PHYSICS LAB MANUAL

Sem : 1

Cource code : PH101

Contents

1. Measurements of Length and Area using Scales attached with Vernier (Vernier Caliper & Screw Gauge).

2. Analyzing virtually frictionless motion using linear air-track.

Perform Elastic and Inelastic collisions between two different masses on linear air track and verify conservation of momentum and energy.

3. Study of photoelectric effect and determination of Planck's constant and Plot I-V graph for different intensity.

4. Analyzing damped oscillation using the spring-mass system in a different medium. Determination of damping constant by varying mass of the spring-mass system.

5. Study of the centripetal acceleration

6. Determination of Rydberg's constant analyzing the Balmer series of hydrogen spectra.

7. Determination of specific heat of the given solid.

Errors:
What they are, and how to deal with them

A series of three lectures plus exercises, by Alan Usher
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Synopsis

1) Introduction

2) Rules for quoting errors

3) Combining errors

4) Statistical analysis of random errors

5) Use of graphs in experimental physics

Text book: this lecture series is self-contained, but enthusiasts might like to look at "An Introduction to Error Analysis" by John R Taylor (Oxford University Press, 1982) ISBN 0-935702-10-5, a copy of which is in the laboratory.

1) Introduction

What is an error?

All measurements in science have an uncertainty (or “error”) associated with them:

- Errors come from the limitations of measuring equipment, or
- in extreme cases, intrinsic uncertainties built in to quantum mechanics
- Errors can be minimised, by choosing an appropriate method of measurement, but they cannot be eliminated.

Notice that errors are not “mistakes” or “blunders”.

Two distinct types:

Random:

These are errors which cause a measurement to be as often larger than the true value, as it is smaller. Taking the average of several measurements of the same quantity reduces this type of error (as we shall see later).

Example: the reading error in measuring a length with a metre rule.

Systematic:

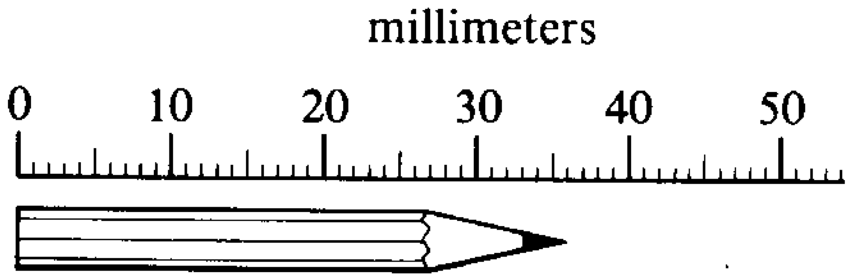
Systematic errors cause the measurement always to differ from the truth in the same way (i.e. the measurement is always larger, or always smaller, than the truth).

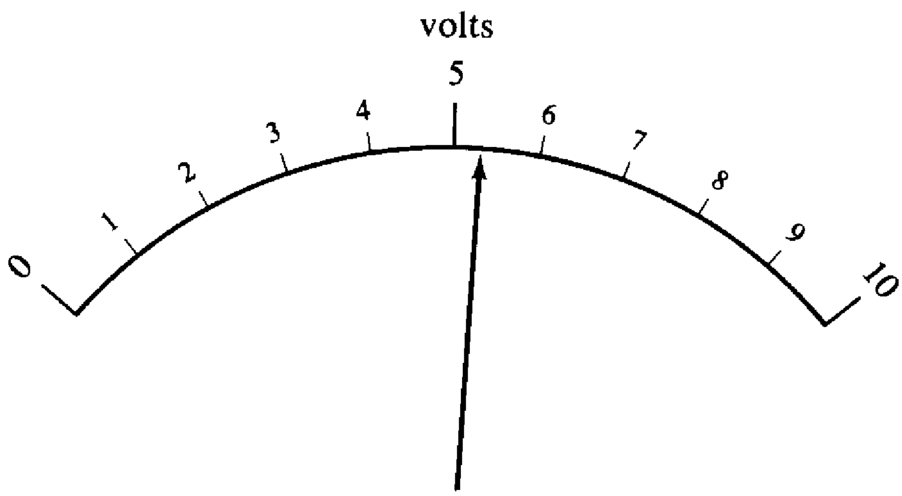
Example: the error caused by using a poorly calibrated instrument.

It is random errors that we will discuss most.

Estimating errors

e.g. measurements involving marked scales:





The process of estimating positions between markings is called “interpolation”

Repeatable measurements

There is a sure-fire way of estimating errors when a measurement can be repeated several times. e.g. measuring the period of a pendulum, with a stopwatch.

Example:

Four measurements are taken of the period of a pendulum. They are:

2.3 sec, 2.4 sec, 2.5 sec, 2.4 sec

In this case:

best estimate = average	=	2.4 sec
probable range		2.3 to 2.5 volts

We will come back to the statistics of repeated measurements later.

2) Rules for quoting errors

The result of a measurement of the quantity x should be quoted as:

$$\text{(measured value of } x) = x_{best} \pm \delta x$$

where x_{best} is the best estimate of x, and the probable range is from $x_{best} - \delta x$ to $x_{best} + \delta x$.

We will be more specific about what is meant by “probable range” later.

Significant figures

Here are two examples of BAD PRACTICE:

(measured g) = $9.82 \pm 0.02385 \ ms^{-2}$

measured speed = $6051.78 \pm 30 \ ms^{-1}$

The rules

- Experimental uncertainties should normally be rounded to one significant figure.
- The last significant figure of the answer should usually be of the same order of magnitude (in the same decimal position) as the uncertainty.

For example the answer 92.81 with error of 0.3 should be stated:

$$92.8 \pm 0.3$$

If the error were 3, then the same answer should be stated as:

$$93 \pm 3$$

If the error were 30 then it should be stated as:

$$90 \pm 30$$

One exception: if the leading digit of the error is small (i.e. 1 or 2) then it is acceptable to retain one extra figure in the best estimate.

e.g. "measured length = 27.6 ± 1 cm" is as acceptable as "28 ± 1 cm"

Quoting measured values involving exponents

It is conventional (and sensible) to do as in the following example:
Suppose the best estimate of the measured mass of an electron is 9.11×10^{-31} kg with an error of $\pm 5 \times 10^{-33}$ kg. Then the result should be written:

This makes it easy to see how large the error is compared with the best estimate.

Convention:

In science, the statement "$x = 1.27$" (without any statement of error) is taken to mean $1.265 \leq x \leq 1.275$.
To avoid any confusion, best practice is always to state an error, with every measurement.

Absolute and fractional errors

The errors we have quoted so far have been absolute ones (they have had the same units as the quantity itself). It is often helpful to consider errors as a fraction (or percentage) of the best estimate. In other words, in the form:

$$\text{fractional error in x} = \frac{\delta x}{|x_{best}|}$$

(the modulus simply ensures that the error is positive - this is conventional)
The fractional error is (sort of) a measure of the quality of a result.

One could then write the result of a measurement as:

$$\text{measured value of x} = x_{best}\left(1 \pm \frac{\delta x}{|x_{best}|}\right)$$

NOTE: it is not conventional to quote errors like this.

Comparison of measured and accepted values

It is often the objective of an experiment to measure some quantity and then compare it with the accepted value (e.g. a measurement of g, or of the speed of light).

Example:

In an experiment to measure the speed of sound in air, a student comes up with the result:

Measured speed = $329 \pm 5\ \mathrm{m\,s^{-1}}$

The accepted value is $331\ \mathrm{m\,s^{-1}}$. Consistent or inconsistent?

If the student had measured the speed to be $345 \pm 5\ \mathrm{ms^{-1}}$ then the conclusion is...?

Note: accepted values can also have errors.

3) Combining errors

In this section we discuss the way errors "propagate" when one combines individual measurements in various ways in order to obtain the desired result. We will start off by looking at a few special cases (very common ones). We will then refine the rules, and finally look at the general rule for combining errors.

Error in a sum or difference

A quantity q is related to two measured quantities x and y by

$$q = x + y$$

The measured value of x is $x_{best} \pm \delta x$, and that of y is $y_{best} \pm \delta y$.

What is the best estimate, and the error in q.

The highest probable value of $x + y$ is:

$$x_{best} + y_{best} + (\delta x + \delta y)$$

and the lowest probable value is:

$$x_{best} + y_{best} - (\delta x + \delta y)$$

A similar argument (check for yourselves) shows that the error in the difference $x - y$ is also $\delta x + \delta y$.

Error in a product or quotient

This time the quantity q is related to two measured quantities x and y by:

$$q = x \times y$$

Writing x and y in terms of their fractional errors:

$$\text{measured value of } x = x_{best}\left(1 \pm \frac{\delta x}{|x_{best}|}\right)$$

$$\text{and measured value of } y = y_{best}\left(1 \pm \frac{\delta y}{|y_{best}|}\right)$$

so the largest probable value of q is:

$$x_{best}\,y_{best}\left(1 + \frac{\delta x}{|x_{best}|}\right)\left(1 + \frac{\delta y}{|y_{best}|}\right)$$

while the smallest probable value is:

$$x_{best}\,y_{best}\left(1 - \frac{\delta x}{|x_{best}|}\right)\left(1 - \frac{\delta y}{|y_{best}|}\right)$$

Just consider the two bracketed terms in the first of these:

$$\left(1 + \frac{\delta x}{|x_{best}|}\right)\left(1 + \frac{\delta y}{|y_{best}|}\right) = 1 + \frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|} + \frac{\delta x}{|x_{best}|}\frac{\delta y}{|y_{best}|}$$

The last term contains the product of two small numbers, and can be neglected in comparison with the other three terms. We therefore conclude that the largest probable value of q is:

$$x_{best}\,y_{best}\left(1 + \frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|}\right)$$

and by a similar argument, the smallest probable value is:

$$x_{best}\,y_{best}\left(1 - \left(\frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|}\right)\right)$$

For the case of $q = \dfrac{x}{y}$ exactly the same result for the error in q is obtained.

Summary

(These rules work for results that depend on any number of measured quantities, not just two)

The error in a power

Suppose $q = x^n$. Now x^n is just a product of x with itself (n times). So applying the rule for errors in a product, we obtain:

$$\frac{\delta q}{|q_{best}|} = n\frac{\delta x}{|x_{best}|}$$

Refinement of the rules for independent errors

Actually we have been a bit pessimistic by saying that we should add the errors: If x and y are independent quantities, the error in x is just as likely to (partially) cancel the error in y, as it is to add to it.

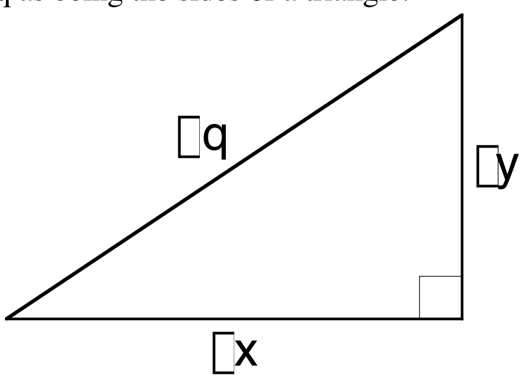
In fact the correct way of combining independent errors is “to add them in quadrature”. In other words, instead of saying (for the case of sums and differences):

$$\delta q = \delta x + \delta y$$

we say:

$$\delta q = \sqrt{\delta x^2 + \delta y^2}$$ (This is what is meant by adding in quadrature)

If we think of δx, δy and δq as being the sides of a triangle:



we can see that we have a right-angled triangle, and the rule for adding in quadrature is just Pythagoras’ theorem.

Note:

- the error in the result, δq is greater than the errors in either of the measurements, but
- it is always less than the sum of the errors in the measurements.

So the process of adding in quadrature has reduced the error, as we required.
It is possible to show rigorously that this is the correct procedure for combining errors.

Summary of the refined rules:

For sums and differences, the absolute error in the result is obtained by taking the root of the sum of the squares of the absolute errors in the original quantities.

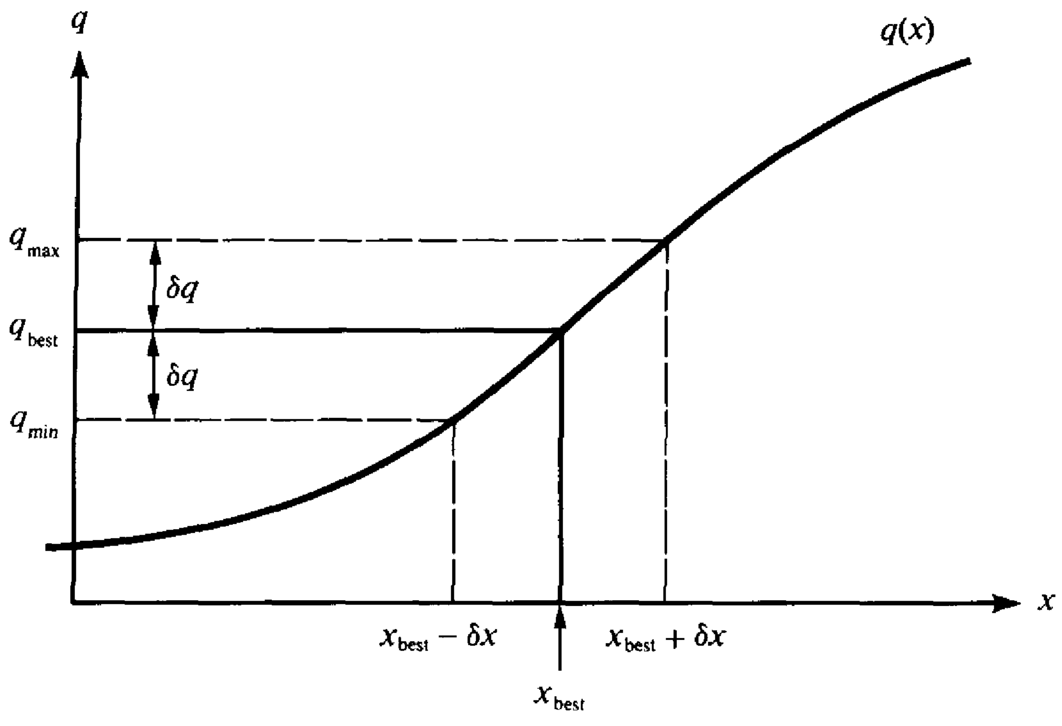
For products and quotients, the fractional error in the result is obtained taking the root of the sum of the squares of the fractional errors in the original quantities.

(These rules work for results that depend on any number of measured quantities, not just two)

NB: the rule for powers remains as above, because each of the 'x's in x^n are the same (and have the same error), so this is not a product of independent quantities.

The uncertainty in any function of one variable

The graph below shows the function $q(x)$ vs. x:



The dashed lines show how the error in the measured quantity x affects the error in q.

Now $\delta q = q(x_{best} + \delta x) - q(x_{best})$

But from calculus, we know that the definition of $\frac{dq}{dx}$ is:

$$\frac{dq}{dx} = \text{limit as } \delta x \to 0 \left[\frac{q(x+\delta x) - q(x)}{\delta x}\right]$$

So for a sufficiently small error in the measured quantity x, we can say that the error in any function of one variable is given by:

$$\delta q = \left|\frac{dq}{dx}\right| \delta x$$

(where the modulus sign ensures that δq is positive - by convention all errors are quoted as positive numbers)

General formula for combining uncertainties

We can extend this to calculating the error for a function of more than one variable, by realising that if $q = q(x, \ldots, z)$ (several measured variables) then the effect that an error in one measured quantity (say the variable u) is given by:

$$\delta q(\text{u only}) = \left|\frac{\partial q}{\partial u}\right| \delta u$$

Errors in each of the measured variables has its own effect on δq, and these effects are combined as follows, to give evaluate the total error in the result q:

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x}\delta x\right)^2 + \ldots + \left(\frac{\partial q}{\partial z}\delta z\right)^2}$$

In other words, we evaluate the error caused by each of the individual measurements and then combine them by taking the root of the sum of the squares.

It can be shown that the rules for combining errors in the special cases discussed above come from this general formula.

Exercises on combining errors

1) $Z = \dfrac{AB}{C}$ with $A = 5.0 \pm 0.5$, $B = 12{,}120 \pm 10$, $C = 10.0 \pm 0.5$ $\quad [Z = 6100 \pm 700]$

2) $Z = AB^2C^{1/2}$ with $A = 10 \pm 1$, $B = 20 \pm 2$, $C = 30 \pm 3$ $\quad [Z = 22000 \pm 5000]$

3) $Z = A + B - C$ with $A = 11 \pm 1$, $B = 20 \pm 2$, $C = 30 \pm 3$ $\quad [Z = 1 \pm 4]$

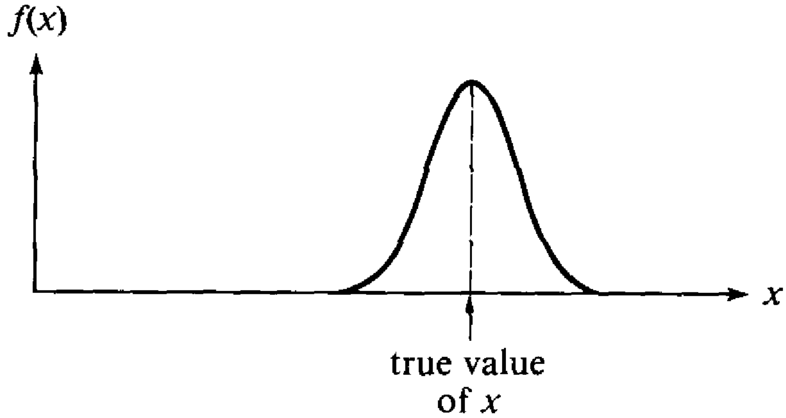
4) $Z = A + 2B - 3C$ with $A = 1.50(\pm 0.01) \times 10^{-6}$, $B = 1.50(\pm 0.01) \times 10^{-6}$, $C = 1.50(\pm 0.01) \times 10^{-6}$ $\quad \left[Z = 0(\pm 4) \times 10^{-8}\right]$

5) $Z = A\left(2B - \dfrac{C}{D}\right)$ with $A = 10 \pm 1$, $B = 20 \pm 2$, $C = 30 \pm 3$, $D = 40 \pm 4$ $\quad [Z = 390 \pm 60]$

6) $Z = A\sin(B)\mathrm{Ln}(C)$ with $A = 1.5 \pm 0.1$, $B = 30 \pm 1$ degrees, $C = 10.0 \pm 0.5$ $\quad [Z = 1.7 \pm 0.1]$

4) Statistical analysis of random errors

In this section, we discuss a number of useful quantities in dealing with random errors. It is helpful first to consider the distribution of values obtained when a measurement is made:



Typically this will be 'bell-shaped' with a peak near the average value.
For measurements subject to many small sources of random error (and no systematic error) is called the NORMAL or GAUSSIAN DISTRIBUTION. It is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-X)^2}{2\sigma^2}\right]$$

The distribution is centred about $x = X$, is bell-shaped, with a width proportional to σ.

Further comments about the Normal Distribution

- The $\frac{1}{\sigma\sqrt{2\pi}}$ in front of the exponential is called the normalisation constant. It makes areas under the curve equal to the probability (rather than just proportional to it).
- The shape of the Gaussian Distribution indicates that a measurement is more likely to yield a result close to the mean than far from it.
- The rule for adding independent errors in quadrature is a property of the Normal Distribution.
- The concepts of the mean and standard deviation have useful interpretations in terms of this distribution.

The mean

We have already agreed that a reasonable best estimate of a measured quantity is given by the average, or mean, of several measurements:

$$x_{best} = \bar{x} = \frac{x_1 + x_2 + \ldots + x_N}{N}$$

$$= \frac{\sum x_i}{N}$$

where the "sigma" simply denotes the sum of all the individual measurements, from x_1 to x_N.

The standard deviation

It is also helpful to have a measure of the average uncertainty of the measurements, and this is given by the standard deviation:

The deviation of the measurement x_i from the mean is $d_i = x_i - \bar{x}$.

