid:

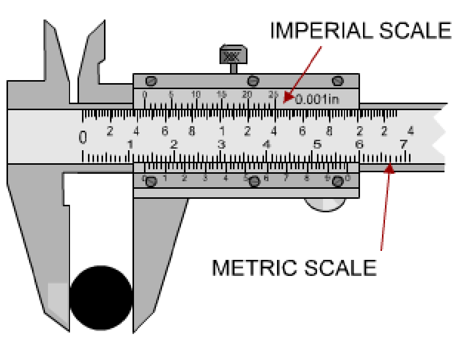


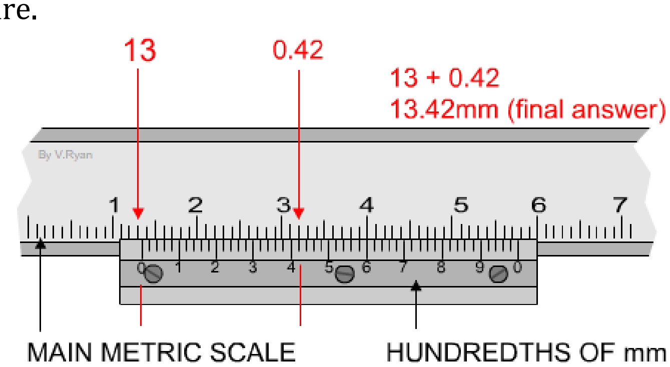
The volume of the cuboid
$V = abc$
Where a, b, and c are the dimensions of the cuboid.
The uncertainty in the density is given by:

$$\Delta\rho = \rho\sqrt{\left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta a}{a}\right)^2 + \left(\frac{\Delta b}{b}\right)^2 + \left(\frac{\Delta c}{c}\right)^2}$$

Procedure:

All the lengths and diameters will be measured with a vernier caliper. A caliper is actually any device used to determine thickness, the diameter of an object, or the distance between two surfaces. Often calipers are in the form of two legs fastened together with a rivet, so they can pivot about the fastened point. The vernier caliper used in this laboratory consists of a fixed rule that contains one jaw, and a second jaw with a vernier scale that slides along the fixed rule scale as shown in Figure.





Here is an example how to read a length of the Vernier :

i) The main metric scale is read first and this shows that there are 13 whole divisions before the 0 on the hundredths scale. Therefore, the first number is 13.

ii) The hundredths of mm scale is then read. This is the number on the sliding scale (hundredth of mm) which is the number you get to the division that **lines up** with the main metric scale, which is 0.42mm.

This the final reading is 13.42 mm = 1.342 cm.

1. Use the laboratory balance to determine the mass of each of the three objects. Record your data in the data sheet.
2. Use the vernier calipers to measure the dimensions of the three objects. Make two separate trials of the measurement of each length. Measure the length at different places on each cylinder for the four trials to sample any variation in length of the cylinders. Record the results in the Data Table.
3. Calculate the density ρ of each of each object. Record the results in the Data Table.
4. Calculate the uncertainty in the density. Remember that the uncertainty in each measuring device is half the smallest digit.

For purposes of this laboratory, assume that the density of aluminum is 2.70 gram/cm^3, the density of brass is 8.40 gram/cm^3, and the density of steel is 7.85 gram/cm^3. Calculate the percentage error in your results for the density of each of these metals.

References:

1. Laboratory Exercises for Physics 101 Department of Physics and Astronomy of Hunter College of the City University of New York. Edited and revised by Theanne Schiros, January 2001.
2. Lab manual, part 1 For PHY 166 and 168 students, Department of Physics and Astronomy, HERBERT LEHMAN COLLEGE, 2018.

EXPERIMENT 3: Measurement of Density

Name: ________________________________ID: ______________________

Instructor: ____

Section: __________________________Date:__________________________

Lab. Partners: ____

DATA AND ANALYSIS

The uncertainty in all length measurements $\Delta x =$ ________(cm)

The uncertainty in all mass measurements $\Delta M =$ ________(g)

Table 1. Cuboid

Mass (M) g	a(cm)	b (cm)	c (cm)	Volume (V) cm^3	Density (ρ) g/cm^3	$\Delta\rho$ g/cm^3

Calculate the average density

……

Calculate the percentage error

$$\%\ error = \frac{|measured\ value - accepted\ value|}{accepted\ value} \times 100\%$$

……………………………………………………………………………………………

Table 2. Cylinder

Mass (M) g	L(cm)	d (cm)	Volume (V) cm^3	Density (ρ) g/cm^3	$\Delta\rho$ g/cm^3

Calculations:

Calculate the percentage error

Table 3. Sphere

Mass (M) g	d (cm)	Volume (V) cm^3	Density (ρ) g/cm^3	$\Delta\rho$ g/cm^3

Calculations:

Calculate the percentage error

EXPERIMENT 4: VECTORS USING THE FORCE TABLE

PURPOSE

In this experiment you will investigate the general properties of vectors noting their resolution into components and their additive properties. The type of vector which will be used to illustrate these properties will be the vector representing forces

The force table is used to experimentally determine the force which balances two other forces. This result is checked by adding the two forces by using their components and by graphically adding the forces.

APPARATUS

Force table; Four clamp-mounted pulleys Ring with four strings attached ;Four hangers; Set of masses; metric ruler; protractor; 2 sheets of paper

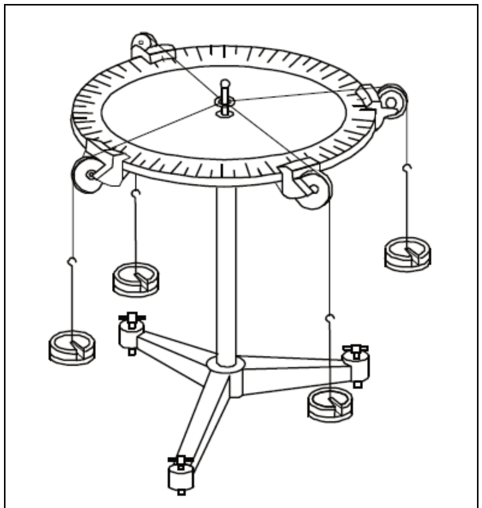


Figure 1: The Force Table

THEORY

A scalar is a physical quantity that possesses magnitude only. Examples of scalar quantities are mass, time, and temperature. A vector is a quantity that possesses both magnitude and direction; examples of vector quantities are velocity, acceleration and force.

A vector can be represented by an arrow pointing in the direction of the vector, the length of the line should be proportional to the magnitude of the vector.

Vectors can be added either graphically or analytically.

The sum or **RESULTANT** of two or more vectors is a single vector which produces the same effect. For example, if two or more forces act at a certain point, their resultant is that force which, if applied at that point, has the same effect as the two separate forces acting together.

The **EQUILIBRANT** is defined as the force equal and opposite to the resultant.

The force table is an apparatus that allows the experimental determination of the resultant of force vectors. The rim of the circular table is calibrated in degrees. Forces are applied to a ring around a metal peg (pin) at the center of the table by means of strings. The strings extend over pulleys clamped to the table and are attached to hangers. The direction of the forces may be adjusted by moving the position of the pulleys. The magnitude of the forces are adjusted by adding or removing masses to the hangers.

The forces used on the force table are actually weights, or

$$W = mg$$

In this exercise, we will simply consider the "force" as the mass that is hung on the string, that is, we will not multiply the mass by the acceleration due to gravity.

In this experiment, three methods for vector addition will be used: the graphical method (head to tail method) and the experimental method (using the force table) and by the component method.

Experimental Method

Two forces are applied on the force table by hanging masses over pulleys positioned at certain angles. Then the angle and mass hung over a third pulley are adjusted until it balances the other two forces. This third force is called the **equilibrant** ($\vec{E}$) since it is the force which establishes equilibrium.

