UNDERGRADUATE PHYSICS LAB MANUAL
PHY102

LIST OF EXPERIMENTS FOR PHY-102

1. **AIR TRACK**
2. **FRICTION AND MOTION ON AN INCLINED PLAIN**
3. **PROJECTILE MOTION**
4. **TORSIONAL PENDULUM**
5. **RIGID BODY MITION**
6. **(i). ELECTROSTATIC FORCES**

   (ii). MAPPING OF ELECTRIC POTENTIAL AND FIELD
7. **CURRENT INDUCED MAGNETIC FIELD AND e/m MEASUREMENT**
8. **DIFFRACTION OF LIGHT**
9. **DIFFRACTION OF LIGHT USING ULTRASONIC WAVE AS A GRATING**
10. **ATWOOD MACHINE**

INTRODUCTION

Physics is a knowledge based on experiments and in physics education experiments play an important role to start knowledge formation and conceptualization. The verificatory role of experiments is the preferred physicists' stance, as expressed by Feynmann et. al. (1963) "The test of all knowledge is experiment. Experiment is the sole judge of scientific truth". Recent reforms of physics education also emphasize on developing effective methods in which experiments are conducted in the physics curriculum and utilizing experiments complimentarily in class room teachings.

The aim of this laboratory is to give the students an opportunity to learn and verify the physical laws using experimental apparatus/tools in the real world and expose students to the scientific methods and instruments of physical investigations.

In PHY102 course there are three components- lecture, tutorial and laboratory. In PHY102 laboratory each experiment offers learning of an important law of physics which will be discussed in lectures and tutorials. Since different lab sections meet on different days of the week and each group of students do different experiment on their turn, few students may deal with the concepts before it discussed in lecture. In this case, the lab will serve as an introduction to the lecture. In other cases the lecture will be an introduction to the lab.

Few instructions for the students are as follows:

1. The students should know well in advance which experiment is to be done during assigned lab turn and come prepared for the same.
2. At the beginning of each lab turn students should check the experimental apparatus and ensure

that all the items required to execute the experiment is available there and it is in good condition. If any component of the apparatus is missing or not functioning properly, please immediately report to the instructor.

3. Data sheets must be verified and signed by the instructor. Unsigned data sheets would not be considered in the lab report so students should ensure that data sheets are verified and signed.

4. Each student is required to submit a lab report which must have objective of the experiment, data recorded by student, data analysis, uncertainty/error analysis, results and conclusions.

5. The lab report must be submitted within a week from the date of experiment.

6. All the lab reports will be graded and discussed with the students.

7. Points for each lab report are distributed as follows:

   A. Preparedness/viva: 3 points.

   B. On experiment: 3 points.

   C. Lab report: 4 points.

The points scored during regular lab classes will constitute 50% of your final laboratory grade. Other 50% laboratory grade will be awarded based on your performance in a laboratory examination scheduled at the end of the semester.

8. **Attendance and grades:** Students are expected to attend all lab sessions without any failure. If you are not able to attend any regular class scheduled for your batch, please immediately contact your lab instructor. The instructor will arrange alternative lab sessions for you. There are no make-up labs in this course.

Satisfactory completion of this lab is required as a part of your course grade. **Students failing in the lab examination will receive 'F' grade in PHY102 course. The laboratory grade makes up 25% of your final course grade.**

LABORATORY ETIQUETTES:

1. Each lab section will be distributed in group of TWO students. More than two students would not be allowed to work in a group.
2. Students should ensure their involvement in executing experiments and demonstrate learning.
3. Students must report on time for each lab sessions. Entry after 5 minutes from the scheduled time of the lab is strictly not allowed.
4. Students should not bring drink or food items in the lab.
5. Usages of mobile phones are not allowed during the lab classes.

6. All the instruments must be handled carefully. Damage/malfunctioning of any instrument/ component must be reported immediately to the lab instructors. In case of any doubt on operating the instruments please consult your lab instructor/assistant.
7. Copying and manipulation of experimental data/lab reports are strictly prohibited.

SAFETY PROCEDURES IN THE LABORATORY:

1. Be aware of power supplies to experimental set-ups. Before connecting/detaching power cord of instruments, please ensure power point is switched OFF.
2. Be aware of sharp/pointed edges of blades/instrument.

LIST OF EXPERIMENTS

1. **MEASUREMENTS AND UNCERTAINITIES**
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1. MEASUREMENTS AND ERROR ANALYSIS

1. Introduction:

"A measurement result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty is required in order to decide if the result is adequate for its intended purpose and to ascertain if it is consistent with other similar results."
National Institute of Standards and Technology

All *measurements* have some degree of uncertainty that may come from a variety of sources. The process of evaluating this uncertainty associated with a measurement result is often called *uncertainty analysis* or *error analysis*.

The complete statement of a measured value should include an estimate of the level of confidence associated with the value. Properly reporting an experimental result along with its uncertainty allows other people to make judgments about the quality of the experiment, and it facilitates meaningful comparisons with other similar values or a theoretical prediction. Without an uncertainty estimate, it is impossible to answer the basic scientific question: "Does my result agree with a theoretical prediction or results from other experiments?" This question is fundamental for deciding if a scientific hypothesis is confirmed or refuted.

When we make a measurement, we generally assume that some exact or true value exists based on how we define what is being measured. While we may never know this true value exactly, we attempt to find this ideal quantity to the best of our ability with the time and resources available. As we make measurements by different methods, or even when making multiple measurements using the *same* method, we may obtain slightly different results. So how do we report our findings for our best estimate of this elusive *true value*? The most common way to show the range of values that we believe includes the true value is:

$$Measurement = Best\ estimate \pm Uncertainty\ (units)$$

Finally we will be trying to compare our calculated values with a value from the text in order to verify that the physical principles we are studying are correct. Such comparisons come down to the question "Is the difference between our value and that in the text consistent with the uncertainty in our measurements?".

The topic of measurement involves many ideas. We shall introduce some of them by means of definitions of the corresponding terms and examples.

Sensitivity - The smallest difference that can be read or estimated on a measuring instrument. Generally a fraction of the smallest division appearing on a scale. About 0.5 mm on our rulers. This results in readings being uncertain by at least this much.

Variability - Differences in the value of a measured quantity between repeated measurements. Generally due to uncontrollable changes in conditions such as temperature or initial conditions.

Range - The difference between largest and smallest repeated measurements. Range is a rough measure of variability provided the number of repetitions is large enough. Six repetitions are reasonable. Since range increases with repetitions, we must note the number used.

Uncertainty - How far from the correct value our result might be. Probability theory is needed to make this definition precise, so we use a simplified approach. We will take the larger of range and sensitivity as our measure of uncertainty.

Example: In measuring the width of a piece of paper torn from a book, we might use a cm ruler with a sensitivity of 0.5 mm (0.05 cm), but find upon 6 repetitions that our measurements range from 15.5 cm to 15.9 cm. Our uncertainty would therefore be 0.4 cm.

Precision - How tightly repeated measurements cluster around their average value. The uncertainty described above is really a measure of our precision.

Accuracy - How far the average value might be from the "true" value. A precise value might not be accurate. For example: a stopped clock gives a precise reading, but is rarely accurate. Factors that affect accuracy include how well our instruments are calibrated (the correctness of the marked values) and how well the constants in our calculations are known. Accuracy is affected by systematic errors, that is, mistakes that are repeated with each measurement. Example: Measuring from the end of a ruler where the zero position is 1 mm in from the end.

Blunders - These are actual mistakes, such as reading an instrument pointer on the wrong scale. They often show up when measurements are repeated and differences are larger than the known uncertainty. Example: recording an 8 for a 3, or reading the wrong scale on a meter.

Comparison - In order to confirm the physical principles we are learning, we calculate the value of a constant whose value appears in our text. Since our calculated result has an uncertainty, we will also calculate a Uncertainty Ratio (UR) which is defined as

$$UR = \frac{|Experimental\ value - theoretical\ value|}{Uncertainty}$$

A value less than 1 indicates very good agreement, while values greater than 3 indicate disagreement. Intermediate values need more examination. The uncertainty is not a limit, but a measure of when the measured value begins to be less likely. There is always some chance that the many effects that cause the variability will all affect the measurement in the same way.

Example: Do the values 900 and 980 agree?

If the uncertainty is 100, then UR = 80=100 = 0:8 and they agree,

but if the uncertainty is 20 then UR = 80=20 = 4 and they do not agree.

2. Combining Measurements:

Consider the simple function $R = a.b$ when a and b have uncertainties of Δa and Δb. Then

$$\Delta R = (a + \Delta a)(b + \Delta b) - a\, b = a\Delta b + b\Delta a + (\Delta b)(\Delta a)$$

Since uncertainties are generally a few percent of the value of the variables, the last product is much less than the other two terms and can be dropped. Finally, we note that dividing by the original value of R separates the terms by the variables.

$$\frac{\Delta R}{R} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$$

The RULE for combining uncertainties is given in terms of fractional uncertainties, $\Delta x/x$. It is simply that each factor contributes equally to the fractional uncertainty of the result. Example: To calculate the acceleration of an object travelling the distance d in time t, we use the relationship: $a = 2\,d\,t^{-2}$. Suppose d and t have uncertainties Δd and Δt, what is the resulting uncertainty in a, Δa?

Note that t is raised to the second power, so that $\Delta t = t$ counts twice. Note also that the numerical factor is the absolute value of the exponent. Being in the denominator counts the same as in the numerator. The result is that

$$\frac{\Delta a}{a} = \frac{\Delta d}{d} + 2\frac{\Delta t}{t}$$

Examination of the individual terms often indicates which measurements contribute the most to the uncertainty of the result. This shows us where more care or a more sensitive measuring instrument is needed.

If d = 100 cm, Δd = 1 cm, t = 2:4 s and Δt = 0:2 s, then $\Delta d/d$ = (1cm) / (100cm) = 0.01 = 1% and $2\Delta t/t$ = 2(0.2s)/(2.4s) = 0:17 = 17%. Clearly the second term controls the uncertainty of the result. Finally, $\Delta a/a$ = 18%. (As you see, fractional uncertainties are most compactly expressed as percentages, and since they are estimates, we round them to one or two meaningful digits.)

Calculating the value of a itself ($2 \times 100/2.4^2$), the calculator will display 34.7222222. However, it is clear that with $\Delta a/a$ = 18% meaning $\Delta a \approx 6$ cm s^{-2}, most of those digits are meaningless. Our result should be rounded to 35 cm s^{-2} with an uncertainty of 6 cm s^{-2}.

In recording data and calculations we should have a sense of the uncertainty in our values and not write figures that are not significant. Writing an excessive number of digits is incorrect as it indicates an uncertainty only in the last decimal place written.

3. A General Rule for Significant Figures :

In multiplication and division we need to count significant figures. These are just the number of digits, starting with the first non-zero digit on the left. For instance: 0.023070 has five significant figures, since we start with the 2 and count the zero in the middle and at the right.

The rule is: Round to the factor or divisor with the fewest significant figures. This can be done either before the multiplication or division, or after.

Example: 7.434 x 0.26 = 1.93284 = 1.9 (2 significant figures in 0.26).

4. Reporting Uncertainties:

There are two methods for reporting a value V, and its uncertainty ΔV.

A. The technical form is (V ±ΔV) units.

Example: A measurement of 7.35 cm with an uncertainty of 0.02 cm would be written as (7.35 ± 0.02) cm. Note the use of parentheses to apply the unit to both parts.

B. Commonly, only the significant figures are reported, without an explicit uncertainty. This implies that the uncertainty is 1 in the last decimal place. Example: Reporting a result of 7.35 cm implies ±0.01 cm. Note that writing 7.352786 cm when the uncertainty is really 0.01 cm is wrong.

C. A special case arises when we have a situation like 1500±100. Scientific notation allows use of a simplified form, reporting the result as 1.5×10^3. In the case of a much smaller uncertainty, 1500±1, we report the result as $1{:}500 \times 10^3$, showing that the zeros on the right are meaningful.

5. Additional Remarks :

A. In the technical literature, the uncertainty also called the error.

B. When measured values are in disagreement with standard values, physicists generally look for mistakes (blunders), re-examining their equipment and procedures. Sometimes a single measurement is clearly very different from the others in a set, such as reading the wrong scale on a clock for a single timing. Those values can be ignored, but NOT erased. A note should be written next to any value that is ignored. Given the limited time we will have, it will not always be possible to find a specific cause for disagreement. However, it is useful to calculate at least a preliminary result while still in the laboratory, so that you have some chance to find mistakes.

C. In adding the absolute values of the fractional uncertainties, we overestimate the total uncertainty since the uncertainties can be either positive or negative. The correct statistical rule is to add the fractional uncertainties in quadrature, i.e.

$$\left(\frac{\Delta y}{y}\right)^2 = \left(\frac{\Delta a}{a}\right)^2 + \left(\frac{\Delta b}{b}\right)^2$$

D. The professional method of measuring variation is to use the Standard-Deviation of many repeated measurements. This is the square root of the total squared deviations from the mean, divided by the square root of the number of repetitions. It is also called the Root- Mean-Square error.

E. Measurements and the quantities calculated from them usually have units. Where values are tabulated, the units may be written once as part of the label for that column The units used must appear in order to avoid confusion. There is a big difference between 15 mm, 15 cm and 15 m.

6. Graphical Representation of Data:

Graphs are an important technique for presenting scientific data. Graphs can be used to suggest physical relationships, compare relationships with data, and determine parameters such as the slope of a straight line.

There is a specific sequence of steps to follow in preparing a graph. (See Figure 1)

1. Arrange the data to be plotted in a table.

2. Decide which quantity is to be plotted on the x-axis (the abscissa), usually the independent variable, and which on the y-axis (the ordinate), usually the dependent variable.

3. Decide whether or not the origin is to appear on the graph. Some uses of graphs require the origin to appear, even though it is not actually part of the data, for example, if an intercept is to be determined.

4. Choose a scale for each axis, that is, how many units on each axis represent a convenient number of the units of the variable represented on that axis. (Example: 5 divisions = 25 cm). Scales should be chosen so that the data span almost all of the graph paper, and also make it easy to locate arbitrary quantities on the graph. (Example: 5 divisions = 23 cm is a poor choice.) Label the major divisions on each axis.

5. Write a label in the margin next to each axis which indicates the quantity being represented and its units. Write a label in the margin at the top of the graph that indicates the nature of the graph, and the date the data were collected. (Example: "Air track: Acceleration vs. Number of blocks, 12/13/05")

6. Plot each point. The recommended style is a dot surrounded by a small circle. A small cross or plus sign may also be used.

7. Draw a smooth curve that comes reasonably close to all of the points. Whenever possible we plot the data or simple functions of the data so that a straight line is expected. A transparent ruler or the edge of a clear plastic sheet can be used to "eyeball" a reasonable fitting straight line, with equal numbers of points on each side of the line. Draw a single line all the way across the page. Do not simply connect the dots.

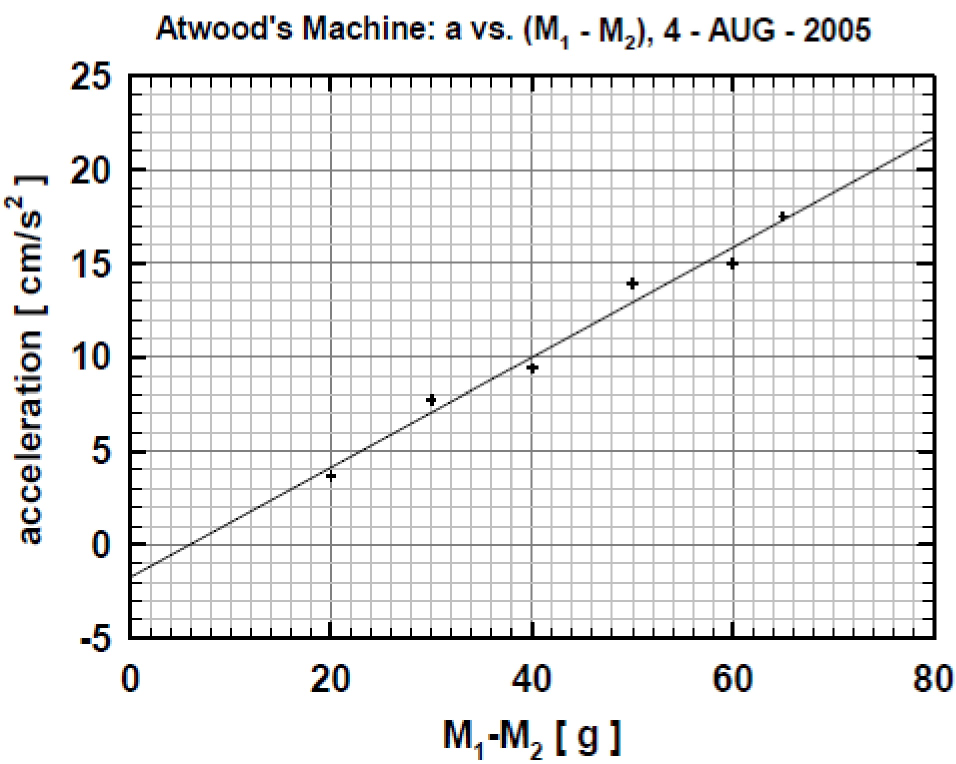

Figure 1: Example graph.

Using Figure 1 as an example, the slope of the straight line shown may be calculated from the values at the left and right edges, (-1.8 cm/s^2 at 0 g and 21.8 cm/s^2 at 80 g) to give the value:

$$Slope = \frac{(21.8 - (-1.8))\ cm/s^2}{(80 - 0)\ g} = \frac{23.6\ cm/s^2}{80\ g} = 0.295\ \frac{cm}{s^2 g}$$

Suppose that the uncertainty is about 1.0 cm/s^2 at the 70 g value. The uncertainty in the slope would then be (1.0 cm/s^2)/(70 - 20) g = 0.02 cm/(s^2 g). We should then report the slope as (0.30±0:02) cm/(s^2-g). (Note the rounding to 2 significant figures.)

If the value of g (the acceleration of free fall) in this experiment is supposed to equal the slope times 3200 g, then our experimental result is

3200 g x (0:30 ± 0:02) cm/(s^2 g) = (9:60 ±0:64) m/s^2

To compare with the standard value of 9.81 m/s^2, we calculate the uncertainty ratio (UR).

UR = (9:81 - 9:60)/0:64 = 0.21/0.64 = 0.33.

so the agreement is very good.

[Note: Making the uncertainty too large (lower precision) can make the result appear in better agreement (seem more accurate), but makes the measurement less meaningful.]