If we simply average the deviations, we will get zero - the deviations are as often positive as negative. A more useful indicator of the average error is to square all the deviations before averaging them, but then to take the square root of the average. This is termed the "ROOT MEAN SQUARE DEVIATION", or the "STANDARD DEVIATION":

$$\sigma_N = \sqrt{\frac{\sum (d_i)^2}{N}}$$

$$= \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}$$

Minor Complication

In fact there is another type of standard deviation, defined as

$$\sigma_{N-1} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N-1}}$$

For technical reasons, this turns out to be a better representation of the error, especially in cases where N is small. However, for our purposes either definition is acceptable, and indeed for large N they become virtually identical.

Jargon:

σ_N is termed "the population standard deviation". σ_{N-1} is termed "the sample standard deviation". From now on I will refer to both types as "the standard deviation", σ.

σ as the uncertainty in a single measurement

If the measurement follows a Normal Distribution, the standard deviation is just the σ in

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-X)^2}{2\sigma^2}\right]$$

Standard deviation of the mean

We know that taking the mean of several measurements improves the "reliability" of the measurements. This should be reflected in the error we quote for the mean. It turns out that the standard deviation of the mean of N measurements is a factor $\sqrt{N}$ smaller than the standard deviation in a single measurement. This is often written:

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

5) Use of graphs in experimental physics

There are two distinct reasons for plotting graphs in Physics. The first is to test the validity of a theoretical relationship between two quantities.

Example

Simple theory says that if a stone is dropped from a height h and takes a time t to fall to the ground, then:

$$h \propto t^2$$

If we took several different pairs of measurements of h and t, and plotted h vs. t^2 confirmation of the theory would be obtained if the result was a straight line.

Jargon

Determining whether or not a set of data points lie on a straight line is called “Linear Correlation”. We won’t discuss it in this course.

The second reason for plotting graphs is to determine a physical quantity from a set of measurements of two variables having a range of values.

Example

In the example of the time of flight of a falling stone, the theoretical relationship is, in fact:

$$h = \frac{1}{2}gt^2$$

If we assume this to be true we can measure t for various values of h, and then a plot of h vs. t^2 will have a gradient of $\frac{g}{2}$.

Jargon

The procedure of determining the best gradient and intercept of a straight-line graph is called “Linear Regression”, or “Least-Squares Fitting”.

Choosing what to plot

In general the aim is to make the quantity which you want to know the gradient of a straight-line graph. In other words obtain an equation of the form $y = mx + c$ with m being the quantity of interest.

In the above example, a plot of h vs. t^2 will have a gradient of $\frac{g}{2}$.

Some other examples

What should one plot in order to determine the constant □ from the measured quantities x and y, related by the expression $y = A\exp(□x)$?

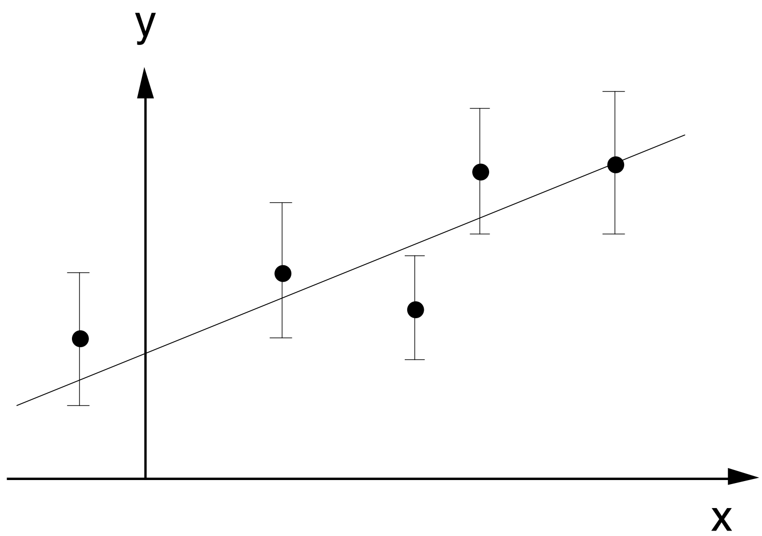
What if one wanted the quantity A rather than □?

What if one wanted to know the exponent n in the expressio $y = x^n$?

Plotting graphs by hand

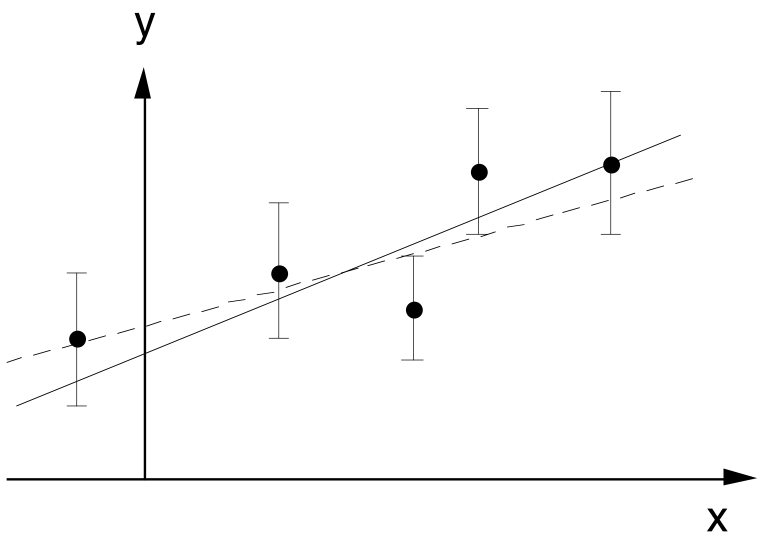
Before we talk about least-squares fitting, it is important to realise that it is perfectly straightforward to determine the best fit gradient and intercept, and the error in these quantities, by eye.

- Plot the points with their error bars.
- to draw the best line, simply position your ruler so that there is a random scatter of points above and below the line:



– about 68% of the points should be within error-bars of the line.

- To find the errors, draw the "worst-fit" line. Swivel your ruler about the "centre of gravity" of your best-fit line until the deviation of points (including their error bars) becomes unacceptable:



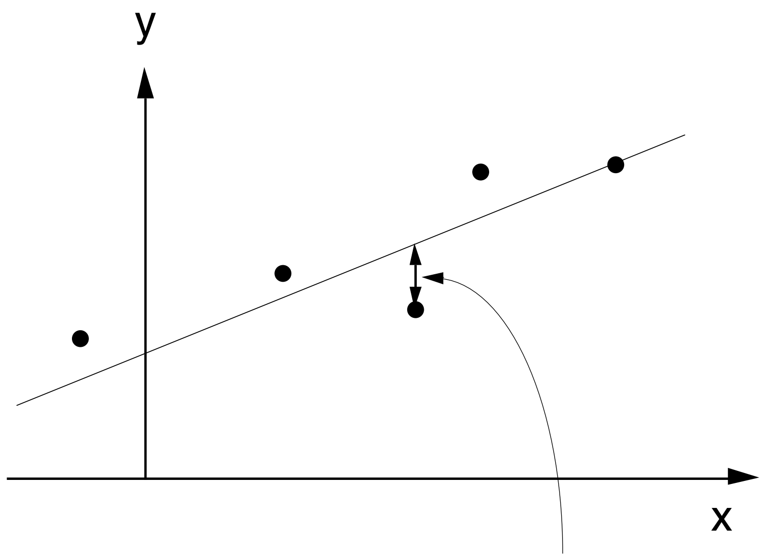
Remember that if your error bars represent standard deviations then you expect 68% of the points to lie within their error bars of the line.

- Now the error in the gradient is given by $\Delta m = \left| m_{\text{best fit}} - m_{\text{worst fit}} \right|$, and a similar expression holds for the intercept.

Least-squares fitting

This is the statistical procedure for finding m and c for the equation $y = mx + c$ of the straight line which most closely fits a given set of data $[x_n, y_n]$.

Specifically, the procedure minimises the sum of the squares of the deviations of each value of y_n from the line:



Deviation, $y_n - y_{\text{best fit}}$

$$= y_n - (mx + c)$$

The fitting procedure obtains values of m and c, and also standard deviations in m and c, σ_m and σ_c.

Points to note:

- The procedure assumes that the x measurements are accurate, and that all the deviation is in y. Bear this in mind when deciding which quantity to plot along which axis.
  If the two measured quantities are subject to similar errors then it is advisable to make two least-squares fits, swapping the x and y axes around. Then
  $$\sigma_m(\text{total}) = \sqrt{\sigma_m(\text{x vs. y})^2 + \sigma_m(\text{y vs. x})^2}$$
- The least-squares fit assumes that the errors in all the individual values of y_n are the same, and is reflected in the scatter of the points about the line. It does not allow you to put different error bars on each point. You can plot graphs with error bars on the computer, but the fitting procedure ignores them.
- FOR THE ENTHUSIAST: the fitting procedure comes up with analytical expressions for m, c, σ_m and σ_c, (i.e. it isn't a sort of trial and error procedure which only the computer can do). In principle one could calculate these by hand.

Summary

Types of error: Random and Systematic.

Reporting errors:

- Experimental uncertainties should normally be rounded to one significant figure.
- The last significant figure of the answer should usually be of the same order of magnitude (in the same decimal position) as the uncertainty.

  e.g. measured electron mass $= 9.11(\pm 0.05) \times 10^{-31}$ kg

Combining Errors:

For sums and differences, the absolute error in the result is obtained by taking the root of the sum of the squares of the absolute errors in the original quantities:

$$\delta q = \sqrt{\delta x^2 + \delta y^2}$$

For products and quotients, the fractional error in the result is obtained taking the root of the sum of the squares of the fractional errors in the original quantities:

$$\frac{\delta q}{q} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$$

For powers (i.e. $q = x^n$): $$\frac{\delta q}{|q|} = n\frac{\delta x}{|x|}$$

And for the general case, $q = q(x, \ldots, z)$:

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x}\delta x\right)^2 + \ldots. + \left(\frac{\partial q}{\partial z}\delta z\right)^2}$$

Statistical definitions:

The mean: $$\bar{x} = \frac{\sum x_i}{N}$$

The standard deviation of a single measurement: $$\sigma_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N - 1}}$$

and the standard deviation of the mean: $$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

Graphs and least-squares fitting

Follow-up to Errors Lectures

Which Rule?

At the beginning of the lectures I gave you some simplistic rules, then refined them.

IN THE LAB, USE THE REFINED VERSIONS

These are:

For pure sums, pure differences or combinations of sums and differences: the absolute error in the result is obtained by taking the root of the sum of the squares of the absolute errors in the original quantities:

e.g. if $q = a - b + c - d$ then $\Delta q = \sqrt{\Delta a^2 + \Delta b^2 + \Delta c^2 + \Delta d^2}$

For pure products, pure quotients or combinations of products and quotients: the fractional error in the result is obtained taking the root of the sum of the squares of the fractional errors in the original quantities:

e.g. if $q = \dfrac{a \times b}{c \times d}$ then $\dfrac{\Delta q}{q} = \sqrt{\left(\dfrac{\Delta a}{a}\right)^2 + \left(\dfrac{\Delta b}{b}\right)^2 + \left(\dfrac{\Delta c}{c}\right)^2 + \left(\dfrac{\Delta d}{d}\right)^2}$

For products and quotients involving powers of the measured quantities: Use the modified rule for products and quotients shown in the following example:

if $q = \dfrac{a^n \times b}{c \times d^m}$ then $\dfrac{\Delta q}{q} = \sqrt{\left(\dfrac{n\Delta a}{a}\right)^2 + \left(\dfrac{\Delta b}{b}\right)^2 + \left(\dfrac{\Delta c}{c}\right)^2 + \left(\dfrac{m\Delta d}{d}\right)^2}$

For any other formulae:

Use the general expression:

if $q = q(a, \ldots, d)$ then $\Delta q = \sqrt{\left(\dfrac{\partial q}{\partial a}\Delta a\right)^2 + \ldots + \left(\dfrac{\partial q}{\partial d}\Delta d\right)^2}$

The following expressions are examples where you should use this rule:

$q = \dfrac{a(b - c)}{d}$ $\qquad q = a^n + b - c + d^m$ $\qquad q = b \sin c$ $\qquad q = a \log b$

Dealing with constants in expressions:

In products and quotients, the constants can be ignored provided you are sure the do not contain errors: fundamental constants like e, or ϵ_0 come into this category.

N.B. numbers given to you in an experiment such as component values are NOT free of errors.

In sums and differences, constants DO play a role:

e.g. $q = a + 2b$

The "2" is a constant and may be assumed exact.
But the absolute error in the quantity 2b is twice that in b.

So the error is given by:

$$\Delta q = \sqrt{\Delta a^2 + (2\Delta b)^2}$$

Reporting errors:

- Experimental uncertainties should normally be rounded to one significant figure.
- The last significant figure of the answer should usually be of the same order of magnitude (in the same decimal position) as the uncertainty.

e.g. measured electron mass = $9.11\,(\pm 0.05) \times 10^{-31}\ \mathrm{kg}$

Experiment 1

Error Analysis and Graph Drawing

I. Introduction:

1.1 It is impossible to do an experimental measurement with perfect accuracy. There is always an uncertainty associated with any measured quantity in an experiment even in the most carefully done experiment and despite using the most sophisticated instruments. This uncertainty in the measured value is known as the error in that particular measured quantity. There is no way by which one can measure a quantity with one hundred percent accuracy. In presenting experimental results it is very important to objectively estimate the error in the measured result. Such an exercise is very basic to experimental science. The importance of characterizing the accuracy and reliability of an experimental result is difficult to understate when we keep in mind that it is experimental evidence that validate scientific theories. Likewise, reliability and accuracy of measurements are also deeply relevant to Engineering.

The complete science of error analysis involves the theory of statistics (see Ref. 1,2) and is too involved to present here. This short presentation is intended to introduce the student to some basic aspects of error analysis and graph drawing, which it is expected that the student will then put into practice when presenting his/her results of the coming experiments.

I.2 When a measurement of a physical quantity is repeated, the results of the various measurements will, in general, spread over a range of values. This spread in the measured results is due to the errors in the experiment. Errors are generally classified into two types: *systematic (or determinate)* errors and *random (or indeterminate)* errors. A systematic error is an error, which is constant throughout a set of readings. Systematic errors lead to a clustering of the measured values around a value displaced from the "true" value of the quantity. Random errors on the other hand, can be both positive or negative and lead to a dispersion of the measurements around a mean value. For example, in a time period measurement, errors in starting and stopping the clock will lead to random errors, while a defect in the working of the clock will lead to systematic error. A striking example of systematic error is the measurement of the value of the electric charge of the electron 'e' by Millikan by his Oil Drop method. Millikan underestimated the viscosity of air, leading to a lower value for his result

$$e = (1.591 \pm .002) \times 10^{-19}\ C \quad \text{-------------------------------------} \quad \mathbf{(1)}$$

Compare this with a more modem and accurate value (Cohen and Taylor 1973, Ref. 3)

$$e = (1.602\ 189 \pm 0.000\ 005) \times 10^{-19} C. \quad \text{----------------------} \quad \mathbf{(2)}$$

Systematic errors need to be carefully uncovered for the particular experimental set-up and eliminated by correcting the results of the measurements.

I.3 Random errors are handled using statistical analysis. Assume that a large number (N) of measurements are taken of a quantity Q giving values Q1, Q2, Q3…QN. Let Q be the mean value of these measurements

$$\overline{Q} = \tfrac{1}{N}\sum_{i=1}^{N} Q_i \qquad i = 1 \quad \text{----------------------------------} \quad \mathbf{(3)}$$

and let 'd' be the deviation in the measurements

$$d = \sqrt{\tfrac{1}{N}\sum_{i=1}^{N}(Q_i - \overline{Q})^2} \quad \text{--} \quad \mathbf{(4)}$$

The result of the measurement is quoted (assuming systematic errors have been eliminated) as

$$Q = \overline{Q} \pm d \quad \text{--} \quad \mathbf{(5)}$$

The error ΔQ in the quantity is then taken to be the deviation d. (This is called the *standard error* in Q)

In a single measurement of a physical quantity, the error can be estimated as the least count (or its fraction) of the instrument being used.

As an example, the result of a measurement of the radius of curvature R, of a plano-convex could be quoted as

$$R = 140 \pm 0.2 \text{ cm.} \quad \text{------------------------------} \quad \mathbf{(6)}$$

This means that we expect that the value of R being in the range 139.8 to 140.2 cm. Note however, that this does not mean that the “true” value of R necessarily lies in this range, only that there is a possibility that it will do so.

The error in measurement can also be quoted as a percent error

$$\frac{\Delta Q}{\overline{Q}} \times 100 = \frac{d}{\overline{Q}} \times 100 \quad \text{--} \ \textbf{(7)}$$

For example, the percentage error in R is 0.143 %.

I.4 Combination of errors:

Many times the value of a measured quantity may depend on other intermediate measured quantities. For example we could have a quantity Q which is a function F of a number of independent intermediate variables say x, y and z i.e.,

$$Q = F(x,y,z) \text{--} \textbf{(8)}$$

If the indeterminate errors related to x, y, z are $\Delta x, \Delta y$ and Δz respectively, then the error in Q can be calculated as

$$\Delta Q = (\partial F/\partial x)\Delta x + (\partial F/\partial y)\Delta y + (\partial F/\partial z)\Delta z = a\Delta x + b\Delta y + c\Delta z \quad \text{------------} \ \textbf{(9)}$$

An important characteristic of errors is that the total error in a function, due to different variables is always additive. Therefore, more accurately, the error ΔQ is calculated as

$$\Delta Q = \left|\frac{\partial F}{\partial x}\Delta x\right| + \left|\frac{\partial F}{\partial y}\Delta y\right| + \left|\frac{\partial F}{\partial z}\Delta z\right| = |a\,\Delta x| + |b\,\Delta y| + |c\,\Delta z| \ \text{--------------} \ \textbf{(10)}$$

$$= \Delta Q_A + \Delta Q_B + \Delta Q_C$$

As an example, consider the quantity $Q = x + y$.

If the error in x (i.e., Δx) is negative and that in y (i.e., Δy) is positive, the total error in the quantity x+y will be $|\Delta x| + |\Delta y|$ not $\Delta x + \Delta y$, which means combination of errors always lowers the quality of the experimental data.

In fact, using statistical analysis (where the. error is defined as the root mean square deviation from the mean) the correct expression for the error in Q can be shown to be $\Delta Q = \sqrt{(\Delta x)^2 + (\Delta y)^2}$.

In general we have the rule that (following statistical analysis) if Q is a function of x, y, z,…., then

$$(\Delta Q)^2 = (\Delta Q_x)^2 + (\Delta Q_y)^2 + (\Delta Q_{z)})^2 \ldots\ldots\ldots\ldots \text{--------------------------} \quad \textbf{(11)}$$

where, $\Delta Q_x = (\frac{\partial Q}{\partial x})\Delta x$; $\Delta Q_y = (\frac{\partial Q}{\partial y})\Delta y$; $\Delta Q_z = (\frac{\partial Q}{\partial z})\Delta z$ etc.

The following table summarizes the results for combining errors for some standard functions. Try to derive some of these results.