The resultant ($\vec{R}$) is the addition of the two forces and is equal in magnitude to the equilibrant and in the opposite direction (see Figure **2**). So the equilibrant is the negative of the resultant:

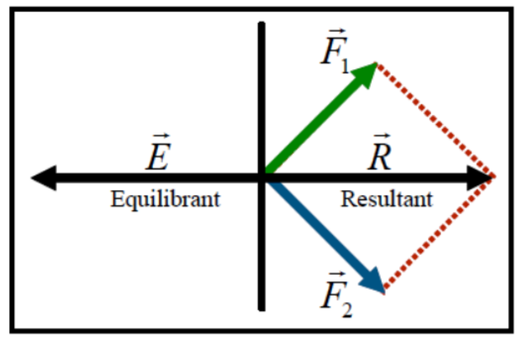


Figure 2. The Equilibrant Balances the Resultant

$$-\vec{E} = \vec{R} = \vec{F}_1 + \vec{F}_2$$

Component (or Analytical) Method

Two forces are added together by adding the x- and y-components of the forces. First the two forces are broken into their x- and y-components using trigonometry:

$$\vec{F} = F_x\hat{\imath} + F_y\hat{\jmath}$$

where F_x is the x-component of vector $\vec{F}$ and $\hat{\imath}$ is the unit vector in the x-direction. F_y is the y-component of vector $\vec{F}$ and $\hat{\jmath}$ is the unit vector in the y-direction (See Figure 3).

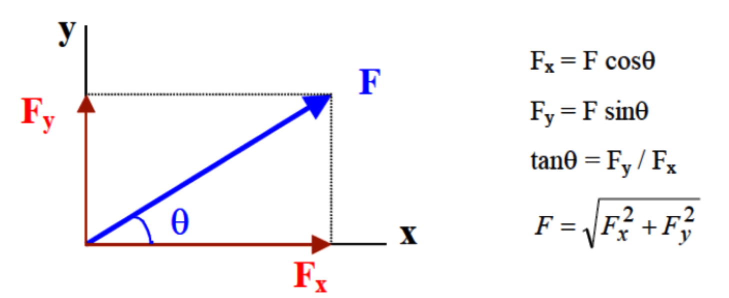


Figure 3: Resolving a vector into its components

To determine the sum of $\vec{F}_1$ and $\vec{F}_2$, the components are added to get the components of the resultant $\vec{R}$:

$$\vec{R} = (F_{1x} + F_{2x})\,\hat{\imath} + (F_{1y} + F_{2y})\,\hat{\jmath} = R_x\,\hat{\imath} + R_y\,\hat{\jmath}$$

$R_x = F_{1x} + F_{2x}$ $and\ R_y = F_{1y} + F_{2y}$

To complete the analysis, the resultant force must be in the form of a magnitude and a direction (angle):

$$R = \sqrt{R_x^2 + R_y^2} \qquad (1)$$

$$\tan\theta = \frac{R_y}{R_x} \Longrightarrow \theta = \tan^{-1}\left(\frac{R_y}{R_x}\right) \qquad (2)$$

Graphical Method
(tail to the head)

Two forces are added together by drawing them to scale using a ruler and protractor. The second force ($\vec{F}2$) is drawn with its **tail to the head** of the first force ($\vec{F}1$). The resultant ($\vec{R}$) is drawn from the tail of $\vec{F}1$ to the head of $\vec{F}2$. See Figure **4**. Then the magnitude of the resultant can be measured directly from the diagram and converted to the proper force using the chosen scale. The angle can also be measured using the protractor.

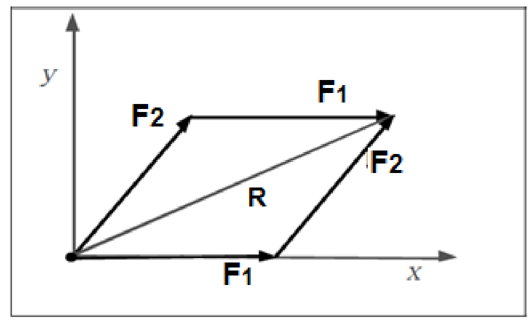


Figure 4: Adding Vectors Head to Tail

PROCEDURE

PART 1. COMPONENTS OF A FORCE.

1. Arrange identical masses of 200 g at positions of 40° and 220°. These masses should balance.
2. Now, remove the mass at 40°and by trial and error find the amounts of mass that can be hung at 0° and 90° to balance the mass at 220°. These are the x- and y-components of the force of 200 g at 40°. Record these in Table-1.
3. Calculate the x- and y-components of the vector with a magnitude of 200 g and direction of 40° as shown in Figure-3 and record them in Table-1.

PART 2. ADDITION OF TWO VECTORS.

Experimental Method

To find the resultant of two forces: a 200 g force at 30° and a 200 g force at 120°.
1. Place one pulley at 30° and the other at 120°.
2. On each string, place a mass of 200g (including hanger - each hanger has a mass of 50 g).
3. With a third pulley and masses, balance the forces exerted by the two 200 g masses. The forces are balanced when the ring is centered around the central metal peg (pin).

NOTE: To balance the forces, move the third pulley around to find the direction of the balancing force, and then add masses to the third hanger until the ring is centered.

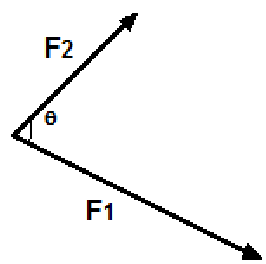
4. The balancing force obtained in (step 3) is the **equilibrant force**. The resultant has the same magnitude as the equilibrant. To determine the direction of the resultant, subtract 180º from the direction of the equilibrant.
Record your results in Table-2 under Experimental Method.

Graphical Method (tail-to-head)

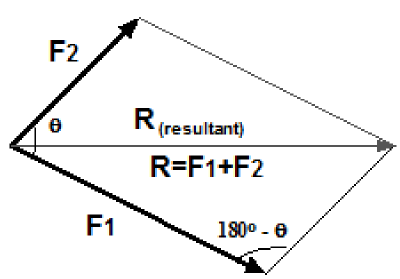
Include a graph **(a piece of quadrille paper)** where you obtain the equilibrant vector using the graphical method. Make sure to label and include direction/magnitude labels and values of each given vector on your graph and the scale used. Record your results in (Table-2) under Graphical Method.

On a separate piece of paper, construct a **tail-to-head diagram** of the vectors of Force $\boldsymbol{F_1}$ and Force $\boldsymbol{F_2}$. Use a metric rule and protractor to measure the magnitude and direction of the resultant. Record the results in Table 2.

1. Pick a convenient scale (for example 2 centimeters = 50 g) and, with a ruler, construct arrows of scaled lengths to represent vectors $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$. Label each vector with magnitude in grams. Measure the angle, $\boldsymbol{\theta}$, between $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$.



2. To find the resultant of $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ graphically, use a protractor and ruler to construct a parallelogram with sides $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$. Make sure the other angle in the parallelogram is $\boldsymbol{180^o} - \boldsymbol{\theta}$ by measuring with a protractor. With a ruler, draw the resultant vector **R.** With a ruler measure the length of the resultant. Use the scale that you set, determine its magnitude. Label the resultant **R** with its magnitude and also record it in Table-2 above. You have just added $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ according to the rules of vector addition.



3. Measure the angle between $\boldsymbol{R}$ and $\boldsymbol{F_1}$. Adding this angle to the angle between $\boldsymbol{F_1}$ and the x-axis gives you the angle between $\boldsymbol{R}$ and the x-axis. Record this angle in Table-2.

Repeat the same procedure in Part-2 for the other forces shown in the Table-2.

References:

1. Physics 150 Laboratory Manual, HWS Physics Department, Hobart & William Smith Colleges, 2015.
2. Physics Laboratory Manual, Third Edition, David H. Loyd, Angelo State University, Thomson Brooks/Cole, Thomson Higher Education, 2008.

EXPERIMENT 4: VECTORS USING THE FORCE TABLE

Name: ___________________________________ID: ________________________

Instructor: ____

Section: ____________________________Date:_____________________________

Lab. Partners: ____

DATA AND ANALYSIS

Part 1. COMPONENTS OF A FORCE VECTOR.

Table-1: Summary of the Data in Part-1, the components of the force vector

F= 200g @ 40^o	x-component (Mass at 0^o)	y-component (Mass at 90^o)
Experimental		
Computational		
% error		

1. Show your calculation for the computational x- and y-components here
Calculation:

2. Compare your computational result with your experimental result by calculating the percent error (%error) as follow:

$$\%\ error = \frac{|measured\ value - accepted\ value|}{accepted\ value} \times 100\%$$

Use the computed (components) values as your accepted values
Show a sample of the calculations here:

PART 2. ADDITION OF TWO VECTORS .