"Log" PAPERS and SCALES: Semi-log and log-log papers and scales are used quantitatively to show relations between quantities when theory predicts exponential or power law behavior. They are also used qualitatively to display data that extends over a very large range of the variables. When a number is plotted on a log scale its position represents the log of that number and the bother of looking up many logs is avoided. **Therefore, when plotting on a "log" scale you must use the printed numbers, multiplying successive "decades" by powers of 10.** For example, you cannot arbitrarily change " 1 2 3 4 56..." into "3 4 5 6 78...". Care in plotting is necessary, as the value of intermediate intervals keeps changing. For ease of reading the graph you should supply the decimal point or powers of 10, so that a typical "x" scale would read: " .1 .2 .3 .4 .6 .8 1 2 3 4 6 8 10 20 30 40 60 .. ". Note that there is no "0" on a log scale (because this would correspond to a position of $-\infty$). **Semi-log paper** is useful if the theoretical relation is $H = H_0\ e^{bt}$. Since $\ln H = \ln H_0 + bt$, a straight line with slope "b" will be obtained when (ln H) is plotted against t.

Evaluating logs graphically: The logs (to the base 10) have already been taken by the paper scale itself. That is, the ratio of a distance on the log paper to the length of a "decade", the 1-to-1 distance, is the log10 of the value of the ratio of the endpoints. This process will be made clear in an example below.

Thus for the semi-log slope:

$$b = (\ln H_2 - \ln H_1)/\Delta t$$

$$= 2.3\{\log H_2 - \log H_1)/\Delta t$$

$$= 2.3 \log (H_2 /H_1)/\Delta t = 2.3 (D_H /D)/(t_2 - t_1)$$

where D_H is the distance (in cm.) between points H_2 and H_1 on the line and D is the decade length (also in cm.) "b" must have units so that the total exponent is unit-less, typically sec^{-1}.

Log-log paper is used to demonstrate the relation: $\mathbf{I = I_0 r^P}$**.** Since (log I) = (log I0) + P (log r), the log-log plot of **I vs. r** is a straight line with slope P and intercept (log I0) {*read the value of* I_0 *directly on the printed scale* at r = 1, (i.e.log r = 0)}. **Evaluation of the slope for log-log paper** to get the power P is: $P = (\ln I_2 – \ln I_1) / (\ln r_2 – \ln r_1) = [2.3 (D_Y/D)/(2.3 D_X/D)]$ which is just $= D_Y/D_X$ {both measured in cm.) i.e. the loglog slope is measured with a ruler, NOT by reading the scale values. ***This assumes you are using good quality log-log paper with the same "decade" size (in cm) both directions.*** [Note that the power P carries no units.]

ASSIGNMENTS

1. Error analysis:

1. To determine the diameter of a metal wire.
2. To determine the diameter of a coin.
3. To determine density of mica sheet.

2. Graph plotting:

1. **“The leaky water bucket”:** In an experiment, a student has recorded the times at which the level in a cylindrical water “bucket” passed each centimeter mark on the side of the cylinder. Analyze the data shown here.

Height (cm.)	Time (Sec.)
18	0
17	5
16	10
15	14
14	19
13	25
12	31
11	37
10	43
9	51
8	60
7	110
6	121
5	134
4	150
3	211
2	246

1 345

2. **“Light intensity vs distance from a small source”:** The measurements of the light intensity (brightness) at a detector that is moved farther and farther from the light source are performed. Analyze the data and evaluate a power law using log-log paper.

Distance (cm.) ±0.2 cm.	5	10	15	20	30	40	60	80
Intensity (ft-cndls.) ±5%	60	16	7.4	4.3	2.1	1.3	0.74	0.55

References: (for measurements and error analysis)

1. Laboratory manual, Introductory Physics, The city college of New York, USA.
2. Introduction to measurements and error analysis, Laboratory manual, Department of Physics and astronomy, University of North Carolina, USA.
3. Estimating errors, using graphs and taking good data, Dr. R. H. Carr, Professor of Physics, California State University, Los Angeles, USA.

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Experiment 2
<u>Air track experiment</u>

OBJECTIVE:

(1). Measurement of velocity, average velocity and instantaneous velocity

(2). Measurement of acceleration and acceleration due to gravity.

(3). Momentum and energy in ‘inelastic’ and ‘elastic’ collisions.

INTRODUCTION:

The air track is a long hollow aluminum casting with many tiny holes in the surface. Air blown out of these holes provides an almost frictionless cushion of air on which the glider can move. The air track and gliders operate best if they are clean and smooth. If their surfaces are dirty or show bumps or nicks, inform your instructor before proceeding. Dirt, bumps, and nicks can result in scratching the surfaces of the track and glider. To avoid scratching, use care in handling the apparatus. The most important rule is this: at no time should the glider be placed on the air track if the blower is not in operation.

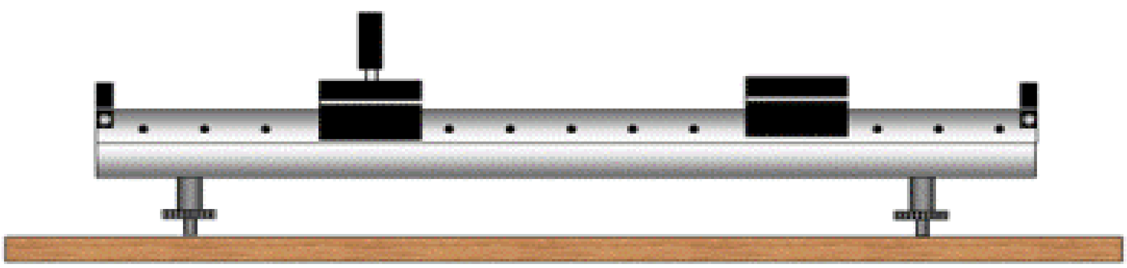
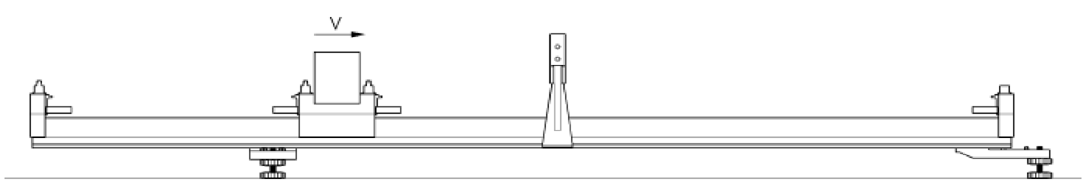


Fig.1: Air-track system (Image: Teaching Advanced Physics (TAP), Institute of Physics, London, UK).

EXPERIMENTS:

1-A: Measurement of velocity:

The air track should be adjusted to be level and a glider should not try to move either direction.



METHOD:

Tape a 100mm long piece of black card to the side of a short glider so that the card breaks the light beam of the Photo Gate mounted across the track. Turn on the air and slide the glider through the Photo Gate. See the time displayed. As a small experiment, see if you can repeat the same speed exactly. Try to slide it again through the Gate at exactly the same speed to get exactly the same time. Try a few times to see if you can read exactly the same speed.

Because of slight errors in cutting the card and the sensitivity of the photogate, it is important to check the exact distance travelled by the glider between the switching on and off of the photo gate. The flag might be 100mm long, but the actual distance travelled by the glider to switch on and off the gate might be slightly different from this dimension.

Very slowly slide the glider into the photogate and, at the instant when the gate switches (see the monitor light on the gate), use a sharp pencil to mark the track with a fine line exactly level with the end of the glider. Then continue passing the glider through the gate and mark the track again at the instant the gate switches again. The exact distance between these lines is the "effective" length of the flag. It should be close to the cut length of the flag, but write this exact dimension on the flag for future reference when using this flag.

ANALYSIS:

Velocity (v)=Distance travelled (d) / Time (t) meter/second.

Distance travelled is 100mm (or the "effective" length of your cardboard flag). The time is the reading shown on the timer in seconds for each time the glider passed through the Gate. Divide the effective length of the flag in millimetres by the time in seconds and you have Velocity of the glider's movement in mm per second. Divide the effective length of the flag by the average time in seconds (press the Average button on the timer until 2 beeps are heard to see the average of all the times) that you noted from the timer and you have the average velocity of all the tries. Try the experiment again using a long glider and using a 200mm long flag.

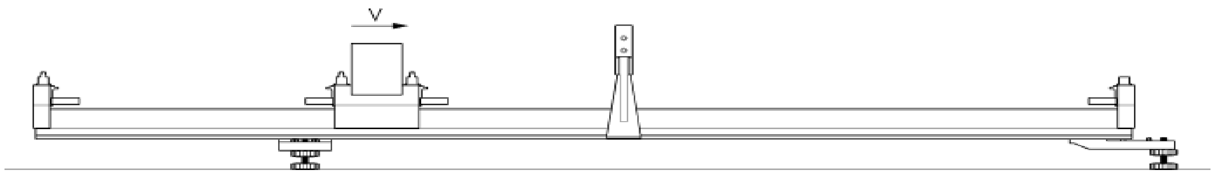
<u>1-B: Average velocity and instantaneous velocity:</u>

Instantaneous velocity is the velocity taken over an infinitely short distance. Average velocity is calculated from the time taken over a long distance.

If the glider velocity is changing, the measurement taken in experiment 1 using the 100mm wide flag will be the average velocity over the 100mm distance. The 10mm wide flag will provide the average velocity over a much shorter distance. If the flag was 3mm wide, the velocity is almost the instant velocity because it is the average over a very short distance.

SETUP:

Lift the single track levelling adjustment screw at one end of the air track and place one of the track inclination blocks provided under the adjustable foot. Use the 20mm thick block. The blocks in the kit are marked with their thickness. The track has inclination and gravity will cause the gliders to slide down the track.



METHOD:

This time, use a 200 mm long glider and a 200 mm long flag. Repeat experiment 1-A by holding the glider to one end of the track and gently releasing it so it glides by itself down the track. Before releasing the glider, be very careful not to compress the spring buffers or provide ANY other initial force to the glider. To be sure of this, it is often best to remove the buffers from the track end and the glider at the starting point.

ANALYSIS:

Measure average velocity of the glider through the photogate using the 200 mm wide flag (check the “effective” length of the flag). Repeat the motion 2 more times and, using the timer’s averaging button, note the average of the 3 readings. Remove the 200 mm wide flag and replace it with the 10mm wide flag taped at the **MID POINT** of the glider. Release the glider in exactly the same way and note the average of 3 readings. Reposition the 10 mm flag to be level with the front end of the glider and repeat to get an average of 3 readings. Reposition the 10mm flag to be level with the rear end of the glider and repeat to get an average of 3 readings.

2-A: Measurement of acceleration:

Acceleration is change of Velocity over Time: V/t Deceleration is: -V/t.

SETUP:

Use the same setup as the experiment 2 with the Air Track on a slope. Leave the two photogates fixed to the track at say 800 mm apart.

METHOD:

Tape a 10 mm wide flag and tape it to the side of a glider. Be sure the glider is placed on the track so that the flag is furthest away from the light source and closer to the sensor side of the gate. If necessary, check the “effective” length of the flag.

Initially, use the timer Function button to select Start/Stop mode and connect the first gate to the Start sockets and the second gate to the Stop sockets. Press Stop then Reset buttons to zero the display and to set the mode. Clear the timer memory by pressing the Clear button until 2 beeps are heard. Carefully release the glider so that the total time taken for the glider to pass from one gate to the other will be measured. Repeat the motion 3 times and press the timer average button until 2 beeps are heard to see and note the average of the readings. After this time is determined, the timer connection must be changed. Connect the two gate signals together to the same Start sockets on the timer. Plug the 4 mm banana plugs from the second Gate into the tops of the other 4mm plugs. Use the function button on the timer to select photogate mode. In this setting, the first gate will start and stop the timer as the flag covers the light beam and the second gate will also start and stop the timer. Both readings are stored in memory and the second reading is displayed.

Note the reading on the timer and, using the memory recall (arrow down) button, the note the previously stored reading. If the glider is moving slowly enough, it is usually possible to take note of the first time as it is measured and to take note of the second time at the finish. This avoids needing to use the memory recall button. Repeat the experiment two or three more times and average the readings from the first gate and from the second gate.

ANALYSIS:

Calculate the two velocities and subtract them to get the change in velocity. Take the average time taken for the glider to pass between the two gates. Divide the change in velocity by the time taken between the gates to have average acceleration in mm/sec^2.

2-B: Measurement of acceleration due to gravity:

SETUP:

The setup is exactly the same as in the previous experiment. Set the air flow so that heavier gliders will float on the track without dragging. The angle of the track will be altered and the glider will be changed in weight and the average accelerations measured. The force due to gravity acting on the glider will be calculated by using vectors.

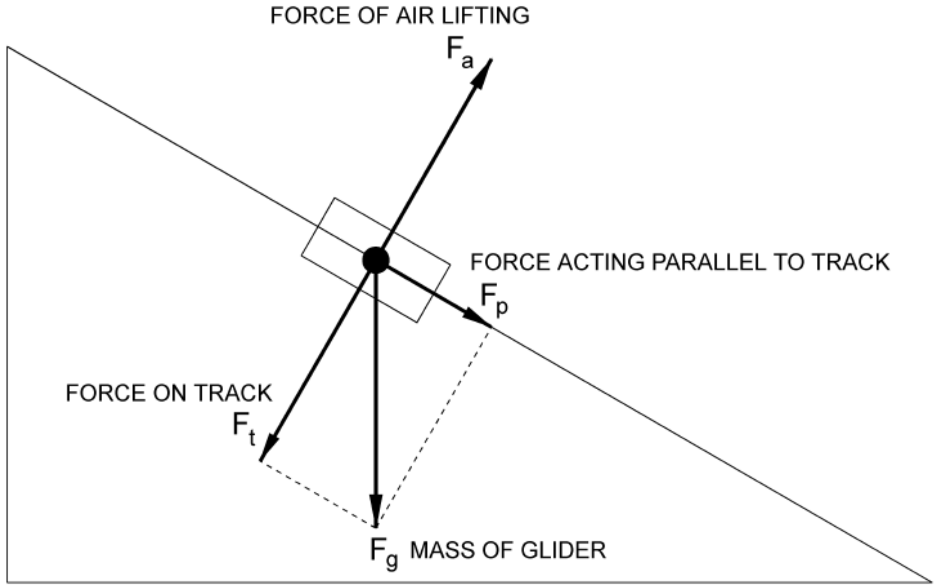
METHOD:

The acceleration down the Air Track should follow Newton's laws of motion and gravity. Preset several long and short gliders with extra weights. Say 100g, 150g, 200g and 300g. Check each glider's exact mass on a balance. With the track set to the existing angle, place one glider behind the other and see if one races the other down the track. Try say 100g against 200g and 150g against 300g. Repeat experiment 3 to measure average acceleration of different mass gliders. Change the angle of the Air Track to maybe half or double the present angle. Check average acceleration again for the various mass gliders.

Measure the exact height (h) of the inclination blocks (the thickness is marked on them) and the distance (d) between the feet along the Air Track to determine the exact angle of inclination. Sine angle = h/d (opposite side over hypotenuse)

ANALYSIS:

Calculate the slope angle by using sine angle = h/d. Then using vectors and the value of the various slope angles to determine what proportion of the forces due to gravity are acting down the slope. Then you can determine how much of the weight of the glider is pushing it down the slope.



From the diagram above, the force of the air lifting $\boldsymbol{F_a}$ equals and cancels the force at the normal to the track F_t. The remaining forces are the action of gravity vertically $\boldsymbol{F_g}$ and also parallel with the track down the slope $\boldsymbol{F_p}$.

Knowing the Force of gravity acting down the slope and knowing the mass of the glider, use the formula ***F=ma*** to determine the expected acceleration down the slope due to gravity.

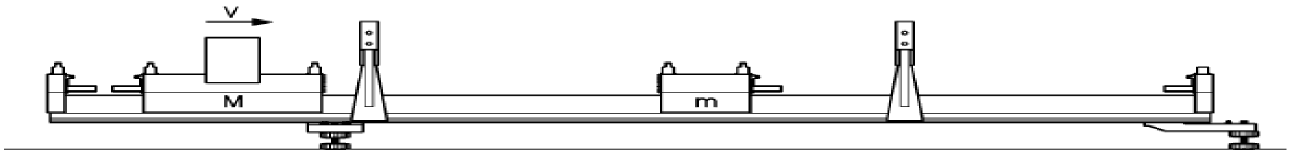
3-A: Momentum and energy in 'inelastic' collisions:

SETUP:

Set the air track as level as possible where the glider will not float in either direction. Take a long glider, remove the buffer spring from one end and fit a "Velcro" pad to replace the normal buffer spring. Load this glider with an extra 100g. Take a short glider and fit the mating "velcro" pad to one end while leaving a buffer spring fitted to the other end. Do not load it with extra weight. Weigh both gliders.

Set up 2x Photo Gates across the track about 500 mm apart and join them together to the same Start sockets of the timer. Using the function button, set the timer to photogate mode. Press Stop then Reset to zero the display and to set the operation mode of the timer. Clear the memory of the timer.

Tape a 100 mm long flag to the 200 mm long glider. If not already done, check the "effective" length of this flag. Place the 200 mm glider at one end of the track and place the lighter glider between the two gates with the "Velcro" pads facing.



METHOD:

By hand, start the motion of the heavy glider to make it pass through the first gate to measure the average velocity. After it strikes and sticks to the second glider, we then measure the new average velocity as the pair of gliders pass through the second gate. As the heavy glider sticks to the second glider, the total mass will increase and the velocity will decrease.

ANALYSIS:

Momentum:

Let ‘M’ be the mass of the heavy glider. Let ‘m’ be the mass of the lighter glider.

Let ‘V’ be the velocity of the heavy glider through the first gate.

Let ‘v’ be the velocity of the combined mass of both gliders passing through the second gate.

Initial momentum = MxV (initial mass x initial velocity)

Final momentum = (M+m) x ‘v’ (total mass x final velocity)

Energy:

We can calculate:

The kinetic energy of the first glider before the collision: ½ $(MV_1)^2$

The kinetic energy of the first glider after the collision: ½ $(MV_B)^2$

The kinetic energy of the second glider before the collision: ½ $(mV_2)^2$

The kinetic energy of the second glider after the collision: ½ $(mV_b)^2$

The loss of kinetic energy from the first glider after the collision: ½ M $[(V_1)^2-(V_B)^2]$

The gain in kinetic energy in the second glider after the collision: ½ m $[(V_2)^2-(V_b)^2]$

(Since glider was stationary, so ‘V2’ was zero)

3-B. Momentum and energy in ‘elastic’ collisions:

SETUP:

Repeat the same setup as experiment 5, BUT this time remove the ‘Velcro’ pads from the ends of the gliders and replace them with the spring buffers. Also, this time, fit a 100mm long flag to the lighter glider.

Because the gliders will bounce quickly away from each other, it is useful to practise a few times to be sure the gliders pass through the gates AFTER they have separated from each other. Also, after the collision, it will be necessary to quickly stop a glider or to remove it from the track to avoid rebounding back through a gate.

METHOD:

The method is the same as in experiment 5 and the results can be tabulated in the same way. The time through the second gate will be separate times made by the smaller glider and the larger glider separately. The calculations are the same as it was in the earlier experiment but the two separate mass and times through the second gate must be added to get the total momentum of both gliders.

