NORTH SOUTH UNIVERSITY

The first private university in Bangladesh

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Department of Mathematics & Physics

Experimental Physics

General Physics-I

PHY-107L

Laboratory Manual

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Content:

Expt-1: Introduction to Measurement and Statistical Error

Objectives:

1. To familiarize the student with random error and bias in laboratory measurements (ruler, Vernier caliper, screw gauge).
2. To introduce the concepts of arithmetic mean, standard deviation and experimental error.

Apparatus:

Vernier caliper, screw gauge, centimeter ruler, a small cylinder.

Theory:

Measurement of different shapes:

The Vernier Caliper

The Vernier caliper is designed to facilitate the estimation of a fractional part of a scale or ruler. The Vernier consists of an auxiliary scale, called the Vernier scale, which is capable of sliding along the edge of a main scale (Figure 1). With the help of the Vernier scale, length can be measured with an accuracy greater than that obtainable from the main scale. The graduations on the Vernier scale are such that n divisions of this scale are generally made to coincide with $(n - 1)$ divisions of the main scale. Under this condition, lengths can be measured with an accuracy of $\frac{1}{n}$ of the main scale division.

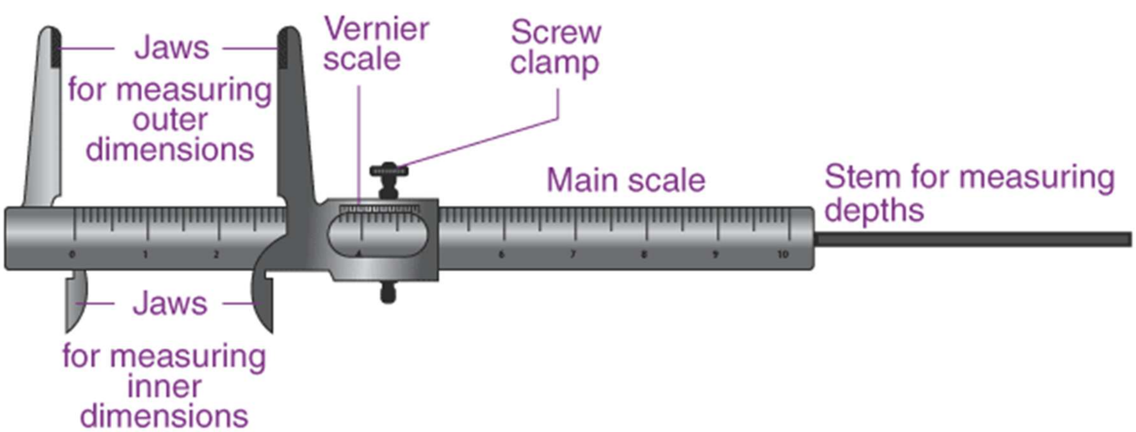


Figure 1: Parts of Vernier Caliper

For example, in the following figure ten units of the Vernier scale have the same length as nine units of the main scale. Each unit on the Vernier scale is therefore 1/10 mm smaller than the smallest unit of the main scale. Thus, the line on the Vernier which is aligned with a line on the main scale indicates the number of tenths of a millimeter that the index is past the last whole millimeter of the main scale. The index in Figure 1 is located to the right of 3.2 centimeters. Hence, the reading is a little more than 3.2 centimeters, but not as large as 3.3 centimeters. The line indicating the third unit of the Vernier scale is directly beneath a line on the main scale. It is the fifth line on the Vernier scale that lines up. This tells us that the reading is 3.25 centimeters

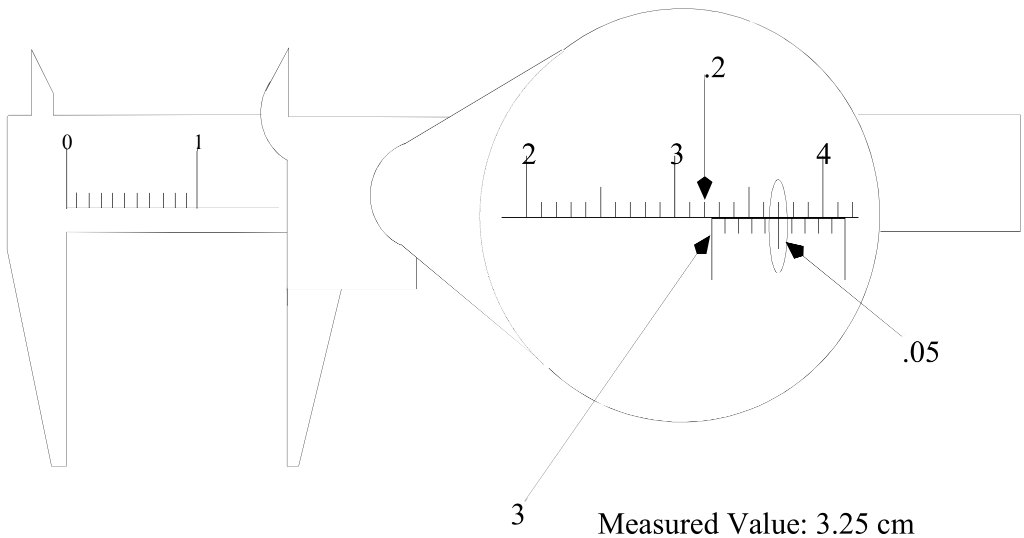


Figure 2: How to Read a Vernier Caliper.

An instrumental error or zero error exists when, with the two jaws touching each other, the zero of the Vernier scale is ahead of or behind the zero of the main scale. The error is positive when the Vernier zero is on the right and is negative when the Vernier zero is cm the left side of the main scale zero. If the instrumental error is positive it is to be subtracted from the measured length to obtain the correct length. If the error in negative is to be added to the measured length.

The Screw Gauge

It consists of a U-shaped piece of steel, one arm of which carries a fixed stud and the other arm is attached to a cylindrical tube. A scale graduated in centimeters or inches is marked on this cylinder. An accurate screw provided with a collar, moves inside the tube. The screw moves axially when it is rotated by the milled head. The fixed and the movable studs are provided with jaws (plane surfaces). The principle of the instrument is the conversion of the circular motion of the screw head into the linear motion of the movable stud.

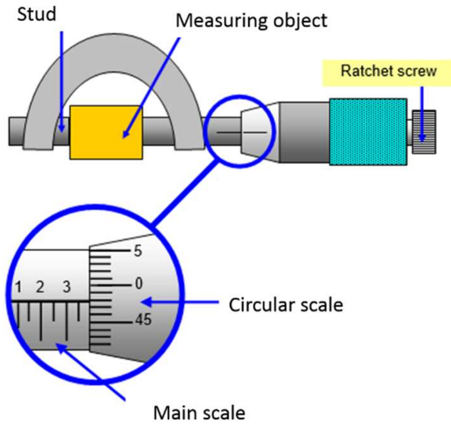


Figure 3: Screw gauge and measuring a shape.

The beveled end of the rotating barrel is generally divided into 50 or 100 equal divisions forming a circular scale. Depending upon the direction of rotation of the screw the collar covers or uncovers the straight scale divisions. When the movable stud is made to touch the fixed stud, the zero of the linear (straight) scale should coincide with the zero of the circular scale. If they do not coincide then the screw gauge is said to possess an instrumental error.

The ***pitch*** of the screw is defined as its axial displacement for a complete rotation. The least count (L.C.) of the screw gauge refers to the axial displacement of the screw for a rotation of one circular division. Thus, if n represents the number of divisions on the circular scale and the pitch of the screw is m scale divisions, then the least count (L.C.) of the screw gauge = $\frac{m}{n}$ scale divisions.

Back-lash error: When a screw moves through a threaded hole there is always some misfit between the two. As a result, when the direction of rotation of the screw is reversed, axial motion of the screw takes place only after the screw head is rotated through a certain angle. This lag between the axial and the circular motion of the screw head is termed the back-lash error. In order to get rid of this error, the screw head should always be rotated in the same direction while measurement is made.

Experimental Error:

Accuracy is the degree to which a measurement agrees with an accepted value for those measurements. The accuracy of a measurement is dependent upon the production and calibration of the instrument. When an instrument is calibrated according to a reliable standard then measurement will be more closely aligned with the accepted value for that measurement.