Experimental Method

Table-2: Summary of the Results to part-2, Addition of two vectors

Forces	Resultant (Magnitude and Direction)		
	Experimental Method	Graphical Method	Component Method
$F_1 = 200g$, $\theta_1 = 30^o$	F=	F=	F=
$F_2 = 200g$, $\theta_2 = 120^o$	θ=	θ=	θ=
$F_1 = 200g$, $\theta_1 = 20^o$	F=	F=	F=
$F_2 = 150g$, $\theta_2 = 80^o$	θ=	θ=	θ=
$F_1 = 200g$, $\theta_1 = 0^o$	F=	F=	F=
$F_2 = 150g$, $\theta_2 = 90^o$	θ=	θ=	θ=

1. Include a graph **(a piece of quadrille paper)** where you obtain the equilibrant vector using the graphical method. Make sure to label and include direction/magnitude labels and values of each given vector on your graph and the scale used. Record your results in (Table-2) under Graphical Method.

2. Express each given vector in component notation, add them up and calculate the resultant vector. From your result, express the resultant vector in magnitude and direction. Record your results in (Table-2) under Component Method.

Show a sample of your calculation for the first two forces in the space below:

Calculation:

3. Calculate the percent error (%error) between the graphical and the component method. Calculate also the percent error between the experimental and the component method. Make sure to do this for both magnitude and direction separately. Use the Component method results as the accepted value.
Record your results in (Table-2)

EXPERIMENT 5: THE COEFFICIENT OF FRICTION

PURPOSE

The goal of this experiment is to:

- Measure the coefficient of static friction for contacting surfaces by measuring the angle of repose for a block on an inclined plane.
- To determine if, within experimental error, the coefficient of friction is independent of the mass of the block.
- To measure the coefficient of kinetic friction for contacting surfaces by the constant speed method.

APPARATUS

- Adjustable inclined plane apparatus
- Wood block; some have felt on the bottom, some don't.
- weights

Figure-1: Apparatus for the inclined plane

THEORY

Friction can be defined as the resistance to motion between contacting surfaces.

When one surface slides (or attempts to slide) over another surface, there is generally some friction between them, which produces a force that opposes the sliding motion. There are two kinds of friction, in terms of their effects: **static friction**, which keeps two surfaces "stuck together" (stationary with respect to each other), and **kinetic friction**, which opposes an ongoing sliding motion.

When you want to push a heavy object, static friction is the force that you must overcome in order to get it moving. The magnitude of the static frictional force, f_s ,satisfies

$f_s \leq \mu_s N$

where $\mu_s$is the coefficient of static friction, a dimensionless constant that depends on the object and thesurface it is laying upon. N is the normal force between the contacting surfaces.

From this equation it is clear that the maximum force of static friction, $f_{s,max}$, that can be exerted on an object by a surface is

$f_{s,max} = \mu_s N$

Once the applied force exceeds this threshold the object will begin to move and a kinetic friction force, f_k ,exists. In general $f_{s,max} > f_k$ and so the object accelerates once it starts to move. The magnitude of the kinetic frictional force is given as follows

$f_k = \mu_k N$

where μ_k is the coefficient of kinetic friction and is approximately constant. **Figure 1** is a plot of frictional force versus applied force.

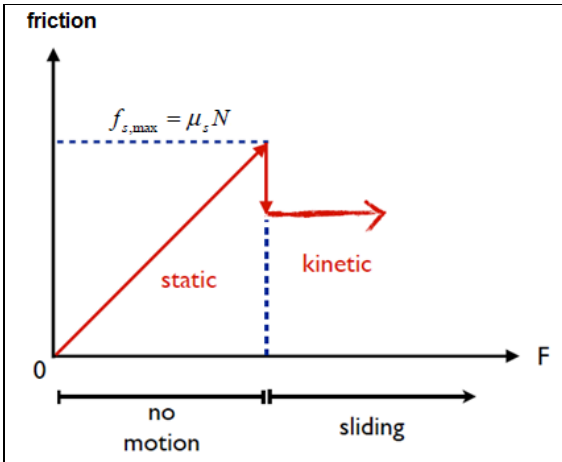


Figure 1: Plot of frictional force versus applied force

Block on an Inclined Plane
Static friction

A common example of a static friction force is that of a stationary mass on an incline. **Figure 2** depicts the free-body diagram of this case.
A block is initially at rest on top of an adjustable inclined plane apparatus. The plane is initially horizontal; a hinge allows its angle to the horizontal to be adjusted between 0^o (horizontal) and about 70^o.

The plane is slowly raised. At first, static friction keeps the block stuck to the incline. As the angle increases, the component of the gravitational force downward along the incline increases, and the upward static friction increases in step, so that the net force on the block remains zero. But the static friction can increase only to a certain size; when the angle gets big enough, the downward force exceeds the maximum static friction, and the block breaks loose and starts sliding downward. We call the angle at which this happens the **angle of repose**, θ_r.

The *angle of repose* is defined as the angle at which an object just starts to slide down an inclined plane.

What is the coefficient of static friction μ_s between the block and the plane?

Figure 2 shows a picture of the situation and a free-body diagram ($w = weight = mg$). The *x*-axis is parallel to the plane and pointing upward along it; the *y*-axis is perpendicular to the plane and pointing upward. Since the block does not move in the y-direction, the net force in that direction must be zero. Hence

$N = w\cos\theta_r$

When $= \theta_r$, the block begins to slide. This is the point at which the downward force in the x-direction is equal to the maximum force of static friction. Hence

$f_s = w\sin\theta_r = \mu_s N = \mu_s w\cos\theta_r$

$$\Longrightarrow \mu_s = \frac{w\sin\theta_r}{w\cos\theta_r} = \frac{\sin\theta_r}{\cos\theta_r}$$

$\mu_s = \tan\theta_r$

Notice that $\theta_s$depends only on the constant μ_s. In particular, notice that the weight of the block w does not appear in the equation. This suggests that the angle of repose of the block will not depend on its weight. It is this that you will be testing in this lab.

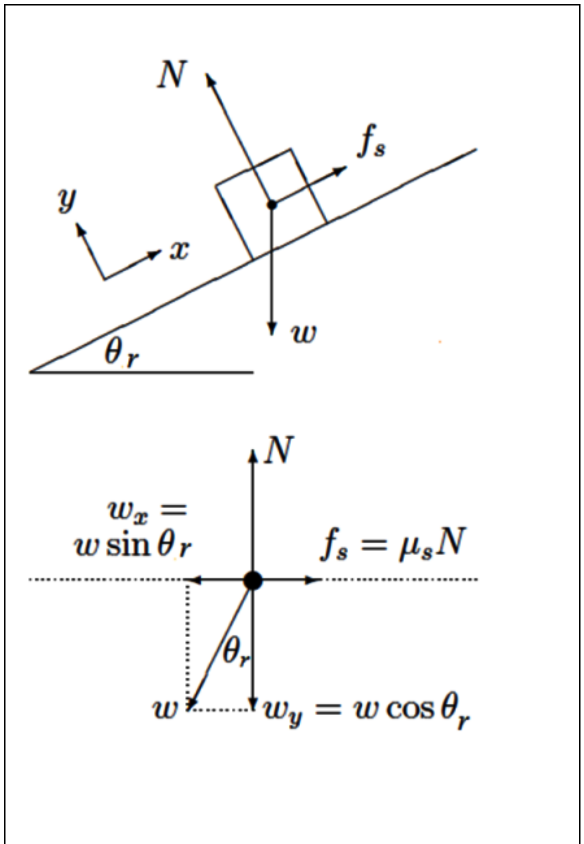


Figure 2: Free-body diagram of a mass on an incline

Kinetic Friction

It can also be shown that when an object slides down an incline at constant velocity, the coefficient of kinetic friction is given by:

$\mu_k = \tan\theta_k$

Where θ_k is the angle at which the block moves with constant velocity.

With our apparatus, it is not possible to measure a constant speed, but it is possible to obtain a close approximation of constant speed.