S.No	Function	Error in ΔQ or Fractional error ΔQ/Q
1.	$Q = x + y$	$\Delta Q = \sqrt{(\Delta x)^2 + (\Delta y)^2}$
2.	$Q = x - y$	$\Delta Q = \sqrt{(\Delta x)^2 + (\Delta y)^2}$
3.	$Q = xy$	$\left(\frac{\Delta Q}{\overline{Q}}\right)^2 = \left(\frac{\Delta x}{\overline{x}}\right)^2 + \left(\frac{\Delta y}{\overline{y}}\right)^2 \Rightarrow \left(\frac{\Delta Q}{\overline{Q}}\right) = \sqrt{\left(\frac{\Delta x}{\overline{x}}\right)^2 + \left(\frac{\Delta y}{\overline{y}}\right)^2}$
4.	$Q = x/y$	$\left(\frac{\Delta Q}{\overline{Q}}\right)^2 = \left(\frac{\Delta x}{\overline{x}}\right)^2 + \left(\frac{\Delta y}{\overline{y}}\right)^2 \Rightarrow \left(\frac{\Delta Q}{\overline{Q}}\right) = \sqrt{\left(\frac{\Delta x}{\overline{x}}\right)^2 + \left(\frac{\Delta y}{\overline{y}}\right)^2}$
5.	$Q = x^n$	$\frac{\Delta Q}{\overline{Q}} = n\frac{\Delta x}{x}$
6.	$Q = \ln x$	$\Delta Q = \frac{\Delta x}{\overline{x}}$
7.	$Q = e^x$	$\frac{\Delta Q}{\overline{Q}} = \Delta x$

II. Drawing of best fit straight line graph:

To draw the best fit straight line graph through a set of scattered experimental data points we will follow a standard statistical method, known as *least squares fit* method.

Let us consider a set of N experimental data points (x_1,y_1), (x_2,y_2), …….(x_N,y_N). It is well known that a straight-line graph is described by the equation

$$y = mx + C. \quad \text{---------------------------------------} \quad \textbf{(12)}$$

We ask the question: how are the slope 'm' and the y-intercept 'c' to be determined such that a straight line best approximates the curve passing through the data points? Let $S_i = y_i - m_i x_i - c$ be the deviation of any experimental point P (xi, yi), from the best fit line. Then, the gradient 'm' and the intercept 'c' of the best fit straight line has to be found such that the quantity

$$S=\sum_i (y_i - m x_i - c)^2$$

is a minimum . We require

$$\frac{\partial S}{\partial m}=-2\sum x_i (y_i - m x_i - c)=0 \text{ and } \frac{\partial S}{\partial c}=-2\sum (y_i - m x_i - c)=0,$$

which give,

$$m\sum x_i^2 + c\sum x_i = \sum x_i y_i \quad \text{and} \quad m\sum x_i + Nc = \sum y_i \ .$$

The second equation can be written as as $\bar{y}=m\bar{x}+c$, where $\bar{y}=\frac{1}{N}\sum y_i$ and $\bar{x}=\left(\frac{1}{N}\sum x_i\right)$ showing that the best fit straight line passes through the centroid $(\bar{x},\bar{y})$ of the points (x_i , y_i) .The requires values of m and c can be calculated from the above two equations to be

$$m=\frac{\sum (x_i-\bar{x})\, y_i}{\sum (x_i-\bar{x})^2} \quad \text{and} \quad c=\bar{y}-m\bar{x} \text{ ----------------------------------}\mathbf{(13)}$$

The best-fit straight line can be drawn by calculating m and c from above. A graphical method of obtaining the best fit line is to rotate a transparent ruler about the centroid so that it passes through the clusters of points at the top right and at the bottom left. This line will give the maximum error in m, $(\Delta m)_1$, on one side. Do the same to find out the maximum error in m, $(\Delta m)_2$ on the other side. Now bisect the angle between these two lines and that will be the best-fit line through the experimental data.

What are the errors in the gradient and intercept due to errors in the experimental data points? The estimates of the standard errors in the slope and intercept are

$$(\Delta m)^2 \approx \frac{1}{D}\frac{\sum S_i^2}{N-2} \quad \text{and} \quad (\Delta c)^2 \approx \left(\frac{1}{N}+\frac{\bar{x}^2}{D}\right)\frac{\sum S_i^2}{N-2},$$

where $D=\sum (x_i-\bar{x})^2$ and S_i is the deviation ,$S_i = y_i - m x_i - c$.

II.1. Presentation of error associated with experimental data in a graph.

Let us consider a function, y = f(x), where x is an independent parameter which in the hand of the experimentalist during performing the experiments and y is the experimental data which is having a value depending upon the x and the instruments. Let the error associated with x be ±Ax and that for y be ±Ay. One can represent ±Ax and ±Ay with the experimental data point P(x,y) on the graph paper. To do that, first plot P(x,y) on the graph paper, then draw a vertical line parallel to y axis about the point P(x,y) of length 2Ay. So upper half of the line represents the error +Ay and the lower half represents -Ay error. To present ±Ax, draw horizontal lines at the two ends of the vertical line of length 2Ax each. The whole presentation is now giving the errors associated with the experimental point P(x,y).

Figure 1 is an example of experimental data of resonance absorption of γ – ray experiment (Mössbauer spectroscopy) with error associated with each experimental data. The solid lines give the fitted curve through the experimental data. Note that the error in the variable along horizontal axis is not shown.

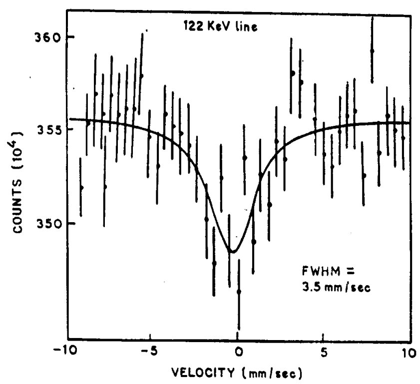


Fig 1

II.2 Use of graphs in experimental physics:

In practical physics, the graph of the experimental data is most important in improving the understanding of the experimental results. Moreover from the graphs one can calculate unknowns related to the experiments and one can compare the experimental data with the theoretical curve when they are presented on same graph. There are different types of graph papers available in market. So, one should choose the appropriate type of graph paper to present their experimental results in the best way depending upon the values of the experimental data and the theoretical expression of the functions. To understand all those some of the assignments are given below in addition to those we discussed before.

III. Exercises and Viva Questions

1. What is the general classification of errors? Give an example of each. How are they taken care of?

2. What is the meaning of standard error? Calculate the standard error for the hypothetical data given in the adjacent table. Express the quantity as in eq(5) i.e. $R = \overline{R} \pm d$

Radius of curvature(cm)
130.121
130.126
130.139
130.148
130.155
130.162
130.162
130.169

3. What is the percentage error in Millikan's experiment of the charge of the electron: $e = (1.591 \pm 0.002) \times 10^{-19}$ C?

4. What is the error in the volume of a cube $V=L^3$ if the error in L is 0.01m? If L is measured as $L= 2 \pm 0.01$, express the value of V in a similar manner.

5. A small steel ball-bearing rests on top of a horizontal table. The radius (R) of the ball is measured using a micrometer screw gauge (with vernier least count 0.05 mm) to be 2.15 mm. The height of the table is found using an ordinary meter scale to be 90 cm. What is the height of the center of the steel ball from the floor (include the error)?.

6. Let $Q = x - y$, where $x= 100 \pm 2$ and $y = 96 \pm 2$ .Calculate Q (express the result with the error included)

7. Consider the quantity $Q = x / y$. If $x = 50 \pm 1$ and $y = 3 \pm 0.2$. Calculate Q (express the result with the error included)

8. In an experiment involving diffraction of sodium light using a diffraction grating, the double lines are unresolved at first order and a single spectral line is seen at an angle of 13^0. If the least count of the vernier of the telescope is $1^{\prime}$, what will be the error in the calculated value of the grating constant d? (Principal maxima of a grating occurs at angles θ such that $d \sin \theta = m\lambda$. The wavelength separation between the sodium double slit lines is 6 A^0)

9 Consider an experiment to measure the gravitational acceleration 'g' by measuring the time period of a simple pendulum. What are the possible sources of systematic error in this experiment?

10. "If there are always errors in any measurement then there is nothing like the 'true' value of any measured quantity ". Comment on this statement. In what sense then do you understand the values of 'physical constants' to be constants?

Experiment 1

Error Analysis and Graph Drawing

Assignments:

1. Experimental data (in arbitrary units) of some experiment is given below :

x	-10	4	10	16	20	35	40	32	40	45	53	60	65	70	80	85
y	-17	-20	-30	-17	-35	-2	-19	-3	-4	10	11	24	20	30	37	47
x	100	115	120	122	129	133	140	141	150	151	154	157	160	170	172	183
y	50	80	77	79	80	83	80	100	90	113	102	110	100	106	101	200

(a) Assuming 10% of error in Y values, plot the data on preferred graph paper showing the errors in terms of error bars.

(b) Calculate the slope and intercept of the best fit graph .Draw the best fit graph on the above graph.

2. The expression of refractive index of a prism id given by the following relation: $\mu = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin(A/2)}$. Assuming the error of A and D as ΔA and ΔD, express the error of μ. Here 'A' is the angle of the prism and 'D' is the angle of deviation.

3. The relation between two independent variables X and Y is given as the empirical expression $Y = a X + b X^3$ .The experimental data for X and Y are given below :

X : 0.130 0.192 0.232 0.263 0.299 0.326 0.376 0.392 0.416 0.454 0.471 Y : 0.280 0.405 0.504 0.593 0.685 0.749 0.922 0.986 1.049 1.192 1.256 X : 0.492 0.533 0.541

Y : 1.332 1.51 1.531

Rearrange the equation to plot the graph in simpler form. (Hint: Plot Y/X vs X^2). (Why?) .Then find out the constants 'a' and 'b' from the graph .Try to co-relate the expression with some practical experiment in physics and give your comments about the constants.

4. Expression of some function is given by, $Y=a X^{b}$, where 'a', 'b' are unknown .Use the following experimental data to find out the constants by plotting an appropriate graph of Y vs. X. Try to co-relate the above expression with some practical experiment in physics and give your comments about the constants.

X :	465	599	688	720	878	922	1025	1220	1311	1410	1509
Y :	2589	7106	12132	15680	25090	40616	60142	117626	168086	222876	287091

5. The ionic conductivity of (C) of a crystal is given as a function of temperature (T) by the equation, $C = C_0 \exp(+ E/kT)$ where k is Boltzmann constant. (T is in Kelvin and C is in $CX10^7$ cgs unit)

T :	746	805	825	853	875	885	915	952	965	990
$CX10^7$:	1.82	2.90	5.85	8.40	19.1	32.7	66.1	120	245	418

Plot the experimental data on suitable graph paper and find out the value of C_0 and E.

(Four graph papers required).

INDOSAW
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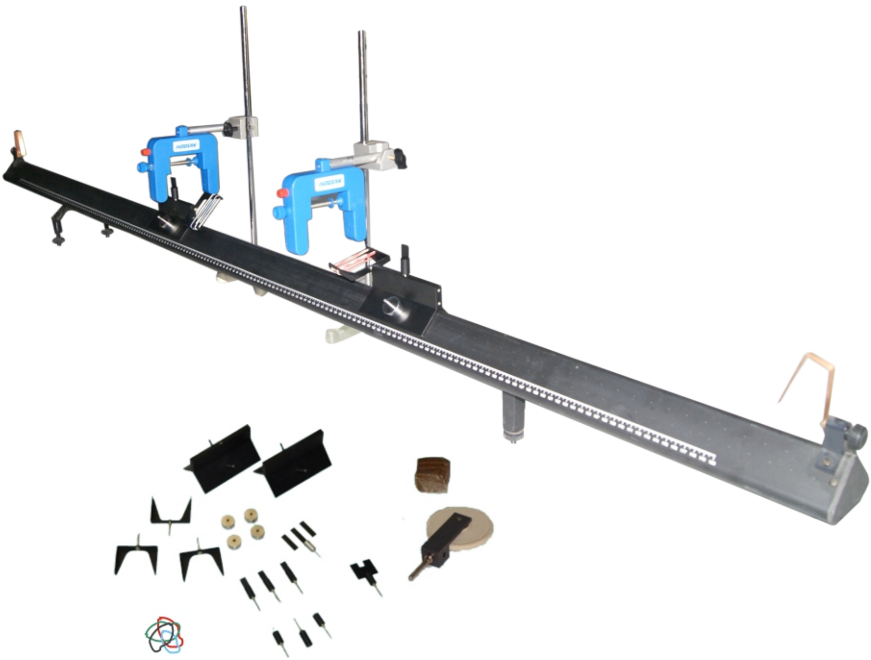
INSTRUCTION MANUAL FOR LINEAR AIR TRACK

Instruction Manual



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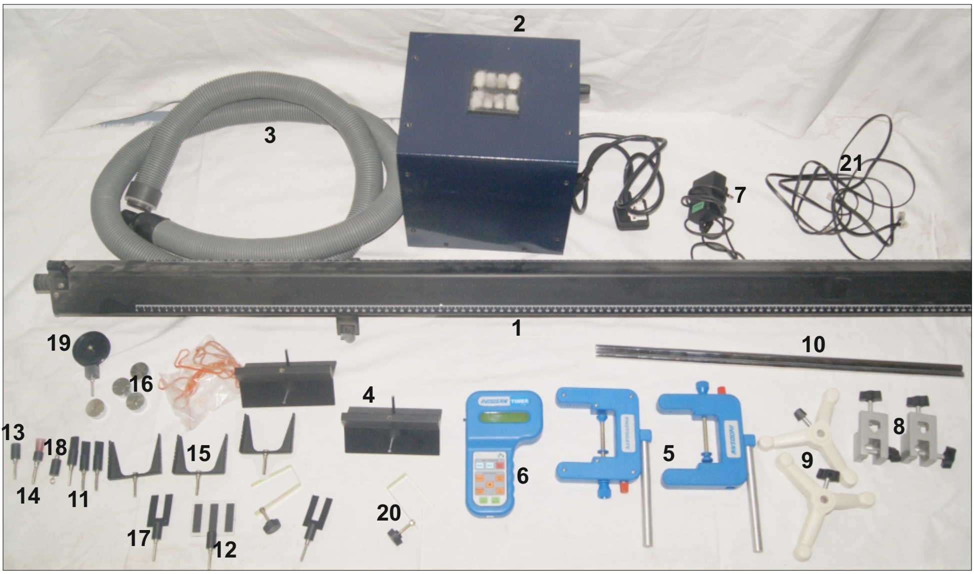
An ISO 9001 :2008 Certified Company

UNPACKING LINEAR AIR TRACK

CONTENTS:

S. No.	Items Name	Qty.
1.	Linear air track	1
2.	Air blower	1
3.	Plastic hose pipe 35mm dia	1
4.	Vehicle 200g	2
5.	Photogate sensors	2
6.	Digital timers	1
7.	5v dc adaptor	1
8.	Boss head	2
9.	Tripod stand	2
10.	Stand rod	2
11.	Plug with aluminium strip	3
12.	3-b - picket	1
13.	Plug with clay	1
14.	Plug with pin	1
15.	Fork with rubber band	3
16.	Weight 50g	4
17.	2- b - picket	2
18.	Plug with hook for attaching card	1
19.	Plug with pulley	1
20.	Steel Spring	2
21.	RJ11 cable	2



EXPERIMENTS:

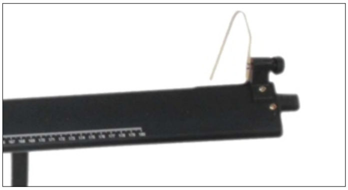
Exp-1 To study the linear motion under virtually frictionless conditions .
Exp-2 To study the elastic and inelastic collision
Exp-3 To study the concept of velocity.
Exp-4 To study the concept of accelerations
Exp-5 To study the conversation of momentum.
Exp-6 To study the dependency of kinetic energy on mass.

LINEAR AIR TRACK

The Linear Air Track facilitates the study of translational motion of an object under conditions of low friction. This track is designed in a triangular aluminum section, length 200cm, with two rows for air holes through which air emerges forming air cushion on which the vehicles float.

AIR TRACK BLOWER (OPTIONAL)

By attaching a suitable blower at inlet on the end of air track, the pressure inside the track is increased or decreased. This pressure is released through the series of two rows drilled holes along the track, creating a cushion of air between the track and vehicles mounted on it.

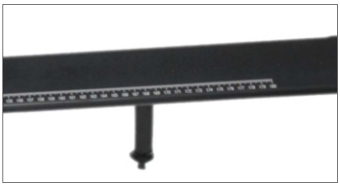


SETUP AND ADJUSTMENT

The track is made from a triangular aluminum section, supported along with three adjustable feet. Fine holes (two rows, one either side of the apex), 1mm diameter and 20mm spacing) are drilled in its upper surface and through these, jets of air emerge and support the vehicles clear of the track providing virtually frictionless motion. An air inlet tube connection is fitted at one end whereas a butterfly valve at the other to adjust the air pressure inside the rack.

For best operation, the air track should be used on a horizontal, flat surface. The air track is supported by three feet that screw into the legs on the bottom of the air track. The feet can be adjusted individually, by being screwed in and out, to compensate for tilt in two dimensions.

First, set the track up so that it looks level to the eye. Attach the blower and turn on. Place a vehicle on the track, hold it still, and then gently release it. If it begins to move along the track without any help, adjust the single leveling screw until the vehicle remains stationary.



Then, look carefully at the vehicle end-on. Both sides should be floating at an equal distance above the air track. If not, adjust the pair of levelling screws until the vehicle floats level. You may need to adjust the single screw again after this step.

The levelling screws are packed separately for transport, but can be left in the air track for storage.

INTELLIGENT TIMER

It is based on microcontroller having crystal controlled time base to accurately measure the time intervals, speed and acceleration in various modes. It has built-in test function for the photogates. Least count resolution 0.1millisecond. It can also calculate acceleration due to gravity 'g'. Instrument is self contained that requires no computer. It can be used with Air track and trolley to comprehensively study several experiments on kinematics and dynamics. It is supplied with Photogate pair.

Salient Features: -

Time Modes

a) Using single gate
b) Using two gates
c) Stop-watch : measures time between pressing start/stop button.
d) Pendulum : measures pendulum period.
e) Fence : measures 10 time values

Speed Modes

a) One gate : Instantaneous
b) Two gates : Average
c) Collision - I : Initial & final speeds of the cart
d) Collision - II : Initial & final speeds of two carts
e) Pulley Lin : Linear speed of cart using pulley
f) Pulley Rad : Angular speed in radians/second
g) Pulley Rev : Angular speed in revolutions/second

Acceleration Modes

a) One gate : Instantaneous
b) Two gates : Average, Initial & Final
c) Pulley Lin : Linear acceleration with pulley
d) Pulley Ang : Angular acceleration
e) g - Free fall

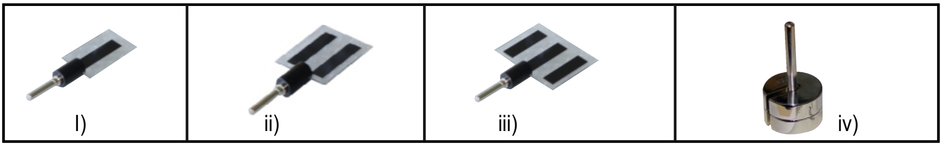
Count Modes : Manual, 15 sec, 30 sec, 1 min, 5 min, 10 min time intervals.

Test Mode : Photogate - I & II Blocked/Unblocked indication.

Specifications: -

1) **Display** : 2x16 Characters alphanumeric LCD display
2) **Inputs** : Provision for four gates (Two pairs, each pair has two gates connected in 'OR' configuration)
3) **Keys** : 4 microswitches are provided for various functions
4) **Time Resolution** : 0.1ms

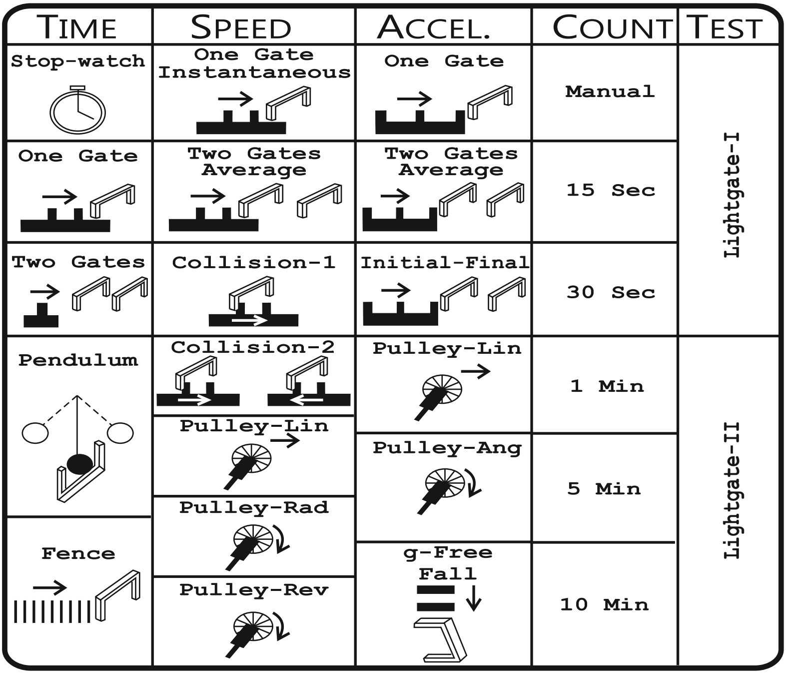
ACCESSORIES:
Modules for Speed (Linear and angular), and Acceleration Value measurement.
I). 1 b Picket, ii). 2 b Picket , iii). 3 b Picket, iv). Mass set with hanger



HOW TO USE:
1. INTELLIGENT TIMER:
Connect power supply cord and Switch ON the power. The timer will show Time: Stop Watch on screen. This means the timer is ready to work. There are four keys below LCD Display.