This experiment is initially done with the second glider stationary, but it can be repeated with the second glider moving towards the first glider or away from it before the collision occurs. When both gliders are moving, you must be very careful with your timing of the collision so that all initial and final velocities are measured for both gliders.

ANALYSIS:

The analysis is the same as in experiment 5.

REFERENCES:

1. Vernier's manual.
2. Web sources.

Experiment-3
Motion on an inclined plane

OBJECTIVE:

(1). A. Analyse displacement (Δx) vs. time (t) and velocity (v) vs. time (t) curve.

B. Study average and instantaneous velocity.

(2). Determine coefficient of static and kinetic friction of a wooden block moving on a track.

APPARATUS:

Motion Detector, force sensor, horizontal/inclined plane, cart/block, string and different masses.

EXPERIMENTAL PROCEDURE:

1. Mount the motion detector at a position near one end of the track.
2. Set the switch of motion detector to 'Track'.
3. Elevate the end of the track opposite the motion detector if you are using a horizontal track.
4. Practice launching the cart with your finger so that it slows to a stop at least 50 cm from its initial position before it returns to the initial position.
5. Hold the cart steady with your finger at least 20 cm from the motion detector1, then zero the motion detector.
6. Begin collecting data, then launch the cart up the ramp. Be sure to catch it once it has returned to its starting position.
7. Repeat, if necessary, until you get a trial with a smooth position-time graph.

DATA ANALYSIS:

Part 1

1. Either print or sketch the position *vs.* time (x-t) graph for your experiment. On this graph identify:
    - Where the cart was rolling freely up the ramp
    - Where the cart was farthest from its initial position
    - Where the cart was rolling freely down the ramp
2. In your investigation of an object moving at constant velocity, you have learnt that the slope of the x-t graph was the average velocity of the object. In this case, however, the slope for any interval on the graph is not constant; instead, it is constantly changing. Based on your observations, sketch a graph of velocity *vs.* time corresponding to that portion of the x-t graph where the cart was moving freely.
3. Now, view both the position *vs.* time and velocity *vs.* time graphs. Compare the v-t graph to the one you sketched in Step 2.

4. Take a moment to think about and discuss how you could determine the cart's velocity at any given instant.
5. If you are using Logger *Pro*, group the two graphs (x-axis), and turn on the Tangent tool for the *x-t* graph and the Examine tool for the *v-t* graph. Using program, compare the slope of the tangent to any point on the *x-t* graph to the value of the velocity on the *v-t* graph. Write a statement describing the relationship between these quantities.

Part 2:

1. Perform a linear fit to that portion of the *v-t* graph where the cart was moving freely. Print or sketch this *v-t* graph. Write the equation that represents the relationship between the velocity and time; be sure to record the value and units of the slope and the vertical intercept.

   On this *v-t* graph identify:

   - Where the cart was being pushed by your hand
   - Where the cart was rolling freely up the ramp
   - The velocity of the cart when it was farthest from its initial position
   - Where the cart was rolling freely down the ramp
2. The slope of a graph represents the rate of change of the variables that were plotted. What can you say about the rate of change of the velocity as a function of time while the cart was rolling freely? In your discussion, you will give a name to this quantity. What is the significance of the algebraic sign of the slope?
3. Compare the value of your slope to those of others in the class. What relationship appears to exist between the value of the slope and the extent to which you elevate the track?
4. The vertical intercept of the equation of the line you fit to the *v-t* graph represents what the velocity of the cart would have been at time $t = 0$ had it been accelerating from the moment you began collecting data. Suggest a reasonable name for this quantity. Now write a general equation relating the velocity and time for an object moving with constant acceleration
5. The position-time graph of an object that is constantly accelerating should appear parabolic. Use the Curve Fit function of your data analysis program to fit a quadratic equation to that portion of the *x-t* graph where the cart was moving freely. Note the values of the *A* and *B* parameters in the quadratic equation. You will have to provide the units.
6. Compare these parameters (values and units) to the slope and intercept of the line used to fit the *v-t* graph. Now write a general equation relating the position and time for an object undergoing constant acceleration.

(2). Coefficient of static and kinetic friction of a wooden block moving on a track.

THEORY:

Friction is the resistive force that impedes the motion of a body when one tries to slide the object along a surface. The friction force acts parallel to the surfaces in contact, opposes the relative velocity of the body with respect to the surface, and its magnitude depends on the nature of the particular materials that are rubbing together, but not on other variables, such as the area of contact. This will be veri_ed experimentally, and is true only in the macroscopic sense, since on the molecular level things are much more complicated. For the case where the surfaces are in motion relative to each other, the force is called the force of kinetic friction, and is found to be proportional to the normal force acting at the region of contact, and always in opposition to the velocity of the body relative to the surface of contact;

$$\vec{F}_{kin} = -\mu_k \left|\vec{N}\right| \frac{\vec{v}}{|\vec{v}|}$$

Thus the magnitude of the friction force can be written as

$$\left|\vec{F}_{kin}\right| = -\mu_k N$$

where the constant of proportionality, μ_k is the coefficient of kinetic friction.

If the two bodies in contact have no relative velocity, an even larger static frictional force must be overcome in order to initiate slipping. This is of the same form

$$\overrightarrow{F_S} = -\overrightarrow{F_e}$$

only now $\boldsymbol{F_e}$ is the externally applied force that is attempting to cause to bodies to slip. This static friction only acts to cancel out the external forces to prevent relative motion, and has a maximum magnitude

$$\left|\vec{F}_s\right| max = \mu_s \left|\vec{N}\right|$$

where μ_s is called the coefficient of static friction. As indicated above, for most surfaces we find that

$$\mu_k \leq \mu_s$$

To study static friction, we can use an inclined plane. As the angle of inclination is increased from zero, the component of the block's weight pointing down the plane increases. Because of the variable nature of static friction, the magnitude of the friction force keeps increasing as the ramp is raised. At a certain critical angle, however, the friction force reaches its maximum value, and any further increase in the angle will cause the block to begin sliding down the ramp. At that critical angle (θ_C), the forces on the block are described by

$$m_o g \sin\theta_C - \mu_S m_o \cos\theta_C = 0$$

from which we find, $$\mu_S = \tan\theta_C$$

Thus, by measuring the angle of inclination at which the block just begins to slide, we can determine the coefficient of static friction.

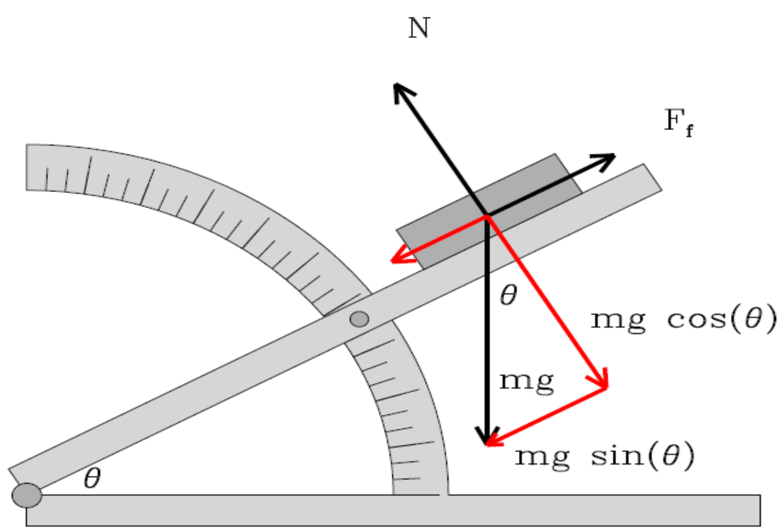
EXPERIMENTAL PROCEDURE:

1. Determination of static friction:

Use the board as an inclined plane to measure the coefficient of static friction. Place the block on the plane with its largest area in contact, and gradually raise the plane until the block just breaks loose and begins to slide down the ramp. Measure the angle at which this occurs. Static friction is overcome at angle 'θ_c' satisfying [As shown in the figure below.].

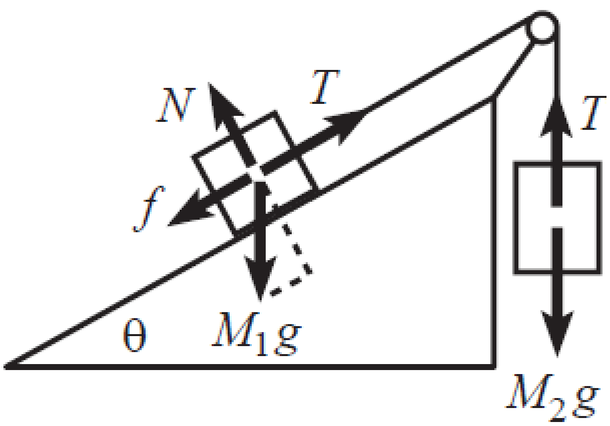
Repeat this process 5 times, lowering the board to its horizontal position at the beginning of each trial. If block faces with different materials are available, carry out this procedure for two samples. Identify the sample in the top line of the data table. Repeat this phase of the experiment with the block placed on its side to reduce the area of contact. Finally use the following equation to calculate the coefficient of static friction.

$$\mu_S = \tan\theta_C$$



2. Determination of kinetic friction:

Measure and record mass M_1 of the block. Place the board in an inclined position (θ) so that its pulley extends beyond the edge of the lab table. If necessary, wipe the block and the board so that they are free of dirt and grime. Place the block with its largest surface in contact with the board. Pass a string from the block over the pulley and place a weight hanger on the free end of the string (As shown in the figure below). Mount the motion detector at the bottom of the inclined plane. Set the switch of motion detector to ‘Track’. Now, increase the mass on the hanger (M_2 = mass of hanger + mass added). It will be necessary to give the block a slight tap for each increase in mass on the hanger, in order to overcome the static friction and initiate motion. The slightest tap will be required when the total mass (M_2) is just enough to overcome the static friction. In a situation, M_2 will be sufficiently large to pull the block (M_1) up the plane with acceleration (*a*). Click to start data collection and collect velocity vs. time data. Repeat this activity 2-3 times and collect data. Draw a graph between velocity and time. Determine acceleration of the block using this velocity *vs.* time graph. Slope of the linear section of velocity *vs.* time graph will provide acceleration. Place different masses on the block, and hence different masses on the hanger to repeat this experiment.



According to the figure above, *f* is the frictional force, *T* the tension of the string and *N* the normal force. Taking care of the different components of the forces on M_1 and M_2, we have the following equations,

$$T - f - M_1 g \sin\theta = M_1 a,$$

$$N - M_1 g \cos\theta = 0,$$

$$M_2 g - T = M_2 a,$$

Now, using $f = \mu_k N$ in the above equation, we can find the expression for μ_k as,

$$\mu_k = \frac{M_2 - \frac{a}{g}(M_1 + M_2) - M_1 \sin\theta}{M_1 \cos\theta}$$

From this equation determine μ_k

Experiment No-4
Projectile Motion

OBJECT:

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. The initial velocity of the ball is determined by shooting it horizontally and measuring the range and the height of the Launcher.

EQUIPMENT NEEDED:

Projectile Launcher and plastic ball, Plumb bob, Meter stick
-Carbon paper
-White paper

THEORY:

To predict where a ball will land on the floor when it is shot off a table at some angle above the horizontal, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by shooting the ball horizontally off the table and measuring the vertical and horizontal distances through which the ball travels. Then the initial velocity can be used to calculate where the ball will land when the ball is shot at an angle.

PART A. HORIZONTAL SHOT:

For a ball shot horizontally off a table with an initial speed, v_o, the horizontal distance travelled by the ball is given by $x = v_o t$, where t is the time the ball is in the air. Air friction is assumed to be negligible. The vertical distance the ball drops in time t is given by,

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

The initial velocity of the ball can be determined by measuring x and y. The time off light of the ball can be found using:

$$t = \sqrt{\frac{2y}{g}}$$

And then the initial velocity can be found using $v_0 = x/t$

SHOT AT AN ANGLE:

To predict the range of a ball shot off with an initial velocity (v_o) at an angle, θ, above the horizontal, first we need to predict the time of flight. As is shown in figure below, after a time t the vertical position of the particle (y) would be,

$$y = y_0 + (v_0 \sin\theta)t - 1/2 g t^2$$

At point B in the figure, $y - y_o = 0$. Hence, the time taken to reach point B,

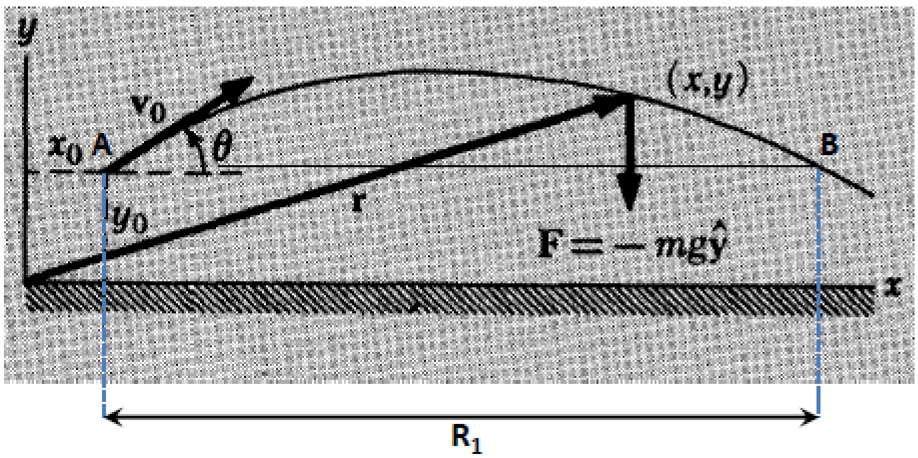
$$t_1 = (2 v_o \sin\theta)/g.$$

Now, the particle further goes down to reach the ground. If it takes another t_2 seconds to reach the ground then,

$$y_o = (v_o \sin\theta)t_2 + (1/2)gt_2^2.$$

Using values of v_0 and y_0 from Part A, we can find out t_1 and t_2. Total time of flight (T) = (t_1 + t_2) seconds. Then, total horizontal distance travelled (total range),

$$R = R_1 + R_2 = (v_0\cos\theta)t_1 + (v_0\cos\theta)t_2 = (v_0\cos\theta)T$$



SET-UP:

1. Clamp the Projectile Launcher to a sturdy table near one end of the table.

2. Adjust the angle of the Projectile Launcher to zero degrees so the ball will be shot off horizontally.

Part A: Determining the Initial Velocity of the Ball

1. Put the plastic ball into the Projectile Launcher and cock it to the long range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.

2. Fire about ten shots.

3. Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.

4. Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the paper. Record is in Table 1.1.

5. Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 1.1.

6. Find the average of the ten distances and record in Table 1.1.

7. Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record is in Table 1.1.

Table 1.1 Determining the Initial Velocity

Vertical Distance = _____________
Calculate time of flight =____________
Horizontal distance to paper edge = _________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Calculate initial Velocity = _______________

Part B: Predicting the Range of the Ball Shot at an Angle

1. Adjust the angle of the Projectile Launcher to an angle between 30 and 60 degrees and record this angle in Table 1.2.

2. Using the initial velocity and vertical distance found in Part A of this experiment, assume the ball is shot off at the same velocity at the new angle you have just selected, calculate the new time of flight and the new horizontal distance. This calculated distance is the predicted range. Record in Table 1.2

3. Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance from the Projectile Launcher .Cover the paper with carbon paper.

4. Shoot the ball ten times.

6. Measure the ten distances and take the average. Record is in Table 1.2.

Table 1.2 Confirming the Predicted Range

Vertical Distance = ____________
Calculated time of flight =___________
Predicted (calculated) Range = ______________
Horizontal distance to paper edge = ________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

1. **Calculate the percent difference between the predicted value and the resulting average** distance when shot at an angle.

2. Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Experiment 5
Rigid body motion

OBJECTIVE:

To determine the moment of inertia of a bicycle wheel about its centre .

APPARATUS:

Bicyle wheel, string, mass, timer etc.

THEORY:

For linear motion, Newton's second law describes the relationship between the applied force, the mass of an object, and its acceleration. Force is the cause of the acceleration, and mass is a measure of the tendency of an object to resist a change in its linear translational motion. Essentially all of the relations between physical quantities associated with linear motion (mass 'm', displacement 'x', velocity 'v', acceleration 'a' and force 'F') have analogous counterparts in the realm of rotational motion (moment of inertia 'I', angular displacement 'θ', angular velocity 'ω', angular acceleration 'α' and torque 'τ') [Eq.^{n} 1-4].

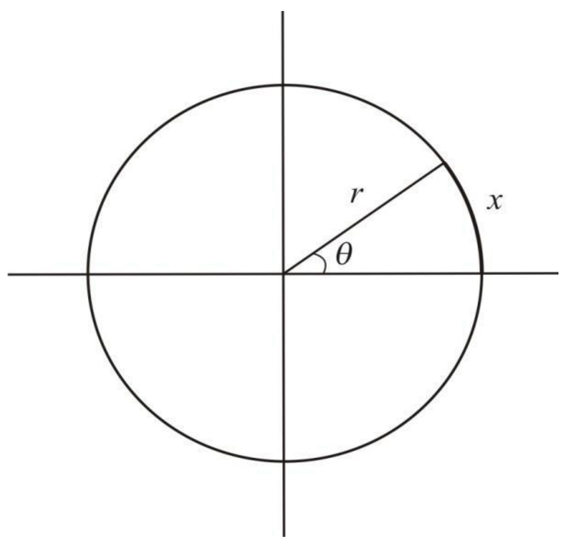


Figure 1: Circular motion.

$$x = r\theta \qquad (1)$$

$$v = \frac{dx}{dt} = r\frac{d\theta}{dt} = r\omega \qquad (2)$$

$$a = \frac{dv}{dt} = r\frac{d\omega}{dt} = r\alpha \qquad 3$$

For rotational motion of some object about a fixed axis, an equivalent description for the relationship between the applied torque , the moment of inertia , and the angular acceleration of the object is given by eq^{n}. 4.

$$\tau = rF = I\alpha = I\frac{a}{r} \qquad 4$$

Torque is the cause of the angular acceleration, and the moment of inertia is a measure of the tendency of a body to resist a change in its rotational motion. The moment of inertia of a rigid body depends upon the mass of the body and the way in which the mass is distributed relative to the axis of rotation.

If the mass of the rotating system is made up of discrete particles (Fig. 2), the total moment of inertia is

$$I = \sum_{i=1}^{N} m_i\, r_i^2 \qquad 5$$

.