PROCEDURE

Part 1. Static friction

For this lab, you will use the adjustable inclined plane apparatus. This consists of a base, which should be horizontal when placed with all four feet solidly on a horizontal surface; an adjustable section, hinged where it joins the base so that it can be raised to make different angles with the horizontal; and a protractor-like arc with angles marked on it, to measure the adjustable section's angle to the horizontal.

1. With the adjustable section horizontal, place the block near its upper end (farthest from the hinge).
2. Slowly and carefully raise the adjustable section, until the block just begins to slide. Read and **record** the angle of elevation θ_r of the adjustable section in Table-1.

Note: Please note "**slowly and carefully**" in the preceding paragraph. Remember that there are both static and kinetic friction, with $\mu_k < \mu_s$. If the adjustable section is at an angle θ such that $\mu_k < \tan\theta < \mu_s$, then the block will not start sliding if it is at rest; but a slight nudge or vibration will start it moving, and it will then continue to slide. You need to avoid giving it that slight nudge, and this requires a certain amount of care. If you think that you have accidentally started the block moving at $< \theta_r$, then you should discard the measurement and take a new one.

3. Repeat this four times, for a total of five trials, recording five different measurements of θ_r . For consistent results, use the same face of the block each time, and start the block from the same place on the board each time.

4. Add 200 g to block and repeat the previous procedure to find μ_s. Record your results in Table-1.

5. Add another 200g to the block for a total of 400 g added mas and repeat the previous procedure to find μ_s. Record your results in Table-1.

6. Repeat the previous procedure for another block (you can call it Block #2) and Record your results in Table-2.

Part 2. Kinetic friction

1. Add 200g to block#1.

2. Slowly and carefully raise the adjustable section until the block slides at constant speed. Note the block will not move by itself but you need to tab it each time you raise the angle. Find *kinetic coefficient* of friction by tilting the inclined plane and noting the angle at which the block slides at a constant speed. Record the obtained angle θ_k in Table-3.

3. Repeat the same procedure four times, for a total of five trials, recording five different measurements of θ_k . For consistent results, use the same face of the block each time, and start the block from the same place on the board each time. Record your results in Table-3.

Note: You should have to tap the block each time you increase the angle in order to get it start moving.

References:

1. Physics Laboratory Manual, Third Edition, David H. Loyd, Angelo State University, Thomson Brooks/Cole, Thomson Higher Education, 2008.
2. Physics Lab 3 book, Phys. 201, University of Illinois, by Cooper, Dick, and Weissman. https://courses.physics.illinois.edu/phys211/sp2010/labs/Manual/lab3.pdf

EXPERIMENT 5: THE COEFFICIENT OF FRICTION

Name: ________________________________ ID: ______________________

Instructor: ____

Section: __________________________ Date: __________________________

Lab. Partners: ____

DATA AND ANALYSIS

Part 1. Static Friction

Block #1 Table 1: Data for computing the coefficient of static friction for Block #1.

Block #1	θ_r (degrees)						μ_s
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	
Block without weight							
Block +200g							
Block +400g							

1. Calculate the average angle θ_r. Then use this average value to calculate the coefficient of *static friction* by using $\mu_s = \tan\theta_r$. Record your data on Table-1 above.
Show sample calculation here:

---

2. Find the average value obtained for the coefficient of *static friction* μ_s
$Average\ \mu_s =$ ____________________

Block #2

Table 2: Data for computing the coefficient of static friction for Block #2.

Block #2	θ_r(degrees)						μ_s
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	
Block without weight							
Block +200g							
Block +400g							

1. Calculate the average angle θ_r. Then use this average value to calculate the coefficient of *static friction* by using $\mu_s = \tan\theta_r$. Record your data on Table-2 above.

2. Find the average value obtained for the coefficient of *static friction* μ_s

$Average\ \mu_s =$ ______________________

Part 2. Kinetic Friction

Block #1

Table 3: Data for computing the coefficient of kinetic friction for Block #1.

Block #1	θ_k(degrees)						μ_k
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	
Block without weight							
Block +200g							
Block +400g							

1. Calculate the average angle θ_k. Then use this average value to calculate the coefficient of *static friction* by using $\mu_k = \tan\theta_k$. Record your data on Table-3 above.

2. Find the average value obtained for the coefficient of *kinetic friction* μ_k

$Average\ \mu_k =$ ______________________

Block #2

Table 4: Data for computing the coefficient of kinetic friction for Block #2.

Block #2	θ_k(degrees)						μ_k
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	
Block without weight							
Block +200g							
Block +400g							

1. Calculate the average angle θ_k. Then use this average value to calculate the coefficient of *static friction* by using $\mu_k = \tan\theta_k$. Record your data on Table-3 above.

2. Find the average value obtained for the coefficient of *kinetic friction* μ_k

$Average\ \mu_k =$ ____________________

- Compare the values of $\mu_k\ and\ \mu_s$ for Block #1 and 2. Do your data confirm the expectation that$\mu_k < \mu_s$?

QUESTIONS

1. Is μ_s more or less constant as you increase the weight on the block? If not, does there appear to be a trend (i.e. μ_s increasing or decreasing with increasing weight)?

---

2. Suppose instead of a wooden block, you place a square ice cube on one of the metal inclined planes. Would you expect the angle of repose, and hence the coefficient of friction to be larger, or smaller than the coefficient of friction due to a wooden block? Why?

EXPERIMENT 6: MEASUREMENT OF (g) BY FREE FALL EXPERIMENT

PURPOSE:

The objective is to determine the value of gravity constant (g), the acceleration of an object in free fall near the surface of the Earth.

APPARATUS

Millisecond timer, metal ball, trapdoor and electromagnet.

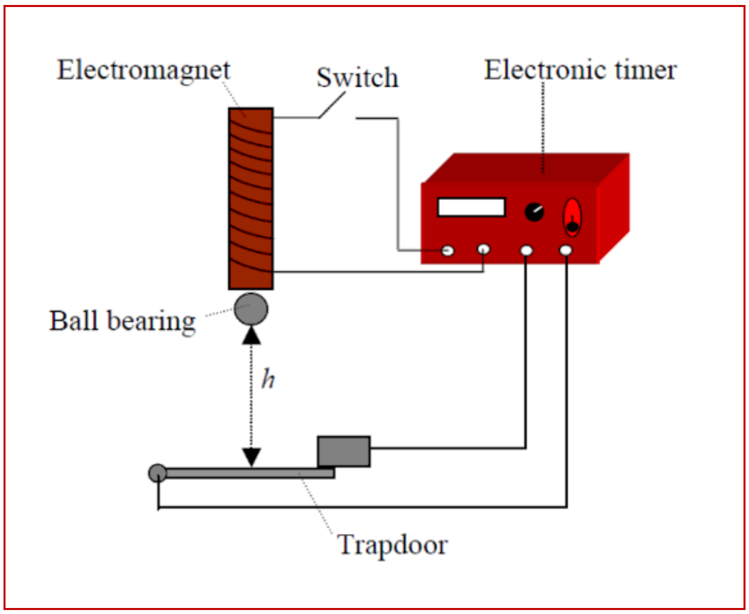


Figure-1: Apparatus for the free fall experiment

THEORY

Newton's law of gravitation gives the force of attraction between two masses. If the Earth were a uniform, non-rotating sphere, Newton's law would give GM/R^2 for the acceleration of a small mass arriving at the Earth's surface; G is the gravitational constant, M is the Earth's mass, and R is the Earth's radius. But the Earth is not spherical, its mass is not distributed uniformly, and it rotates; in addition, a falling object may be at some altitude above the ground. Any measurement of the acceleration g of a freely falling object is affected by these factors, but we expect these to be small effects, and that g should be quite close to the customary value of 9.8 m/s^2.

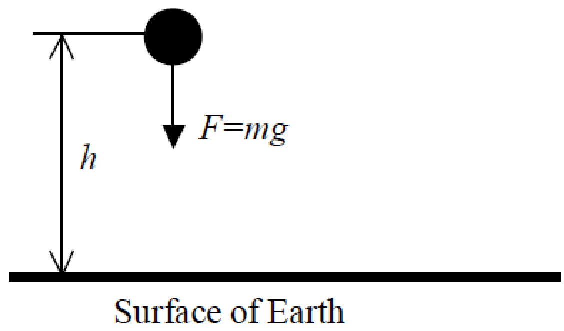


Figure-2. Any object is a subject to force *F=mg* toward Earth

A measurement of g can be based on the positions of a falling object at different times. Since the motion is downward, let the y direction be positive downward. Assuming constant acceleration g, the vertical position y at a time t is

$$y(t) = y_0 + v_0 t + \frac{1}{2} g t^2$$

measured from the starting position y_0 with an initial velocity v_0.