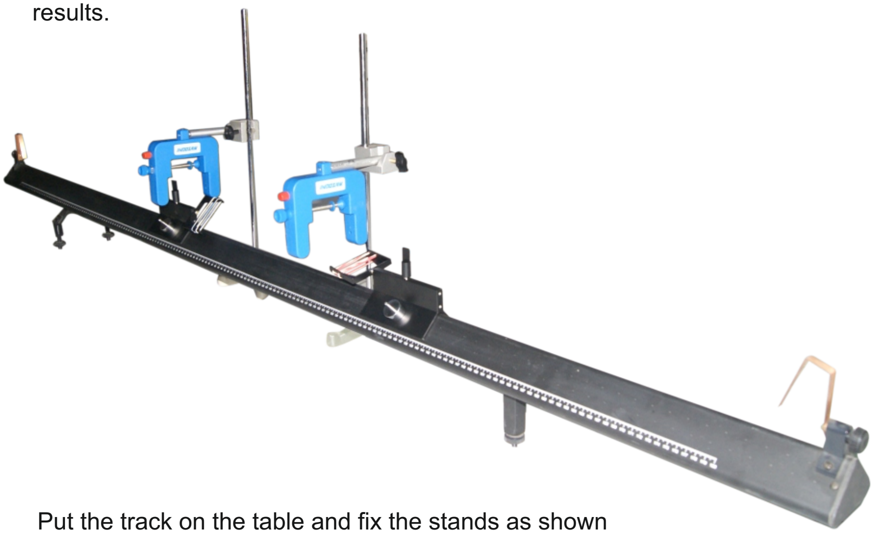
i). MODE: Key is used to select the desired type of measurement (Time, Speed, Acceleration, Count, and Test). Press Mode key until desired type of measurement is displayed. The menu will roll over to the beginning after the last type is selected.

ii). SELECT: key is used to select the function, under given Mode. Press the select key until it shows the desired selected measurement e.g. one gate, two gate, pendulum, fence etc. under Time Mode and so on.



iii). START: After selecting the function, press start/stop key to start your measurement. The Timer will display -- -- * ---which means that timer is ready. When any event occurs (blocked/unblocked in the photogate) the -- -- * -- -- will disappear and Timer will display the result. Press start/stop key again to stop the timer.

iv). REVIEW: key roll up the result If there are more than one value of readings is used to see the result. e.g. in collision, fence etc. Press review key again and again to see all results.



1. Put the track on the table and fix the stands as shown in the figure.
2. Attach one or two no. of photogates as per requirement as shown.
3. Plug-in adapter to intelligent timer.

PHOTOGATE:

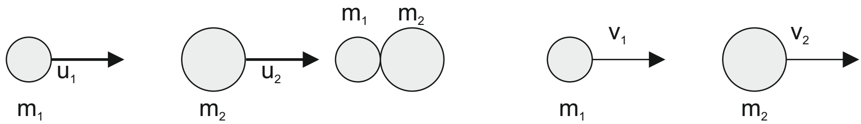
Phototgate is narrow beam infrared radiation detector connected directly to Timer and used to provide the timing signals. The LED in one arm of the Phototgate emit a narrow infrared beam. As long as the beam strike the detector in opposite arm of the Phototgate, the signal to the timer indicates unblocked. Signal to the timer change when any object blocks it. A single Phototgate is used to measure the time, speed, acceleration, counts and g - free fall. Two photogate allow us to study experiments with two trolleys such as collision, speed, acceleration. Gate '2' is used only for collision between two trolleys.

Connect Phototgate in socket of timer as shown. Clamp the photogate on stand and place near track as shown. Adjust the height of Phototgate so that the 2b-picket block the sensor of photogate but should not touch Phototgate .

Theory:

ELASTIC COLLISION IN ONE DIMENSION.

Are those in which momentum and kinetic energy both are conserved.



$u_1 > u_2$

Before collision | During Collision | After Collision by conservation of K.E

By conservation of momentum

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

using these equation we can derive

By conservation of kinetic energy

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$

$$\mathbf{v_1 = \frac{m_1 - m_2}{m_1 + m_2} u_1 + \frac{2m_2}{m_1 + m_2} u_2} \quad \text{-------(1)}$$

$$\mathbf{v_2 = \frac{m_2 - m_1}{m_2 + m_1} u_2 + \frac{2m_1}{m_1 + m_2} u_1} \quad \text{-------(2)}$$

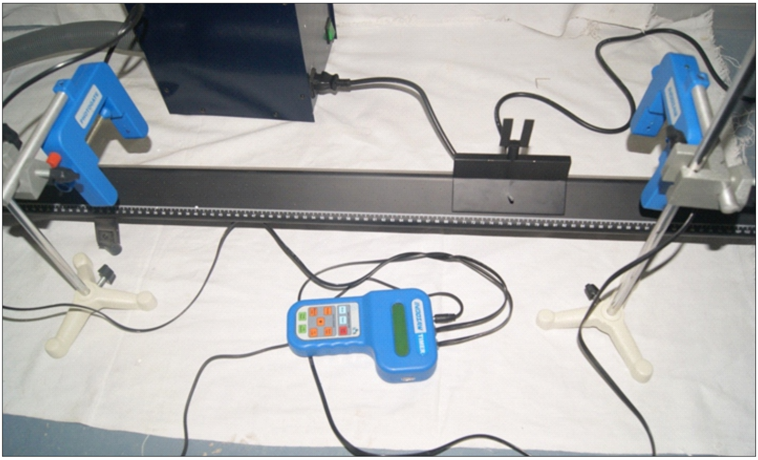
EXPERMENT-1: TO STUDY THE LINEAR MOTION UNDER VIRTUALLY FRICTIONLESS CONDITIONS .

CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	1

Assemble the items mentioned in experiment 1 as shown in picture-A below .

By attaching a suitable blower at inlet on the end of air track, the pressure inside the track is increased or decreased. This pressure is released through the series of two rows drilled holes along the track, creating a cushion of air between the track and vehicles mounted on it. This arrangement offers very low friction to the vehicle. Note that vehicle once started keep on moving itself.



Picture-A

EXPERIMENT 2. : TO STUDY THE ELASTIC COLLISION

CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	2
9.	Fork with rubber band	2
10.	2 -b - picket	2

Set the timer in collision 2 mode .

Elastic collision:

Special case:1. When bodies are of equal masses and m_2 is at rest i.e $m_1 = m_2 = m$ and $v_2 = 0$ using eq^ns (1.) and (2.) We get $v_1 = 0$ and $v_2 = u_1$ i.e both exchange their velocities.

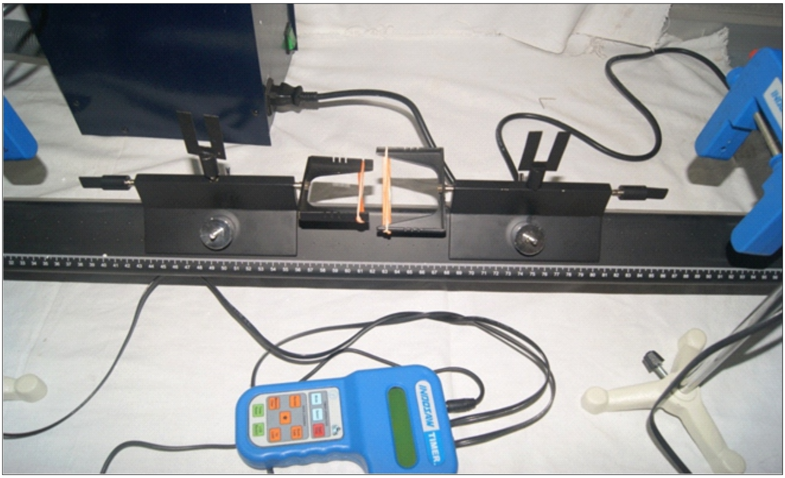
Setting:

Assemble the items as mentioned in Experiment 2 as shown in picture-B below.

The forks with rubber bands are suitable for producing elastic collisions between vehicles. The horn arms are flexible, and can be spread to ensure the elastic bands are tight between them, as illustrated. They are very lightweight but, when a horn with elastic band is used, a plastic counterweight should be attached to the other end of the vehicle. When two horns are to be used, they should be mounted at 45° to the vehicle, so the elastic bands are perpendicular to each other. This ensures the bands have plenty of room to stretch.

Demonstration:
Use two vehicles of equal mass and set the rubber bands so that they touch at right angles to each other. Position one vehicle in the middle of the track and catapult the other one at various speeds. After the collision the first vehicle should move off at the same speed and second should stop. i.e both exchange their velocities. It can be observed by timer after next collision, after rebounding of the vehicle from spring that initial1 is equal to initial2 and final1 is equal to final2.

This principle is used in nuclear reactor, to slow down the fast neutrons on colliding with slow protons in moderator. Note that mass of proton = mass of neutron and fast neutrons escape, the fissionable material without interacting with nuclei. Remember that fission of U_{235} is possible only by slow neutron.



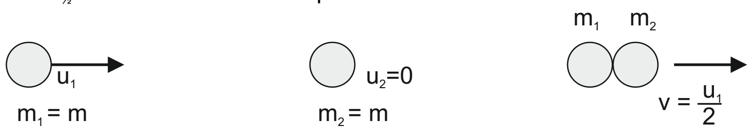
Picture-B

EXPERIMENT 3. : TO STUDY THE INELASTIC COLLISION
CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	2
9.	2 - b - picket	1
10.	Plug with pin	1
11.	Plug with clay	1

PERFECTLY INELASTIC COLLISION : Are those in which there is max. Loss of K.E, but momentum is conserved. Both bodies stick together and move with common velocity v. Note that $v = u_{½}$ it both bodies are of equal masses.

Theory:



By conservation of momentum $m_1u_1+0 = (m_1+m_2)v$

So $$v = \frac{m_1u_1}{m_1+m_2}$$

By conservation o kinetic energy

$$\frac{Kf}{Ki} = \frac{\frac{1}{2}(m_1+m_2)v^2}{\frac{1}{2}m_1u_1^2} = \frac{m_1+m_2}{m_1}\left(\frac{m_1}{m_1+m_2}\right)^2 = \frac{m_1}{m_1+m_2}$$

Which is less than one

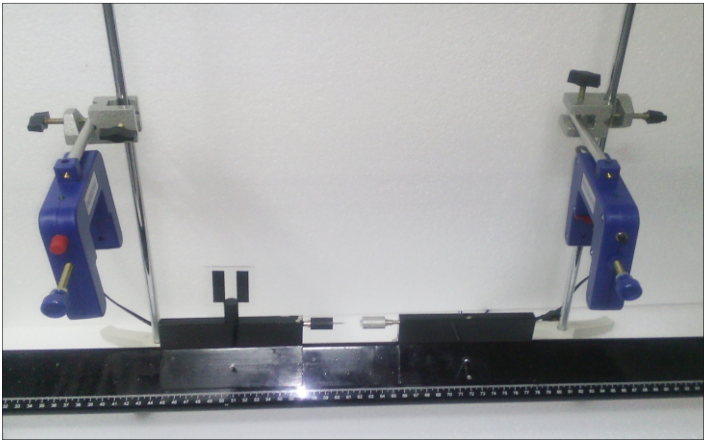
If $m_1 = m_2 = m$

then $$\frac{Kf}{Ki} = \frac{1}{2}$$

Set the Timer in collision 2 mode

Assemble the items of experiment - 3 as shown fig.-C.

Attach plug with pin to one vehicle and plug with clay to the other vehicle. Place the two photogates 25-30cm a port. Place one vehicle in between the photogates and keep it stationary. Place another vehicle at one corner of the air track and mount the 2b-picket over it. The plugs attached to the vehicle should point to each other. Push the second vehicle towards the stationary vehicle. After crossing the nearby photogate, it sticks to the stationary vehicle and crosses the second photogate. Note that Velocity of the combined vehicle as indicated by timer is nearly equal to half of the initial velocity u_1 of m_1.

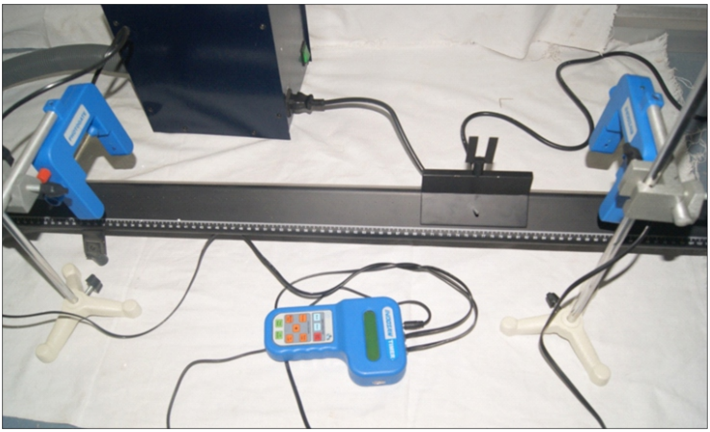


Picture-C

EXPERIMENT 4: TO STUDY THE CONCEPT OF VELOCITY.

CONTENTS:

S. No.	**Items Name**	**Qty.**
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	1
9.	Weight	4
10.	2 - b - picket	1



Picture-D

Velocity is directly proportional to displacement

Because PE ($=\frac{1}{2}kx^2$) = K.E ($=\frac{1}{2}mv^2$)

Set the timer on velocity mode . Assemble the items mentioned in exp 3 as shown in picture-D.
Mount the plug with card on vehicle and note down the velocities using different displacement and putting different weights on vehicle. Note that greater is displacement, more is the velocity. Also smaller is the velocity greater is mass

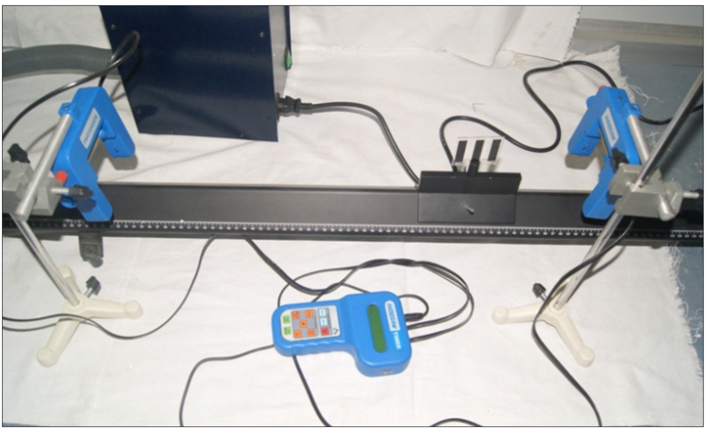
EXPERIMENT-5 : TO STUDY THE CONCEPT OF ACCELERATIONS
CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	1
9.	Weight	4
10.	3-b- picket	1

Increase elevation of one side of track with leveling screws, provided at the bottom of the track.

Set the timer in acceleration mode. Assemble the items mentioned in exp-5 as shown in picture-E. Mount the plug with slit on vehicle and note down the acceleration using different weights on vehicle.

Note: Greater is the elevation of track of one side greater is the acceleration.



Picture-E

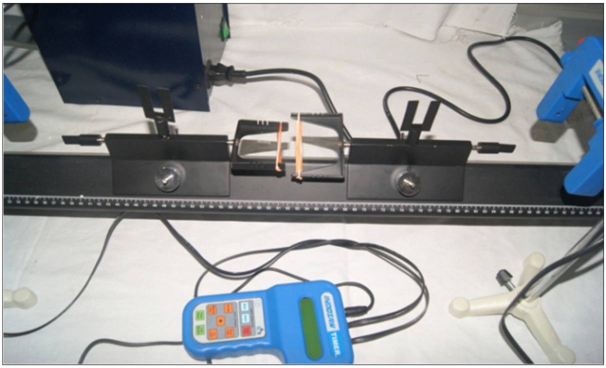
EXPERIMENT 5 : TO STUDY THE CONVERSATION OF MOMENTUM.

CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	1
9.	Weight	4
10.	Fork with rubber band	2
11.	Steel strip	2
12.	Plug with 2b-picket strip	2

Conversation of momentum:

Set the timer in Collision 2 mode. Assemble the items mentioned in experiment 5 as shown in picture-F.



Picture-F

Do as in experiment - 2 and verify **the relation of conservation of momentum**.

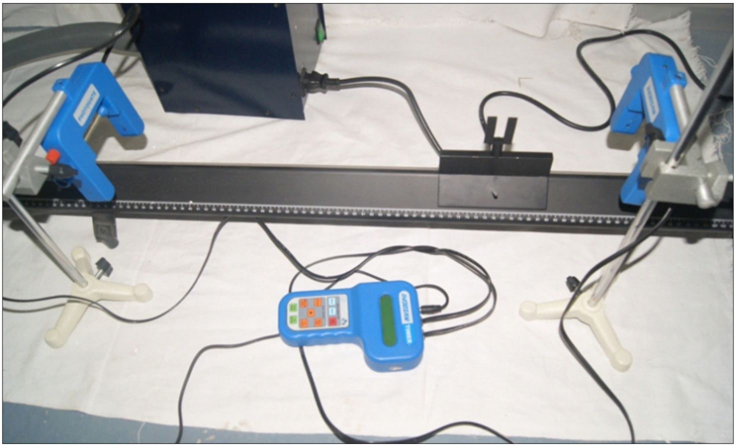
$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

EXPERIMENT 6:TO STUDY THE DEPENDENCY OF KINETIC ENERGY ON MASS..

CONTENTS:

S. No.	Items Name	Qty.
1.	Linear track	1
2.	Timer	1
3.	Photogate	2
4.	RJ11 cables	2
5.	A base stand with rod	2
6.	Boss head	2
7.	Blower with hose pipe	1
8.	Vehicle	1
9.	Weight	4
10.	2b-picket	1

Set the timer in velocity mode and assemble the itmes mentioned in experiment 6 as shown in picture-H below .Calcute the kinectic energy by formula K.E=1/2mv2 . Use different masses on vehicles to see the effect of mass and velocity on K.E



Picture-G

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User's Manual

PLANCK'S CONSTANT MEASURING SET-UP
Model: PC-101
(Rev : 01/04/2010)

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COPYRIGHT NOTICE

LIMITED WARRANTY

SES Instruments Pvt. Ltd warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. SES Instruments Pvt. Ltd will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of manufacturing defect or improper use by the customer shall be made solely by SES Instruments Pvt. Ltd. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packaging of the equipment for return shipment will not be covered by the warranty). Shipping costs for returning the equipment, after repair, will be paid by SES Instruments Pvt. Ltd.