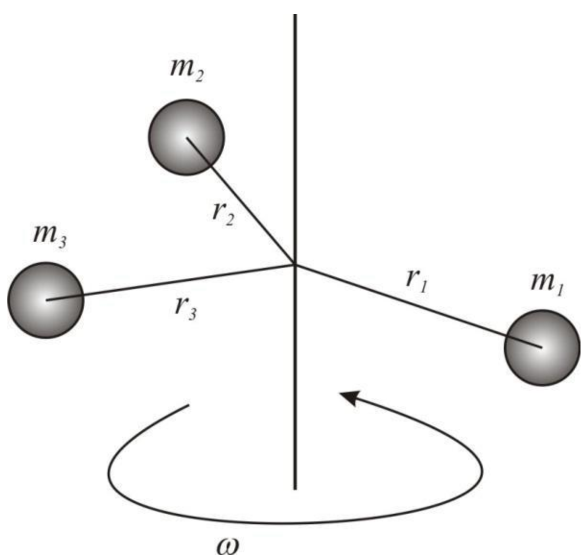


Figure 2: Element of mass contributing to moment of inertia.

If the mass of the rotating system is made up of a continuous shape instead of discrete particles, the total moment of inertia becomes

$$I = r^2 dm \qquad 6$$

EXPERIMENTAL PROCEDURE:

1. Setup is shown in Fig. 3. Measure the radius of the bike wheel and record it on the table 3.

2. Measure the distance between the mass and the floor that the body travels. Record it on the table 3.

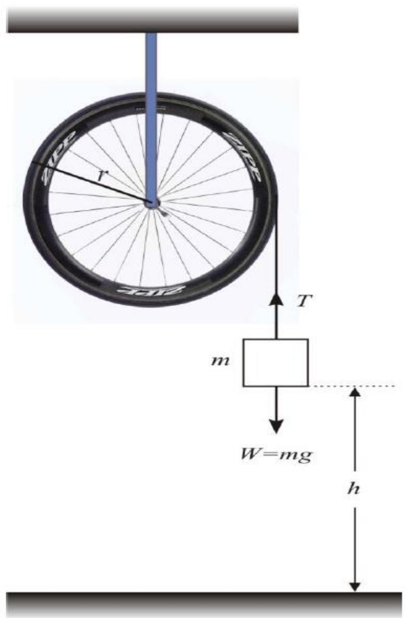


Figure 3: Set-up of the moment of inertia measurement.

3. Release the mass and using a counter measure the time required for ‘h’ for five times. Repeat each measurement for four-five different masses. Record the measurements on table 1. Calculate the average of the time using arithmetic mean and record it.

Table-1

r = ----------------- unit.			
h=--------------------unit.			
	Mass-1 (M_1) unit.	Mass-2 (M_2) unit.	Mass-3 (M_3) unit.
	Time (T) unit.	Time (T) unit.	Time (T) unit.
Trial-1			
Trial-2			
Trial-3			
Trial-4			
Trial-5			
	$T_{1avg.}$= --------------- unit.	$T_{1avg.}$= --------------- unit.	$T_{1avg.}$= --------------- unit.

4. Calculate the acceleration of mass for each mass using the following kinematic equation:

$$h = v_o t + \frac{1}{2}at^2 = \frac{1}{2}at^2 \quad or\ a = \frac{2h}{t^2} \qquad \textit{(for } v_o\textit{=0)} \quad \mathbf{7}$$

5. Using Newton's second law of motion for the falling mass we write,

$$F = ma = mg - T \qquad \mathbf{8}$$

substituting Eq^n. 4 in Eq^n. 8 we get the moment of inertia of inertia of the bi-cycle wheel,

$$I = mr^2\left(\frac{g}{a} - 1\right) \qquad 9$$

Calculate the average of the moment of inertia of the bike wheel using arithmetic mean and report it.

6. Calculate and report the angular acceleration, torque, and force using Eq. (3) and (4). Compare the '***F***' value and corresponding weight '***W=m.g***'.

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[2] University Physics with Modern Physics with MasteringPhysics™, 12/E, Hugh D. Young and Roger A. Freedman, 2008.
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EXPERIMENT 6
TORSION PENDULUM

AIM:

To determine (i) Moment of Inertia of the disc & (ii) Rigidity Modulus of the material of the given wire by torsion oscillations.

APPARATUS REQUIRED:

1. Torsion Pendulum (uniform circular disc suspended by a wire)
2. Two equal cylindrical masses
3. Stop watch
4. Screw Gauge
5. Metre scale, etc.

THEORY:

Moment of inertia is a property of a body that defines its resistance to a change in angular velocity about an axis of rotation. When a body is rotating around an axis, a torque must be applied to change its angular momentum. The amount of torque needed for any given change in angular momentum is proportional to the size of that change. The constant of proportionality is a property of the body that combines its mass and its shape, known as the moment of inertia. In classical mechanics, moment of inertia may also be called mass moment of inertia, rotational inertia, polar moment of inertia, or the angular mass (SI units kg·m^2).

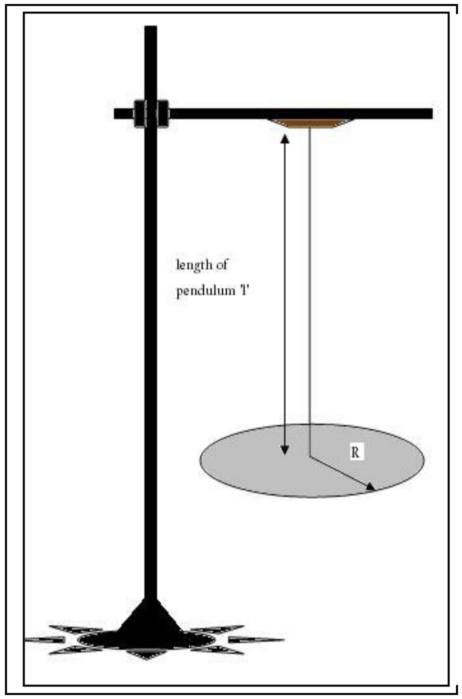
What is Torsional Oscillation?

A body suspended by a thread or wire which twists first in one direction and then in the reverse direction, in the horizontal plane is called a torsional pendulum. The first torsion pendulum was developed by Robert Leslie in 1793.

The period of oscillation of torsion pendulum is given as,

$$T = 2\pi\sqrt{\frac{I}{C}} \text{ .... } (1)$$

Where I=moment of inertia of the suspended body; C=couple/unit twist



But we have an expression for couple per unit twist C as,

$$C = \frac{1}{2}\frac{\pi n r^4}{l} \ldots\ldots\ldots\ldots [2]$$

Where l = length of the suspension wire; r = radius of the wire; n = rigidity modulus of the suspension Wire

Substituting (2) in (1) and squaring, we get an expression for rigidity modulus for the suspension wire as,

$$n = \frac{8\pi I l}{r^4 T^2} \ldots\ldots\ldots\ldots (A)$$

We can use the above formula directly if we calculate the moment of inertia of the disc,I as (1/2)MR^2.

Now, let I0 be the moment of inertia of the disc alone and I1 & I2 be the moment of inertia of the disc with identical masses at distances d1&d2 respectively. If I1 is the moment of inertia of each identical mass about the vertical axis passing through its centre of gravity, then

$$I_1 = I_0 + 2\ I^1 + 2md_1^{\ 2} \ldots\ldots\ldots\ldots (3)$$

$$I_2 = I_0 + 2I^1 + 2md_2^{\ 2} \ldots\ldots\ldots\ldots (4)$$

$$I_2 - I_1 = 2m(d_2^{\ 2} - d_1^{\ 2}) \ldots\ldots\ldots (5)$$

But from equation (1),

$$T_0^{\ 2} = 4\pi^2 \frac{I_0}{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$T_1^{\ 2} = 4\pi^2 \frac{I_1}{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$T_2^{\ 2} = 4\pi^2 \frac{I_2}{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$T_2^{\ 2} - T_1^{\ 2} = \frac{4\pi^2}{C}(I_2 - I_1) \ldots\ldots\ldots\ldots (9)$$

Where T0, T1, T2 are the periods of torsional oscillation without identical mass,with identical pass at position d1,d2 respectively
Dividing equation (6) by (9) and using (5),

$$\frac{T_0^{\ 2}}{\left(T_2^{\ 2} - T_1^{\ 2}\right)} = \frac{I_0}{[I_2 - I_1]} = \frac{I_0}{2m\left(d_2^{\ 2} - d_1^{\ 2}\right)} \ldots\ldots\ldots (10)$$

Therefore, the moment of inertia of the disc,

$$I_0 = 2m\left(d_2^{\ 2} - d_1^{\ 2}\right)\frac{T_0^{\ 2}}{\left(T_2^{\ 2} - T_1^{\ 2}\right)} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Formula:

S.No	Description	By Experiment	By Theory
1.	Moment of Inertia of the disc	$I_{exp} = \frac{2m(d_2^2 - d_1^2)T_0^2}{T_2^2 - T_1^2}$ kg m^2	$I_{th} = \frac{MR^2}{2}$ kg m^2
2.	Rigidity Modulus of the material of the wire	$\eta_{exp} = \frac{8\pi I_{exp}\ell}{T_0^2 r^4}$ N/m^2	$\eta_{th} = \frac{8\pi I_{th}\ell}{T_0^2 r^4}$ N/m^2

Symbol	Description	Unit
m	Mass (mass of one of the cylinders) placed on the disc	**kg**
d_1	Minimum distance between axis of rotation and the centre of one of the symmetrical masses	**m**
d_2	Maximum distance between axis of rotation and centre of one of the symmetrical masses	**m**
T_0	Time period without any mass placed on the disc	**s**
T_1	Time period with equal masses placed at d_1	**s**
T_2	Time period with equal masses placed at d_2	**s**
ℓ	Length of the suspension wire	**m**
`r’	Radius of the wire	**m**
M	Mass of the Inertia disc	**kg**
R	Radius of the Inertia disc	**m**

PROCEDURE:

One end of a long, uniform wire whose rigidity modulus is to be determined is clamped by a vertical chuck. To the lower end, a heavy uniform circular disc (Inertia disc) is attached by another chuck. The length of the suspension wire ‘ℓ’ is fixed at a particular value (say, 70 cm or 80 cm). The suspended disc is slightly twisted so that it executes torsional oscillations. Care is taken to see that the disc oscillates without wobbling.

The first few oscillations are omitted. By using a pointer, a mark is made in the disc and the

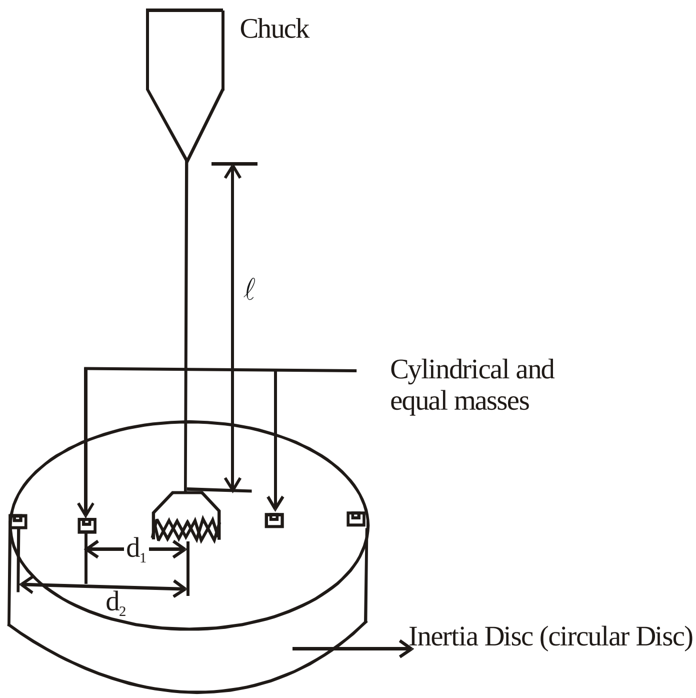


Fig.1 - Torsional pendulum

time taken for 10 complete oscillations is noted. Two trials are taken. Then the mean time period (Time for one oscillation), T_0 is found.

The two cylindrical masses (equal masses) are placed on the disc symmetrically and diametrically opposite to each other close to the suspension wire (at minimum distance). The closest distance 'd_1' from the centre of the cylindrical mass and the axis of rotation is found. The disc with masses at distance 'd_1' is made to execute torsional oscillations by twisting the disc. The time taken for 10 oscillations is noted. Two trials are taken. The mean time period 'T_1' is determined.

The two equal masses are now moved from the current position to the extreme ends so that the edges of the masses coincide with the edge of the disc and the centres of masses are equidistant. The distance 'd_2' from the centre of the cylindrical mass to the centre of the suspension wire is noted. The disc with masses at distance 'd_2' is allowed to execute torsional oscillations by twisting the disc. The time taken for 10 oscillations is noted for two trials and the mean time period 'T_2' is calculated.

The mass of one of the cylindrical masses placed on the disc is noted. The diameter of the wire is accurately measured at various places along its length using screw gauge. From this the radius of the wire is calculated. The mass of the Inertia disc and the diameter of the same are measured. The moment of inertia of the disc and the rigidity modulus of the suspension wire are calculated using the given formulae.

Observations:

(i) To find the time period at different stages:

Length of the suspension wire ℓ = ________ m

Position of the equal masses	Time for 10 oscillations			Time Period
	Trial I	Trial II	Mean	
	s	S	s	S
Without masses				T_0 =
With masses at d_1 = ________m				T_1 =
With masses at d_2 = ________m				T_2 =

(ii) Measurement of diameter (d) of the suspension wire using screw gauge: Least count of screw gauge:

$$\text{Pitch} = \frac{\text{Distance moved by the head scale on the pitch scale}}{\text{Number of rotations given to the head scale}}$$

= ______________ **mm**

Number of head scale divisions = ______________

Least Count (L.C) = Pitch/Total no. of head scale divisions (div.)

= __________ **mm**

Zero error (Z.E) = __________ **div.**

Zero Correction (Z.C) = **div.** = ________**mm**

Trial No.	Pitch Scale Reading (P.S.R)	Head Scale Coincidence (H.S.C)	Observed Reading (O.R) =P.S.R + [H.S.C x L.C]	Corrected Reading (C.R) = (O.R. ± Z.C)
	mm	**div.**	**mm**	**Mm**
1.				
2.				
3.				

Mean diameter of the wire, d = ____________ x 10^{-3} m

Mean radius of the wire, $r = \frac{d}{2} =$ ____________ x 10^{-3} m

Data for Calculations:

Time period of oscillation without masses, T_0 = __________

Time period when cylindrical masses are at distance `d_1', T_1 = __________

Time period when cylindrical masses are at distance `d_2', T_2 = __________

Minimum distance between the axis of rotation and
the centre of the cylindrical mass, d_1 = __________ (measured using scale)

Maximum distance between the axis of rotation and
the centre of the cylindrical mass, d_2 = __________ (measured using scale)

Mass of one of the cylindrical mass, m = __________

Length of the suspension wire, ℓ = __________ (measured using thread)

Mean diameter of the wire, d = __________

Mean radius of the wire, r = d/2 = __________

Mass of the Inertia disc, M = ________

Diameter of the Inertia disc, D= ________ (measured using scale)

Radius of the inertia disc, R = D/2 = ________

<u>CALCULATIONS:-</u>

Moment of Inertia of the disc:

(i) Experimental value

$$I_{exp} = \frac{2m\left(d_2^2 - d_1^2\right)T_0^2}{T_2^2 - T_1^2} =$$

I_{exp} = ________

1. **Theoretical value**

$$I_{th} = \frac{MR^2}{2} =$$

I_{th} = ________

Rigidity modulus of the material of the wire:

1. **Experimental value**

$$\eta_{exp} = \frac{8\pi I_{exp}\ell}{T_0^2 r^4} =$$

η_{exp} = ________

(ii) Theoretical value

$$\eta_{th} = \frac{8\pi I_{th}\ell}{T_0^2 r^4} =$$

η_{th} = ________

Results:

1. **The Moment of inertia of the disc,**

   (i) by experiment = ________

   (ii) by theory = ________

2. **The Rigidity modulus of the material of the given wire,**

   (i) by experiment = ________

   (ii) by theory = ________

PRECAUTIONS:

1. The plane of the circular disc must be horizontal

1. The suspension wire should be well clamped, thin, long and free from kinks.

2. The motion of the circular disc should be purely torsional rotation in horizontal plane. Up and down and lateral oscillations must be completely removed.

3. The radius of the wire and the period of oscillations should be measured accurately since they occur in fourth and second power in the formula respectively.

VIVA-VOCE:

1. What is a torsion pendulum? Why is it called so?
2. What type of rigid bodies can you use for a torsion pendulum?
3. Is torsional oscillation simple harmonic?
4. On what factors does the time period depend?
5. How does the pendulum oscillate?
6. What type of wire do you prefer for this experiment?
7. How will you determine the rigidity of fluids?

Experiment- 7 Electrostatic Force

Objective:

To study electrostatic forces and quantitative analysis of charge generated.

- To determine the charge of the pith ball (q)
- To determine the charge of the aluminium dome (Q)
- Verify the inverse square Law

Apparatus : Van de Graff Generator, pith balls, protector, and ruler.

Theory:

Coulomb's Law

The quantitative expression for the effect of three variables (charges on two objects and the distance between them) on electric force is known as Coulomb's Law. Coulomb's Law states that the electrostatic force between two charged objects is directly proportional to the product of the quantity of charge on the objects and inversely proportional to the square of the separation distance between the two objects. In equation form, Coulomb's Law (in scalar form) is given as

$$F = \frac{kQq}{r^2} \tag{1}$$

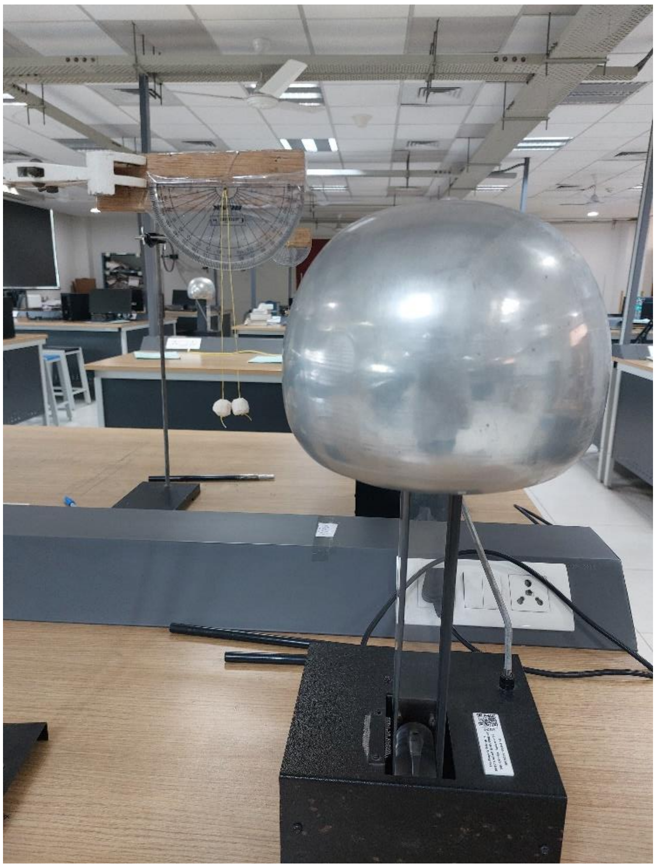
where, **Q** represents the quantity of charge on object 1 (in Coulombs), **q** represents the quantity of charge on object 2 (in Coulombs), and **r** represents the distance of separation between the two objects (in meters). The symbol **k** is a proportionality constant known as Coulomb's law constant (9×10^9 Nm^2/C^2). This constant's value depends on the medium in which the charged objects are immersed. In the case of air, the value is approximately 9.0 x 10^9 N • m^2 / C^2. If the charged objects are present in water, the value of **k** will reduce by as much as a factor of 80.