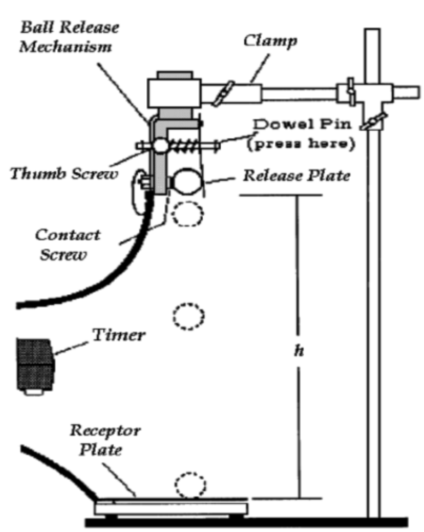
when the ball is dropped from rest ($v_0 = 0$) and choosing the initial point as the zero point $y_0 = 0$, we have for h (the falling distance the body has traveled from its starting point during time t)

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

Therefore, to calculate the value of g, you should study the relation between the falling distance h and t^2.

PROCEDURE

1. Set up the apparatus. The millisecond timer starts when the ball is released and stops when the ball hits the trapdoor. Use the first steel ball



2. Set the height h to 40 cm (using a meter stick). **Press** the reset button on the timer, and then **push** to release the ball which drops and falls on the receptor plate. **Record** the time of fall t in Table-1

3. Repeat the measurement three times for this height h and take the **smallest** time as the correct value for t.

4. **Increase** the height h by about 10 cm and **repeat** the measurements made in the previous steps. Increase the height again by 10 cm and repeat the measurements until the height increases to approximately 100 cm.

5. **Repeat** steps 1 through 5 for a different steel ball and record your data in Table-2.

References:

1. Lab manual, part 1 For PHY 166 and 168 students, Department of Physics and Astronomy, HERBERT LEHMAN COLLEGE, 2018.
2. Phys 101 Lab Manual, Lab manual, King Fahd University for Petroleum and Minerals, Dhahran 31261, KSA, 2007.

EXPERIMENT 6: MEASUREMENT OF g BY FREE FALL EXPERIMENT

Name: ________________________________**ID:** ______________________

Instructor: ____

Section: __________________________**Date:**__________________________

Lab. Partners: ____

DATA AND ANALYSIS

Table-1: Summary of the free fall experimental data (Ball #1)

$h\ (m)$	$t\ (s)$				$t^2 (s^2)$	$g\ (m/s^2)$
	Trial-1	Trial-2	Trial-3	Average		

1. Calculate the value of $\boldsymbol{g}$ for each height using the Equation-1, $g = 2h/t^2$ and record it in the appropriate column of your data table.
Show a sample calculation here:

2. Calculate the average value of g

$$Aveage\ acceleration\quad g = \text{...}$$

Compare your result with the accepted value of 9.8 m/s^2 by calculating the percent error (% error).

$$\% \, error = \frac{|measured \ value - accepted \ value|}{accepted \ value} \times 100\%$$

% error = …………………………………………...

3. Plot a graph of height t^2 versus h . *Draw the best straight line fit of the data.* and determine the acceleration due to gravity from the slope. With h on the x-axis and t^2 on the y-axis, the slope is $2/g$.
Show your calculation of the slope on the graph.

Slope = ……………………………………………….

$g =$…………………………………………………….

Ball#2

Table-2: Summary of the free fall experimental data (Ball #2)

$h\ (m)$	$t\ (s)$				$t^2 (s^2)$	$g\ (m/s^2)$
	Trial-1	Trial-2	Trial-3	Average		

5. Calculate the average value of g. Compare your result with the accepted value of 9.8 m/s^2 by calculating the percent error (%error).

$Average \quad g =$…………………………………………………

% error = …………………………………………...

EXPERIMENT 7: HOOK'S LAW

PURPOSE

The primary purpose of the lab is to study Hooke's Law and simple harmonic motion by studying the behavior of a mass on a spring. Your goal will be to measure the spring constant of one particular spring by two methods:

- Directly determine the spring constant k of a spring by measuring the elongation versus applied force.
- Determine the spring constant k from measurements of the period T of oscillation.

APPARATUS

The equipment needed includes (See Figure):

- a helical spring (cylindrical and slightly tapered)
- a support stand with metric scale attached
- a mass holder with 50 gram masses
- a timer

THEORY

Any material that tends to return to its original form or shape after being deformed is called an elastic material. The degree of elasticity depends on the internal properties of the deformed material. In many elastic materials the deformation is directly proportional to a restoring force that resists the deformation. This linear relationship is called *Hooke's Law.* For our purposes, we consider motion in one dimension (vertical dimension), and Hooke's Law takes on the more familiar form

$F = -k\Delta y$

where F is the restoring force, Δy is the displacement of the body from its equilibrium position, and k is a constant with dimensions of N/m. The negative sign indicates that the force is in the opposite direction of the displacement. If a spring exerts the force, the constant k is **the spring constant**.

Suppose we hang a mass, M, on the spring and a *new* equilibrium position is established, as seen in Figure-2. According to Newton's 2nd Law the magnitude of the restoring force is equal to the magnitude of the weight of the hanging mass. When the mass M is attached to the spring and the spring is in equilibrium, the restoring force is balanced by the weight

$$W = Mg = k\Delta y \quad (1)$$

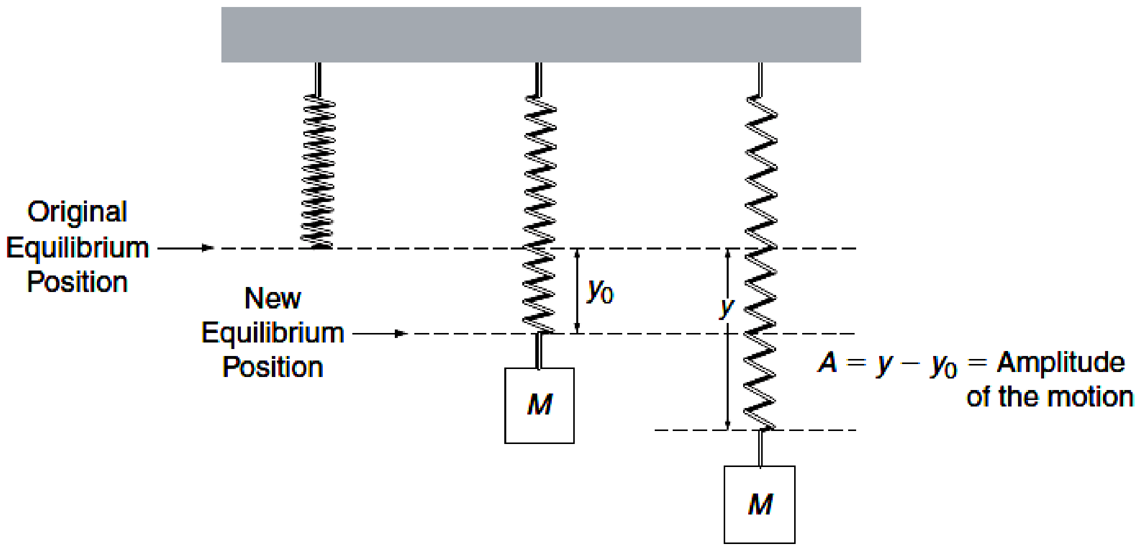


Figure-2: The effect on the equilibrium position of a spring when a mass M is attached to it

If a body, which obeys Hooke's Law, is displaced from equilibrium and released, the body will undergo "simple harmonic motion". Many systems, such as water waves, sound waves, ac circuits and atoms in a molecule, exhibit this type of motion. A particularly easy example to study is a massive object on a spring. The time for one complete oscillation is defined as the **period** T and is given by :

$$T = 2\pi\sqrt{M/k} \quad (2)$$

Where M is the mass of the object and k is the force constant.