Measurement can be evaluated in absolute or relative terms. The absolute error is the absolute value of the difference between the accepted value and the measurement. This can be written as an equation as shown below.

Absolute error = |Observed value - Accepted known value|

$$E_a = |O - A| \tag{1i}$$

This can be expressed as a percentage error also as:

$$E_a = \frac{|O-A|}{A} \times 100\% \tag{1ii}$$

Data can also be evaluated in terms of how measurements, which are made in the same manner, deviate from one another. The deviation of experimental data is dependent upon the reproducibility with which the experimenter can take data. This is known as precision and is evaluated in terms of absolute and relative deviation. Absolute deviation is the absolute value of the difference between the mean or average value and the measured value. This is expressed below in the equation.

Absolute deviation = |Observed value - Mean value|

$$D_a = |O - M| \tag{2i}$$

Another way to express the deviation is as a percentage. This is the relative deviation and is expressed as follows.

Relative deviation = Average absolute deviation × 100%

$$D_r = D_a \times 100\% \tag{2ii}$$

Statistically the **uncertainty** of a measurement can be determined using a quantity called the **standard deviation**, σ.

The standard deviation for a sample of N measurements is defined as follows:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{3i}$$

where $\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$, N is the number of observation and x_i is each observation.

The standard deviation is a measure of spread. If the standard deviation is *small*, then the spread in the measured values about the mean is *small*, and so the *uncertainty* is low but the *precision* in the measurements is *high*. The standard deviation is always positive and has the same units as the measured values. Therefore, the measured value of X can be written as: $X = \bar{X} \pm \sigma_X$.

Standard error SE: one can measure the standard error of the measurement using the relation:

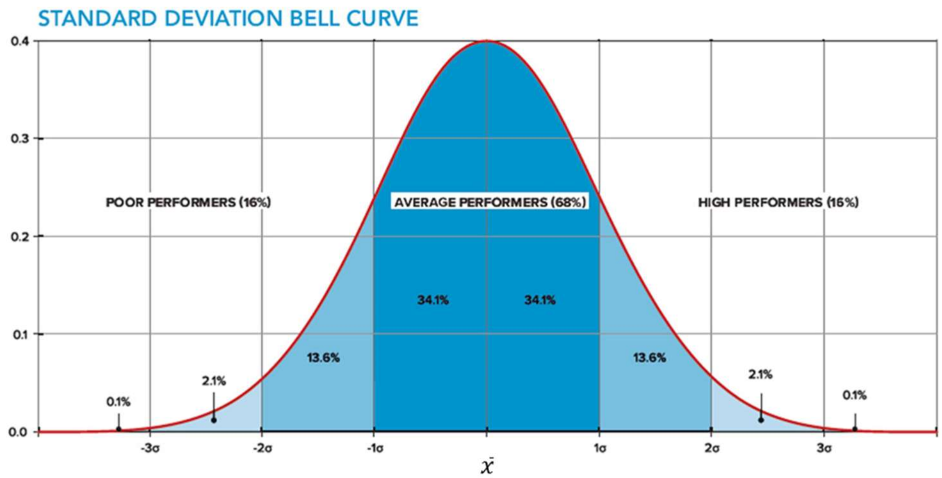
$$SE = \frac{\sigma}{\sqrt{N}} \tag{3ii}$$

The standard error is smaller than the standard deviation by a factor of $\frac{1}{\sqrt{N}}$, this reflects the fact that we expect the uncertainty of the average value to get smaller when we use a larger number of measurements, N.

Graphical interpretation of the standard deviation in normal distribution

Suppose, N number of trials has been taken to measure the value of X. If you now make one more measurement, you can reasonably expect with about 68% confidence that the new measurement will be within one standard deviation of the mean value $\bar{x} \pm 1\sigma$, 95% of the readings will be in the interval two standard deviations of the mean value $\bar{x} \pm 2\sigma$, and nearly all (99.7%) of readings will lie within three standard deviations from the mean, $\bar{x} \pm 3\sigma$. So, for example, if an experimental data point lies 3σ from prediction, there is a strong chance that either the prediction is not correct or there are systematic errors which affect the experiment.

The distribution of values symmetric with respect to the mean the so called "normal" distribution, or bell-shaped curve. Schematically shown below:



Propagation of Error

Suppose A and B are two physical quantities with standard deviations σ_A and σ_B respectively. Let F defines a new physical variable that is determined by $F = f(A,B)$. Using statistical analysis, the average value and the standard deviation of F can be calculated as follows:

If $F = f(A,B) = A \pm B$, corresponding mean value and the standard deviation are given by

$$F = \bar{A} \mp \bar{B} \tag{4}$$

$$\sigma_F = \sqrt{\sigma_A^2 + \sigma_B^2} \tag{5}$$

If $F = f(A,B,C) = ABC$, corresponding mean value and the standard deviation are given by

$$F = \bar{A} \times \bar{B} \times \bar{C} \tag{6}$$

$$\sigma_F = |F| \times \sqrt{(\frac{\sigma_A}{\bar{A}})^2 + (\frac{\sigma_B}{\bar{B}})^2 + (\frac{\sigma_C}{\bar{C}})^2} \tag{7}$$

Significant Figures

According to the discussion in the previous sections, it is clear that the accuracy of the measurement depends on the number of trials in addition to other factors. The question is how many digits we need to keep in a calculation or measurement. There is no fixed answer, however, more digits means better accuracy. As for example, the numbers 2, 2.0, 2.00, looks same. But 2.00 has better accuracy than 2. This feature is expressed by the notion of significant figures. The rule to find the significant figures in a number is the following: express the number in the scientific form

$$abcd... = a.bcd... \times 10^d,$$

where a,b,c,d etc are digits (i.e., 0,1,2,3, ...). The number of nonzero digits before the exponential factor is called the significant figure. That is, 2 is a one significant number, 2.0 a two significant number, 2.00 a three significant number, and so on. Similarly 2.05, 0.00375, 9.11×10^{-11} are all three significant numbers.

Procedure:

1. Measure the length and diameter of the cylindrical rod using your ruler. Use eyeball guessing to approximate the value when necessary. Record the values in Table-1.
2. Before using the Vernier Ruler, find the Vernier constant using the formula:

$$\text{Vernier constant} = \frac{\textit{Value of the smallest division in the Main Scale}}{\textit{Total number of divisions in the Vernier Scale}}$$

3. Find the length of the cylinder using the Vernier scale and record in Table-2, each data will be calculated using the formula: Vernier scale reading = Main scale reading + Vernier Scale division × Vernier constant

5. Measure the length of the cylinder by putting in between the jaws of the Vernier scale. Read the main scale and Vernier scale readings, and record these in the Table-2. Use eyeball guessing to approximate the value when necessary. Compute the total reading using the formula given in the previous step.

6. Compute the average length and using Eq.(2), compute the standard deviation of the length measurement (or simply called error in measurement), and write it in the Table-2.

7. Before using the screw gauge find out the ***pitch*** (the distance along the linear scale traveled by circular scale when it is completed one rotation) and the total number of divisions of the circular scale of the screw gauge and calculate least count ($L.C$) using the formula:

$$\text{Least Count} = \frac{\text{Pitch (m)}}{\text{Total number of divisions in the circular scale (n)}}$$

8. Now measure the diameter of the cylinder, by setting in between the studs of the screw gauge. Read the linear scale and circular scale readings, use the expression below, find out the diameter of the cylinder and record these in the Table-3.

Screw gauge reading = Linear scale reading + Circular scale division × Least count

**Note:

-Please carefully consider the instrumental error. You should add or subtract accordingly where needed.

-In order to get rid of the backlash error, the screw head should always be rotated in the same direction while measurement is made.

Calculations:

1. Now calculate the volume of the cylinder. Show the detail calculations in the designated area.
2. Using Eq. (7), compute the standard deviations of the calculated radius (r), length (l) and volume (V).
3. Answer the questions in the Questions section.