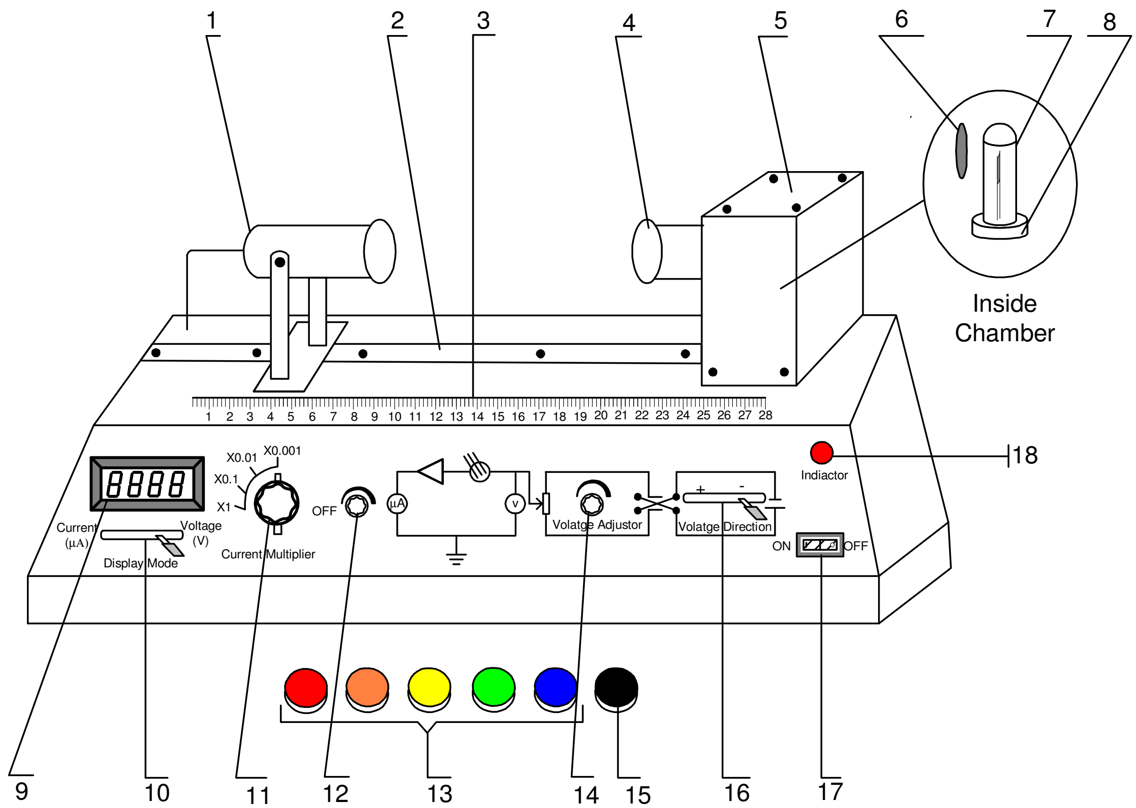
EQUIPMENT RETURN

Should this product have to be returned to SES Instruments Pvt. Ltd, for whatever reason, notify SES Instruments Pvt. Ltd BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

Note : No equipment will be accepted for return without an authorization.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

1. The carton must be strong enough for the item shipped.
2. Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.
3. Make certain that the packing material can not displace in the box, or get compressed, thus letting the instrument come in contact with the edge of the box.



1-Light source, 2-Guide, 3-Scale, 4-Drawtube, 5-Cover, 6-Focus lens, 7-Vacuum Phototube, 8-Base for holding the Phototube, 9-Digital Meter, 10-Display mode switch, 11-Current multiplier, 12-Light intensity switch, 13-Filter set, 14-Accelerate voltage adjustor, 15-Lens cover, 16-Voltage direction switch, 17-Power switch, 18-Power indicator.

Panel Diagram of Planck’s Constant Experiment, PC-101

PACKING LIST

1. Planck's Constant measuring Set-up, PC-101: One
2. A Set of Filters:
   (i) Red: One
   (ii) Yellow I: One
   (iii) Yellow II: One
   (iv) Green: One
   (v) Blue: One
3. Lens Cover : One

MAJOR COMPONENTS OF SETUP

a. **Photo Sensitive Device**: Vacuum photo tube.
b. **Light Source**: Halogen tungsten lamp 12V/35W.
c. **Color Filters**: Red (635nm), Yellow – I (570nm), Yellow – II (540nm), Green (500nm) & Blue (460nm).
d. **Accelerating Voltage** : Regulated Voltage Power Supply

Output	:	± 15 V continuously variable through multi-turn pot
Display	:	3 ½ digit 7-segment LED
Accuracy	:	±0.2%

e. **Current Detecting Unit** : Digital Nanoammeter
It is high stability low current measuring instrument

Range	:	X 1μA, 0.1μA, 0.01μA & 0.001μA with 100% over ranging facility
Resolution	:	1nA at 0.001μA range
Display	:	3½ digit 7-segment LED
Accuracy	:	± 0.2%

f. **Power Requirement**: 220V ± 10%, 50Hz.
g. **Optical Bench:** The light source can be moved along it to adjust the distance between light source and phototube scale length is 400 mm. A drawtube is provided to install color filter; a focus lens is fixed in the back end.

BRIEF DECRIPTION OF APPARATUS REQUIRED

1. **Light source :** 12V/35W halogen tungsten lamp.
2. **Guide :** Move the light source along it, the distance between light source and dark box chamber can be adjusted.
3. **Scale :** 400mm total length. The center of the vacuum phototube is used as zero point.
4. **Drawtube :** The forepart is used for installing color filter; a focus lens is fixed in the back end.
5. **Cover :** Used to cover chamber containing Phototube.
6. **Focus lens :** Make a clear image of light source on the cathode area of phototube.
7. Vacuum Phototube.

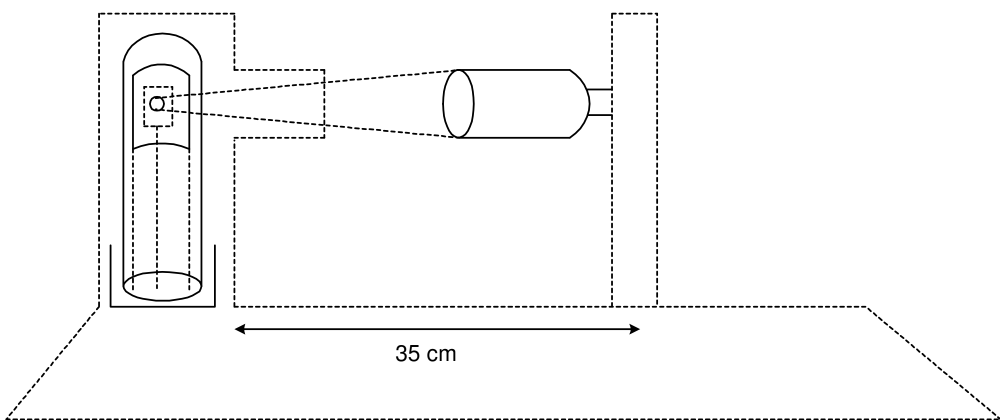


Fig. 1

8. Base for holding the Phototube
9. **Digital meter :** Show current (μA), or voltage (V).
10. **Display mode switch :** For switching the display between voltage and current mode.
11. Current Multiplier.
12. **Light intensity switch :** Switch for choosing light intensity. Up is for strong, middle is for off; down is for weak.
13. Filter set : Five pieces
14. **Accelerate voltage adjustor :** Knob for adjusting accelerating voltage.
15. **Lens Cover :** (For protecting the phototube from stray light during ideal period)
16. **Voltage direction, switch :** Switch for choosing voltage direction. ±15V accelerating voltage is provided.
17. Power switch.
18. Power indicator.

INSTALLATION AND ADJUSTMENT

1. Open the carton and takeout the apparatus. Put it on the table, open the top cover (5) and take out all the packing material around the phototube.
2. Install the phototube (7) on its base (8) such that the cathode plate of the tube faces the lens (if already not installed or loose). See that the phototube is sitting firmly in its base and is not inclined or loose.
3. Adjust the light source (1) such that light is parallel to the guide (2) and maximum lights falls directly on drawtube (4).
4. Slide the light source (1) to about 350 mm position. Set light switch (12) to medium intensity. The light should shine on the middle area of the phototube cathode plate as shown in figure 1. If required user can make slight adjustment in the position of phototube by moving it gently too and for in its base to get a maximum current display, while other conditions are not changed.
5. Cover the phototube chamber by screwing back its cover (5).
6. Put the lens cover to stop the light and check the dark current to ≤ 0.003μA. Now all parts of the instruments are tested and adjusted.
7. Now adjust the light source (i) to about 250 mm position (optional). Set light switch (12) at medium to maximum intensity and take reading as per procedure given.

EXPERIMENT 1

Determination of Planck's Constant

Theory:

It was observed as early as 1905 that most metals under influence of radiation, emit electrons. This phenomenon was termed as photoelectric emission. The detailed study of it has shown.

1. That the emission process depends strongly on frequency of radiation.
2. For each metal there exists a critical frequency such that light of lower frequency is unable to liberate electrons, while light of higher frequency always does.
3. The emission of electron occurs within a very short time interval after arrival of the radiation and member of electrons is strictly proportional to the intensity of this radiation.

The experimental facts given above are among the strongest evidence that the electromagnetic field is quantified and the field consists of quanta of energy E= $h\nu$ where ν is the frequency of the radiation and h is the Planck's constant. These quanta are called photons.

Further it is assumed that electrons are bound inside the metal surface with an energy $e\phi$, where ϕ is called work function. It then follows that if the frequency of the light is such that

$$h\nu > e\phi$$

it will be possible to eject photoelectron, while if $h\nu<e\phi$, it would be impossible. In the former case, the excess energy of quantum appears as kinetic energy of the electron, so that

$$h\nu = \frac{1}{2}mv^2 + e\phi \qquad (1)$$

which is the famous photoelectrons equation formulated by Einstein in 1905.

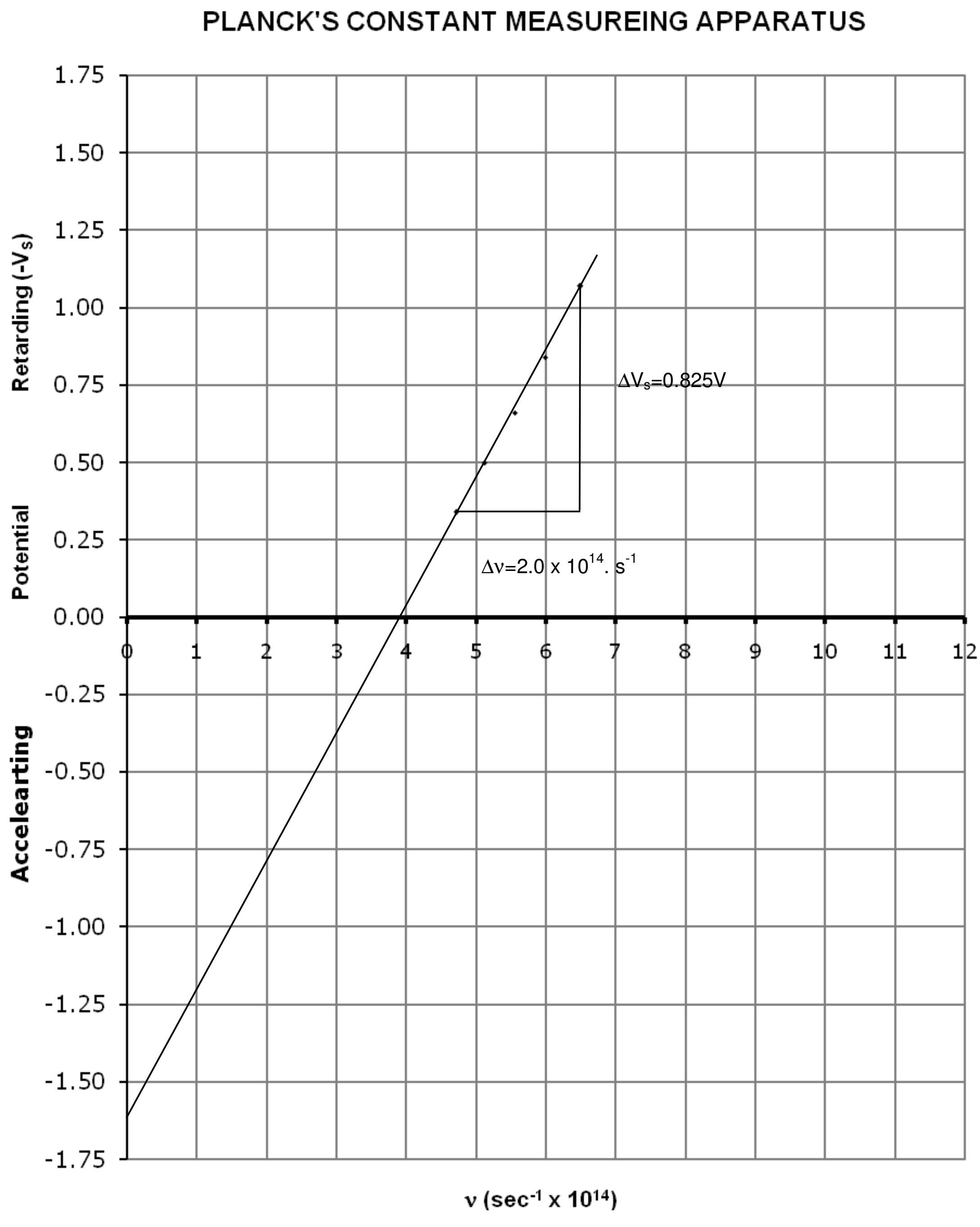
The energy of emitted photoelectrons can be measured by simple retarding potential techniques as is done in this experiment. Retarding potential at which the photo current stop, we call it stopping potential V_s and is used to measure kinetic energy of electrons E_e, we have,

$$E_e = \frac{1}{2}mv^2 = eV_s \quad \text{or} \quad V_s = \frac{h}{e}\nu - \phi$$

So when we plot a graph V_s as a function of ν, the slope of the straight line yields $\frac{h}{e}$ and the intercept of extrapolated point ν=0 can give work function ϕ.

PROCEDURE

1. Insert the red color filter (635 nm), set light intensity switch (12) at strong light, voltage direction switch (14) at `-', display mode switch (10) at current display.
2. Adjust to de-accelerating voltage to 0 V and set current multiplier (4) at X 0.001. Increase the de-accelerating to decrease the photo current to zero. Take down the de-accelerating voltage (V_s) corresponding to zero current of 635 nm wavelength. Get the Vs of other wave lengths, in the same way.


PLANCK'S CONSTANT MEASUREING APPARATUS
Retarding (-Vs)
Potential
Accelearting
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
0
1
2
3
4
5
6
7
8
9
10
11
12
ΔVs=0.825V
Δν=2.0 x 10^14. s^-1
ν (sec^-1 x 10^14)

OBSERVATIONS

S. No	Filters	ν (sec^{-1} x 10^{14})	Stopping Voltage (V)
1	Red (635 nm)	4.72	- 0.34
2	Yellow I (585 nm)	5.13	- 0.50
3	Yellow II (540 nm)	5.56	- 0.66
4	Green (500 nm)	6.00	- 0.84
5	Blue (460 nm)	6.50	- 1.07

CALCULATIONS

Planck's Constant: $h = e\frac{\Delta V_s}{\Delta \nu}$

Where e is the charge of electron

By putting the value of ΔV_s & $\Delta \nu$ from graph

$$h = 1.602 \times 10^{-19} \times \frac{0.825}{2.00 \times 10^{14}}$$

$= 1.602 \text{ x } 10^{-19} \text{ x } 0.413 \text{ x } 10^{-14}$

$= 6.61 \text{ x } 10^{-34}$ Joules sec.

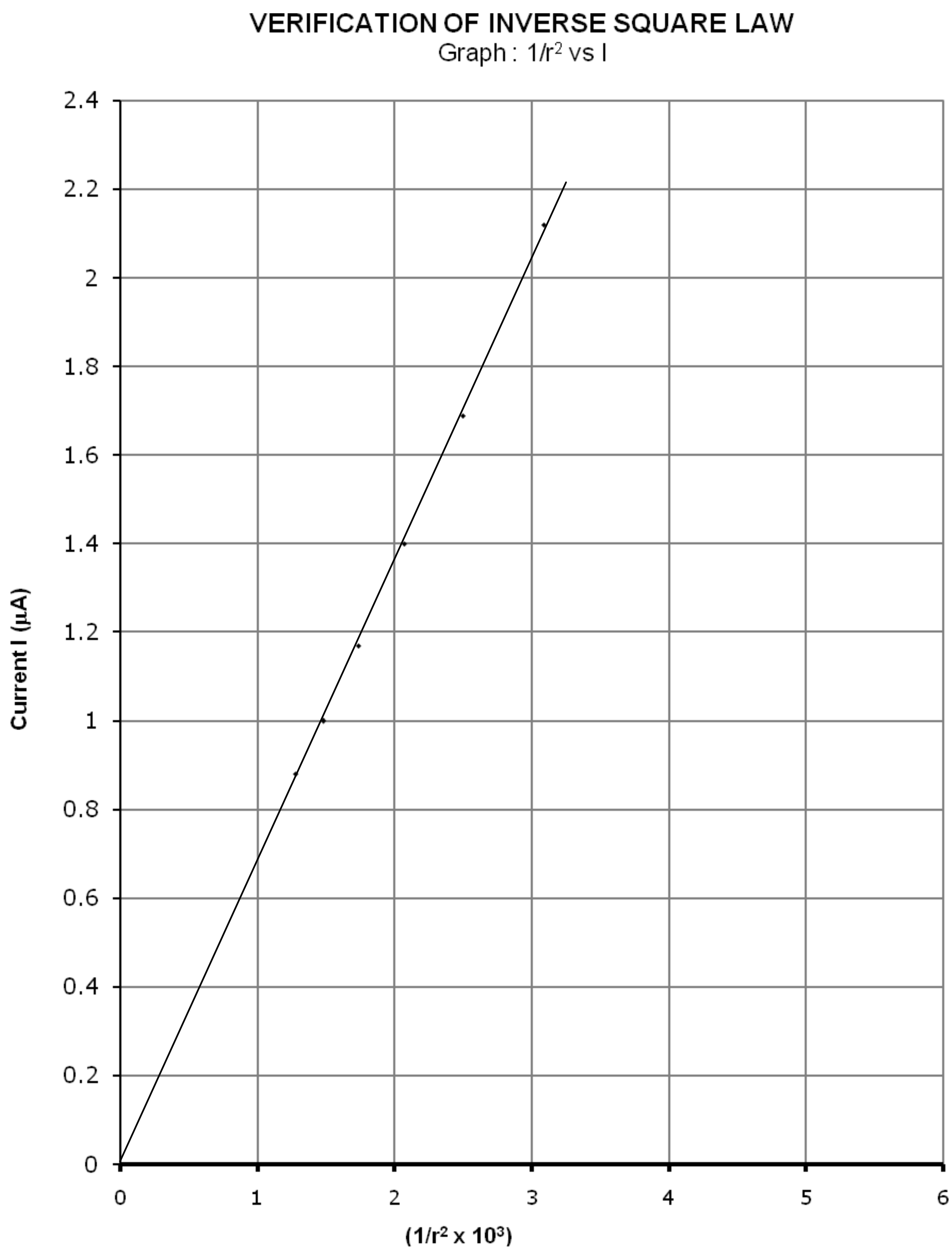
From Graph 1 intercept at $\nu = 0$ the value of

$\phi = 1.625$ V

Compared with accepted value of $h = 6.62 \text{ x } 10^{-34}$ Joules. sec. the results are well within accepted error range.

PRECAUTIONS

1. This instrument should be operated in a dry, cool indoor space.
2. Phototube particularly should not be exposed to direct light, particularly at the time of installation of phototube; the room should be only dimly lit.
3. The instrument should be kept in dust proof and moisture proof environment, if there is dust on the phototube, color filter, lens etc. clean it by using absorbent cotton with a few drops of alcohol.
4. The color filter should be stored in dry and dust proof environment.
5. After finishing the experiment remember to switch off power and cover the drawtube (4) with the lens cover (15) provided. Phototube is light sensitive device and its sensitivity decreases with exposure to light, due to ageing.