PROCEDURE

In this lab, you will observe a mass on a spring and, from this, determine the value of k for that spring. There are two straight-forward ways of doing this. The first method is referred to as the "static method," which utilizes Hooke's Law, given in Equation (1). The second method, the "dynamic method", makes use of the fact that the system exhibits simple harmonic motion with period T, given in Equation 2. Thus, you are able to perform two independent experiments to extract a property of spring – its spring constant.

Part 1: The Static Method

1. Begin by measuring the position of the spring. This is your equilibrium position. Record this as $\boldsymbol{y_0}$ in your data sheet (Table-1).

> (Note: Choose a convenient reference point near the bottom of the spring (lower end of the spring) with which to measure the position of the spring.)

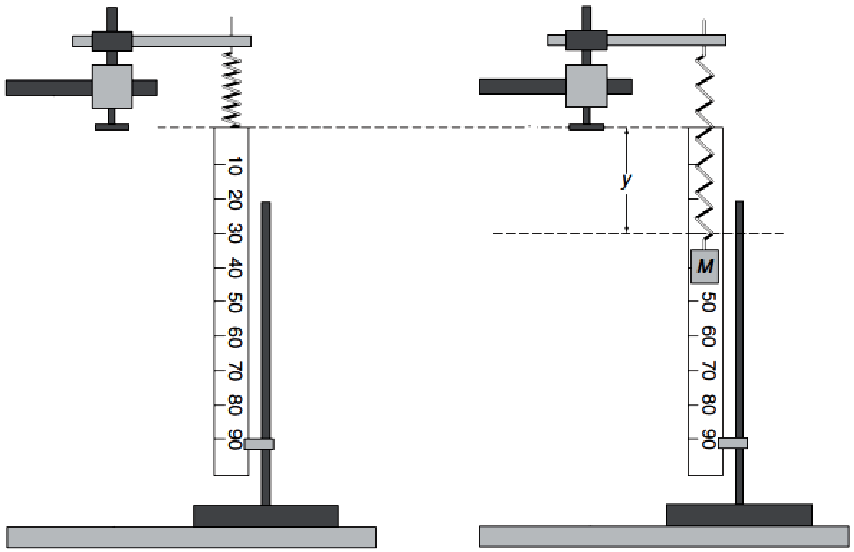


Figure-3: Arrangement to measure displacement of spring caused by mass *M*.

2. Attach a 50 gram (0.050 kg) mass holder to the spring and measure the new position $\boldsymbol{y_1}$ to which the reference point on the spring is extended. Record mass and the position with the 50 gram mass holder in Table-1.

3. Add additional 50 gram masses to the mass holder and record the position of extension $\boldsymbol{y_i}$ each time the mass is increased by 50 grams until the total mass reaches 350 grams.

4. Compute the applied force F that the masses exert on the spring by calculating the weights of the masses. Remember that the weight W is given by $W = mg$ and is measured in Newtons if M is the mass measured in kilograms and g is the acceleration due to gravity, $g = 9.80\ \text{m/s}^2$. Record these forces F in Table-1.

5. Calculate the displacement Δy of the spring, which is the amount the spring is stretched and is calculated by taking the difference between the extended position y_i and the equilibrium position y_0, ($\Delta y = y_i - y_0$). Record your results in Table-1.

Note: Displacements are to be calculated relative to the equilibrium position (for example, if the equilibrium position is 20 cm, you would subtract 20 cm from all of your position measurements.

Part 2: Dynamic Method

By displacing the spring from equilibrium, the system will oscillate. By measuring the mass of the system and its period of oscillation, the value of the spring constant can be deduced using Equation 2.

1. Attach the hanger to the spring (mass = 0.050 kg) and let it hang at rest.

2. With only the hanger attached to the spring, measure the period of vibration by first displacing the holder about 5 cm below the equilibrium. Release it, and let the system oscillate and then measuring the total time (t) for 30 complete oscillations. Record your data in Table-2.

3. Add an additional 50 grams to the hanger and repeat step 2 until the total mass reaches 350 grams (including the hanger).

4. Calculate the period of oscillation T for each oscillating mass by dividing the total time t by 30. Record the results in Table-2. Also record the values of T^2 in Table-2.

References:

1. Physics Laboratory Manual, Third Edition, David H. Loyd, Angelo State University, Thomson Brooks/Cole, Thomson Higher Education, 2008.
2. Physics 150 Laboratory Manual, HWS Physics Department, Hobart & William Smith Colleges, 2015.

EXPERIMENT 7: HOOK'S LAW

Name: ________________________________ **ID:** ______________________

Instructor: ____

Section: ___________________________ **Date:** __________________________

Lab. Partners: ____

DATA AND ANALYSIS

Part 1: The Static Method

Table-1: Summary of the Data for the displacement of the spring versus applied force

$y_0 =$..................................			
Mass	Force=Weight	Actual meter stick reading	Displacement (m)
M (kg)	$F = Mg$ (N)	$y_i(m)$	$\Delta y = y_i - y_0$
0.050			

1. Graph the applied force F to the spring as a function of its displacement Δy. Plot the displacement Δy on the horizontal axis (x-axis) and the applied force on the vertical axis (y- axis). Draw the best straight line fit of the data.
2. The spring constant k will be the slope of the straight line (slope $=k$). Calculate k from the slope.

$k_1 =$..

Part 2: Dynamic Method

Table-1: Summary of the Data for the period of the spring versus the mass

Total mass hanger + added mass	Total time of 30 oscillations	Period	Period squared
M (kg)	$t(s)$	$T(s)$	$T^2(s^2)$
0.050			

1. Plot T^2 (y-axis) vs. M (x-axis). Draw the best line fit of the data. The slope is equal to $4\pi^2/k$. Calculate the spring constant k from your value of the slope.

$$k = 4\pi^2/slope$$

Show your calculations here

k_2 = ……………………………………………………

2. Recall your value for the spring constant found in Part-1using Hooke's Law (call this k_1). Compare it with the value found in this part (call this k_2). Compute the percent difference in these values.

$$\% \, Difference = \frac{|k_1 - k_2|}{k_1} \times 100\%$$

$$\% \, Difference = \text{………………………………}$$

EXPERIMENT 8: SIMPLE PENDULUM

PURPOSE

The purpose of this experiment is to use the apparatus for a simple pendulum to:

- Investigate the dependence of the period T of a pendulum on the length L and the mass M of the bob.
- Determine an experimental value of the acceleration due to gravity g by comparing the measured period of a pendulum with the theoretical prediction.

APPARATUS

The apparatus for this experiment consists of a support stand with a string clamp, a small spherical ball with a string, a meter stick, and a timer. The apparatus is shown in Figure 1.

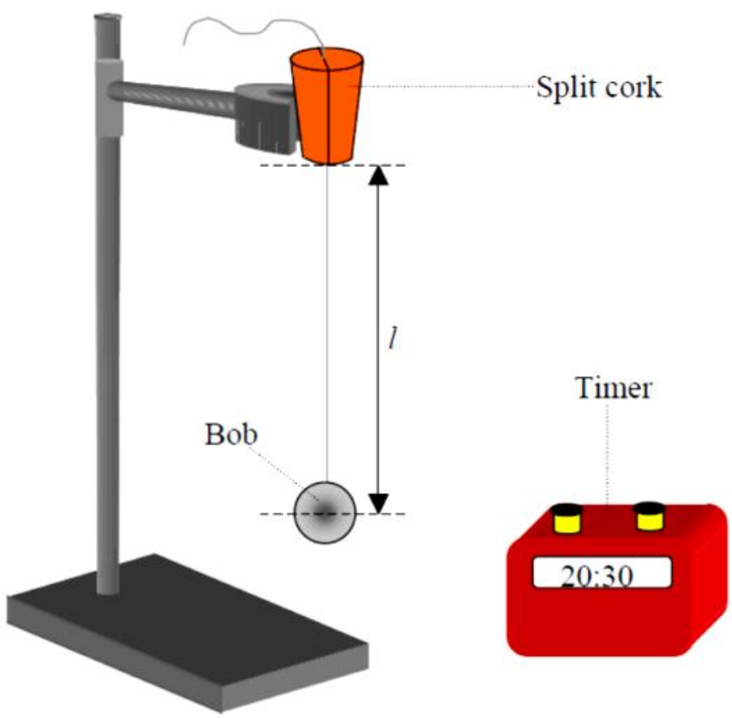


Figure-1: The apparatus of the Simple Pendulum experiment

THEORY

A simple pendulum consists of a bob suspended from a string whose weight is insignificant compared to the bob. When initially displaced, it will swing in a plane back and forth under the influence of gravity over its central (lowest) point. The motion of the pendulum is nearly periodic. Several of the bob's parameters can be varied: the mass of the bob, length of the string, and amplitude of the motion.