Lab Report

Name of the Experiment :

Your Name :

Your ID # :

Name of the Lab Partner :

Date :

Instructor's comments:

Data Tables:

Table 1: Ruler measurements

Data No.	Length, L (cm)	Radius, R (cm)	$\bar{L}$ (cm)	$\bar{R}$ (cm)
1				
2				
3				
4				
5				
6				

Table 2: Finding Length using Vernier Scale

Vernier constant: ____________________ cm

Data No.	Main Scale reading (cm)	Vernier scale division, d	Length (cm)	$\bar{L}$ (cm)	$(\bar{L} - L_i)^2$ (cm^2)	σ_L (cm)
1						
2						
3						
4						
5						
6						

Table-3: Data for the radius of the cylinder

Least count, LC=______________cm

Instrumental error (if any) = _______________ cm

Data	Linear scale reading, x (cm)	Circular scale reading, $y = d \times L_c$ (cm)	Diameter x + y (cm)	Instrumental error (cm)	Corrected diameter, D (cm)	Radius, $r = \frac{D}{2}$ (cm)	Mean radius, $\bar{r}$ (cm)	$(\bar{r} - r_i)^2$ (cm^2)	σ_r (cm)
1									
2									
3									
4									
5									
6									

Calculation for Volume and its error:

Volume of a cylinder = $\boldsymbol{\pi r^2 l}$

1. Using the ordinary ruler: Volume of the cylindrical rod, V_1 =

2. Using the Vernier scale and screw gauge: Volume of the cylinder, V_2 =

3. Error in volume calculation from Vernier ruler and screw gauge measurement (use **propagation of error**, equations 6,7),

   σ_V =

4. Final result, $V_2 \pm \sigma_V$ =

Results:

Questions:

1. How many of the length readings lie in the interval $L_{\text{av}} \pm \sigma_L$?

2. What fraction of the 6 readings is this?

3. How does the percentage compare with 68.3 %?

4. Which is a more precise measuring tool: ruler or Vernier caliper? Why?

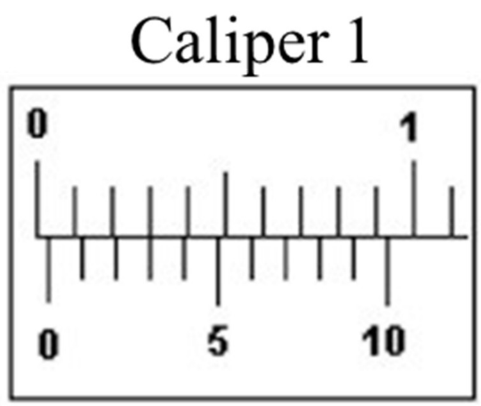
Discussion:

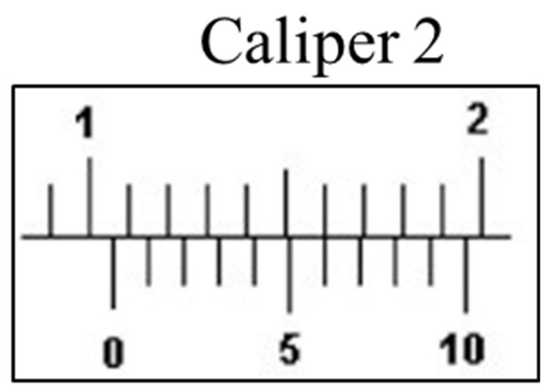
Pre-lab 1:

Your name: ID#:

The following questions must be answered and turned in at the beginning of the lab.

1. Look at the figure below and correctly read each slide caliper reading. Consider the Vernier constant 0.01 cm.





Caliper 1= ____________ *cm*   Caliper 2 = ______________ *cm*

2. Suppose two students measure the length of a piece of wire three times each. Student A obtains results of 8.09, 8.10, and 8.11 centimeters. Student B obtains determines a length of 8.1 centimeters for all of his three measurements. Although the average length found for each student's measurements was 8.1 cm, what qualitative statements can be made concerning the measurements made by students A and B?

Exp-2: Experiment with a Bouncing Ball

Objectives:

1. Observe the potential and kinetic energy conversion and dissipation of total energy due to friction, etc.
2. Observe the coefficient of bouncing for different balls.

Apparatus:

Meter scale, Tape, Assorted types of balls, for example tennis ball, golf ball and table tennis ball

Theory:

The Law of Conservation of Energy states that energy cannot be created or destroyed, but can be transformed**.**

In the Bouncing Ball Drop experiment, we would see energy transformation.

Before dropping a ball, you must lift it up from its' resting surface. When you do this, you are transferring energy from your muscles to the ball. You are giving the ball **potential energy**, specifically **gravitational potential energy**.
Gravitational potential energy (PE) is the energy gained by an object as its height above ground level increases. An object's GPE is determined using this formula:

PE = *height* × *mass* × *acceleration due to gravity, g*

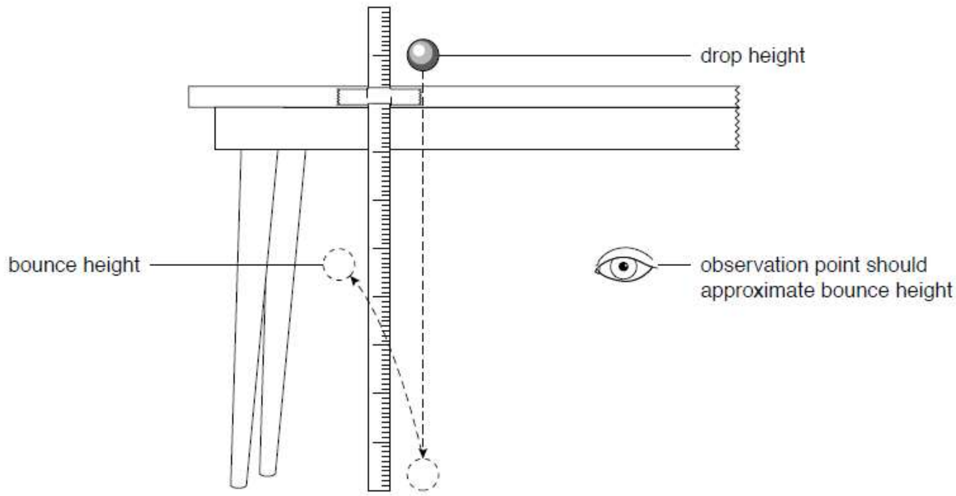
Objects that are the same weight will gain more GPE the higher they are positioned. If one object is heavier than the other at the same height, the heavier object will have more GPE.
As the ball falls towards the ground, its gravitational potential energy is transformed into **kinetic energy (KE)**.
Kinetic energy is the energy of mass in motion. An object that has motion (velocity *v*) no matter the direction has kinetic energy. KE $=\frac{1}{2}mv^2$
The kinetic energy of the ball will continue increasing as the ball gains momentum, until it finally collides with a surface (floor).

At the floor, PE must equal the kinetic energy on impact, PE = KE, thus velocity of the falling ball,

$$v = \sqrt{2gh}$$

Newton's third law says that the floor will then push back on the ball, sending it rising. Thus KE will transform to PE again to send the ball at bounce height.

For an ideal case of **elastic collision,** the ball would reach the drop height after the bounce. However, a ball dropping (not thrown) is an example of an **inelastic collision** where part of the kinetic energy is changed to some other form when colliding with a surface. Thus, a ball that is dropped **never** bounces back up to the original height, and will rise less with each bounce.



When a ball hits a surface, some energy is transformed into *sound energy*, some is transformed into *thermal energy* from the friction created, and some becomes *elastic potential energy* resulting from the instantaneous deformation of the ball when it collides.

Now due to the elastic PE the ball is able to bounce, or rebound. When the ball bounces back up from the ground its elastic PE is converted back into KE. At the bounce height KE again converted to gravitational PE as the ball resumes its original shape. In this experiment you would see how the velocity of the ball changes before and after the impact with the floor.