VERIFICATION OF INVERSE SQUARE LAW
Graph : 1/r2 vs I
Current I (μA)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
(1/r2 x 103)

Indian Institute of Information Technology Vadodara

Laboratory Manual: Physics-PH101

Objective: Study of damped harmonic oscillation.

Theory:

An ideal harmonic oscillator is frictionless and keep oscillating with its natural frequency $\omega_o^2 = k/m$ where k is the spring constant and m is the mass of the oscillator. However, when friction force is present then the harmonic oscillator damps. Let a given harmonic oscillator is executing oscillation in a medium (such as air, water, oil or glycerin etc.) in which it is experiencing viscous friction force $f_{fric.} = -bv$ where b is the damping constant and v is the instantaneous velocity of the oscillator. The equation of motion will be

$$\ddot{x} + \gamma\dot{x} + \omega_o^2 x = 0$$

where $\gamma = b/m$ called damping parameter, and $\omega_o^2 = k/m$ is the natural frequency of oscillation when there is no frictional force. The solution of the differential equation is

$$x(t) = X_o e^{-t/\tau} Cos\,(\omega_1 t + \varphi)$$

where X_o is arbitrary constant, $\tau = 2/\gamma$ is time constant of exponential decay of amplitude, $\omega_1 = \sqrt{\omega_o^2 - (\gamma/2)^2}$ is the frequency of oscillation and φ is the phase factor.

Now, analyzing the decay profile of the amplitude of damped oscillation, one can estimate the value the value of damping parameter γ. Using the value of γ one can determine damping constant b of the medium. In addition, knowing the time period of damped oscillation one can determine the frequency of oscillation (i.e., using $\omega_1 = \frac{2\pi}{T_1}$,) and thereby the natural frequency of oscillation ω_o can be determined. Using the determined value of $\omega_o$one can also estimate the value of spring constant k of the harmonic oscillator.

Observation Table:

(I) Time vs angular displacement for different masses

Sr. No	M_1 = _____ gm		M_2 = _____ gm		M_3= _____ gm	
	Time	Angular Displacement	Time	Angular Displacement	Time	Angular Displacement

(II) Variation of Amplitude with time for different masses

Sr. No	M_1 = ____ gm		M_2 = ____ gm		M_3= ____ gm	
	TIME	Maxima	TIME	Maxima	TIME	Maxima

Analysis of data and results:

1. Decaying profile of the amplitude of oscillation with varying masses

Mass	Time constant (τ)	Damping parameter (γ)	Damping constant (b)

Average damping constant b = ……………………………

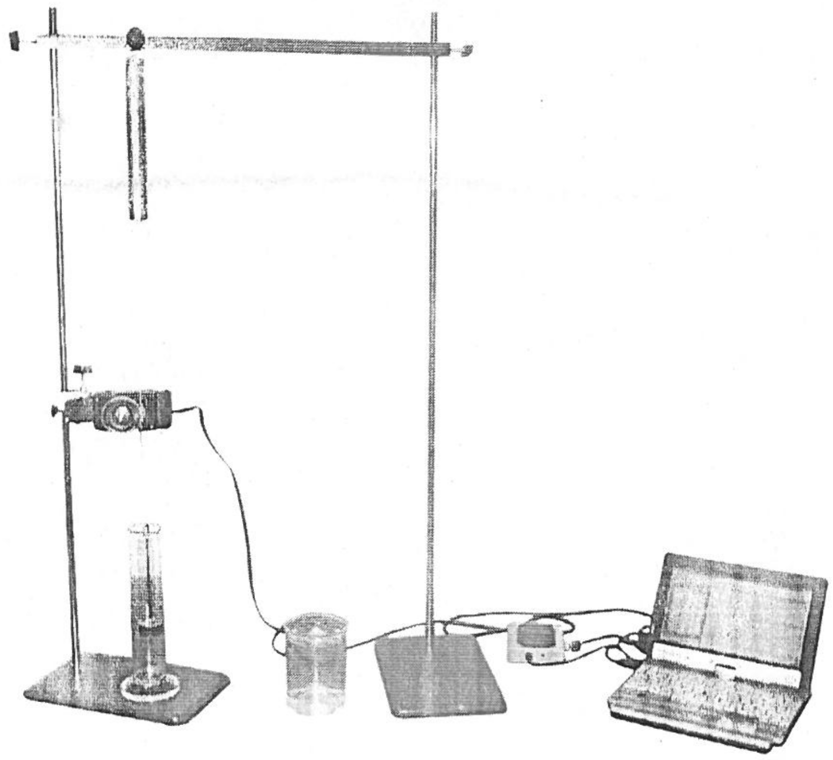
2. Time-Period of Oscillation of different Masses

Mass	Time period (T_1)	Frequency (ω_1)	Natural Freq. (ω_0)	Spring constant (k)

Average spring constant k = ……………………………

EXPERIMENT (A) DAMPING IN VARIOUS MEDIUMS LIKE AIR, GLYCERIN, WATER

Objective: To investigate the damping effect of air, water and oil or glycerin on an oscillating spring.



Principle: For a damped oscillation, energy is lost to overcome the resisting forces i.e. damping forces, such as air resistance, viscosity and friction. In different media, the strength of resisting forces varies, so does the extent of damping.

EQUIPMENT AND MATERIALS

PC x1, Datalogging interface × 1, Rotary Sensor × 1, spring × 1, 50 gram mass set × 1 Retort stands Assembly × 1, Beakers × 1, and Glycerine

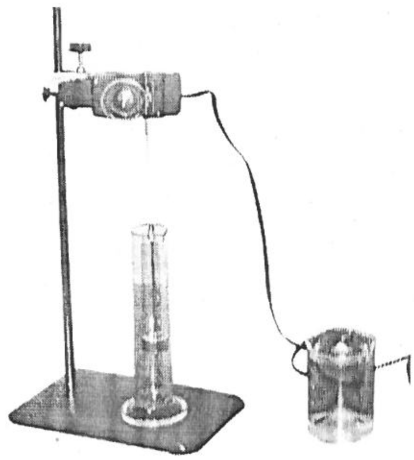
SET-UP PROCEDURE

Photograph showing set-up of oscillating spring, rotary sensor and datalogger

1. Hang a spring from a support rod on retort stand beam and attach to its lower end the pulley of a rotary sensor.
2. A mass set is hung from its lower end through thread.
3. Adjust its position of rotary sensor so that its pulley is horizontal and the springs are vertical.
4. Connect the rotary motion sensot to Datalogger interface DIG-1 OR DIG 2 Port.

5. Connect PC to Datalogger.

6. Open the Logger Pro-3 software from START>ALL PROGRAMME> VERNIER SOFTWARE>LOGGER PRO 3.X.X.X.



7. Click to EXPERIMENT> SETUP SENSOR>LABQUEST MINI 1: >DIG/SONIC1 OR DIG/SONIC2> Select CHOSE SENSOR> ROTARY SENSOR.

8. Go to MENU>Experiment>DATA COLLECTION and set the desired parameters.

9. Extend the spring by pulling the mass set downwards, and then release it.

10. Record the movement of the system on the computer.

11. Plot a graph of amplitude of oscillation against time.

12. Repeat steps 9 to 11 with the mass set completely immersed in a beaker of water and a beaker of oil.

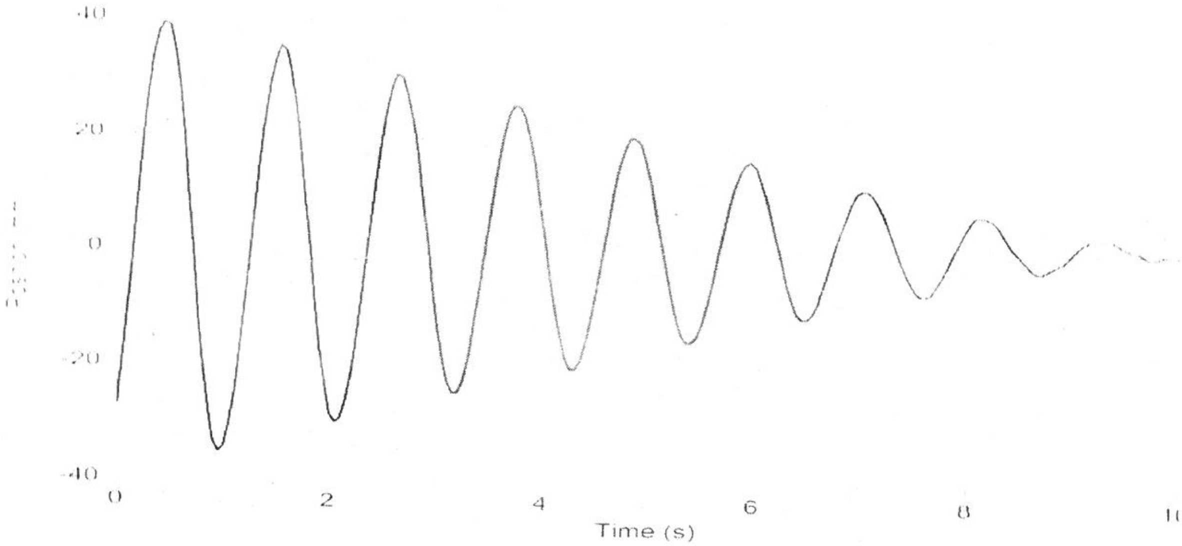
13. Compare the three graphs obtained.

PRECAUTIONS

1. As the maximum range of the angle of the rotary sensor position is 0° - 360°, the amplitude of oscillation should be kept small.
2. Make sure that the mass set is oscillating totally within the water and the oil.

RESULTS

A. **Air** Graph showing oscillation of spring in air

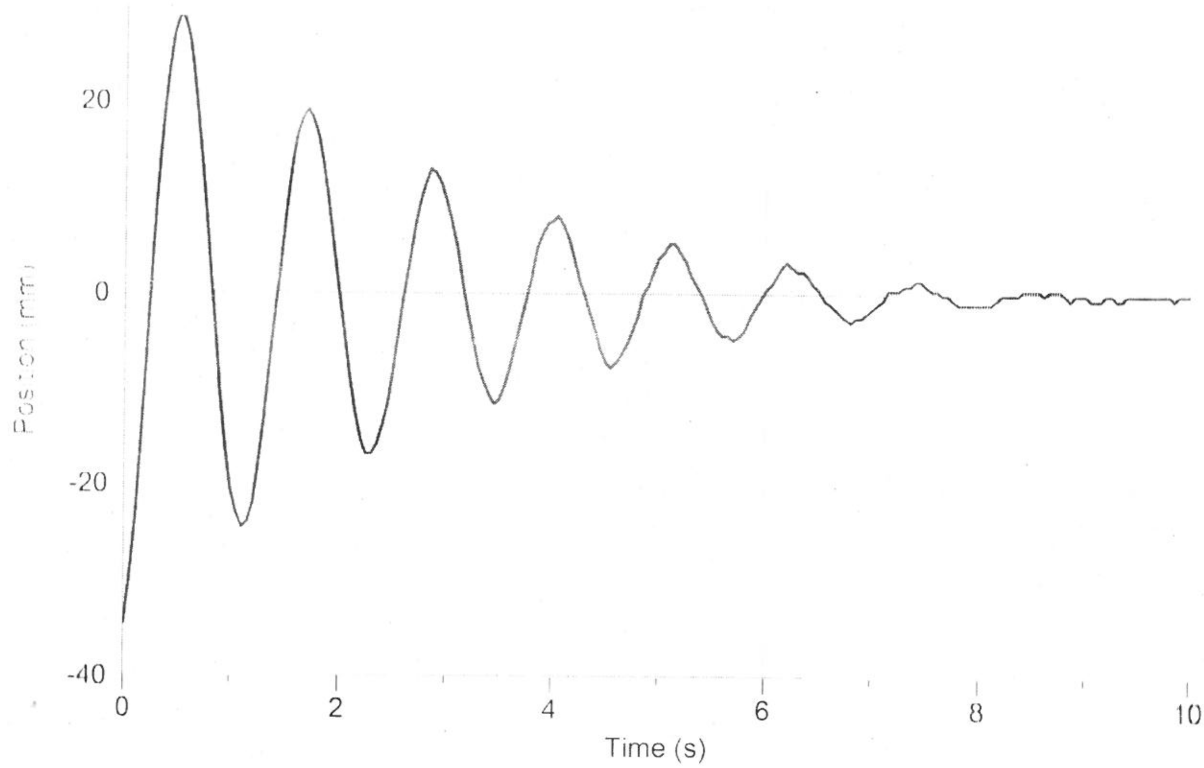


TIME	AMPLITUDE (MM)		CORRESPONDING RATIO	
0.40	A1	38.9		
1.50	A2	35.0	A1/A2	1.11
2.60	A3	30.2	A2/A3	1.16
3.75	A4	25.0	A3/A4	1.21
4.85	A5	19.7	A4/A5	1.27
5.95	A6	15.8	A5/A6	1.25
7.05	A7	11.0	A6/A7	1.44
8.10	A8	6.70	A7/A8	1.64
9.25	A9	2.90	A8/A9	2.31

In air, the oscillation was slightly damped. The amplitude died away gradually. The oscillation lasted for about 8 cycles, or 10s. The corresponding ratios were gradually increasing in order from 1.11 to 2.31. and average ratio 1.24 for 6 cycle.

Water

Graph showing oscillation of spring in water

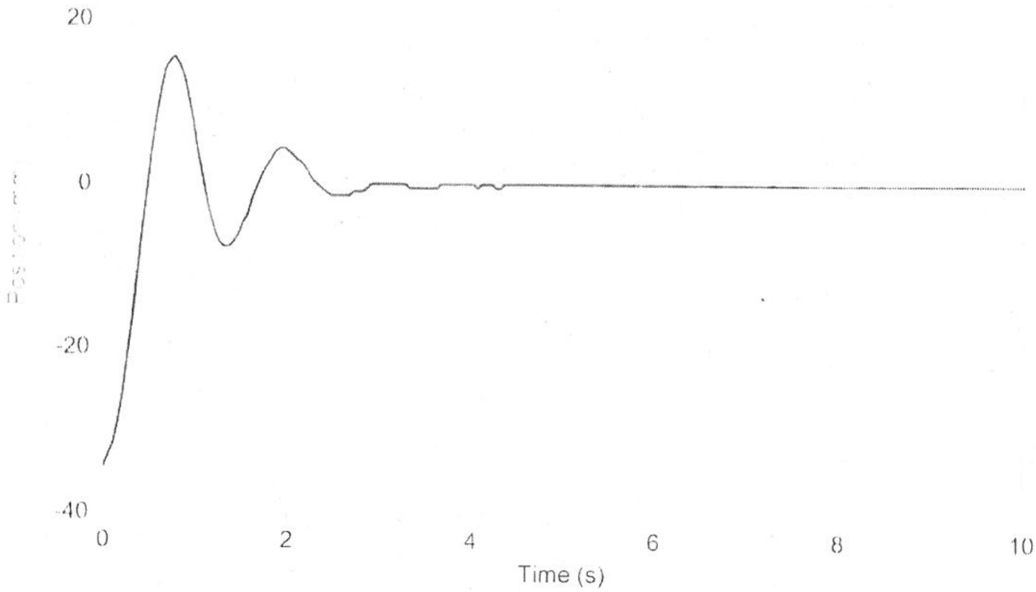


TIME	AMPLITUDE (MM)		CORRESPONDING RATIO	
0.50	A1	28.8		
1.70	A2	19.2	A1/A2	1.50
2.85	A3	13.0	A2/A3	1.48
4.05	A4	8.20	A3/A4	1.59
5.10	A5	5.30	A4/A5	1.55
6.20	A6	3.40	A5/A6	1.56
7.45	A7	1.40	A6/A7	2.43

In water, the oscillation was also slightly damped, but the oscillation lasted for only about 5 cycles, or 6s. Compared with the oscillation in air, the corresponding ratios were of a larger constant, around 1.53 for 6 cycles. It showed that the amplitude of oscillation decreased at a faster rate in water.

Glycerin

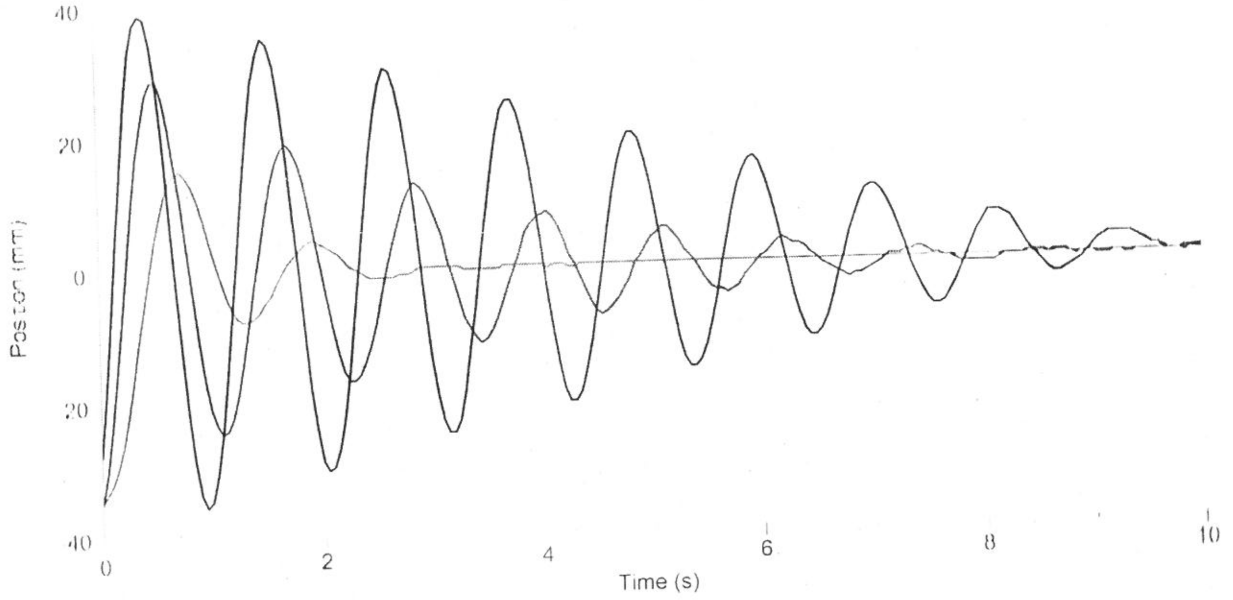
Graph showing the oscillation of spring in Glycerin



In Glycerin, the motion was heavily damped. The system returned to the equilibrium position in less than 3s and remained stationary afterwards. No oscillation could be observed.

CONCLUSION

Media Corresponding ratio: Air 1.24, Water 1.53, and Glycerin (no oscillation)



EXPLANATION

In air and water, where the resisting forces were smaller, energy was dissipated at slower rates. Oscillations were still allowed, but with gradually decreasing amplitudes. These are called light dampings.

Since the resisting force in water was greater than that in air, the damping effect in water was stronger. Thus, in water, the rate of decrease in the amplitude of oscillations was faster and the oscillation took a shorter period of time to come to an end.

Glycerin, being more viscous than water, exerted a greater damping force; energy was dissipated at a faster rate. The system returned to the equilibrium position without oscillating. This is called heavy damping.

CONCLUSIONS

Different damping effects were observed when the spring oscillated in different media. Under light damping, the system oscillated with decreasing amplitude and finally came to rest. The amplitude decreased with a constant ratio over the same period of time. Under heavy damping, the system returned to equilibrium without oscillation.