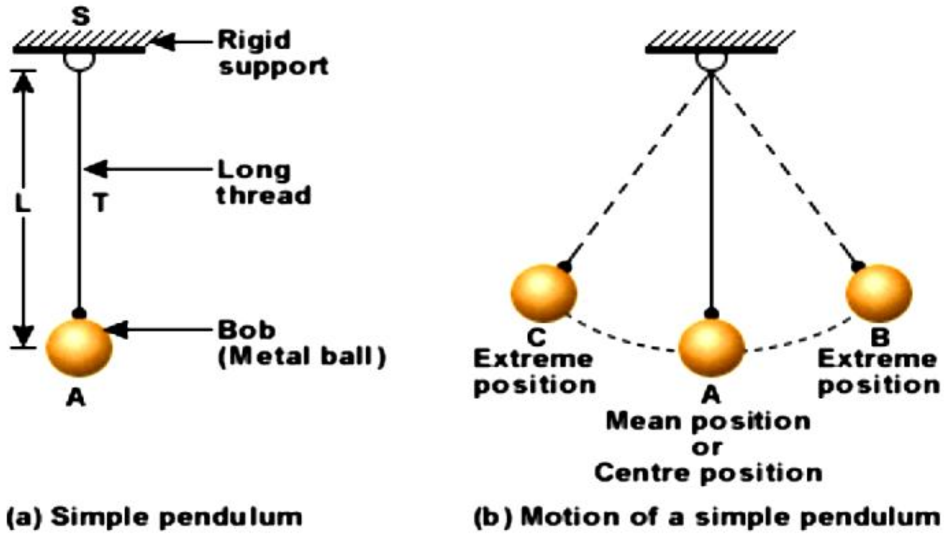


Figure-2: Schematic diagram of the Simple Pendulum and its periodic motion

Oscillations of the pendulum: One oscillation is the motion taken for the bob to go from position B (initial position) to A (mean position) to C (the other extreme position) and back to B (see Figure-2).

Period of the pendulum: The time taken to complete one oscillation by the pendulum. This is denoted by T.

The pendulum that we will use in this experiment consists of a small object, called a bob, attached to a string, which in turn is attached to a fixed point called the pivot point.

The length of a pendulum: is the distance from the pivot point to the center of mass of the bob.

There are four fundamental physical properties of the pendulum:

• the length • the mass • the angle • the period

The force that causes the pendulum to oscillate is the gravitational force (see Figure-3).

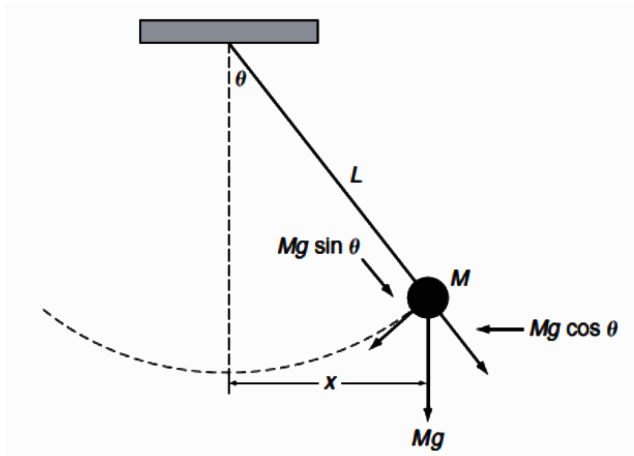


Figure-3: Force components acting on the mass bob of a simple pendulum.

The period of the simple pendulum is given by $T = 2\pi\sqrt{\frac{L}{g}}$

Where L is the length of the pendulum and g is the acceleration of gravity.

PROCEDURE

1. Set up the pendulum as in the Figure 1, and Adjust the length L to about 20 cm. The length of the simple pendulum is the distance from the pivot point to the center of the ball.

2. Displace the bob from its equilibrium position by a small angle (<10°) and then release the bob to swing back and forth.

3. Measure the total time (t) it takes to make 10 oscillations. Record your data in Table-1. (If the swing becomes elliptical you must repeat the swinging again to be in a vertical plane.) Note: Greater accuracy can be obtained by timing for ten oscillations and dividing the result by 10 rather than to time just a single oscillation)

4. Calculate T by dividing the total time t by 10 to get the periodic time T. Record your results in Table-1. Calculate also T^2 and record it in Table-1.

5. Repeat the procedure for lengths near 40cm, 60cm, 70 cm, and 80cm. Be sure to record the length L for each pendulum.

6. Repeat the same procedure for another bulb and record the data in Table-2.

References:

1. Physics 101 Lab Manual, Princeton University, USA, 2014
2. Laboratory Exercises for Physics 101 Department of Physics and Astronomy of Hunter College of the City University of New York. Edited and revised by The anne Schiros, January 2001.

EXPERIMENT 8: SIMPLE PENDULUM

Name: ______________________________ **ID:** ______________________

Instructor: ____

Section: __________________________ **Date:** __________________________

Lab. Partners: ____

DATA AND ANALYSIS

Table1: Summary of the data for simple pendulum

$L\ (m)$	$t\ (s)$	$T\ (s)$	$T^2 (s^2)$	$g\ (m/s^2)$

1. Calculate the value of $\boldsymbol{g}$ for each length and record it in the appropriate column of your data table using:

$$g = \frac{4\pi^2\, L}{T^2}$$

Show a sample calculation here:

2. Calculate the average value of g

$$Average\ \ g = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Compare your result with the accepted value of 9.8 m/s^2 by calculating the percent error (%error).

$$\%\ error = \frac{|measured\ value - accepted\ value|}{accepted\ value} \times 100\%$$

% error = ……………………………………………..

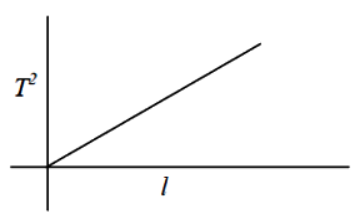
3. Plot a graph of height T^2 versus L. *Draw the best straight line fit of the data.*
Determine the acceleration due to gravity from the slope. With L on the x-axis and T^2 on the y-axis, the slope is $\frac{4\pi^2}{g}$.
Show your calculations of the slope on the graph. Compare your result with the accepted value of 9.8 m/s^2 by calculating the percent error (%error).

Slope = ……………………………………………..

$g = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$

% error = ……………………………………………..

see below how to calculate g from the graph.



$$T^2 = 4\pi^2 \frac{l}{g}$$
$$\Rightarrow \frac{T^2}{l} = \frac{4\pi^2}{g} = \text{slope}$$
$$\Rightarrow \text{g} = \frac{4\pi^2}{\text{(slope)}}$$

Ball #2

Table2: Summary of the data for simple pendulum (Ball #2)

$L\ (m)$	$t\ (s)$	$T\ (s)$	$T^2 (s^2)$	$g\ (m/s^2)$

5. Calculate the value of ***g*** for each length and record it in the appropriate column of your data table using:

$$g = \frac{4\pi^2 L}{T^2}$$

6. Calculate the average value g. Compare your result with the accepted value of 9.8 m/s^2 by calculating the percent error (%error).

$Average \quad g =$……………………………………………………

% error = ………………………………………………..

EXPERIMENT 9: NEWTON'S SECOND LAW

PURPOSE

To investigate Newton's Second Law using a dynamics cart in order to find the relationship between force, mass, and acceleration.

APPARATUS

Car track system with cart, Photogate timer , Pulley, mass pieces, weight hanger, and string.