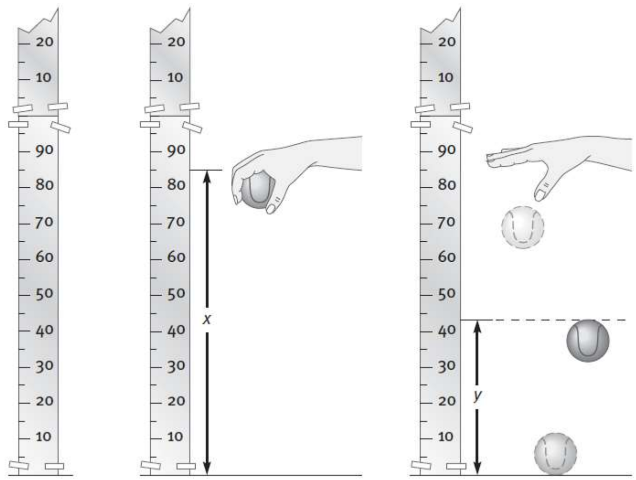
Some balls, however, are more efficient in how they store and release their elastic PE than others. The more efficiently a ball stores and converts elastic PE back into KE, the higher the ball bounces.

For a ball the ratio of drop height and bounce height (= H_1 / H_2), which we call the coefficient of bouncing, should be roughly the same for each height. In this lab you would see the efficiency of ball bouncing for different balls.

In the ball dropping experiment the total mechanical energy, E = KE + PE decreases with each bounce of the ball. In this lab you would see that with each successive bounce, it dissipates more energy to friction, air resistance and heat.

Procedure:

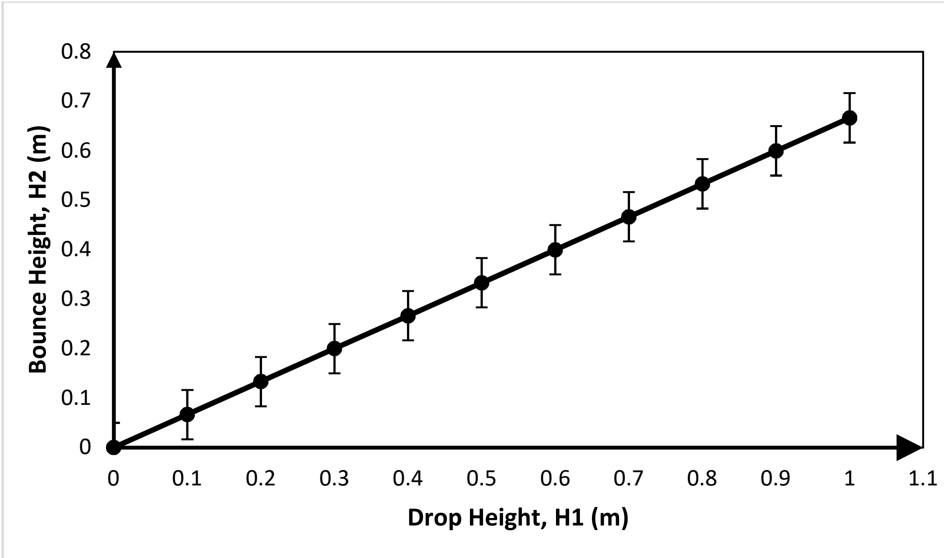
1. Measure the mass of each ball by using the top pan balance.
2. Divide the activities so that one student drops the ball, one student watches the bounce and estimates the height to which it bounces, and one student records the data. Tape/hold the scale to the edge of a table (you need to do this on a hard surface).
3. The height to which the ball bounces is to be estimated as carefully as possible. Both the height of drop (H_1) and the height of bounce (H_2) should be recorded in data Table A.



4. Select one ball, for example table tennis ball and drop the ball and record how high it rebounds.
5. Drop the ball at least five times and average of the bounce heights.
6. Find the potential energy of before it dropped, $PE_1 = m\, g\, H_1$ (J) and potential energy of ball after one bounce, $PE_2 = m\, g\, H_2$ (J)
7. Find the velocity of falling, $v_1 = \sqrt{2gH_1}$ and velocity of bouncing, $v_2 = \sqrt{2gH_2}$
8. Calculate the KE during falling and bouncing, and record in Table B.
9. Now repeat this whole process for each of the other balls, and record in Table B.

   <u>Study of bouncing coefficient</u>

10. Take the table tennis/golf ball and drop the ball from different dropping heights (mentioned in the table C).
11. Both the height of drop (H_1) and the height of bounce (H_2) should be recorded in data Table C.
12. Draw a graph of bounce height (H_2) vs drop height (H_1), use the standard deviation values as error bars.
13. Draw a best fit line for the data points. Note: This is NOT a line drawn to connect each point. It is a line which best shows the relationship involved - in this case a straight line.



14. Use the graph to predict the height of the bounce for a ball dropped half way between two drop heights, for example 0.85 m. This method is called **interpolation**, when the value to be calculated lies within your data.
15. Use your graph to predict the height of the bounce for a ball dropped from more than 1 m height, for example 1.10 m. This method is similar to interpolation, but is called **extrapolation**, when the value to be calculated lies outside the data.
16. Find the slope of fitted line and calculate the bouncing efficiency of the ball.

Lab Report

Name of the Experiment :

Your Name :

Your ID # :

Name of the Lab Partner :

Date :

Instructor’s comments:

Data tables:

Table A

Drop Height, H_1 (m)		First Bounce height (m) Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean bounce height, H_2 (m)	Ratio of heights, H_1/H_2
Tennis	1.0							
Golf								
Table Tennis								

Mass of the Tennis ball = kg

Mass of the Golf ball = kg

Mass of the Table Tennis ball = kg

Table B

Ball	$PE_1 = mgH_1$ (J)	$v_1 = \sqrt{2gH_1}$ (m/s)	$KE_1 = \frac{1}{2}mv_1^2$ (J)	E_1 (PE_1 or KE_1) (J)	$PE_2 = mgH_2$ (J)	$v_2 = \sqrt{2gH_2}$ (m/s)	$KE_2 = \frac{1}{2}mv_2^2$ (J)	E_2 (PE_2 or KE_2) (J)	Lost energy (J)	% Energy loss
Tennis										
Golf										
Table Tennis										

You have already learned how to calculate standard deviation, σ (see Experiment 1). The standard deviation of a distribution of measurements is defined as follows:

$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(H_i - \overline{H})^2}$ Where $\overline{H} = \frac{\sum_{i=1}^{N} H_i}{N}$

You can easily do it by using your scientific calculator in STAT mode.

Table C

Drop Height, H_1 (m)		First Bounce height (m)					Mean bounce height, H_2 (m)	Standard deviation, σ_{H2} (m)
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
Golf ball	1.0							
	0.9							
	0.8							
	0.7							
	0.6							

Calculations from graph:

$Slope^{-1}$ (coefficient of bouncing for golf ball) =

Interpolated bounce height for example at 0.85 m =

Extrapolated bounce height for example at 1.10m =

<u>Results:</u>

Questions:

1. Which ball was the most efficient? What characteristics does that ball have that you think helped it be efficient?

2. Why is it impossible for a ball to be 100% efficient?

3. How did the GPE change with height?

4. What percentage of the initial potential energy was ‘wasted’ as the ball was hitting the ground?

Discussion:

Pre-lab 2:

Your name: ID#:

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1. Consider a ball of mass 0.050 kg release from 0.85 m height, what velocity does the ball will attain when it hits the floor?

2. In a bouncing ball lab experiment what do you expect about the bounce height of the ball?

3. Without air resistance, the ball is still not be able to bounce to its original drop height, why?

4. Name some factors that would affect the bounce height.

Expt-3: Demonstration of Hooke's Law using spiral spring

Objectives:

1. To measure the spring constant of a spiral spring and corresponding elastic potential energy using the Hooke's Law.
2. To determine the effective mass of the spring.

Apparatus:

Stand with a clamp, a set of slotted masses, spiral spring, meter scale, weighing scale and stop watch.

Theory:

Hooke's law of elasticity states that, for relatively small deformations of an object, the displacement or size of the deformation is directly proportional to the deforming force or load.