Coulomb's law equation accurately describes the force between two objects whenever the objects act as **point charges**. A charged conducting sphere interacts with other charged objects as though all of its charge were located at its centre. While the charge is uniformly spread across the surface of the sphere, the centre of charge can be considered to be the sphere's centre. The sphere acts as a point charge with its excess charge located at its centre. Since Coulomb's

Law applies to point charges, the distance **d** in the equation is the distance between the centres of charge for both objects (not the distance between their nearest surfaces).

The symbols **Q** and **q** in Coulomb's law equation represent the quantities of charge on the two interacting objects. Since an object can be charged positively or negatively, these quantities are often expressed as "+" or "-" values. The sign on the charge is simply representative of whether the object has an excess of electrons (a negatively charged object) or a shortage of electrons (a positively charged object). It might be tempting to utilize the "+" and "-" signs in the calculations of force. While the practice is not recommended, there is certainly no harm in doing so. When using the "+" and "-" signs in the calculation of force, the result will be that a "-" value for force is a sign of an attractive force and a "+" value for force signifies a repulsive force. Mathematically, the force value would be found to be positive when **Q** and **q** are of like charge, either both "+" or both "-". And the force value would be found to be negative when **Q** and **q** are of opposite charge. It is consistent with the concept that oppositely charged objects have an attractive interaction, and like charged objects have a repulsive interaction. In the end, if you're thinking conceptually (and not merely mathematically), you would be very able to determine the nature of the force - attractive or repulsive - without the use of "+" and "-" signs in the equation. Coulomb's Law describes three properties of electrical forces:

1. The force is inversely proportional to the square of the distance between the charges
2. The force is proportional to the product of the magnitude of the charges.
3. Two objects of the same magnitude of charge exert a repulsive force on each other, and two objects of the opposite magnitude of charge exert an attractive force on each other.



Figure(1) Experimental setup of electrostatic forces

Part 1

How to charge the pith ball?

It's essential to ensure that both the pith balls are neutral before charging them by touching them with the dull aluminium sphere (ground). Then wrap the fur around the pointed end of the rubber rod and briskly rub the rod with the fur to produce a net negative charge on the end of the rod. In the next step, bring the negatively charged pointed end of the rod to the pith ball. By the phenomenon of induction positive charge will induce on the sides of the pith balls closest to the rod. If the negative rod is brought near neutral pith balls, both pith balls will also be polarized. In each pith ball, electrons are free to move through the material, and some of them are repelled over to the opposite surface of the pith ball, leaving the surface near the negative rod with a net positive charge. Each pith ball has been polarized and will now be attracted to the charged rod. The pith ball has been charged without actually being touched with the charged rod, and its charge is opposite the rods. This procedure is called charging by induction.

Part 2

Van De Graff Generator:

A Van de Graaff generator is an electrostatic generator invented by an American physicist Robert J. Van de Graaff. It uses a moving belt that accumulates charge on a hollow metal structure designed like a globe, placed on the top of a column that is insulating in nature and thus, creating a very high electric potential in the order of a few million volts. This results in a very large electric field that accelerates charged particles.

Working Principle of Van de Graaff Generator:

In the Figure (2), we can see a schematic diagram of Van de Graff generator. Here, a large spherical shell is at a height of several meters above the ground (kept on a wooden table). An insulating column holds it. Two pulleys are wound with a belt-like insulating material, one at ground level and the other at the centre of the shell.

This belt undertakes a continuous motion, thus carrying a positive charge continuously from the ground to the top. This belt is constantly kept moving by a motor driving the lower pulley. The positive charge is transferred to the larger shell by a carbon brush, thus rendering the outer shell with a very high potential over time.

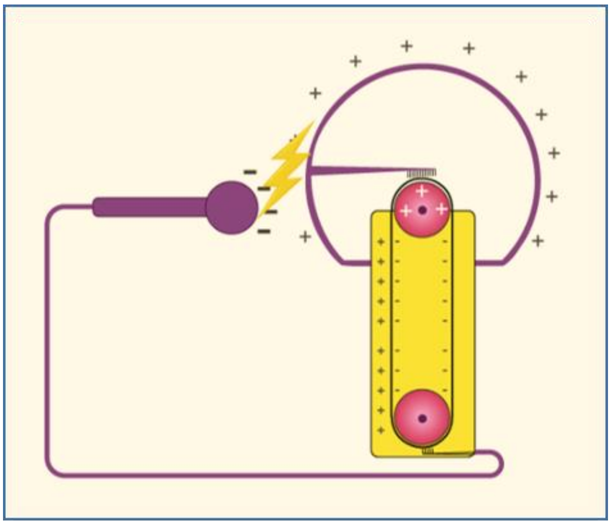


Figure (2): Van De Graff Generator

Let us consider the radius of a large spherical shell is R. If we place a charge of magnitude Q on such a sphere, the charge will spread uniformly over the surface of the globe. The electric field inside the sphere is zero (according to Gauss's law), and that outside the sphere is due to the charge Q at the centre of the sphere. So, the potential outside is that of a point charge; and inside it is constant. We, thus, have:

Potential inside conducting spherical shell of radius R carrying charge Q = constant and is as follows

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} \tag{2}$$

The Accumulation of Charges on Aluminium Sphere

A simple Van de Graff generator consists of a belt of rubber moving over two rollers of differing materials, one of which is surrounded by a hollow metal sphere. A comb-shaped metal electrode with sharp points is positioned near each roller. The upper comb is connected to the globe, and the lower one is to the ground. When a motor is used to drive the belt, the triboelectric effect causes the transfer of electrons from the dissimilar materials of the belt and the two rollers. In the example shown, the rubber of the belt will become negatively charged while the acrylic glass of the upper roller will become positively charged. The belt carries away negative charge on its inner surface while the upper roller accumulates positive charge.

Next, the strong electric field surrounding the positive upper roller induces a very high electric field near the points of the nearby comb. At the points of the comb, the electric field becomes strong enough to ionize air molecules. The electrons from the air molecules are attracted to the outside of the belt, while the positive ions go to the comb. At the comb, they are neutralized by electrons from the metal, thus leaving the comb and the attached outer shell with fewer net electrons and a net positive charge. By Gauss's Law, the excess positive charge is accumulated on the outer surface of the outer shell, leaving no electric field inside the shell. Continuing to drive the belt causes further electrostatic induction, which can build up large amounts of charge on the shell. The charge will continue to accumulate until the rate of charge leaving the sphere (through leakage and corona discharge) equals the rate at which the new charge is being carried into the globe by the belt.

Outside the terminal sphere, a high electric field results from the high voltage on the globe, which would prevent the addition of further charge from the outside. However, since electrically charged conductors do not have any electric field inside, charges can be added continuously from the inside without needing to overcome the full potential of the outer shell.

Calculations:

Step 1: To find the charge on the pith ball.

Let the force between two static charges be F_{Elect}. Figure (3) shows the vector diagram for the three forces acting on each pith ball in equilibrium. Since the pith balls are in mechanical equilibrium, from Newton's 2^{nd} law:

$$F_{Elect} = T \sin\theta \tag{3}$$

$$F_{rest} = T\cos\theta \tag{4}$$

Eliminating T from two equations,

$$\frac{F_{Elect}}{F_{rest}} = \tan\theta \tag{5}$$

From two similar triangles OCB and BED in Figure 2:

$$\tan\theta = \frac{r/2}{\sqrt{l^2 - \frac{r^2}{4}}} \tag{6}$$

$$F_{Eelct} = F_{rest} \times \frac{r}{\sqrt{4l^2 - r^2}} \tag{7}$$

$$q = \sqrt{\frac{mgr^3}{k\sqrt{4l^2 - r^2}}} \tag{8}$$

Where, $k = 1/4\pi\varepsilon_0 = 9\times10^9$ Nm^2/C^2 and $g = 9.81$ ms^{-1}. Thus by knowing the value of the mass of the pith ball and thread length, the charge induced on each pith ball can be estimated.

Observation :

No. of Trail	2θ	θ	$r = 2l \sin\Theta$	$q = \sqrt{\frac{mgr^3}{2kl}}$
1				
2				
3				
4				
5				

where, r = the distance between two pith balls after charging (Figure 2), m = mass of a pith ball, $k = 9\times10^{9}\ Nm^2/C^{2,}$ and l = length of the thread.

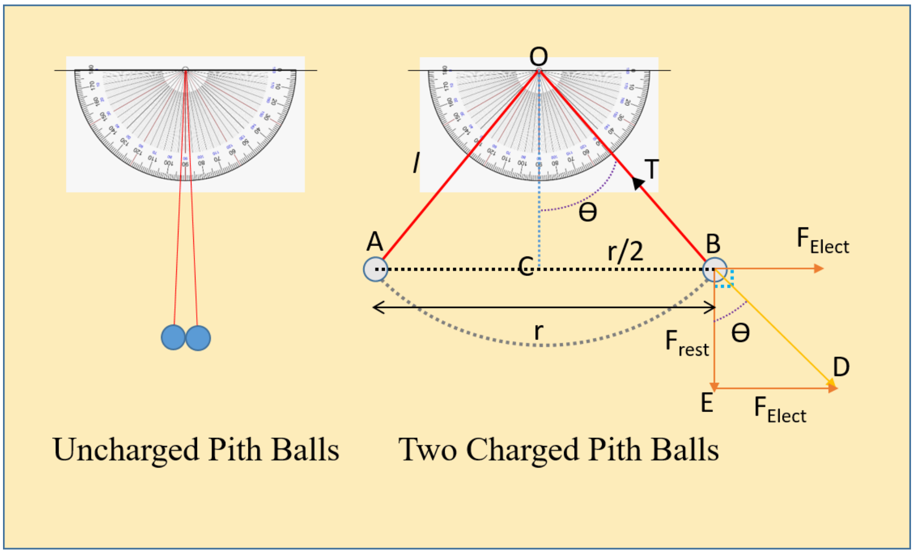


Figure (3), Shows the states of pith balls when they are uncharged and charged.

Step 2: To find the charge Q on the big aluminium dome.

The measurement to be made and later analysed using the set-up in Figure (3), critical basic steps are:

- Before starting the experiment, ensure all components connect to ground to make these components neutral, i.e. no additional charges on them.
- Align of pith ball with respect to the electrostatic generator's conducting dome.
- Measuring the displacement between the charge Q on the generator and q on the pith ball (which has been estimated in Step 1)

Aligning of the Apparatus:

As shown in Figure (3), the electrostatic generator is arranged so it can be displaced along the ruler fastened to your laboratory bench. First, required to mark the position of the voltage generator so that the pith ball (which is hanging vertically) is at its center. To do this, ground the generator sphere by touching it with the dull aluminium sphere. Remove the top half of the dome, and place the small plastic ruler across a diameter for guidance in locating the globe's centre. Record the position of the right side of the generator along the table. This measured location along the ruler is called $\mathbf{X_0}$, we will use it later to calculate the horizontal distance R.

Now move the generator along the ruler in the direction away from the vertical pole until the pith pall clears the dome, and replace the top of the dome.

First, we need to determine the position, X_0, of the voltage generator at the point where the pith ball, hanging vertically, is at its center. To do this, ground the generator sphere by touching it with the dull aluminium sphere. Remove the top half of the dome, relocate one of the pith balls to the plastic screw, place the small plastic ruler across the dome's diameter, accurately locate the center, and shift the generator's base until the center of the pith ball lies at the center of the sphere. Note that the Van de Graaff generator is somewhat flimsy, so carelessness can cause the dome to move without the base moving commensurately. Take care to handle the generator from the bottom only.

Record the position of the side of the generator along the table on the meter stick. This measured location along the ruler is called X_0 in the equations we will be using later. Record your error and units: How accurately can you determine the sphere's centre? How accurately can you measure the location of the pith ball's centre? How accurately can you read the meter stick? Record the protractor reading for the un-deflected string as θ_0. Angles toward the support rod are positive and angles toward the Van de Graaff generator are negative. Record your error and units

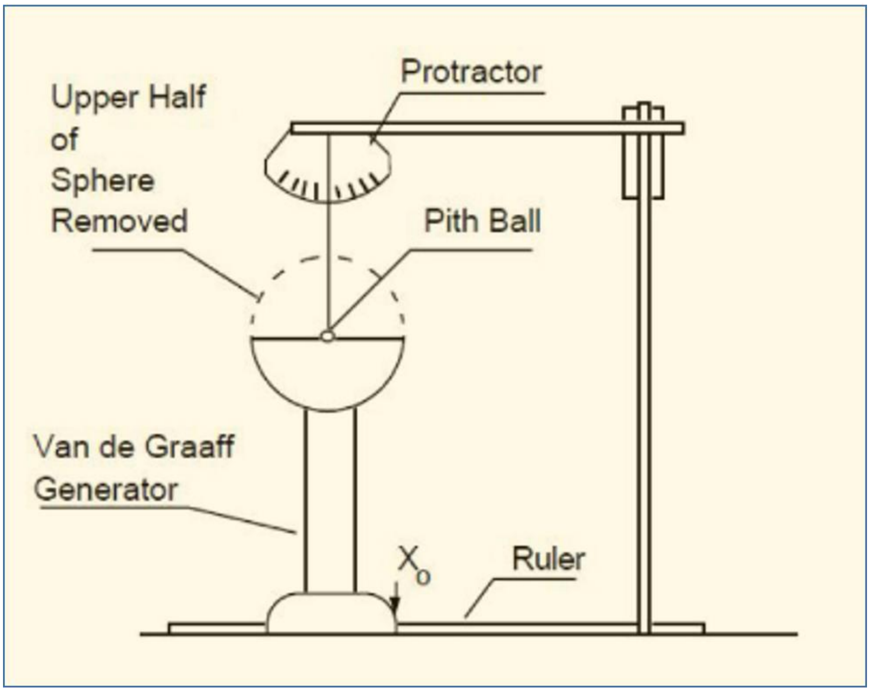


Figure (4): The top of the dome is removable so that we can accurately match the spheres centres and measure X_0.

Now move the pith ball holding stand along the ruler in the direction away from the vertical pole until the pith ball clears the dome by more than 10 cm and cover the top of the dome. If the experiment were done with the Van de Graff generator too close to the vertical pole, the charge induced in the conducting pole would exert Coulomb forces to redistribute the charge in the dome, making it spherically asymmetric.

The measurement described next must be done quickly because the charge on the pith balls dissipates in time. The rate of loss depends on the humidity in the air. Therefore, be sure to know clearly what to do, and once you start, continue taking measurements until you finish, saving the calculation for later.

Lift one of the charged balls by its line and drape it over the insulated plastic peg mounted on the stick without touching or discharging the other ball. Now slide the electrostatic generator or the pith ball holding stand along the table until the charged ball is about 5 cm from the generator sphere. Switch on the generator for several short bursts until the ball is deflected between 10-15 degrees as measured by the protector at the line support point. Record the deflection angle θ and the horizontal position X of the generator. Now shift the pith ball holding stand sideways to decrease the deflection angle and record X and θ. Make six separate measurements to obtain values of θ for $\Delta X = X - X_0$ between 10 cm and 60 cm. The data obtained will determine the total charge Q on the generator sphere and verify the inverse square dependence on distance in Coulomb's Law.

Immediately after the last measurement, return the pith ball holder stand to the first measurement position and record the value of the charge that affected your results.

When there is repulsive force between Van de Graff generator dome and pith ball

With the help of Figure 4 (b), it can show by trigonometry where

$$R^2 = (\Delta X + l\sin\theta)^2 + (l - l\cos\theta)^2 \qquad (9)$$

where, $|\Delta X| = (Xo - X)$, X_o is the initial position of pith ball (distance in cm between centre of dome to centre of pith ball) when it is near to the dome surface (Van de Graff generator is not charged) and X is the final position of pith ball after repulsion (Van de Graff generator is charged).

From Figure (5), by using the sine law.

$$\frac{F_{Elect}}{F_{rest}} = \frac{\sin\theta}{\sin\beta} \qquad (10)$$

$$F_{Elect} = \frac{F_{rest} \ \sin\theta}{\sin(90-\theta+\alpha)} = \frac{mg \ \sin\theta}{\cos(\theta-\alpha)} \quad (11)$$

Calculation of the angle (α) between the line joining the two centres and the horizontal, from Figure (5), is

$$x = l \ sin\theta \quad (12)$$

$$y = l - l \ cos\theta \quad (13)$$

$$\tan\alpha = \frac{y}{X+\Delta X} = \frac{l - l\cos\theta}{\Delta X + l\sin\theta} \quad (14)$$

$$\alpha = \tan^{-1}\left(\frac{l(1-\cos\theta)}{\Delta X + l\sin\theta)}\right) \quad (15)$$

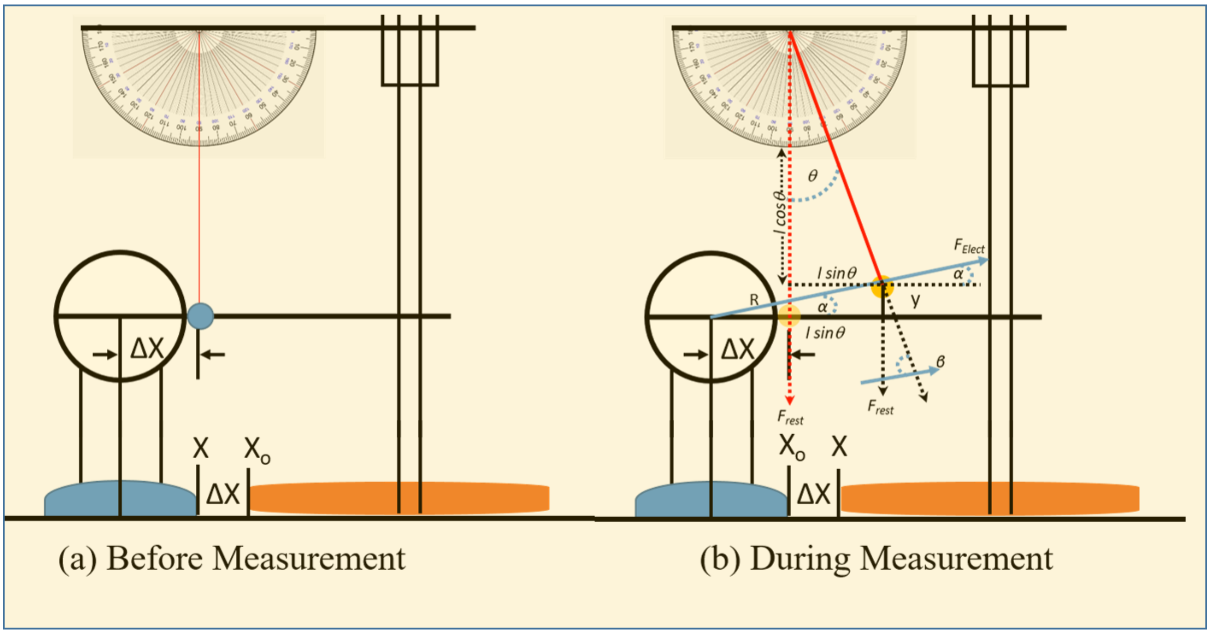


Figure (5), Apparatus set up for Coulomb's Law experiment and geometric consideration when repulsive force acting between dome and pith ball.