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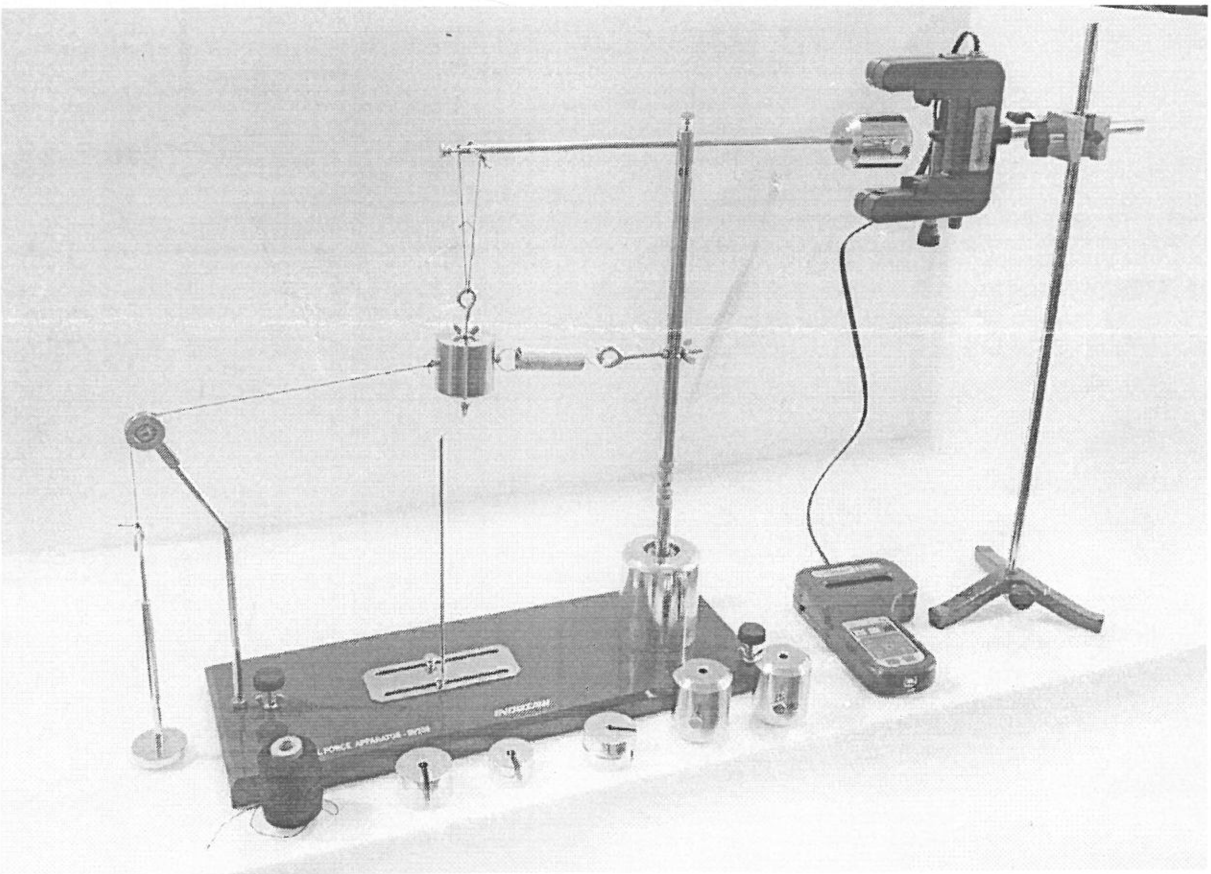
INSTRUCTION MANUAL
FOR
CENTRIPETAL FORCE APPARATUS
AND
MOMENT OF INERTIA ACCESSORY



NOTE: Before operating the Experiment Read this manual.

Manufacturer :

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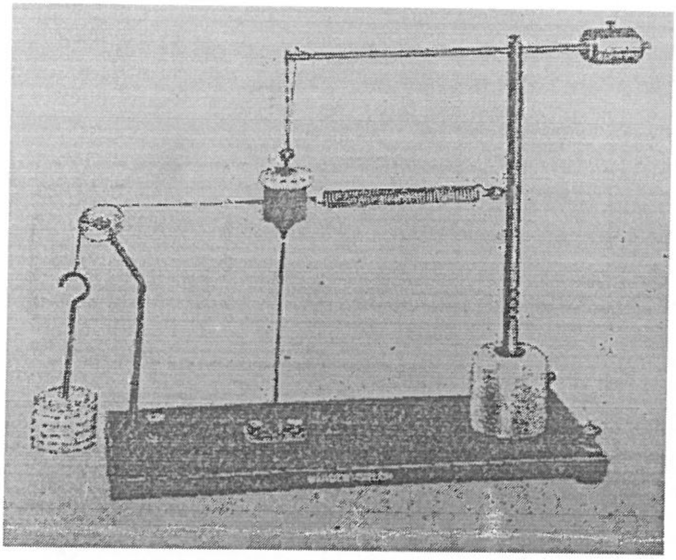
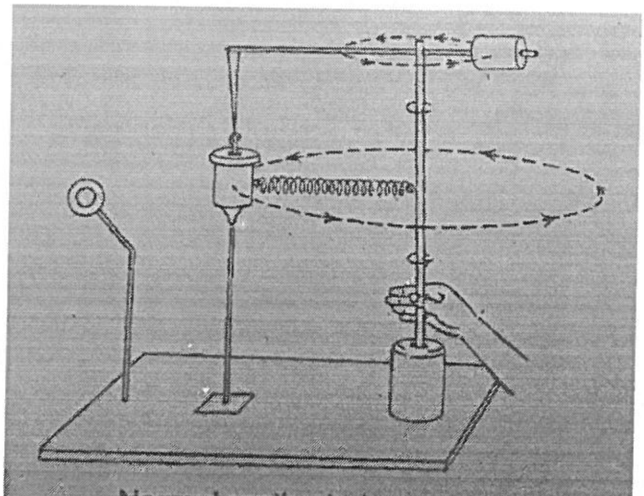
DESCRIPTION:

The Centripetal force apparatus is intended for the study and verification of the law of force for uniform circular motion. It consist essentially of a heavy mass bifilarly supported from a cross-arm attached to a vertical shaft. The shaft is supported in a metal housing on a wooden base. Radial and thrust bearings permit the shaft to rotate freely without wobbling. The cross-arm is counter balanced. An adjustably positioned vertical rod mounted on the base serves as a radius indicator. A ball bearing pulley mounted on a rod near one end of the base is used in measuring the force exerted by a spring with which the mass is coupled to the shaft. A supply of cord, a coiled spring, a 50gram weight hanger and a metal hook are supplied.





Normal method of operation

The Moment of inertia accessory consist of a threaded rod 34 cm long and four wing nuts. This accessory can be used to study angular acceleration, to determine the moment of inertia of a body, and to study of dependence of the moment of inertia on this mass of the body and on the distance of the body from its center of rotation.

ASSEMBLING THE APPARATUS:

The apparatus is shipped disassembled. Attach the metal housing and shaft to the wooden base with three flat-headed screws. Secure the cross-arm to the vertical shaft and attach the counter-balance to one end of the cross-arm. Mount the indicator rod on the wooden base and secure with the thumbscrews. Note that its position may be adjusted radially. Attach the pulley and its support rod to the base.

Cut a two-foot length of cord and make a firm knot at one end. Thread the cord downward through the hole in one end of the small cross rod and then upward through the hole in the other end. Holding the free end of the cord, hang the heavy mass on the loop. Now adjust the length of the loop until the bluntly pointed tip of the mass clears the indicator by1 or 2mm. Secure the cord by wrapping it under the ends of the small cleat on the cross-arm.

Orient the mass on the screw eye so that when it is hanging freely the small lugs on opposite sides of the mass are in line with the shaft and pulley. Then lock the mass and screw eye together with the knurled nut. Connect the mass to the vertical shaft by the coiled spring. Attach the weight pan to the mass by a length of cord passing over the pulley, using the small metal hook for fastening the cord to the mass. Add weights to the pan until the mass is hanging vertically downward, and adjust the height of the pulley until the cord is approximately horizontal. Disconnect the weight pan from the mass and adjust the leveling screws in the base until the rotating shaft is vertical. When the shaft is vertical there will be no tendency for the system to rotate after it has been stopped in any angular position. The apparatus is now ready for use.

THEORY:

When a body is caused to revolve in a circle with uniform velocity, the resultant in- ward force on the body is called "**centripetal**" force. The centripetal force produces an inward radial acceleration,a, given by Newton's Second law, Equation 1:

$$F = m * a \qquad \text{.................(1)}$$

In which m is the mass of the revolving object.

Since $\mathbf{a = v^2 / r}$ and $\mathbf{v = 2 \pi n r}$,

$$F = 4\pi^2 m n^2 r \qquad \text{....................(2)}$$

For this dynamic configuration the spring force F provides the Centripetal force. In the static configuration the spring is stretched by the same amount r by the weight Mg. The spring force is

$F = Mg$

The spring force will be the same in both static and dynamic configuration hence

$$Mg = 4\pi^2 m n^2 r = m r \omega^2 = m r \frac{(2\pi)^2}{T}$$

where r is the radius of the circular path, and n is the number of revolutions per second.
Equation (2) is the working equation for this apparatus. If m is in grams and r is in centimeters, F will be dynes. If m is in kilograms and r is in meters, F will be in newtons.

PROCEDURE:

The object of this experiment if to verify Equation 2 for several values of m and r by comparing the computed value of the centripetal force using this equation with the static force required to displace the mass to the same radial position. While the exact method of accomplishing this is left to the instructor, the following suggestion may be helpful:

1. In any given trial, the position of the cross-arm and radial indicator rod must be such that the heavy mass hangs freely exactly over the indicator, when the spring is detached. Therefore when changing the radius of rotation, both indicator and cross-arm must be moved correspondingly. It will be observed that the location of the counter-balance on the cross-arm is not critical.
2. The radius of rotation is the distance from the center of the top of the radius indicator to the axis of the vertical shaft. To obtain this value, add one-half the diameter of the shaft—as measured with a vernier caliper—to the distance from the shaft to the center of the top of the indicator—as measured with the metal ruler.
3. Determine the mass of the revolving object with a trip scale or laboratory balance. To change this value, add slotted weights. Place these weights on the mass with the open end of the slot outward and secure in place with the knurled nut. Up to 100g may be added.
4. A piece of white paper located to provide a light background is helpful in seeing that the rotating mass passes exactly over the indicator. Rotate the system by applying torque with the fingers on the knurled portion of the shaft. With a little practice, the rotation rate can be adjusted to keep the mass passing directly over the indicator.
5. For an accurate determination of n, the rate of rotation, the time of 50 or more complete revolutions should be measured with a stopwatch or electric stop clock. It is desirable to make three or more trials and average the results.
6. It is suggested that equation 2 be tested for several values of the radius of rotation and likewise for two or more values of the mass. Note that the value of the centripetal force remains constant for different values of m—providing r remains constant—whereas it varies directly as r.

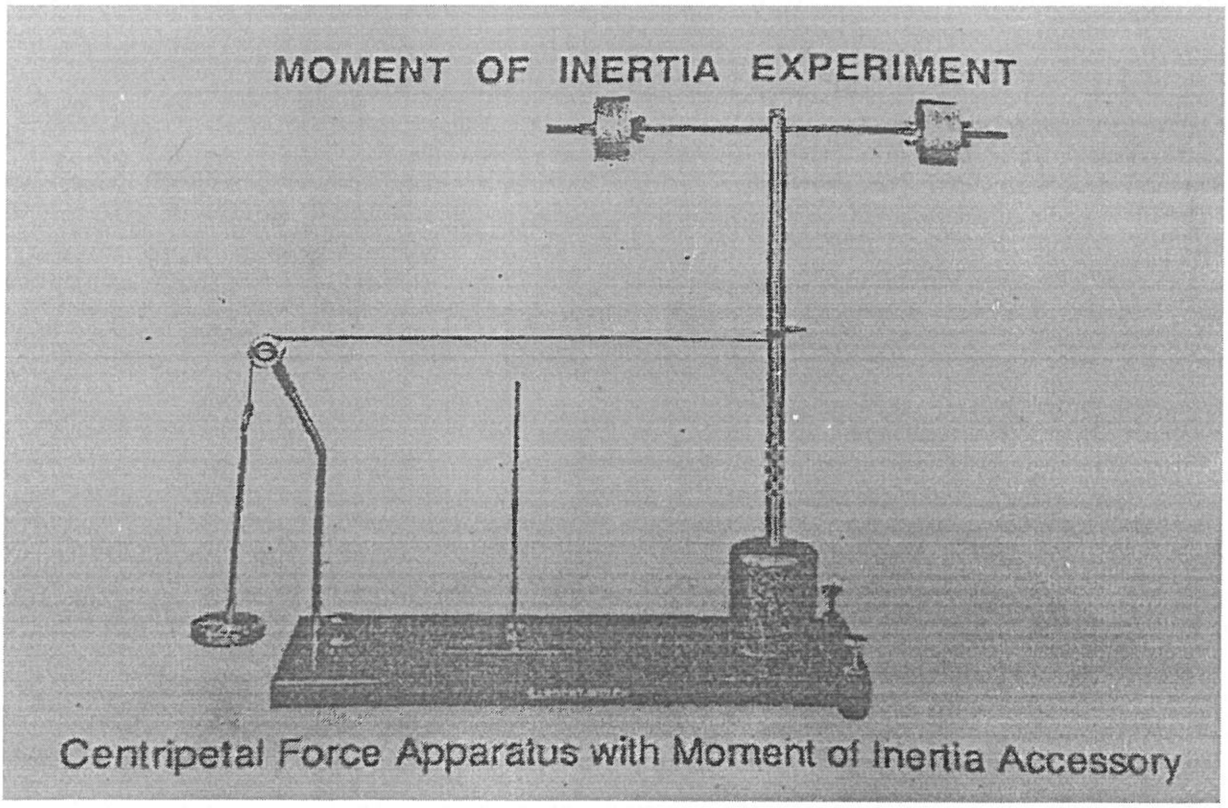
7. The velocity of fall v, the angular velocity w, and the radius of the vertical shaft r are related by:
   v = r w

The following form is suggested for recording results for comparison:

Trial No.	Mass (*g*)	Radius (mm)	rps	Froce Computed $F = mr\omega^2$ $where\ \omega = \frac{(2\pi)}{T}$	Force Measured F=Mg	% Difference
1						
2						
3						
4						

8. To provide greater variety in the experiment, springs with other force constants may be substituted for the one supplied.

Additional experiment **MOMENT OF INERTIA EXPERIMENT**



ASSEMBLING THE APPARATUS:

Remove the cross-arm and spring from the vertical shaft. Secure the moment of inertia rod at its center to the top of the vertical shaft. Use the wing nuts provided to secure a 100 gram slotted mass to each side of the rod about 12 cm from the center of the rod. Secure one end of a cord which is about 130 cm long to the screw in the vertical shaft and wind the cord evenly around the shaft. Pass the other end of the cord over the pulley, and attach a 100 gram mass to it.

THEORY:

The moment of inertia of a body can be determined as follows: The mass M whose moment of inertia is under study is attached to a vertical shaft of radius r by means of the moment of inertia rod. The vertical shaft is mounted on bearings which make it (and the mass M) free to rotate when a torque is applied to it. A torque is supplied by a falling mass m which is connected to the shaft by means of a cord, one end of which is wrapped around the circumference of the shaft and the other end of which is attached to the mass.

If the mass m starts from rest and falls through a distance h in time t, Potential energy of the amount mgh changes to kinetic energy. This kinetic energy consists of the translational energy of the falling mass ½ mv^2 plus the rotational energy of the rotating system ½ Iw^2

Where v is velocity of falling mass;
I is moment of inertia of rotating system;
w is angular velocity of rotating system;

The potential energy is equal to the kinetic energy, Equation 1:

$$mgh = \tfrac{1}{2} mv^2 + \tfrac{1}{2} Iw^2 \qquad \text{..............................(1)}$$

Because the force of gravity is a constant , the mass m will be uniformly accelerated and its velocity v, time of fall t, and distance of fall h are related by Equation 2:

$$v = 2h/t \qquad \text{..............................(2)}$$

The velocity of fall v, the angular velocity w, and the radius of the vertical shaft r are related by:

$$v = rw \qquad \text{..............................(3)}$$

Solving equation 1, 2, and 3 for moment of Inertia we get:

$$I = m\, r2\, (g\, t2 / 2\, h - 1) \qquad \text{..............................(4)}$$

The moment of Inertia of the rotating system I will be the sum of two parts, $I_0 + I_1$, where I_0 is the moment of inertia of the vertical shaft with rod and wing nuts attached, and I_1 is the moment of inertia of the load attached to the rod.

PROCEDURE:

1. Release the 100 gram mass and let it fall downward, causing the vertical shaft to rotate. Measure and record the following:

h –distance the accelerating mass falls;
T –time for the mass to fall the distance h;
m –magnitude of the accelerating mass;
r –radius of the vertical shaft;
R –distance of the slotted masses from the vertical shaft;
M –magnitude of the slotted mass.

2. Repeat the experiment several time to get a good value for t.
3. Remove the two100 gram masses from the moment of inertia arm, and again wind the cord; release the accelerating mass and measure the time t.
4. Use Equation 4 to calculate the moments of inertia of the rotating system with the additional mass(I) and without the additional mass (I_0). Subtract the two numbers to obtain the moment of inertia I_1 of the load alone.
5. Repeat steps 1,2, and 3 for various values of the mass M and R at 12 cm. Plot I_1, vs M for constant R.
6. Repeat steps 1, 2 and 3 for various values of R with a fixed M. Plot I_1, vs R for constant M.
7. When R is large compared to the dimensions of the object whose mass is M, I_1 is equal to $2MR^2$. Using this relation, calculate the moment of inertia I_1 for each value of M and R in steps 4 and 5. What is the difference as a percent of the experimental value of I_1?

NOTE: A manufacturing change has been made to alter the way the spring attaches to the vertical post. Instead of the eye-hook pictured, a threaded rod has been inserted through the vertical rod, to be used to tension the spring. Older units used as “S” hook to hold the spring. This new device allows better spring tensioning for better data.

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INTELLIGENT TIMER

It is based on microcontroller having crystal controlled time base to accurately measure the time intervals, speed and acceleration in various modes. It has built-in test function for the photogates. Least count resolution 0.1millisecond. It can also calculate acceleration due to gravity 'g'. Instrument is self contained that requires no computer. It can be used with Air track and trolley to comprehensively study several experiments on kinematics and dynamics. It is supplied with Photogate pair.

Salient Features: -

Time Modes

a) Using single gate
b) Using two gates
c) Stop-watch : measures time between pressing start/stop button.
d) Pendulum : measures pendulum period.
e) Fence : measures 10 time values

Speed Modes

a) One gate : Instantaneous
b) Two gates : Average
c) Collision - I : Initial & final speeds of the cart
d) Collision - II : Initial & final speeds of two carts
e) Pulley Lin : Linear speed of cart using pulley
f) Pulley Rad : Angular speed in radians/second
g) Pulley Rev : Angular speed in revolutions/second

Acceleration Modes

a) One gate : Instantaneous
b) Two gates : Average, Initial & Final
c) Pulley Lin : Linear acceleration with pulley
d) Pulley Ang : Angular acceleration
e) g - Free fall

Count Modes : Manual, 15 sec, 30 sec, 1 min, 5 min, 10 min time intervals.
Test Mode : Photogate - I & II Blocked/Unblocked indication.

Specifications: -

1) **Display** : 2x16 Characters alphanumeric LCD display
2) **Inputs** : Provision for four gates (Two pairs, each pair has two gates connected in 'OR' configuration)
3) **Keys** : 4 micro switches are provided for various functions
4) **Time Resolution** : 0.1ms

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HOW TO USE:

1. INTELLIGENT TIMER:

Connect power supply cord and Switch ON the power. The timer will show Time: Stop Watch on screen. This means the timer is ready to work. There are four keys below LCD Display.

i). MODE: Key is used to select the desired type of measurement (Time, Speed, Acceleration, Count, and Test). Press Mode key until desired type of measurement is displayed. The menu will roll over to the beginning after the last type is selected.

ii). SELECT: key is used to select the function, under given Mode. Press the select key until it shows the desired selected measurement e.g. one gate, two gate, pendulum, fence etc. under Time Mode and so on.