Consider a spring in its **relaxed state** that is, neither compressed nor extended. One end is fixed, and a particle-like object a block, say is attached to the other, free end. If we stretch the spring by pulling the block, the spring pulls on the block in the opposite direction. Similarly, if we compress the spring by pushing the block, the spring now pushes on the block in the opposite direction. This is because a spring force acts to restore the relaxed state, called the *restoring force.*

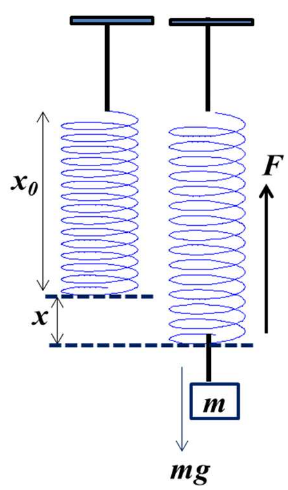

Figure 1: Spring mass system setup for Hooke's Law demonstration

To a good approximation for many springs, the force from a spring is proportional to the displacement of the free end from its position when the spring is in the relaxed state. The *spring force* is given by

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

which is known as **Hooke's law** for a spring mass system**.** The minus sign indicates that the direction of the spring force is always opposite the direction of the displacement of the spring's free end.

The constant k is called the **spring constant** (or **force constant**) and is a measure of the stiffness of the spring. The larger k is, the stiffer the spring; that is, the larger k is, the stronger the spring's pull or push for a given displacement. The SI unit for k is the Newton per meter.

In figure 1, x_o is the length of the spring with the mass holder hanging at rest at the equilibrium point. The displacement, x, is measured relative to the equilibrium point. Hooke's Law is valid within the elastic limit of the spring.

The work done by the spring force: $W = -\int_{x_i}^{x_f} F dx$ (since force and displacement oppositely directed)

$$= \int_{x_i}^{x_f} kx\, dx = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2 \qquad (2)$$

If $x_i = 0$, $W = -\frac{1}{2}kx^2$ (work done by a spring force)

We know that the work done by a variable force could also be represented by the area under the *force-displacement* curve.
Also the corresponding elastic potential energy can be expressed as,

$$U = -W = \frac{1}{2}kx^2 \qquad (3)$$

The theoretical period of a system composed of a mass M oscillating at the end of a mass less spring of force constant k is given by,

$$T = 2\pi\sqrt{\frac{M}{k}} \qquad (4)$$

In a real spring–mass system, since no spring is mass less, the equation should modify by considering the effective mass m_e of the spring, which is defined as the mass that needs to be considered to correctly predict the behavior of the system.

$$T = 2\pi\sqrt{\frac{m_0+m_e}{k}}, \qquad (5)$$

where m_0 is the applied load.

The effective mass of the spring, in a spring-mass system when using an ideal spring of uniform linear density is 1/3 of the mass of the spring, i.e. $m_e = \frac{1}{3}m_s$ and is independent of the direction of the spring-mass system. Note that this effective spring mass is responsible for elongation when the spring is vertical.

Procedure:

1. Measure the mass of the spring M by using the digital balance.
2. Hang the spring vertically from the clamp and measure the length with meter ruler.
3. Add masses, one at a time, beginning with 150 grams. Increment the mass by 50 grams and record the length of the spring, *X*.
4. Compute the length of the spring for each added mass. Record the data in Table 1.
5. Determine the Force = *mg* (N) applied for each mass and record it in Table-1.
6. Slightly change the position of the mass holder and then release it - do not apply any external forces. The mass should be oscillating straight up and down. If not, stop it and try again until you get vertical oscillation.
7. With the digital stop watch count the time for 10 cycles for each mass added twice and then find the average time period. Note: All of your time values should have to the same first two digits - otherwise your experimental setup might have some flaws. Record your results in Table 1.
8. To gather the best results, one has to be very careful and consistent. The base of the apparatus should be firmly held and not allowed to move. Any motion of the apparatus outside the spring and the holder will increase the error in your results.
9. Plot the Force Applied (*F*) vs. Total Elongation (*X*), and determine the slope of the line. See Figure 2.
10. Using the slope of the graph determine the value of the spring constant, *k*.

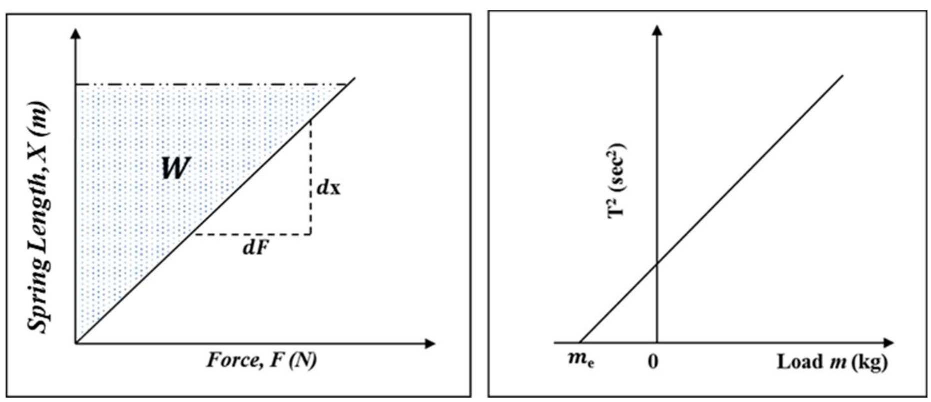

Figure 2: Extension vs Force and T^2 vs load graph for a spring mass system

11. For a specific load and extension find the area from F-X graph, for a triangle: area = ½ × base× height, this is the work done, W.
12. For the above load and extension find the corresponding elastic potential energy using the relation, $U = \frac{1}{2}kx^2$
13. Plot another graph with *m* (abscissa) against T^2 (ordinate) as shown in Figure 2 (right). Find out the effective mass (m_e) by taking the point of intercept of the resulting lines on *horizontal* axis.

Lab Report

Name of the Experiment :

Your Name :

Your ID # :

Name of the Lab Partner :

Date :

Instructor's comments:

Data tables:

Table 1. Static Determination of the Spring Constant, *k*

Mass added to the spring, m (kg)	Force, m×g (N)	Length after stretch, X (m)	Time for 10 Oscillations (sec)		Average Time Period (T_{av}) (sec)	Time Period² (T^2) (sec^2)
0.000			-	-	-	-
0.150			-	-	-	-
0.200			-	-	-	-
0.250						
0.300						
0.350						
0.400						
0.450						
0.500						

From graph-1, Slope $= \frac{dX}{dF} =$ m/N

Spring constant, $k =$ *slope*$^{-1}$ = N/m

Work done from the F-X graph, W = J

Elastic potential energy, U = J

Table 2. Calculation of Effective mass

Mass of spring by digital balance, M_s	**kg**
Effective mass of the spring (take x intercept from the T^2 vs m graph), m_e	**kg**
Mass of the spring, $M_{s,exp} = 3 \times m_e$	**Kg**
Percentage Error	

Results:

Questions:

1. To what extent does your graph agree with Hooke's Law?

2. According to your understanding what is the relation between the added mass and frequency of oscillations of the spring mass system?

3. Did the m against T^2 graph passes through the origin? If not, interpret the meaning of the intercept in horizontal axis.

4. From your understanding of the spring mass system, what would be the relation between kinetic energy and potential energy during the oscillations?

Discussion:

Pre-lab 3:

Your name: ID# :

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1. What is the meaning of negative sign in the Hooke's law?

2. You have a certain set-up of a vertical spring, and when hung freely the equilibrium position reading is 30cm on earth. If you take the same set-up on the moon surface, would the equilibrium position be more than, less than or equal to 30cm? Explain.

Experiment-:4 Determination of Shear Modulus using Dynamic Method

Objectives:

1. Understand how a torsional pendulum works.
2. To determine the sheer modulus of the element of wire by the method of oscillation with the prior knowledge of Angular force and Simple Harmonic motion.

Apparatus:

A uniform wire, a cylindrical bar, suitable clamp, stopwatch, screw gauge, slide calipers, meter scale.

Theory:

A torsion pendulum consists of a mass suspended from a thin wire. When the mass is twisted about the axis of the wire, the wire exerts a torque on the mass, tending to rotate it back to its original position. If twisted and released, the mass will oscillate back and forth to its original position executing a simple harmonic motion.

For example, a cylindrical mass is suspended by a vertical wire of length l and radius r as shown in Fig. 1.1. The axis of the wire passes through its center of gravity. If at any instant the angle of twist is θ, the restoring torque exerted by the wire will be proportional to the angular displacement,

$$\tau = -C\theta \tag{1}$$

And the time period for torsional oscillations will be,

$$T = 2\pi\sqrt{\frac{I}{C}} \tag{2}$$

where I is the moment of inertia of the cylindrical body and C is the couple per angle of twist.