Therefore, F_{Elect} will be

$$F_{Elect} = \frac{mg\sin\theta}{\cos(\theta-\alpha)} \quad (16)$$

If we assume that α is very small as compared to θ, F_{Elect} can be written as

$$F_{Elect} = mg\tan\theta \quad (17)$$

The above equation (17) can calculate the force F_{Elect} for each measured value of θ. Finally, compare the observed dependence of F_{Elect} on R with that in Coulomb's Law.

$$F_{Elect} = \frac{qQ}{4\pi\varepsilon_0 R^2} \tag{18}$$

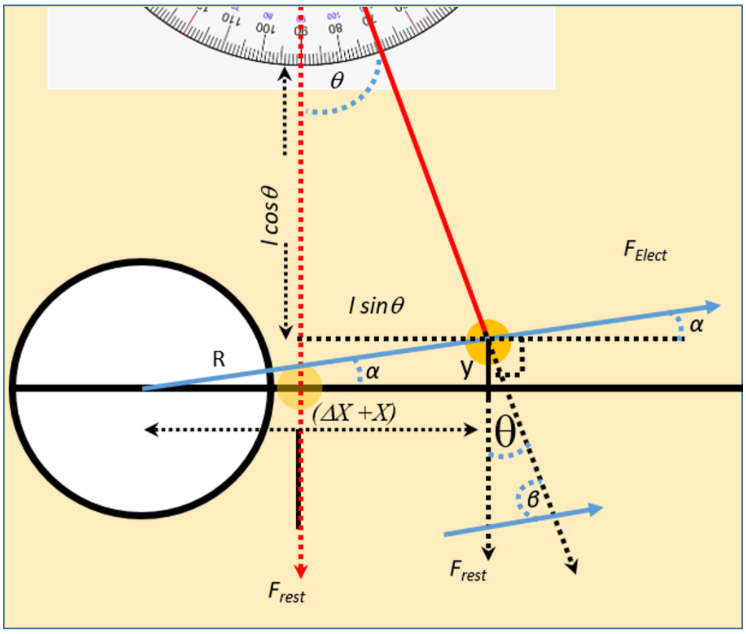


Figure (6), The Geometric Consideration to determine the value of *R* and angle *α when there is repulsion between pith ball and dome.*

The observation Table:

No. of Trail	*X_o (distance from the center of dome to center of pith ball)*	*X (New distance of the pith ball from the dome)*	*$\Delta X = (X_o - X)$*	*θ*	*R^2*	*F_{Elect}*
1						
2						
3						
4						
5						
6						

By using equations (17) and (18), calculate the charge of the aluminium dome by putting the value of q and k (=$\frac{1}{4\pi\varepsilon_0}$).

When there is attractive force between Van de Graff generator dome and pith ball

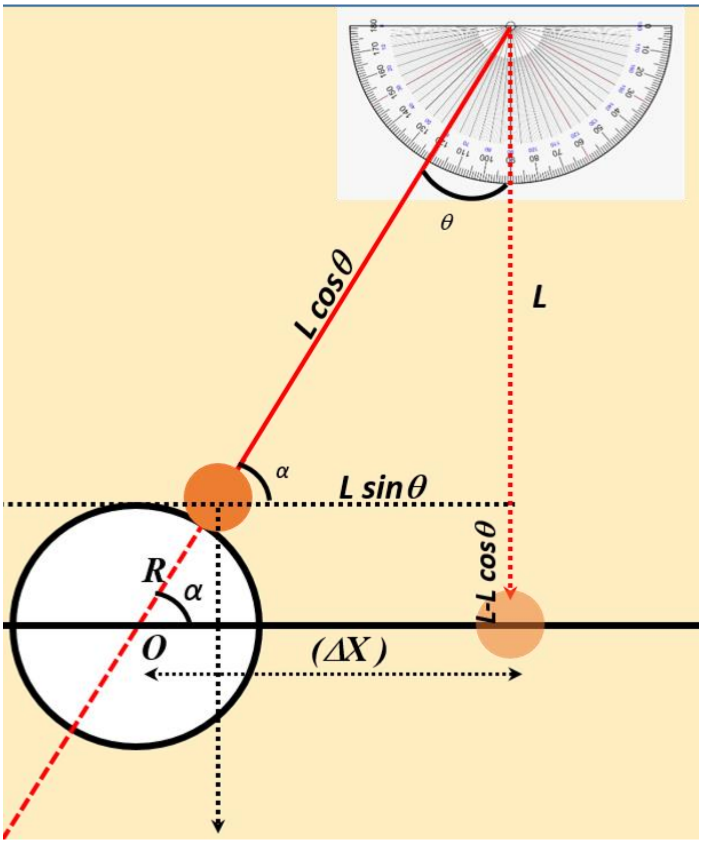


Figure (7), The Geometric Consideration to determine the value of *R* and angle *α when there is attraction between pith ball and dome.*

Calculation of the angle (α) and R between the line joining the two centres and the horizontal, from Figure (7), is

$$R^2 = (\varDelta X - l\sin\theta)^2 + (l - l\cos\theta)^2 \tag{19}$$

$$x = l\ sin\theta \tag{20}$$

$$y = l - l\ cos\theta \tag{21}$$

$$\tan\alpha = \frac{y}{\Delta X - X} = \frac{l - l\cos\theta}{\Delta X - l\sin\theta} \tag{22}$$

$$\alpha = \tan^{-1}\left(\frac{l(1-\cos\theta)}{\Delta X - l\sin\theta)}\right) \tag{23}$$

The observation Table:

No. of Trail	ΔX	θ	R^2	F_{Elect}
1				
2				
3				
4				
5				
6				

Therefore, F_{Elect} will be

$$F_{Elect} = \frac{mg \sin\theta}{\cos(\theta - \alpha)} \tag{24}$$

If we assume that α is very small as compared to θ, F_{Elect} can be written as

$$F_{Elect} = mg \tan\theta \tag{25}$$

The above equation (24) can calculate the force F_{Elect} for each measured value of θ. Finally, compare the observed dependence of F_{Elect} on R with that in Coulomb's Law.

$$F_{Elect} = \frac{qQ}{4\pi\varepsilon_0 R^2} \tag{26}$$

Step 3: Verify the inverse square law

Plot a graph between $\boldsymbol{F_{Elect}}$ and $\boldsymbol{R^2}$ and draw a conclusion based on the observation. Is it an inverse square relationship? How did the first θ value differ when remeasured at the end, and what does this tell you about any experimental error caused by the charge leaking off the pith balls and the generator? Is your B too large or too small? Is this consistent with the charge dissipating to the ground? What are some subtle sources of error that we have not recorded? Might wind from the temperature control be significant? What about your classmates' charges? Are the charge distributions spherically symmetric, or does the presence of the other charge disturb this? Would this improve your agreement if all R's were a little larger? What if the Van de Graff generator tilted on its base while the experiment was in progress? What if the line between the charge centres was not very horizontal? Is the ratio of your calculated charges approximately the same as the ratio of surface areas? Do your data satisfy Coulomb's Law to within reasonable experimental error? Explain the possible sources of any disagreement. How do the values of the charges you measured compare with your expectations? How hard would it be to place a coulomb or two of charge on the dome of the generator?

Precautions :

Charge the pith ball carefully using ebonite rod and read the separation angle.

Conclusions:

What values, errors, and units of charge did you measure? Does your data support, contradict, or say nothing about Coulomb's Law? What is Coulomb's Law? Your reader should be able to understand your conclusions without reading anything else in your lab report.

Error:

Estimate percentage error for your each set of data and think about it.

EXPERIMENT- 7(B)

Experiment: **To draw Equipotential Lines and Field lines for electrodes of different shapes.**

Apparatus: SK044-

Power Supply, Digital Multimeter, Acrylic Trough, Flat electrode, Disc Electrode, flexible plug leads set, cylindrical base, Probe.

Procedure: An equipotential surface is a collection of points in space where each point has the same value of electric potential as every other point. For example, the set of all points which have a potential of 3 volts(say) is an equipotential surface.

Electric field lines are imaginary lines which point in the direction a positive charge will encounter a force in an electric field.

Electric field lines are always perpendicular to the equipotential lines wherever the two cross.

Electric field lines and equipotential lines each behave in a certain way in the vicinity of a source any distribution of charges which give rise to an Electric field and in the vicinity of a conducting surface:

In a shallow tray of water the equipotential surfaces are vertical surfaces in the water which can be represented as lines when viewed from above. Equiptential lines can be mapped for different arrangements of electrodes:

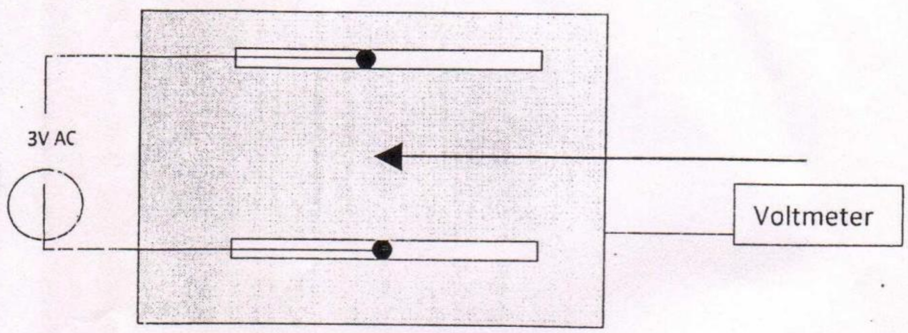
1. Two parallel plate sources with a circular conductor between them
2. Two point sources
3. Two parallel plates/point sources with conducting ring.

Procedure:

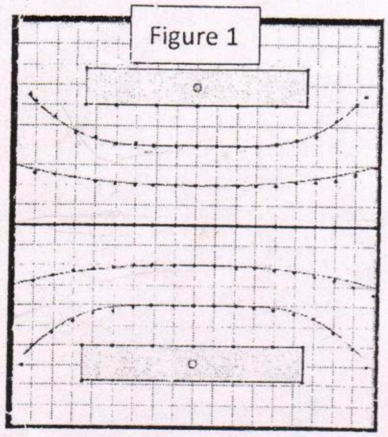
1. Take two graph papers and place the electrodes at a distance of 15 cm on the graph paper and mark their position. Label the two sheets of graph paper identically. On the long side and short side of the paper assign a letter for each row. The two sheets of graph paper should be labeled identically with references to each other.

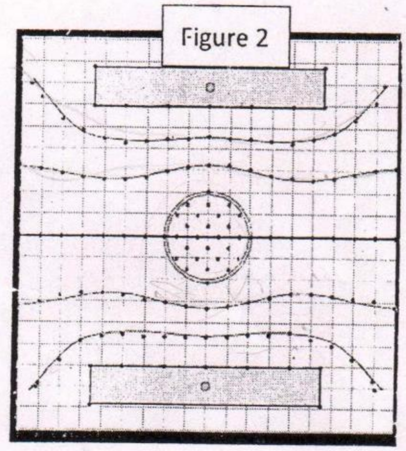
2. Place the clear dish on top of one of the sheets of graph paper and also place the electrodes on the marked position.

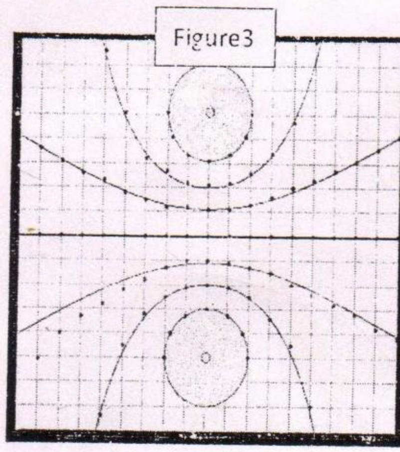
3. Make the connections as shown in figure with the needle as the test probe connected to the multimeter to measure the voltage.



3. Fill the transparent acrylic trough with water such that the electrodes are half dipped in the water.
4. Starting with the points close to the on of the electrode, place the test probe into the water directly over the position above the box of the graph paper and search for the points of equal potential.
5. Read the voltage off of the multimeter and write the value in the corresponding box on another graph paper.
6. Continue this process until the entire graph paper is filled out.
7. Join the points with equal potential on the graph paper to find out that near a source, the equipotential lines are parallel to the surface of the charge distribution, and the electric field lines are perpendicular to the surface of the charge distribution.
8. Similarly, draw the equipotential lines with disc electrode.
9. Place a conducting ring, which will not be connected to any voltage source. Map the equipotential lines and electric field lines in the region containing the two plates and the conducting ring.
10. Draw the equipotential lines for different arrangements of electrodes of your choice.
11. Figure 1, figure 2, figure3 shows the electrode arrangement with parallel electrodes, parallel electrodes with a conductor ring and disc electrodes respectively.





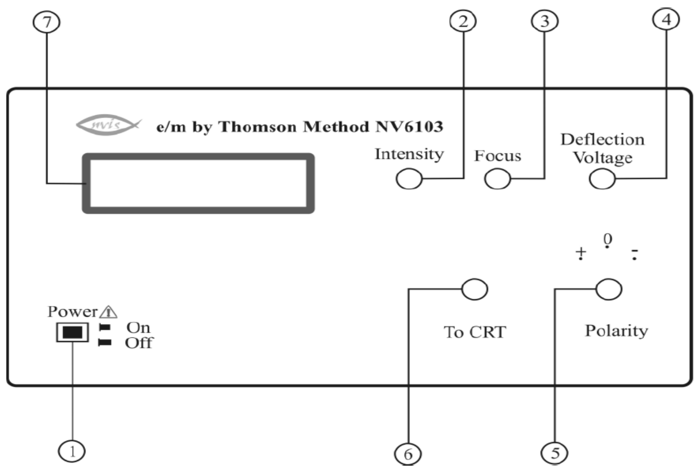


12. Electric field is everywhere at right angles to the equipotential surfaces and the fact that electric fields start on positive charges and end on negative charges can now be used to draw the field lines in the region where equipotentials are traced. On your drawing, place your pencil at a point representing the bar conductor surface and draw a line perpendicular to the bar going toward the nearest equipotential line. As your line approaches the equipotential, be sure that it curves to meet the line at a right angle. Proceed similarly to the next equipotential, and so on until your line ends on the drawing of the round conductor.

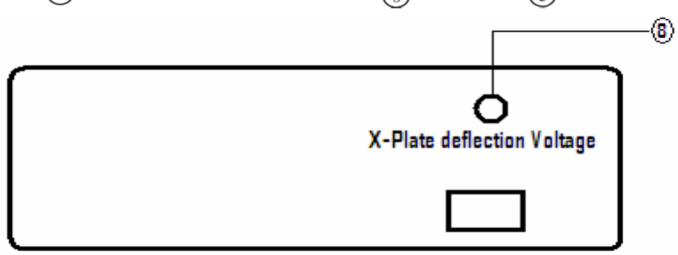
e/m New

Measurement Unit

Front Panel Controls



Rear Panel Control



1. **Power:** It is used to switch on/off the instrument.
2. **Intensity:** It controls the intensity of spot.
3. **Focus:** it controls the sharpness of the spot.
4. **Deflection Voltage:** With the help of it Y – plate deflection voltage can be adjusted.
5. **Polarity:** It is three position rotary switches to select direction of spot deflection. It has three positions, + for upward – for downward and 0 in centre position.
6. **To CRT:** Octal base provided to connect CRT.
7. **Liquid Crystal Display:** To display DC voltage value applied to plates.
8. **X-Plate Deflection Voltage:** With the help of it X- plate deflection voltage can be adjusted.

Precautions: CRT can break handle it with care.

Experiment

Objective: Determining the value of specific charge e/m of an electron by Thomson Method

Items Required

1. Deflection Magnetometer
2. Two Bar Magnets
3. CRT
4. Stand Arrangement

Theory

In this method cathode ray tube is used in which cathode emits electrons, anode accelerate them, passes through a small hole, to another anode which concentrate them into a fine beam. Then passes through between two parallel plates, which can deflect the beam in a vertical plane by an electric field E applied between both the plates. The beam of electron can also be deflected in same plane applying a magnetic field B perpendicular to the plane of plates. This narrowed collimated beam of accelerated electrons than strikes the fluorescent screen to produce a glowing spot. Three terms arise as,

1. If an electric field E applied by a potential difference of V volts between plates the electrons experience a force F in a direction perpendicular to the direction of motion of the beam.

$$F_e = E\,e \qquad \dots 1$$

2. If B be the uniform magnetic field applied in the region P-P in a horizontal direction perpendicular to the direction of electrons beam, the force experienced by electrons is,

$$F_{mag} = B\,e\,v \qquad \dots 2$$

   Where e is the electron charge, v is the velocity of electron and F_{mag} is the magnetic force.

   This force F_{mag} acts perpendicular to the direction of B as well as in the original direction of electron motion (in accordance to Fleming's left thumb rule). The speed of electrons remains unchanged, but its path becomes circular providing the amount of centripetal force.

$$Fmag = B\,ev = \frac{mv^2}{r} \qquad \dots 3$$

   Where m is the mass of an electron and r is the radius of circular path.

$$\text{Thus } \frac{e}{m} = \frac{v}{Br} \qquad \dots 4$$

3. If an electric field E applied to deflect the beam in OO' direction, than a magnetic field B is applied to bring beam back to O. It means that the force of electrostatic field is equal and opposite to applied magnetic field, so $F_e = F_{mag}$, and two forces nulled each other to bring beam back to original position.