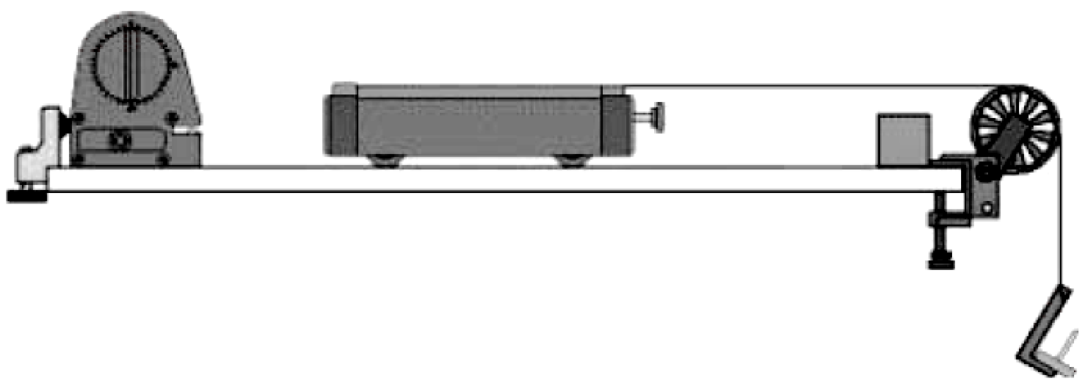


Figure-1: Apparatus for Newton's second law experiment

THEORY

An important equation in physics is the mathematical form of Newton's second law,

$\mathbf{F} = m\mathbf{a}$

Where **F** is the net external applied force on an object of mass *m* and **a** is the resulting acceleration. This law states that when a net force is not zero then the object will accelerate. If the external force is increased the acceleration will increase (assuming constant mass). If the net force is doubled, the acceleration is doubled *i. e.* the net force is directly proportional to the acceleration.

$F \propto a$

Also, Newton's second law states that the acceleration is inversely proportional to the mass.

$a \propto 1/m$

In this experiment, a cart of mass M is accelerated along a horizontal cart track by a tension *T (see Figure-2)* . Neglecting friction, The only force acting on the cart is T,

$F = T$

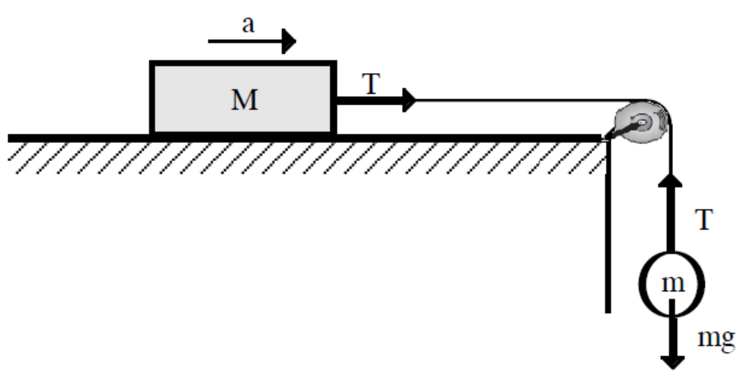


Figure-2: Shematic diagram of the system to be studied

The tension is provided by a string which is attached over a pulley to another mass m. The gravitational force acting upon m gives both masses an acceleration a along their respective lines of motion. Newton's law applied to each mass allows the value of a to be calculated in terms of M, m, and g, which gives:

$$a = g\left(\frac{m}{m + M}\right)$$

Where m is the total mass of the hanger and M is the mass of the cart. This value is compared to the "measured" value of a.

PROCEDURE

Part 1. Acceleration vs. Force (constant mass)

Note: Before beginning, make sure to level the track with the leveling device on the end of the track. Level the air track using the cart without the hanging mass attached. The air track can be considered to be level when the cart is able to remain stationary for several seconds.

1. Keep the cart a distance of at least 5 cm from the front of the photogate before releasing it . Starting the cart a nearer distance than this, may cause the gate not to function properly.

BE CAREFUL TO PREVENT THE CART FROM SLAMMING INTO THE PULLEY.
Note: Remember to catch the cart before it hits the pulley or you may damage the cart and pulley.

2. Put 500g on the cart and place the cart at the starting position. With no masses attached to the hanger, release the hanger and record the acceleration recorded by your timer. Record the acceleration and the total mass of the hanger in Table-1.

3. Repeat the previous step for a total of three trials and record the acceleration each time in Table-1.

4. Add 20 g to the mass hanger and repeat steps 2 and 3. Keep adding 20g each time until the hanger has a total mass of 140 g. Make sure to be recording the acceleration for each trial in Table-1.

PART2: Acceleration vs. Mass (Constant Force)

1. Put a total mass of 100g on the hanger (including the mass of the hanger). DO NOT change the added mass on the hanger in this part.

2. Place the cart at the starting position. It should not have any weights on it. Release the hanger and record the acceleration of the cart in Table-2.

3. Repeat this step for a total of three trials and record the acceleration for each trial in TABLE-2.

4. Add 100 g to the cart and repeat steps 2 and 3. Keep adding 100g masses until the added mass is 500 g. Make sure to be recording the acceleration for each trial in TABLE-2.

References:

1. Physics 136-1: General Physics Lab, Laboratory Manual – Mechanics, Northwestern University, Version 1.1b, USA, June 21, 2019.
2. Physics Laboratory Manual, Third Edition, David H. Loyd, Angelo State University, Thomson Brooks/Cole, Thomson Higher Education, 2008.

EXPERIMENT 9: NEWTON'S SECOND LAW

Name: ______________________________**ID:** ____________________

Instructor: ____

Section: ________________________**Date:**________________________

Lab. Partners: ____

DATA AND ANALYSIS

Part 1. Acceleration vs. Force (constant mass)

TABLE-1: Acceleration vs. Force

Mass of the cart, M						
Mass of the hanger+ added mass	Calculated net external force	Experimental Acceleration				
$m\ (kg)$	$F\ (N)$	$a\ (m/s^2)$				
		Trial 1	Trial 2	Trial 3	Average
0.050					

1. Calculate the external force acting on the cart, which is the total weight of the hanger $F = W = mg$. Record these TABLE-1.

2. Calculate the average acceleration of the tree Trials and record this in TABLE-2.

3. Plot the average acceleration (a) versus the external force (F). With (F) on the y-axis and (a) on the x-axis. Draw the best straight line fit of the data. From the slope calculate the mass of the empty cart.

$$a = g\left(\frac{m}{m+M}\right) \Rightarrow a = mg\left(\frac{1}{m+M}\right) \Rightarrow$$

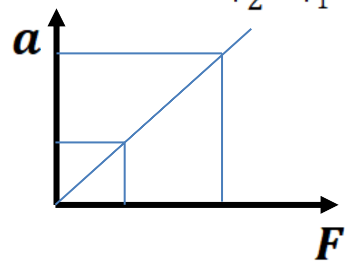
Divide nominator and denominator by **M**: $\Rightarrow a = \frac{m}{M} g \left(\frac{1}{\frac{m}{M}+\frac{M}{M}}\right)$

$$a = \frac{m}{M} g \left(\frac{1}{\frac{m}{M}+1}\right) \Rightarrow$$

Consider **m/M** negligible compared to 1: $\Rightarrow a = \frac{m}{M} g \Rightarrow a = \frac{mg}{M} \Rightarrow$

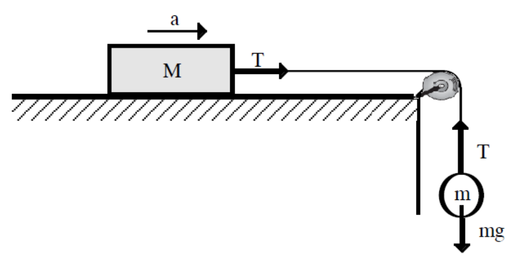
$$\textit{Thus} \quad F = Ma \Rightarrow slope = \frac{a}{F} = \left(\frac{1}{M}\right)$$

$$slope = \frac{a_2 - a_1}{F_2 - F_1}$$



Slope = ……………………………..

Mass of the cart (M) = ………………………..



QUESTIONS:

1) Derive the equation given in part 2.

$$a = g\left(\frac{m}{m+M}\right)$$

2) What does the theoretical formula predict for the acceleration in the limit as $M \rightarrow 0$? Justify why this result is sensible.

3) What does the theoretical formula predict for the acceleration in the limit as $m \rightarrow 0$? Justify why this result is sensible.