Given by, $I = \frac{1}{2}Ma^2$, 'M' and 'a' are the mass and radius of the cylinder respectively.

$$\text{and } C = \frac{\eta\pi\ ^4}{2l} \tag{3}$$

η is the modulus of rigidity of the material of the wire, l is the length of the wire, r is the radius of the wire. From above equations, we get

$$T^2 = \frac{4\pi^2 I}{C} = \frac{8\pi I\, l}{\eta r^4} \tag{4}$$

by rearranging the expression, $$\eta = \frac{8\pi I\, l}{T^2 r^4} \tag{5}$$

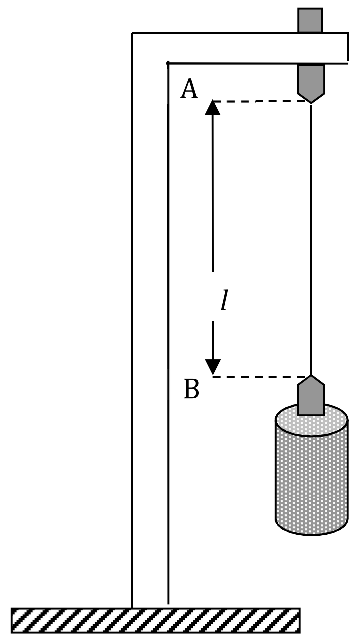

Fig 1 Torsional Pendulum

Procedure:

1. Find out the value of one smallest division of the main scale and the total number of divisions of the Vernier scale of the slide calipers and calculate Vernier constant ($V.C$).
2. Find out the value of pitch (the distance along the linear scale traveled by circular scale when it is completed one rotation) and the total number of divisions of the circular scale of the screw gauge and calculate least count ($L.C$).
3. Measure the radius, a of the cylinder by using the slide calipers.
4. Measure the mass, M of the cylinder. Calculate moment of inertia, $I = \frac{1}{2}Ma^2$.
5. Measure the radius, r of the wire by using the screw gauge.
6. Measure the length, l of the wire from the point of suspension and the point at which the wire is attached to the cylinder with a meter scale.
7. Twist the cylinder from its equilibrium position through a fixed 90-degree angle and release so that it begins to oscillate. Measure the time for **10** complete oscillations with a stop watch. Find out time period (T) of the oscillation.
8. Calculate the value of the modulus of rigidity (η) of the material of the given wire.

Lab Report

Name of the Experiment :

Your Name :

Your ID # :

Name of the Lab Partner :

Date :

Instructor's comments:

Data Tables:

Vernier Constant (V.C.) of the slide calipers,

$$V.C = \frac{The\ value\ of\ one\ smallest\ division\ of\ the\ main\ scale}{Total\ number\ of\ divisions\ in\ the\ vernier\ scale}$$

Least Count (L.C.) of the Screw Gauge

$$L.C. = \frac{Pitch}{Total\ number\ of\ divisions\ in\ the\ circular\ scale}$$

Table-1: Data for the radius of the cylinder, a

No. of obs.	Main scale reading, x (cm)	Vernier scale division, d	Vernier constant V_C (cm)	Diameter $y = x + V_c \times d$ (cm)	Mean diameter, D (cm)	Radius, $a = \frac{D}{2}$ (cm)
1						
2						
3						
4						
5						

Table-2: Data for the radius of the wire, r

No. of obs.	Linear scale reading, x (cm)	Circular scale division, d	Least count, L_c (cm)	Diameter $y = x + d \times L_c$ (cm)	Mean diameter, D (cm)	Instru-mental error (cm)	Corrected diameter, D (cm)	Radius $r = \frac{D}{2}$ (cm)
1								
2								
3								
4								
5								

Table-3: Data for the time period

No. of obs.	Time for 10 oscillations, t (sec)	Time period, T= t/10 (sec)	Mean T (sec)
1			
2			
3			
4			
5			

Length of the wire, l: (i) __________cm (ii) __________cm (iii) __________cm

Average length of the wire, l = __________cm

Mass of the cylinder, M= ______________ kg

Calculations:

Moment of Inertia of the cylinder, $I = \frac{1}{2}Ma^2 =$

Modulus of rigidity of the wire, $\eta = \frac{8\,\pi I\,l}{T^2 r^4}$ (SI unit)

Error Calculation:

Standard value of the modulus of rigidity of the material of the wire = 7.7 x 10^{10} SI Unit.

Percentage error = $\frac{Standard\ value \sim Experimental\ value}{Standard\ value}$ x 100

= ___________________

Results:

Questions:

1. How will the period of oscillation be affected if the cylindrical mass of the pendulum be made heavy?

2 .Discuss about the sensitivity of the calculation of the radius of the wire and hence its effect on the resultant modulus of the rigidity.

Discussion:

Pre-lab 4:

Your name: ID#:

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1. Do you think the radius and length of the wire would change the rigidity modulus? Explain your answer.

2. How the moment of inertia of the cylinder would change with its radius?

3. Do you think, we would get the similar results for the rigidity modulus, if we use a circular disc instead of cylindrical mass? Explain your answer.

Expt-5: Period of Oscillation for a Pendulum and determination of value of 'g'

Objectives:

1. To determine whether the period of oscillation is dependent on the mass, the angle of displacement or the length of the pendulum.
2. To measure the acceleration due to gravity.

Apparatus:

Digital stop watch, sample masses with hooks, meter stick, stand with clamp, digital weight balance. The students need to bring a protractor for angle measurements.

Theory:

A simple pendulum consists of a mass suspended by a light string of length L. By observation, one notices the very regular motion it takes, which makes one curious as to what affects this regular motion or period. This regular motion can be thought of, ideally, as being simple harmonic in nature. The period, T, can be defined as the point where the mass is released to the time where it returns to its original position.

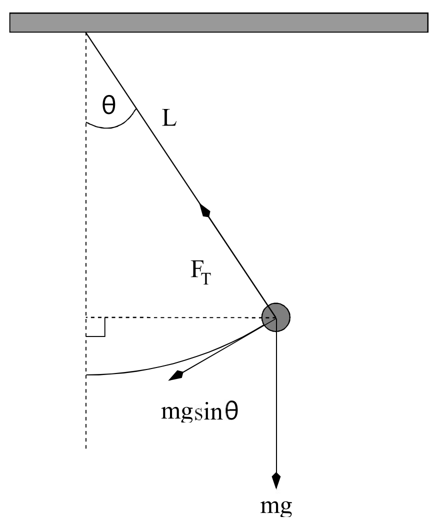

Figure 1: Free-Body Diagram of the Forces.

Outside of its equilibrium position (when it is at rest) the following diagram (Figure 1) with the forces labelled will apply. Consider the forces acting on the mass, we see that *mg* is the weight due to the force of gravity and that F_T is the tension in the string. The tangential component of the gravitational force acting on the mass is the following:

$$F_{tangential} = mg\sin\theta. \tag{1}$$

The direction of this force is always toward the equilibrium and can be thought of as the restoring force. Now let us make an approximation that says that the period of oscillation for the pendulum is small and for small angles the following statement is true: $sin\theta \approx \theta$.

Since the angles are small, determining the arc length that is oscillated can be defined as $s = L\theta$ or rearranging it we get $\theta = s/L$. Applying both the approximation and the arc length to equation (1) we get the following:

$$F_{tangential} = mgsin\theta \approx mg\theta = (mg/L)s \qquad (2)$$

Hooke's Law ($F = kx$) also works in a similar fashion, which is called Simple Harmonic Motion.

Comparing both equations, we see that $k = mg/L$, which makes s similar to the displacement, x, in Hooke's Law. Therefore, the period, T, of a simple pendulum can be described similarly to the period of a mass on a spring, which is already known. Taking that equation and the value of k, it can be transformed into this final result.

$$T = 2\pi\sqrt{\frac{m}{k}} \text{ and } T = 2\pi\sqrt{\frac{L}{g}} \qquad (3)$$

Now, the length L is the sum of the string length l and the radius of the metal block R. Substituting $L = l + R$ in Eq. (3), squaring both sides and rearranging, we can write,

$$T^2 = \frac{4\pi^2 l}{g} + \frac{4\pi^2 R}{g} \qquad (4)$$

Look carefully at the transformed equation and take notice to what directly affects the period of a simple pendulum and remember what assumptions and approximations were made to get the final result.