Thus $$Ee = B\,e\,v$$ … 5

Or $$v = \frac{E}{B}$$ ….6

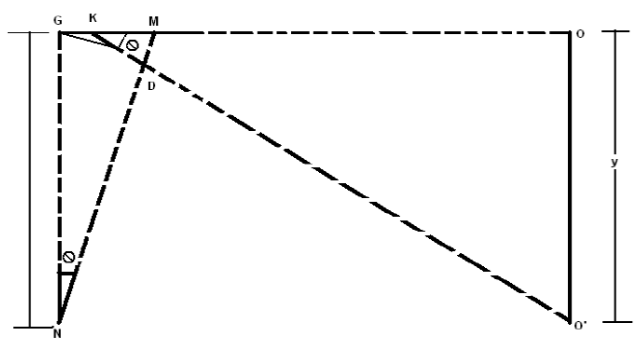
Substituting values of v from 6 into 4

$$e/m = E/B^2 r \qquad ….7$$

Radius 'r':

According to the figure below, the original electron beam is preceding straight path G, M, O and impressed upon screen at a point O. In the presence of magnetic field, the beam travels along a circular arc G, D whose radius is r. beyond point D, the beam leave magnetic field and proceeds straight in direction along with the tangent K, DO' (drawn on the circular arc at point D). Drawing GN normal to GKO and MDN normal to KDO'. Let these normal meet at point N. Then GN = ND = r = the radius of circular arc. Let GND = OK 0' = θ

Then in angle KOO'…… $\tan\theta = \frac{00'}{K0}$ and the angle θ is small enough,



$$\theta = \tan\theta = \frac{y}{L}$$

Where L is distance of the screen from mid point of magnetic field region (generally mid point of electric field too).

$$\text{Again } \theta = \tan\theta = \frac{\text{arc GD}}{r} = \frac{GM}{r} \text{ since GD is nearly equal to GM.}$$

$$\text{Or } \theta = \frac{l}{r}$$

Where l is the length of the region of magnetic field equals to electric field too. By comparing both values of θ.

$$\frac{l}{r} = \frac{y}{L}, \text{ so } r = \frac{lL}{y} \qquad … 8$$

Substituting values of r into …7,

$$\frac{e}{m} = \frac{Ey}{B^2 l\,L} \qquad …9$$

If a potential difference of V volts is applied between the plates P-P, and d is the gap between both plates than, the electric field is given by, E = V / d

Therefore,
$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$
… 10

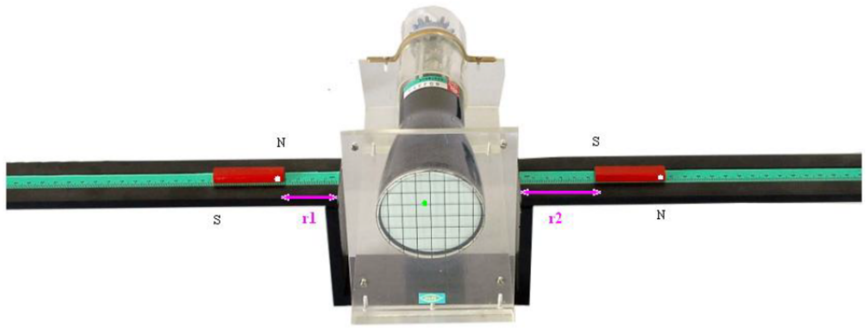
Where y = distance between spot positions displayed on the screen of CRT in centimeters.

l is the length of the deflection plates. L is the distance between screen and plates, d is the distance between plates, V is applied DC voltages across plates and B is magnetic field strength determined by B = H tan θ where H is the Horizontal component of earth's magnetic field at that place.

Procedure:

Note: While performing experiments keep other electronics equipment away from the e/m setup.

1. Using compass needle, find and note **North-South** and **East-West** directions. Place CRT in between stand in such a way that the marked area of CRT should be parallel to its screen is faced towards North and both arms of stand to East – West direction.
2. Adjust the **Intensity** and **Focus** potentiometer in its mid position.
3. Connect the CRT to octal socket of instrument (socket provided upon the panel). Care should be taken while inserting CRT plug.
4. Keep instrument to south direction far from CRT.
5. Select **Polarity** selector switch at '**0**' position.
6. Set the Deflection Voltage potentiometer at anti clockwise direction.
7. Switch on the Power Supply and wait for some times (3-5 minutes) to warm up the CRT. A bright spot appears on the screen.
8. Adjust intensity and focus controls to obtain sharp spot.
9. Bring the spot at the middle position of the CRT by the help of X-plate deflection voltage pot given to back side of the instrument.
10. Set polarity selector to '+' position, adjust **Deflection Voltage** to deflect the spot 1cm away towards upward. Note the deflection voltage from the meter as **V1** and spot deflection as **y**.
11. Now place the bar magnets (on the stand arm) to both sides of CRT such that their opposite pole faces each other.



Adjust position of magnets to get spot back downward to original position.

12. Note the distances of bar magnet (poles facing the screen) as $\mathbf{r_1}$ and $\mathbf{r_2}$ from the scale.
13. Now remove magnets from the arms of stand.
14. Select '–' **position** from polarity switch. Apply DC voltage to deflect the spot 1 cm away in downward direction. Note deflection voltage from display as **V2** and deflection as y.
15. Place bar magnets again and adjust the position of magnets to bring spot back to original position. Note the distance of the magnets (poles facing the screen) as $\mathbf{r_1'}$ and $\mathbf{r_2'}$.
16. Remove CRT and magnets. Place Magnetometer arrangement in between stand such that its centre lies on the center of the stand arm.

    Note: Position of stand should not be disturbed.
17. Rotate Magnetometer and adjust the needle to read 0º - 0º.
18. Now place magnets at a distance equal to $\mathbf{r_1}$ & $\mathbf{r_2}$ as previous polarity adjusted. The pointer deflects along the scale. Note the deflections as $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$.
19. Repeat similar procedure placing magnets at $\mathbf{r_1'}$ and $\mathbf{r_2'}$ distances. Note the deflection of compass needle as $\boldsymbol{\theta_3}$ and $\boldsymbol{\theta_4}$.
20. Now we know that magnetic field

$$B = H \tan \theta$$

Where

$$\theta = \frac{\theta 1 + \theta 2 + \theta 3 + \theta 4}{4}$$

$$H = \sim 0.37 \times 10^{-4} \text{ Tesla}$$

21. Calculate e / m using following formula

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Where

- $H = \sim 0.37 \times 10^{-4}$ Tesla
- Distance between plates, $d = 2.85$ cm $= 2.85 \times 10^{-2}$ m
- Length of plates, $l = 3.15$ cm $= 3.15 \times 10^{-2}$ m
- Distance between screen and plates, $L = 12$ cm $= 12 \times 10^{-2}$ m

- V = deflection voltage **(V1+V2)/2**
- Deflection of spot, y = 1cm = $1x10^{-2}$ m
  Deflection Voltage Deflection in cm **y** = 1cm

22. Take more readings by repeating experiment and deflecting spot to other distances.
23. Calculate the % error as

$$= \frac{\text{Standard value} - \text{calculated value}}{\text{Standard value}} \times 100$$

Precautions and sources of error:

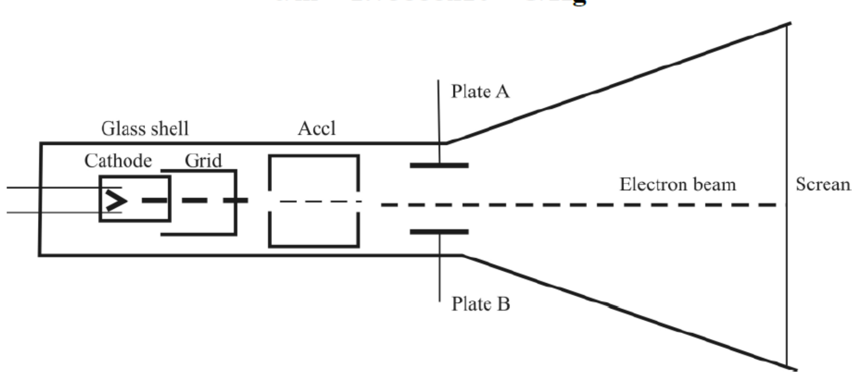
- The cathode ray tube should be handled carefully. There should not be any magnetic substance nearby the place of experiment.
- Axis of magnets and axis of tube should lie perpendicular to each other in same horizontal plane. To correct it loose the neck clamp of CRT and rotate CRT so the spot deflects right up/down with deflection voltage.
- When magnets are place upon the arms. It is better to move stand slightly back & forth to obtain maximum magnetic field at deflecting plates. It should be done before bringing spot back to original position.
- Rotate magnet (s) on there axis if spot does not come back to its original position.
- When direction of spot is reversed the direction of magnets should also be reversed.
  The magnets should move tight to the scale in closest possible distances.
- The electric field between plates cannot be uniform due to shorter distance between them.
- The given constants are generally taken from data; there may be slight variations to produce error.

Specification of given CRT:

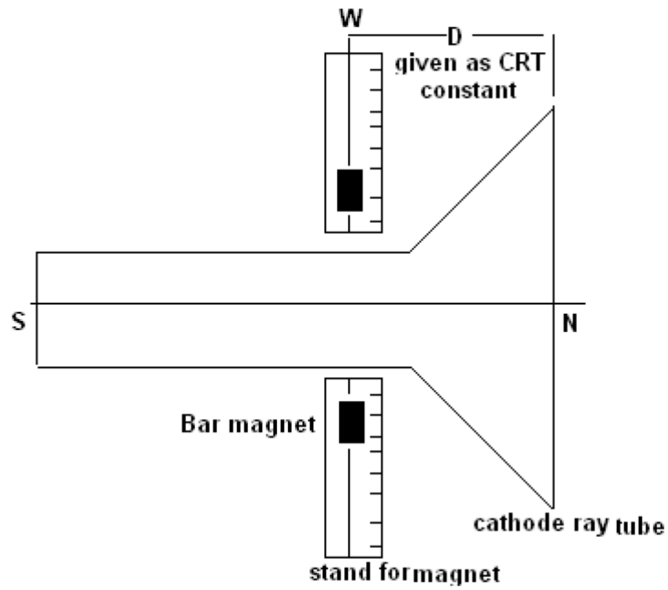
- Distance between plates, : d = 2.85 cm
- Length of plates : l = 3.15 cm
- Distance between screen and plates (edge) : L = 12 cm

Standard Value of e/m:

$e/m = 1.75888x10^{11}$ C/Kg



Cathode ray tube used in Thomson method



Way to place cathode ray tube

Sample Reading

Experiment

Objective : Determining the value of specific charge e/m of an electron by Thomson Method.

Formula Used :

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Standard values :

- $H = \sim 0.37 \times 10^{-4}$ Tesla
- Distance between plates, $d = 2.85$ cm $= 2.85 \times 10^{-2}$ m
- Length of plates, $l = 3.15$ cm $= 3.15 \times 10^{-2}$ m
- Distance between screen and plates, $L = 12$ cm $= 12 \times 10^{-2}$ m
- V = deflection voltage
- Deflection of spot, $y = 1$cm $= 1 \times 10^{-2}$ m

Calculated value :
V = 15.2 Volt
$\theta 1 = 76^0$
$\theta 2 = 73^0$
$\theta 3 = 60^0$
$\theta 4 = 60^0$

Formula used for calculation :-

Formula for calculation Value of magnetic field

$$B = H \tan \theta$$

$$\theta = \frac{\theta 1 + \theta 2 + \theta 3 + \theta 4}{4}$$

Putting the values of θ in above formula,

we have

$$\theta = \frac{76+73+60+60}{4}$$

It gives, $\theta = 67.25^0$

Now putting value of θ for calculating B

$B = 0.37 \times 10^{-4} \times \tan(67.25^0)$

$= 0.37 \times 2.38 \times 10^{-4}$

$= 0.880 \times 10^{-4}$ Tesla

Formula for calculating e/m ratio

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Substituting all the above values to determine the e/m ratio

$$\frac{e}{m} = \frac{15.2 \times 1 \times 10^{-2}}{(0.880 \times 10^{-4})^2 \times 3.15 \times 10^{-2} \times 12 \times 10^{-2} \times 2.85 \times 10^{-2}}$$

On solving the above equation we have

e/m = 1.82×10^{11} C/Kg

Standard value of **e/m =** 1.75×10^{11} C/Kg

Calculation of Percentage Error

$$\frac{(\text{Standard value} - \text{calculated value}) \times 100}{\text{Standard value}}$$

$$\%\ \text{Error} = \frac{1.75 - 1.82}{1.75} \times 100$$

% Error = 4 %

Experiment-9
Diffraction of light by grating .

OBJECTIVE:

To determine the different wavelengths present in the light emitted by a mercury vapour lamp.

APPARATUS:

Mercury vapour lamp, grating, spectrometer, spirit level, magnifying glass, etc.

THEORY:

A grating is a plane sheet of transparent material like glass with a large number of opaque rulings, about 600 rulings / mm made on it. The transparent spaces between the opaque rulings act as slits. Thus it behaves like a grating consisting of many slits. The light transmitted through it produces the diffraction pattern in the field of view.

Formula:

During normal incidence, the wavelength of light $\lambda = \frac{\sin\theta}{Nn}$ **m**

Symbol	**Description**	**Unit**
θ	Angle of diffraction	Degrees
N	No. of rulings per metre made on the grating	lines/m
N	Order of diffraction	-
λ	Wavelength of light	m

EXPERIMENTALPROCEDURE:

Adjust the spectrometer such that its slit is narrow and cross wires are clearly seen. Further using a spirit level, first the vernier table and then the prism table are adjusted to be perfectly horizontal and plane. The telescope is first adjusted for distant object view. It is then brought in line with the collimator and the slit of the collimator is directed towards the mercury vapour lamp. The fixed edge of the image of the slit is made to coincide with the vertical cross wire of the telescope.

Part I : Adjustment of the spectrometer for normal incidence

The spectrometer is adjusted such that its initial readings on the vernier scale A and B are 0° and 180° respectively. Now the telescope is turned through 90° exactly and fixed. The grating is mounted vertically on the prism table which is rotated gently so that the reflected image of the slit coincides with the vertical crosswire of the telescope. It is fixed in that position. Now the grating is at 45° angle of inclination to the incident rays as shown in Fig.1(a). The prism table with the vernier is now turned through another 45° so that the grating in the vertical plane is perpendicular to the line of the collimator. The grating is now said to be adjusted for normal incidence (Fig.1(b)). The prism table is fixed in this position.

The telescope is now released and turned to the direct position and then moved to the right little by little. At a particular position, the first order spectrum Violet I to Red II is seen,. The telescope must be moved on both the sides to see the prominent colours available before taking the readings. The telescope is first fixed such that the extreme first order (Red II) coincides with the cross wire. The readings of both the verniers are noted. Slowly the telescope is moved so that it moves towards the direct reading. As it moves, the prominent colours are made to coincide with the cross wire and readings are noted in each case. After Violet I on the right hand side, as the telescope is moved further, the direct ray can be viewed. The telescope is moved further (Now away from the direct reading) so that the cross wire coincides with Violet I on the left. Again all prominent colours are made to coincide with the cross wire upto Red II. Note that the readings are taken by moving the telescope only in one direction either from right to left or left to right to avoid confusion.

From the above readings, the angle of diffraction for different colours are calculated. Then using the formula, the wavelength of different colours present in the mercury vapour lamp are calculated assuming the value of N.

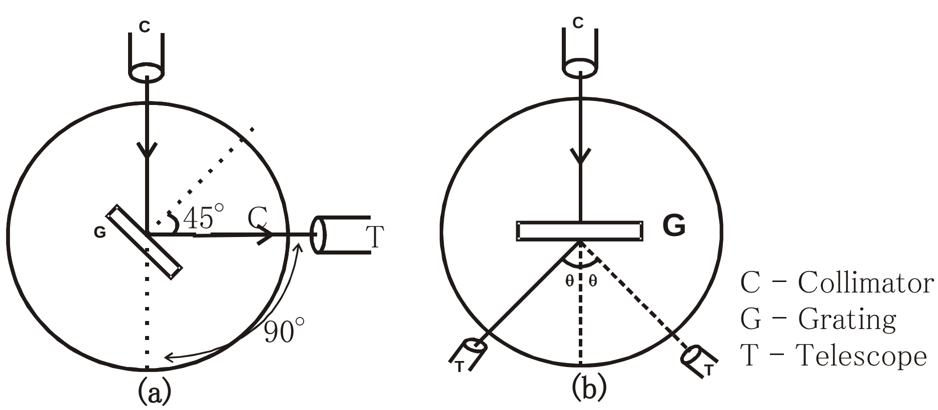
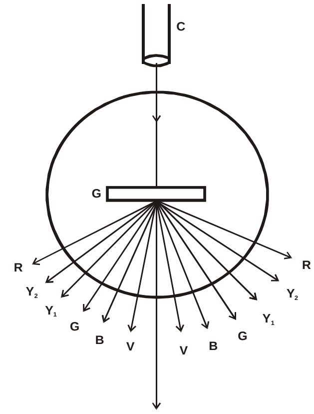


Fig. 1(a) : Adjustment of the grating for normal incidence
(b) : Measurement of angle of diffraction



(c) : Order in which the 1st order spectrum of mercury occurs

PRECAUTIONS

1. The telescope should be adjusted for distant object properly and not altered thereafter.

2. The vernier and the prism tables should be horizontal.

3. The grating should be handled with care and mounted properly using a grating stand.

4. The slit width in the collimator should be made as narrow as possible so that the readings are accurate.

Least count of spectrometer

10 divisions on Main scale = ______________________________

$\therefore$ Value of 1 M.S.D. = ______________________________

= ______________________________

Total number of divisions on the vernier scale = ______________________________

$$\therefore \text{Least Count (L.C.)} = \frac{\text{Value of 1 M.S.D.}}{\textbf{Total number of Vernier Scale divisions}}$$

$\therefore$ L.C. = ______________________________

To find λ

L.C. = ___________ : Number of lines/m in the grating, N = ________________; Order of diffraction, n = _________________

Name of the Colour	Diffracted ray reading				Angle between the diffracted rays (2θ)		Angle of diffraction $\theta = \frac{(x+y)}{4}$	Wavelength of the colour $\lambda = \frac{\sin\theta}{Nn}$
	Left		**Right**					
	V_A (° & ′)	V_B (° & ′)	V'_A (° & ′)	V'_B (° & ′)	$X = V_A \sim V'_A$ (° & ′)	$Y = V_B \sim V'_B$ (° & ′)	(° & ′)	$\times 10^{-10}$ m
Red II								
Red I								
Orange								
Yellow II								
Yellow I								
Green								
Bluish Green								
Blue								
Violet								

Calculation:-

To find wavelength of different colours:

1) Red II → $\lambda = \frac{Sin\theta}{Nn} =$

2) Red I → $\lambda = \frac{Sin\theta}{Nn} =$

3) Orange → $\lambda = \frac{Sin\theta}{Nn} =$

4) Yellow II → $\lambda = \frac{Sin\theta}{Nn} =$

5) Yellow I → $\lambda = \frac{Sin\theta}{Nn} =$

6) Green → $\lambda = \frac{Sin\theta}{Nn} =$

7) Bluish Green → $\lambda = \frac{Sin\theta}{Nn} =$

8) Blue → $\lambda = \frac{Sin\theta}{Nn} =$

9) Violet → $\lambda = \frac{Sin\theta}{Nn} =$

<u>RESULT :</u>

The value of different wavelengths present in the light from the mercury vapour lamp are determined and tabulated.