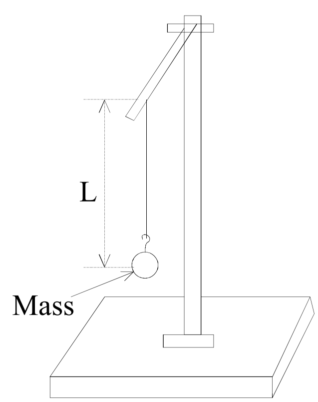

Figure 2: The Experimental Setup

Procedure:

Part I: Mass Dependence

1. First, the apparatus should look similar to Figure 2.
2. Next, we want to vary the mass, but keep the length and angle of deviation constant. Use a length greater than 50 cm and record the value. Note that the length of the pendulum is the sum of the length of the string from the hanging point up to the hook attached with the mass of bob and the distance from the top of the hook up to the center of the mass of the bob**. Note:** Use the digital balance to weigh your masses. The effective length of the pendulum is the sum of the length of the string and the distance of the center of mass of the bob (radius of bob). Use a protractor to keep the angle of oscillation less than or equal to 5 degrees.
3. Measure the time for 10 complete oscillations with a stop watch and record the time period (T) of the oscillation. After the first period is recorded, repeat for two more times. Fill in Table 1 accordingly, where T_{avg} is the average period of the three trials.
4. Repeat steps 2 and 3 for two more masses, and complete Table-1.
5. Construct a graph of T_{avg}^2 vs. m. This should like a horizontal line.

Part II: Angle Dependence

1. This time keep the mass constant and record the data. Keep the same length from Part I. Use a protractor to vary the angle of oscillation to take data. Fill in Table 2 accordingly.
2. Construct a graph of T_{avg}^2 vs. θ. This should look like a nonlinear line.

Part III: Length Dependence

1. Keep the same mass from Part II as well as keep the angle less than or equal to 5 degrees, but vary the length (l) of the pendulum by increasing or decreasing the string length. Fill in Table 3.
2. Construct a graph of T_{avg}^2 vs. l. Notice that the equation of a simple pendulum can be used to determine the acceleration due to gravity, g, by manipulating it from Eq. (4), where we see that it is similar to $y = mx + b$. The slope, m, equals $4\pi^2/g$. Use this expression to calculate the experimental value of acceleration due to gravity, g_{exp}.

Calculations:

1.Calculate the slope using the data from your best-fit line.
2.Calculate g_{exp} using the expression at the end of Part III.
3.Calculate the percent error of your gravitational acceleration, g_{exp}, by comparing it to the accepted value, $g = 9.81 m/s^2$.

Lab Report

Name of the Experiment :

Your Name :

Your ID # :

Name of the Lab Partner :

Date :

Instructor's comments:

Data tables:

Table 1. Mass Dependence of the Period

Length of Pendulum, L = ____________ m

Mass (grams)	A Single Period (sec)			T_{avg} (sec)	$T_{avg}2$ (sec^2)

Table 2. Angle Dependence of the Period

Mass of Pendulum =____________ grams

Angle (degrees)	A Single Period (sec)			T_{avg} (sec)	$T_{avg}2$ (sec^2)
5					
8					
10					
15					
20					
30					
40					

Table 3. Length Dependence of the Period

Length l (m)	A Single Period (sec)			T_{avg} (sec)	$T_{avg}2$ (sec^2)
0.40					
0.45					
0.50					
0.55					
0.60					

Slope of the best fit line = ____________________________ s^2/m.

g_{exp} = ____________________________ m/s^2.

Percent error = ____________________________

<u>Results:</u>

Questions:

1. Does the period of a simple pendulum depend on the mass?

2. Is the period constant over small angles? Does it vary when one reaches larger angles?

3. Does the period depend on the length of the pendulum?

4. Of the three parameters explored in this experiment, which has the strongest influence?

5. Is your best-fit line in form Table-3 goes through the origin? Explain why or explain not?

Discussion:

Pre-lab 5:

Your name: ID#:

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1. What is the acceleration due to gravity in a region where a simple pendulum having a length 75.000 cm has a period of 1.7357 s?

2. An engineer builds two simple pendulums. Both are suspended from small wires secured to the ceiling of a room. Each pendulum hovers 2 cm above the floor. Pendulum 1 has a bob with a mass of 10 kg. Pendulum 2 has a bob with a mass of 100 kg. Describe how the motion of the pendulums will differ if the bobs are both displaced by 12°.

Expt-6: Experiment with Compound Pendulum and determination of value of 'g'

Objectives:

1. To determine the g, the acceleration due to gravity.
2. To determine k, the radius of the gyration of the pendulum.

Apparatus:

1. Compound pendulum
2. Meter rule
3. Stop watch

Theory:

A physical pendulum or compound pendulum is a rigid object, which is free to rotate about a fixed horizontal axis. In this experiment, we use a special type of compound pendulum which is symmetric about its center of mass. This compound pendulum is nothing but a metal bar, containing a number of holes with equal intervals. The pendulum can be suspended by the help of knife edge passing through different holes. The point of suspension is known as pivot point. If we swing the bar from different holes then the moment of inertia of the pendulum and the time period will change.

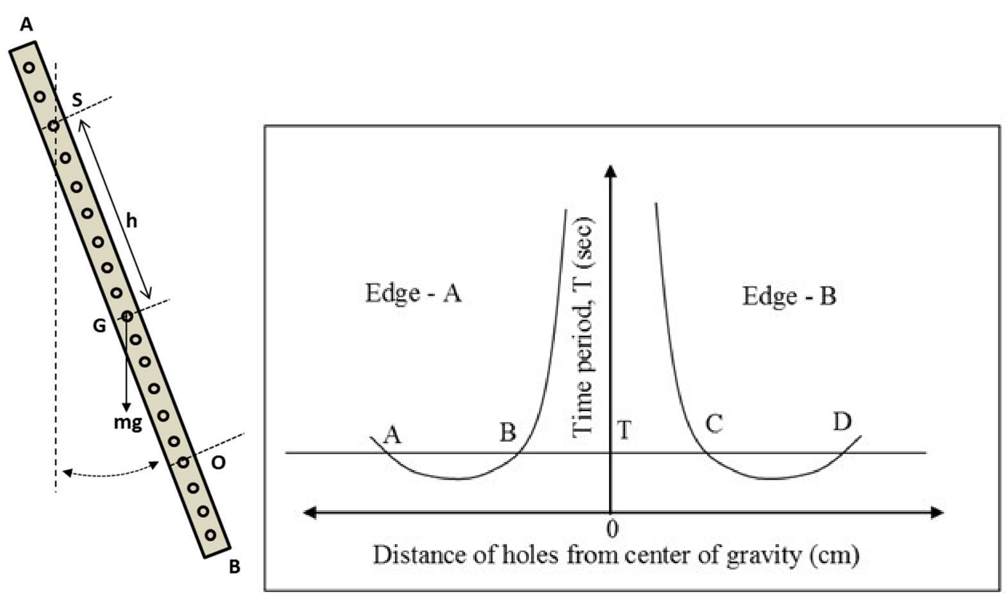

Figure 1: Demonstration of compound pendulum oscillations and corresponding time period vs distance graph.

Allowing the bar to swing it will approximately follow a simple harmonic motion. According to Newton's 2^{nd} law of motion for rotation the torque (τ):

$$\tau = I\,\alpha \qquad (1)$$

where, I is the moment of inertia of the pendulum about the axis of rotation, and α the angular acceleration.

Torque is given by $\tau = -mgl\ sin\phi$**,** here l is the distance of the pivot from the center of the pendulum.