Sl. No.	Colour	Wavelength x10^{-10} m
1.	**Red II**	
2.	**Red I**	
3.	**Orange**	
4.	**Yellow II**	
5.	**Yellow I**	
6.	**Green**	
7.	**Bluish Green**	
8.	**Blue**	
9.	**Violet**	

Experiment-10

Diffraction of light using ultrasonic wave as a grating

OBJECT:

Determination of compressibility of a given liquid by ultrasonic diffraction grating method.

APPARATUS:

RF Oscillator, Piezo electric crystal, spectrometer, glass cell, light source (sodium lamp) etc.

THEORY:

Diffraction Phenomenon similar to those with ordinary ruled grating is observed when ultrasonic waves traverse through a liquid.

The Ultrasonic wave passing through a liquid is an elastic wave in which compressions and rarefactions travel one behind the other spaced regularly apart. The successive separations between two compressions or rarefaction is equal to the wave length of ultrasonic wave, λu- in the liquid. Due to reflections at the sides of the tank or the container, a stationary wave pattern is obtained with nodes and antinodes at regular intervals. We are thus dealing with a liquid with density changing periodically and hence having a periodically changing index of refractions which produces diffraction of light according to the grating rule.

If λu denoes the wavelength of sound in the liquid, A the wavelength of incident light in air and On is angle of diffraction of nth the order, then we have:

$$(a+b) \sin \theta n = n\lambda$$

where $(a+b)$ is equal to λu, thus-

$$\lambda u \sin \theta n = n\lambda \qquad (1)$$

If v is the frequency of the crystal, the velocity, C of Ultrasonic wave in the liquid is given by-

$$C = v\lambda u \qquad (2)$$

Thus by measuring the angle of diffraction θn, the order of diffraction n, the wavelength of light,

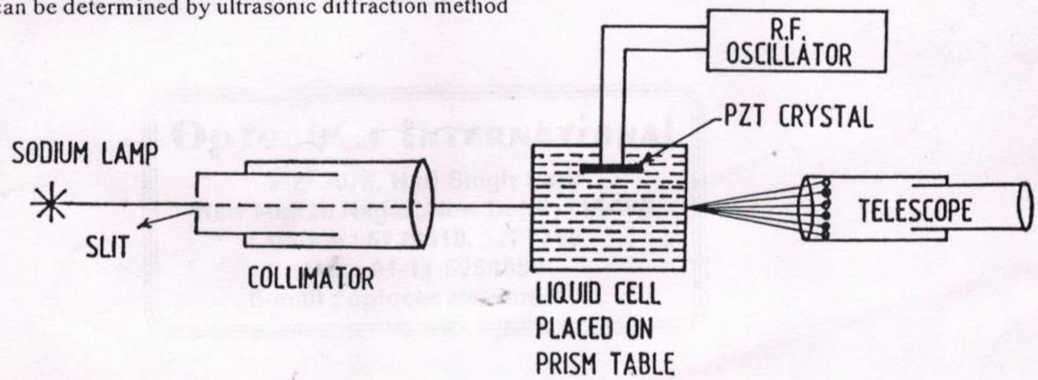
the wavelength of Ultrasonic wave in the liquid can be determined by using equation 1 and then knowing the frequency of sound wave, its velocity C can be obtained from equation 2.
It is known that the velocity of sound wave in a liquid is related to its bulk elasticity E by the relation

$$C = \sqrt{E/p}$$

where p is its density, Hence by knowing C, its elasticity E can be calculated. The reciprocal of this bulk elasticity, E is known as the compressibility of the liquid, K i.e.

$$K = \frac{1}{E}$$

Thus K can be determined by ultrasonic diffraction method



PROCEDURE:

2.Mount the glass cell on the prism iable and fill it by the given liquid upto its 3/4 height.

3. Turn the prism table till the front & back faces of the cell are exactly normal to the incident light.
4. Immerse the piezo electric crystal in the liquid and rotate it till situation is such that the ultrasonic waves generated by it travel in direction perpendicular to the direction of light.
5. Switch on the R.F. Oscillator and adjust its frequency to match with the natural frequency of the crystal. At this instant, diffraction pattern will be observed in the spectrometer telescope. Usually five lines including the slit are seen in the telescope.
6. 1.Adjust the spectrometer as usual to produce a collimate
7. Measure the angle 20, between the first order spectrum lines, similarly measure 20_3, 20_3 etc.

7.Note down the frequency υ of R.F. Oscillator from its frequency meter. This is also the frequency of vibration of piezo electric crystal.

OBSERVATIONS

Wavelength of light ……..

Frequency of vibrating crystal…….

Density of liquid…………

		Left of centre	Left of centre	Right of centre	Right of centre					
S.N	Order of diffraction	Vernier a	Vernier a'	Vernier b	Vernier b'	a-a'	b-b'	Mean 2θ	θ	$\lambda_u = \frac{n\lambda}{Sin\theta}$
1 2 3 4 5	2 1 0 1 2									

Mean λ_u=……

C=……

RESULT……

Newton's second law: Atwood's machine

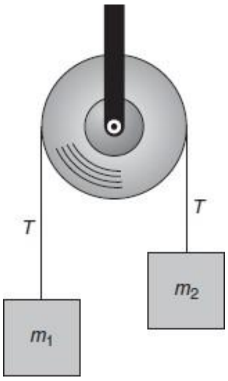
OBJECTIVE: To verify Newton's second law to show that the acceleration is proportional to the applied force.

EQUIPMENT NEEDED:

Atwood's machine, different masses, required mass holders, Laboratory timer and meter stick.

THEORY:

The system shown in the figure is called an Atwood's machine. It consists of two masses at the ends of a string passing over a pulley. For $m_2 > m_1$, applying Newton's law to each



mass gives,

$T - m_1 g = m_1 a$ and $m_2 g - T = m_2 a$

where, T is the tension in the string and a is the magnitude of the acceleration of either masses.
Combining these two equations,

$$(m_2 - m_1)g = a\,(m_2 + m_1)$$

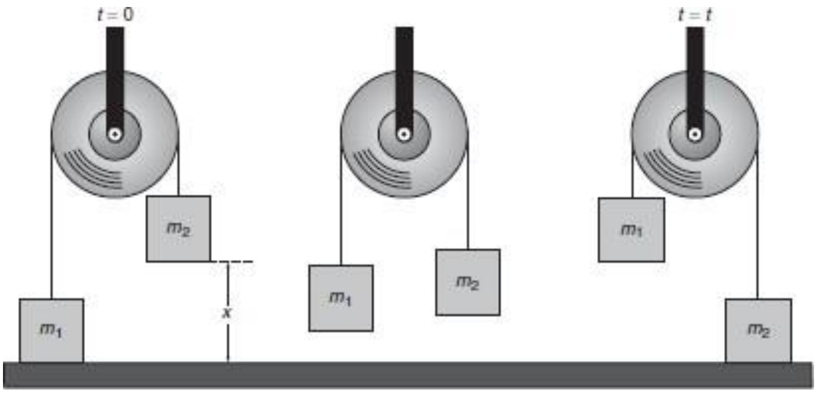
This equation states that the force $(m_2 - m_1)g$ acts on the sum of the masses $(m_2 + m_1)$ to produce an acceleration a of the system. This is true if we consider the frictional force is zero.

An Atwood's machine is shown in figure below where $m_2 > m_1$, the mass m_1 is initially on the floor, and m_2 is released from rest at distance x above the floor at t= 0. Successive positions of the two masses are shown in the figure at later times until the final picture shows m_2 as it strikes the floor at some time t after its release. The relationship between the distance x, the acceleration a of the system, and the time t is,

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

which, provides the acceleration as,

$$a = \frac{2x}{t^2}$$



EXPERIMENTAL PROCEDURE:

(a) Place mass m_2 = 250gm and mass m_1 = 240 gm. Hold mass m_1 on the floor and measure the distance *x* from the bottom of mass m_2 to the floor as shown as shown in the figure. The height of the pulley above the floor should be chosen as high as feasible. Record this distance. Use this same distance for all repeated measurements.

(b) Release mass m_1 and simultaneously start the timer. Stop the timer when mass m_2 strikes the floor. Repeat this measurement four more times for a total of five trials.

(c) Take 5gm of mass from m_1 (now effective m_1 = 235gm) and add it to m_2 (now, effective m_2 = 255). Repeat (a) & (b). Similarly, make three more trials (total of five trials) and find average time for each trial.

Data table

Distance (*x*) of mass m_2 = ________________ cm

Mass (m_2) (gm)	Mass (m_1) (gm)	Time (sec)	Average time (*t*) (sec)
250	240		
255	235		
260	230		
265	225		

260	220		

Calculations

a) Using the average time, calculate the standard error for the five measurements of time at each of the mass (m_1).

(d) Calculate the acceleration *a* from *x* and *t* for each value of applied force. Record these values of *a* in the table below.

Applied force: $(m_2 - m_1)g$	Calculated acceleration (a) (cm/sec^2)

(e) Perform a linear least squares fit with the applied force $(m_2 - m_1)g$ as the vertical axis and the acceleration *a* as the horizontal axis. What is the value of the slope of the fit? How do your results support Newton's second law of motion?

(d) Does the fitted line pass through the origin? If not, why?
(*Hints*: There will be a frictional force *f* in the system that opposes the applied force $(m_2 - m_1)g$. Including the frictional force the equation becomes,
$$(m_2 - m_1)g = (m_2 + m_1)a + f$$
The intercept of the fit should provide us *f*.)

III. APPENDIX:

Appendix 1.

The Vernier Caliper:

A vernier is a device that extends the sensitivity of a scale. It consists of a parallel scale whose divisions are less than that of the main scale by a small fraction, typically 1/10 of a division. Each vernier division is then 9/10 of the divisions on the main scale. The lower scale in Figure A1.1 is the vernier scale, the upper one, extending to 120 mm is the main scale.

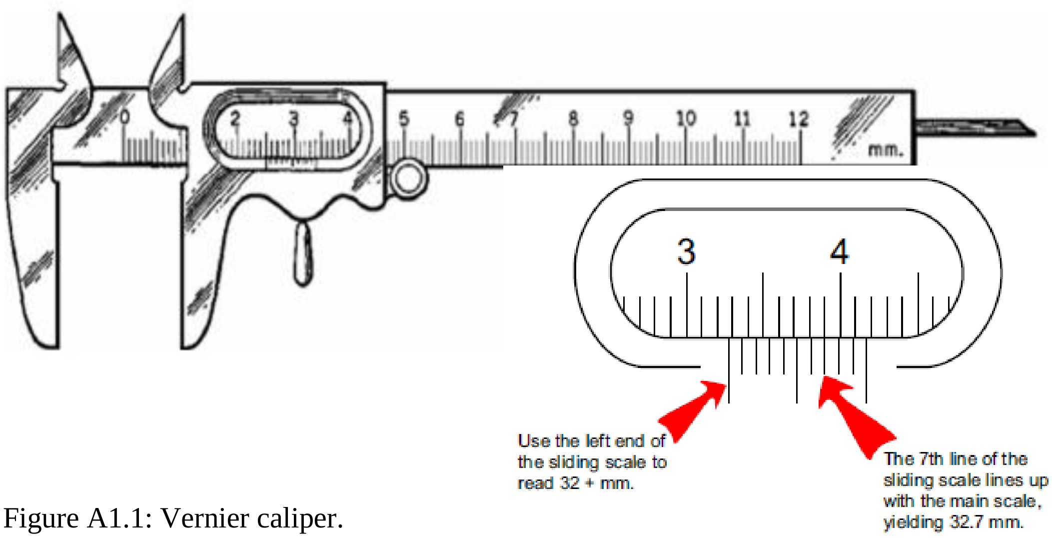


Figure A1.1: Vernier caliper.

The left edge of the vernier is called the index, or pointer. The position of the index is what is to be read. When the index is beyond a line on the main scale by 1/10 then the first vernier line after the index will line up with the next main scale line. If the index is beyond by 2/10 then the second vernier line will line up with the second main scale line, and so forth.

If you line up the index with the zero position on the main scale you will see that the ten divisions on the vernier span only nine divisions on the main scale. (It is always a good idea to check that the vernier index lines up with zero when the caliper is completely closed. Otherwise this zero reading might have to be subtracted from all measurements.)

Note how the vernier lines on either side of the matching line are inside those of the main scale. This pattern can help you locate the matching line. The sensitivity of the vernier caliper is then 1/10 that of the main scale. Keep in mind that the variability of the object being measured may be much larger than this. Also be aware that too much pressure on the caliper slide may distort the object being measured.

<u>Appendix 2.</u>

<u>The Micrometer Caliper:</u>

Also called a screw micrometer, this measuring device consists of a screw of pitch 0.5 mm and two scales, as shown in Figure A1.2 A linear scale along the barrel is divided into half millimeters, and the other is along the curved edge of the thimble, with 50 divisions.

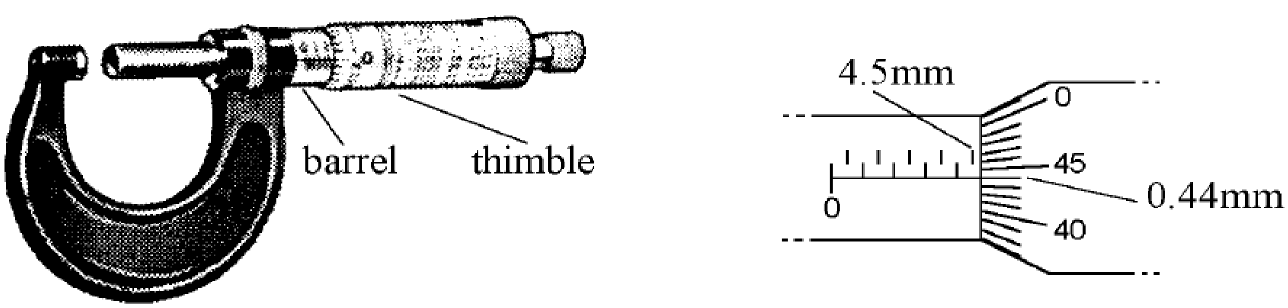


Figure A2.1: Micrometer caliper.

The pointer for the linear scale is the edge of the thimble, while that for the curved scale is the solid line on the linear scale. The reading is the sum of the two parts in mm. The divisions on the linear scale are equal to the pitch, 0.5 mm. Since this corresponds to one revolution of the thimble, with its 50 divisions, then each division on the thimble corresponds to a linear shift of (0.50 mm)/50 = 0.01 mm .

In Figure A2.1, the value on the linear scale can be read as 4.5 mm, and the thimble reading is 44X0.01=0.44mm. The reading of the micrometer is then (4.5+0.44=4.94 mm).

Since a screw of this pitch can exert a considerable force on an object between the spindle and anvil, we use a ratchet at the end of the spindle to limit the force applied and thereby, the distortion of the object being measured. The micrometer zero reading should be checked by using the ratchet to close the spindle directly on the anvil. If it is not zero, then this value will have to be subtracted from all the readings.

Appendix 3.

Angle Scale Vernier:

This type of vernier appears on spectrometers, where a precise measure of angle is required. Angles arc measured in degrees (°) and minutes ('), where 1 degree = 60 minutes. Figure A3.1 shows an enlarged view of a typical spectrometer vernier, against a main scale which is divided in 0.5° = 30'.

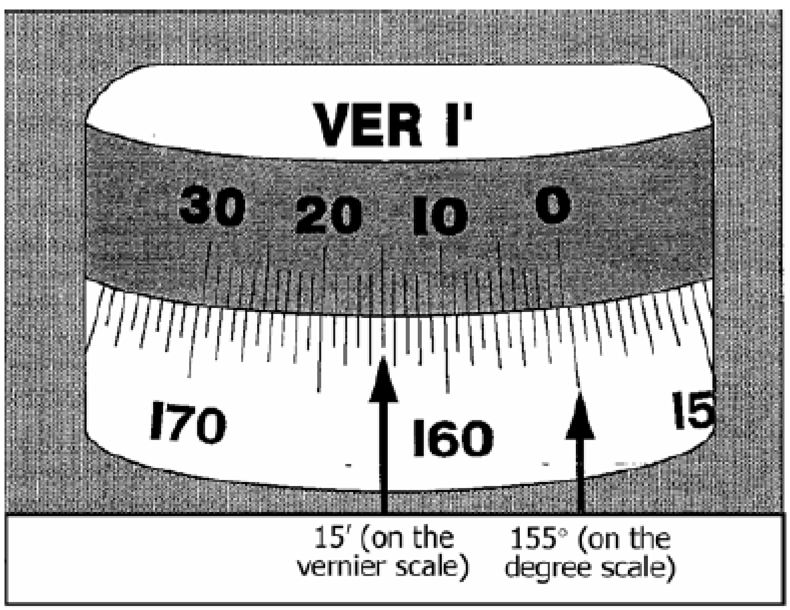


Figure A3.1: Angle scale vernier.

The Vernier has 30 divisions, so that the sensitivity of the vernier is one minute. (There are also two extra divisions, one before 0 and the other after 30, to assist in checking for those values.) Each division on the vernier is by 1/30 smaller than the division of the main scale. When the index is beyond a main scale line by 1/30 of a division or 1', line 1 on the vernier is lined up with the next main scale line. When that difference is 2/30 or 2', line 2 on the vernier lines up with the next line on the main scale, and so on.

Figure A3.1 shows an example where degree and Vernier scale run from right to left. Again, reading the angle is a two step process. First we note the position of the index (zero line on the Vernier) on the main scale. In the figure it is just beyond 155.0^{o}. To read the vernier, we note that line 15 seems to be the best match between a vernier line and a main scale line. The reading is then $155.0^{o}+15'=155.25^{o}$.

The example shows one problem working with angles, the common necessity of converting between decimal fraction and degree-minute-second (DMS) notation. We illustrate another place where this arise with the problem of determining the angle between the direction of light entering the spectrometer, and the telescope used to observe light of a particular wavelength.

Example: The position of the telescope to observe the zeroth diffraction order is $121^{o}55'$. Light of a certain wavelength is observed at $138^{o}48'$. The steps in the subtraction are illustrated below, using DMS and decimal notation, respectively.

$$
\begin{array}{rcrcr}
 & \qquad & \text{DMS} & \qquad & \text{decimal} \\
138^\circ\,48' & & 137^\circ\,108' & & 138.80^\circ \\
-\ 121^\circ\,55' & & -\ 121^\circ\quad 55' & & -\ 121.92^\circ \\
\hline
????? & & 16^\circ\quad 53' & & 16.88^\circ
\end{array}
$$

Reference: Introductory Physics Laboratory Manual, The city college, The city University, New York.