For very small angle of rotation $sin\phi$ can be approximated by $\emptyset$, then from equation (1)

$$I\frac{d^2\emptyset}{dt^2} = -mgl \quad (2)$$

By rearranging the equation, $$\frac{d^2\emptyset}{dt^2} + \frac{mgl}{I}\emptyset = 0 \quad (3)$$

This 2nd order differential equation describes the simple harmonic motion with the angular frequency, $\omega = \frac{2\pi}{T}$ and the time period from (3): $T = 2\pi\sqrt{\frac{I}{mgl}}$ (4)

Using "Parallel Axis Theorem: moment of inertia I, of an object about an axis parallel to the axis that passes through the center of mass,

$$I = I_G + ml^2 \quad (5)$$

where I_G the moment of inertia of the object about the axis through the center of mass, m is the total mass of the object, and l is the distance between the axes. We would also show that,

$$I_G = mK^2 \quad (6)$$

where K is the radius of gyration about the axis passing through the G. It is the radial distance from the point to the axis of rotation where whole mass of the body is supposed to be concentrated.

Substituting Eq. 5 and Eq.6 in Eq.4 we get,

$$T = 2\pi\sqrt{\frac{\frac{K^2}{l}+l}{g}} \quad (7)$$

Comparing the time period relation for simple pendulum of length L, $T = 2\pi\sqrt{\frac{L}{g}}$, we can deduce,

$$L = l + \frac{k^2}{l} \quad (8)$$

From the above equation we can obtain a quadratic equation of l, which has 2 roots l_1 and l_2 such that,

$$L = l_1 + l_2 \quad (9)$$

$$K^2 = l_1 l_2 \quad (10)$$

The value of K and g can be determined from,

$$g = 4\pi^2\frac{L}{T^2} \quad (11)$$

$$K = \sqrt{l_1 l_2} \quad (12)$$

Since the "effective length L is composed of two roots l_1 and l_2, so there are infinite ways to combine l_1 and l_2 to make the same L.

In this experiment, we will determine the length L and corresponding time period T graphically [see Figure 1]. If we plot a graph using table (1), two curves symmetric about the position of COM should appear.

Horizontal lines in the lower portion will intersect the curves in four points. l_1 and l_2 can be determined by measuring the distances from the COM position. Using eqns. (11), acceleration due to gravity g and radius of gyration K would be calculated.

Procedure:

1. With the help of the knife edge suspend the metal bar by passing through the hook to the hole closer to the Edge A.
2. Measure the distance d from the center of gravity (middle hole) to the edge of the hole.
3. Oscillate the metal bar with an angle for a small angle.
4. Record the time for 10 oscillations using a stopwatch. Repeat it for two times and obtain the average time period T for that distance.
5. Repeat the procedure 1-4 for more holes of the bar, except the center of mass.
6. After procedure 5, again repeat procedures 1-4 by inverting the metal bar (Edge B) for all the holes.
7. Draw a graph $T\ vs\ d$ for Edge A and Edge B observations as shown in the Figure 1.
8. Draw a suitable horizontal line that intersects both curves. Mark A, B, C and D to the four points of intersection with the graph. Measure the length AC and BD, then find the length $L = \frac{AC+B}{2}$ and corresponding T for the line and then find the value of$g$.
9. Repeat procedure 8 by drawing another horizontal line and find the value of$g$. Calculate the mean of g.
10. Calculate the value of K, by using the formula $K = \sqrt{l_1 \times l_2} = K = \sqrt{OA \times OC} = K = \sqrt{OD \times OB}$. Repeat the procedure for another line and then find the average value of K.

Lab Report

Name of the Experiment	:
Your Name	:
Your ID #	:
Name of the Lab Partner	:
Date	:

Instructor's comments:

Data Table 1

Hole Number		Distance from COM, d (cm)	Time for 10 oscillations (s)		Mean time t (s)	Time Period $T=\frac{t}{10}$ (s)
Edge A	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Edge B	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					

Note: COM means Center of Mass

<u>TABLE 2</u> (From the graph)

<table>
<tr><th>Observations from the horizontal lines</th><th>L (m)</th><th>T (sec)</th><th>$g = 4\pi^2 \frac{L}{T^2}$ (m/s^2)</th><th>Mean g (m/s^2)</th><th>K (m)</th><th>Mean K (m)</th></tr>
<tr><td>1. ABCD</td><td>$L = \frac{AC + BD}{2}$</td><td></td><td></td><td rowspan="2"></td><td></td><td rowspan="2"></td></tr>
<tr><td>2. $A'B'C'D'$</td><td>$L' = \frac{A'C' + B'D'}{2}$</td><td></td><td></td><td></td></tr>
</table>

<u>Calculations for L, g and K:</u>

<u>Results:</u>

Questions:

1. According to your understanding and the data you have obtained in this experiment, explain the time variation with different suspension of the compound pendulum.

2. Do you think compound pendulum in comparison to simple pendulum would show better oscillatory motion in air for measurement of g? Why?

Discussion:

Pre-lab 6:

Your name: ID#:

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1. Distinguish between a simple pendulum and a compound pendulum.

2. What do you understand by moment of inertia and torque?

Appendix

Lab 4

Restoring torque exerted by the wire, $\tau = -C\theta$ and θ $= \frac{r\varphi}{l}$ ……………….(1)

Tangential stress = $\frac{F}{drdx}$

So, rigidity modulus, η = $\frac{\frac{F}{drdx}}{\theta} = \frac{Fl}{\text{drdxr}}$

Hence F= $\frac{\eta\ \varphi\ \text{r dr dx}}{l}$ ……………… (2)

The moment of this force about the axis of the cylinder is given by

F.r = $\frac{\eta\ \varphi\ r^2\ \text{dr dx}}{l}$

Therefore the restoring torque over the entire surface of the annulus is given by

δ $\tau = \frac{\eta\ \varphi\ r^2\ \text{dr}\sum\text{dx}}{l} = \frac{\eta\ \varphi\ r^2\ \text{dr}2\pi\text{r}}{l}$ where ($\sum$ dx=2πr)

$= \frac{2\pi\eta\ \varphi\ r^3\ \text{dr}}{l}$

The total restoring torque that comes to play during the twisting of the entire cylinder of radius r is, $\tau = \frac{2\pi\eta}{l} \int_0^r r^3\ \text{dr} = \frac{2\pi\eta\varphi}{l}$ ($r^4/4$) = $\frac{\pi\eta\ \varphi\ r^4}{2l}$………………(3)

Tortional rigidity or tortional constant is restoring torque per unit twist

C = $\frac{\tau}{\varphi} = \frac{\pi\eta\ \varphi\ r^4}{2l}$………………………..(4)

Again, I $\frac{d^2\theta}{dt^2}$= - C θ ⇒ $\frac{d^2\theta}{dt^2}$= - $\frac{C}{I}\theta$ ⇒ $\frac{d^2\theta}{dt^2} + \frac{C}{I}\theta = 0$

$$\Rightarrow \frac{d^2\theta}{dt^2} + \omega^2\theta = 0 \text{ , where } \omega^2 = \frac{C}{I}$$

The motion is simple harmonic motion with time period, T= $2\pi/\omega$

⇒ T=$2\pi\sqrt{}$(I/C)

I = $\frac{MR^2}{2}$ and C =$\frac{\pi\eta\ r^4}{2l}$ ⇒T =$2\pi\sqrt{((MR\text{^}2)/2)/((\pi\eta\ r^4\ )/2l)}$

⇒ $T^2 = 4\pi^2$ (MR^2 /2) ($2l/\ \pi\eta r^4$) Therefore η =$4\pi\frac{MR^2 l}{T^2 r^4}$ ……………(5)

So, η= $\frac{8\ \pi\ I\ l}{T^2 r^4}$

Lab 5

Small-Angle Approximation:

For small θ (in radians), sinθ ≈ θ. The equation of motion reduces to:

$$\frac{d^2\theta}{dt^2} = + \left(\frac{g}{L}\right) \theta = 0$$

This is the equation of simple harmonic motion with angular frequency $\omega = \sqrt{\left(\frac{g}{L}\right)}$.

Thus, the period is:

$$T_0 = 2\pi \sqrt{\left(\left(\frac{L}{g}\right)\right.}$$

Correction for Finite Amplitudes:

For larger amplitudes, the exact solution involves elliptic integrals. The first-order correction can be written as:

$$T \approx T_0 \left(1 + 1/16\ \theta_0^2\right)$$

where θ_0 is the maximum angular displacement (in radians).