TIME	SPEED	ACCEL.	COUNT	TEST
Stop-watch	One Gate Instantaneous	One Gate	Manual	Lightgate-I
One Gate	Two Gates Average	Two Gates Average	15 Sec	
Two Gates	Collision-1	Initial-Final	30 Sec	
Pendulum	Collision-2	Pulley-Lin	1 Min	Lightgate-II
	Pulley-Lin	Pulley-Ang	5 Min	
Fence	Pulley-Rad	g-Free Fall	10 Min	
	Pulley-Rev			

Test Report

Exp. - 1. Comparision of applied force, producing centripetal force.

Observations:-

Formula Used Mg = $\frac{(4\pi^2 mr)}{T^2}$

Suspended mass M = 500 g = 0.5 kg

Mass to be rotated m = 456 g

Radius r = 15.1 cm

Time for 17 rotations = 12.86 seconds

Time Period T = $\frac{12.86}{17} = 0.76$

Applied force = F = Mg = 500x980 = 490000 dynes OR 4.9 N

Calculated Centripetal Force $F^I = \frac{456x15.1x4x3.14x3.14}{0.74^2}$

$= 47260.8$dynes or 4.73 newton

% error $= \frac{F-F^1}{F} x100 = 3.5$

where Mg = F^I

Exp-2 Determination of g :-

$$g = \frac{(4mr\pi^2)}{(T^2M)} = \frac{4.73}{0.5} = 9.46\, m/s^2$$

Exp. - 3. Determination of moment of inertia.

Observations

Falling Mass m = 550g

radius of vertical rod r = 0.65cm

g = 980cm/s^2

h = 74.5 cm

M = 545 g

(a). Total moment of inertia for complete system.

Falling time = 11.4 sec

$$I + Io = (mr^2)[\frac{(gt^2)}{(2h)} - 1]$$

$$= 550x(.65)^2 \left[\frac{980\, x\, (11.4)^2}{2x74.5} - 1\right] = 198378.5gcm^2$$

(b). Moment of Inertia without sides masses

Fallig time t = 2.2 sec

$$I_0 = 550x(.65)^2 980\, x \left[\frac{(2.2)^2}{2x74.5} - 1\right] = 7164.948gm^2$$

(c). Moment of inertia by expt of two moves m at distance of 13.8 cm from centre by expt

$I = I+I_0-I_0 = 191213.55g\ cm^2$

(d). Moment of inertia of both masses M by formula (numerically)

$I^1 = 2xMR^2 = 2x545x(13.8)^2 = 207579.6g\ cm^2$

Difference $\Delta I = I^1 - I = 16366g\ cm^{-2}$

error $= \frac{\Delta I}{I^1} x100 = 7.7$

Results may change slightly from instrument to instrument.

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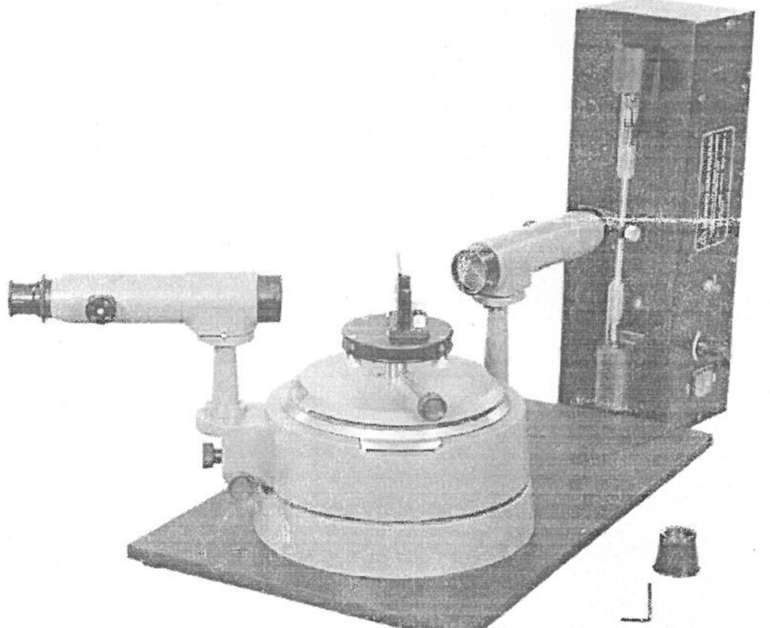
BALMER SERIES

Instruction Manual



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An ISO 9001 :2008 Certified Company

Aim:

1. To find the wave lengths of balmer series of visible emission lines .
2. To find the value of Rydberg Constant.

Scope of Supply:

S.No.	Item Name	Qty.
1.	Advanced Spectrometer (LC=20").	1
2.	Spectrum tube power supply.	1
3.	Hydrogen tube	1
4.	Diffraction grating (100 lines/mm, 300lines/mm, 600lines/mm)	1
5.	EDF glass prism (38 x 38mm)	1
6.	Wooden box	1
7.	Allen key	1
8.	Magnifier with light source	1

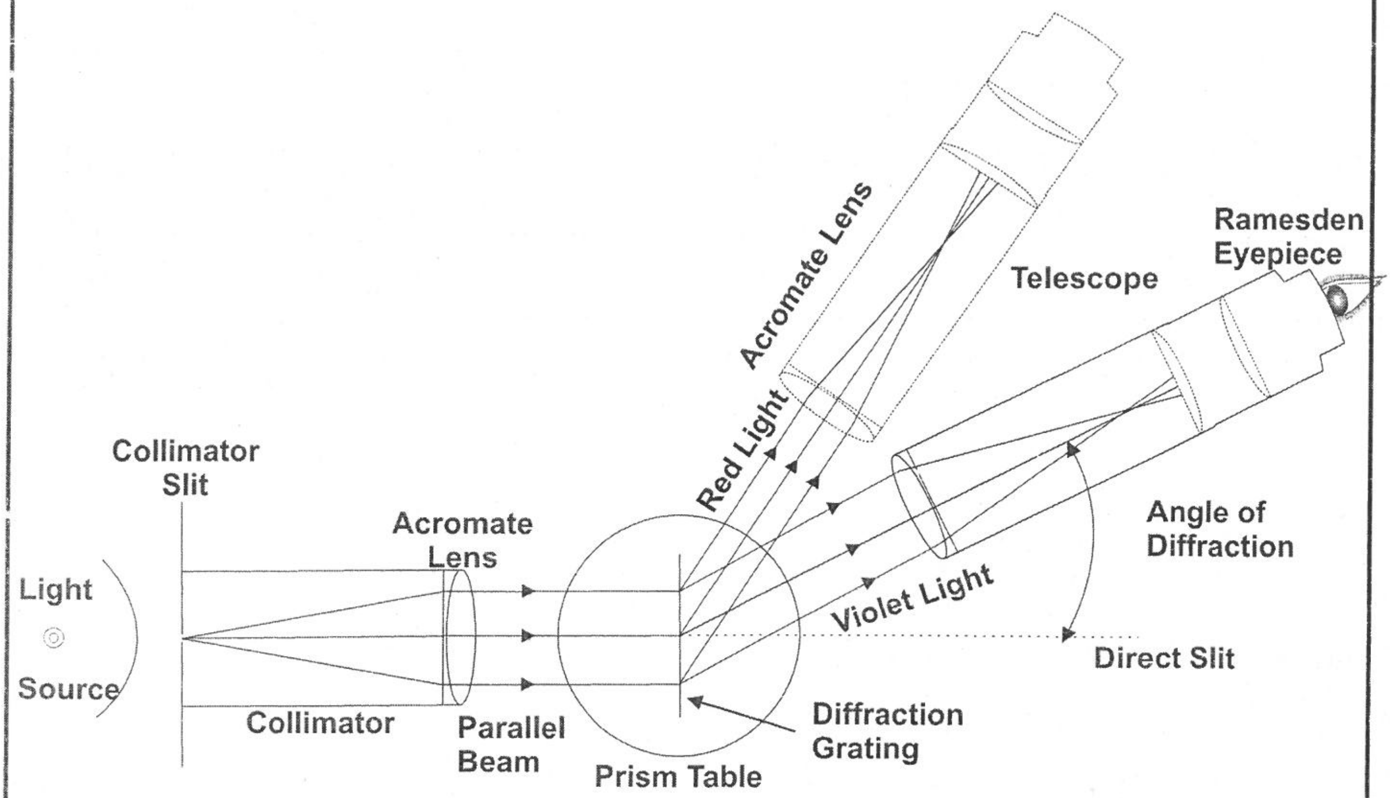

Figure-1

Theory:

In 1885 J.J. Balmer discovered that wave number ($\overline{v}=\frac{1}{\lambda}$) of spectral lines in visible region is given by

$$\overline{v}=\frac{1}{\lambda} = R\left(\frac{1}{n_i^2}-\frac{1}{n_f^2}\right)$$

Where $n_i=2$, $n_f=3,4,5,6,......$

Where $\overline{v}$= wave number which gives the number of waves per unit length.
The spectral lines which appear in invisible region are:

When	$n_i=1$,	$n_f=2,3,4,6,.....$	for Lymen series in ultra violet region
	$n_i=3$,	$n_f=4,5,6,7,.....$	for Paschen series in near infrared
	$n_i=4$,	$n_f=5,6,7,8$	for Bracket series in middle infrared
	$n_i=5$,	$n_f=6,7,8$	for Pfund series in far infrared

BALMER SERIES: Wave lengths emitted by hydrogen tube supplied are as shown:

	H_α $n_f=3$	H_β $n_f=4$	H_γ $n_f=5$	H_δ $n_f=6$
	670nm Red	**490nm Blue**	**440nm Violet**	**420nm Violet**

$n_i=2$, for the 1st excited state ie state to which transition take place for Balmer spectral series.

The three bright visible lines of balmer series correspond to $n_f=5,4$ and 3
There is a fourth one corresponding to $n_f=6$, but it is very week and many times not observed.
The room must be fully dark to see this line if at all possible.

NOTE: There are bands of very week transitions, due to mulecular hydrogen, which some times are seen between violet, blue and red lines. The emissions from these bands grow stronger as tube ages and at the some time hydrogen lines grow weaker.

Observation:

Vernier constant of spectrometer =.........................

No. of lines per mm=N

grating element (a+b)= $\frac{1}{10} \times \frac{1}{N}$ cm

Formula used :- $(a+b)\mathrm{Sin}\theta = p\lambda$ **For wave length,** p=order of spectrum

θ= angle of diffraction

$$R = \frac{n_f^2}{\lambda(n_f^2-4)}$$

For Rydberg Constant, n_f=Excited state from which electron fall to 1st excited state i.e. n_i=2

ORDER	SPECTRAL LINE	TRANSITION FROM n_f	READING OF VERNIER						MEAN ANGLE		RYDBERG CONSTANT
			V_1			V_2					
			ON RIGHT SIDE θ_2	ON LEFT SILD θ_1	$\theta^I = \frac{\theta_1 - \theta_2}{2}$	ON RIGHT SIDE θ_2	ON LEFT SILD θ_1	$\theta^{II} = \frac{\theta_1 - \theta_2}{2}$	$\theta = \frac{\theta^I + \theta^{II}}{2}$	$\lambda = \frac{(a+b)\mathrm{Sin}\theta}{p}$	$R = \frac{n_f^2}{\lambda(n_f^2-4)}$
p=1	Hα	3									
	Hβ	4									
	Hγ	5									
p=2	Hα	3									
	Hβ	4									
	Hγ	5									

Mean value of Rydberg constant = ...

Actual value R= $1.09677 \times 10^5\ \mathrm{cm}^{-1}$

$= 1.09677 \times 10^7\ \mathrm{m}^{-1}$

% of error = ...

Knowledge Upgrade:

1. Radius of nth orbit in hydrogen atom
   $r_n = 0.53\, n^2 A_0,\ \ n = 1,2,3.......$

2. Velocity of electron in the nth orbit of hydrogen atom

   $V = \frac{1}{n} \times \frac{c}{137}$ $\qquad c = 3 \times 10^8 ms^{-1},\ \ n = 1,2,3.......$

3. The velocity of electron in case of hydrogen like atoms

   $V = \frac{Z}{n} \times \frac{c}{137}$

   Single ionized $2He^4$
   Doubly ionized $3Li^6$
   Triply ionized $4Be^8$

4. The binding energy of electron in the ground state of hydrogen atoms is called as Rydberg
   1Rydberg = 13.6 eV

5. Frequency of revolutions in any orbit

   $f = 6.57 \times \frac{10^{15}}{n^3}$ cps (Hz)

6. Rydberg Constant is different for different material and same for hydrogen like atoms

Procedure:

1. Direct the telescope through an open window of dark room toward a distant object like wall tree etc.
2. Using rack and pinion set the distance between eyepiece and objective , so that a sharp image of object is seen. Mark the position of sliding tube. Set the eyepiece by drawing it in or out so that cross-wire is as distinct as possible. Also make one of the cross-wire vertical and other horizontal by rotating graticule alignment ring.
3. Illuminate the slit of collimator with source. Direct the telescope toward collimator and adjust the distance between its lens and slit by rack and pinion so that slit is distinct. Make the slit width as small as possible.
4. Calculate the vernier constant of spectrometer .
5. Mount the grating stand of the prism table and slide the grating into it so that its ruled surface faces the telescope.
6. **Optical leveling of grating and setting the grating for normal incidence.** Let α is the reading of vernier V_1 when telescope is toward the direct image of slit seen through collimator as figure 2 . Now turn the telescope without disturbing prism table, so that reading of vernier V_1 become $(90+\alpha)$. Clamp the telescope. Rotate the prism table so that reflected image of slit by grating coincide the cross-wire as figure 3. Note the reading of vernier. Again turn the prism table by 45° from this position in such a way that ruled surface of grating is toward the telescope on rotation in line of collimator. Now grating is set for normal incidences. Clamp the table.
7. Un-clamp the telescope and turn it to view 1st order and 2nd order maxima.
8. Angle of diffraction are measured for the following lines.
   a) Red coloured $H\alpha$ line = 670nm
   b) Blue green coloured $H\beta$ = 490nm
   c) Violet coloured $H\gamma$ = 420nm

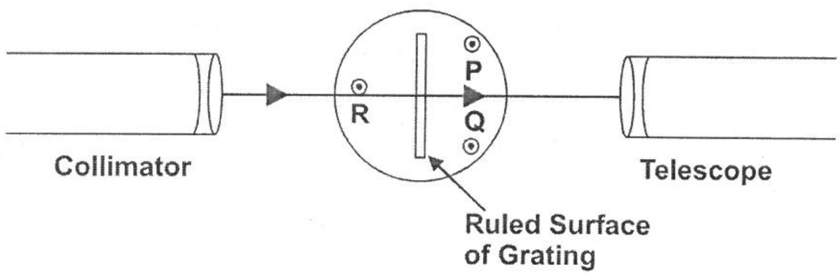

Figure-2

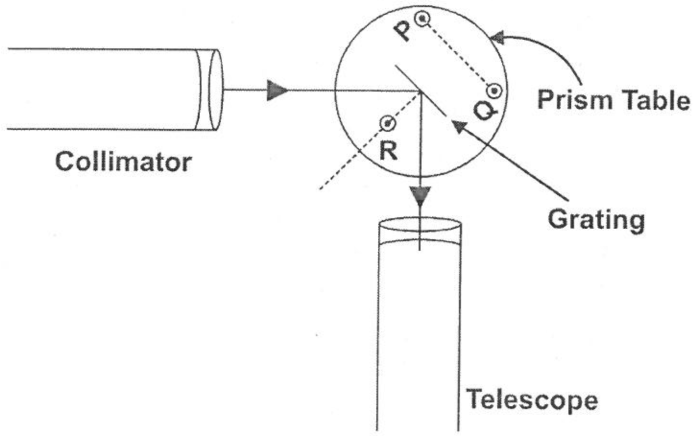

Figure-3

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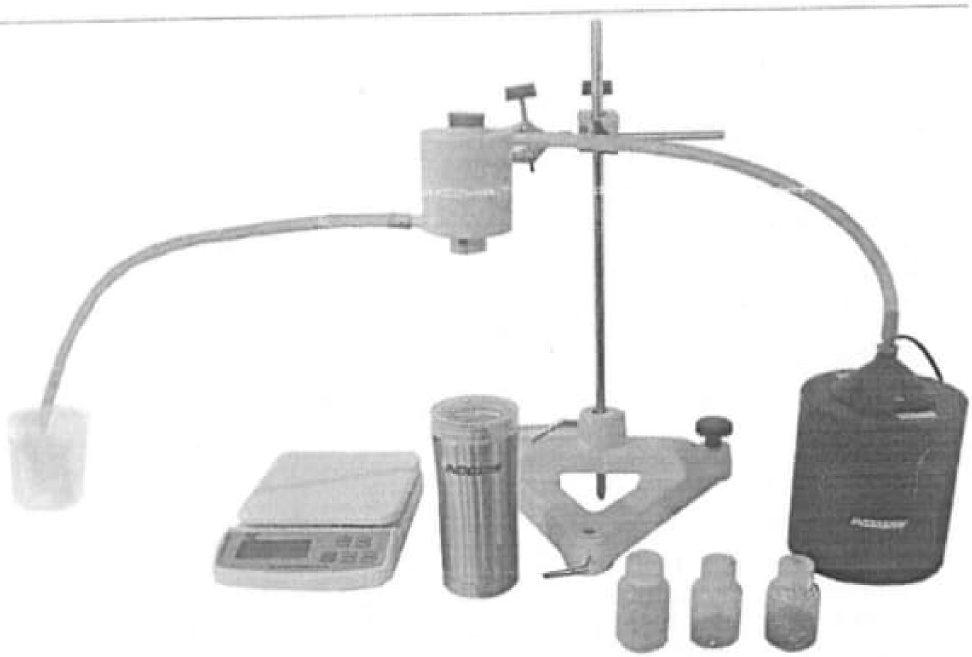
SPECIFIC HEAT OF SOLIDS SK051

Instruction Manual



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Experiment: Determining the specific heat of copper, lead and glass.

Requirement: SK051

Theory: Heat is a form of energy. It is expressed either in joules (J), calories (cal), or kilo-calories (kcal). The change in thermal energy of an object is proportional to the change in its temperature. The heat capacity C of an object is defined as $C = \frac{\Delta Q}{\Delta T}$, where ΔQ is the amount of heat required to change the temperature of the object by ΔT. The specific heat c of a substance

is the heat capacity per unit mass.

$$c = \frac{C}{m} = \frac{\Delta Q}{m\Delta T} \qquad (1)$$

Which gives $\Delta Q = mc\Delta T$ (2)

The specific heat is measured in J/kg°C or cal/g°C or kcal/kg°C. Suppose we have two objects, one hot and one cold. Let $m1$ and $m2$ be the masses of the hot and cold objects, $T1$ and $T2$ be the temperatures of the hot and cold objects, and c_1 and c_2 be their specific heats respectively. These two objects are brought into thermal contact with each other and allowed to reach a common final equilibrium temperature T_f. We are assuming the system to be thermally insulated from the surroundings. According to conservation of energy, the heat gained by the cold object would equal the heat lost by the hot object.

ΔQgained = ΔQlost (3)

or

$$m_2c_2(T_f - T_2) = m_1c_1(T_1 - T_f) \qquad (4)$$

For this experiment, consider the system to consist of mixing a given mass m_1 of a hot metal specimen with specific heat c_1 at temperature T_1 and a known mass m_2 of water with specific heat c_2 at a lower temperature T_2 contained in a calorimeter of mass m_3 with specific heat c_3 also initially at temperature T_2. Once again we assume the system to be thermally insulated from the surroundings, and the heat capacity of the thermometer, which records the temperature, can be neglected. Let the final temperature of the mixturebe T_f. Energy conservation gives:

ΔQlost(Metal) = ΔQgained(Water) + ΔQgained(Calorimeter) (5)

$$m_1c_1(T_1 - T_f) = m_2c_2(T_f - T_2) + m_3c_3(T_f - T_2)$$

which, yields the unknown specific heat $c1$ of the metal specimen as

If W = Water equivalent of calorimeter then

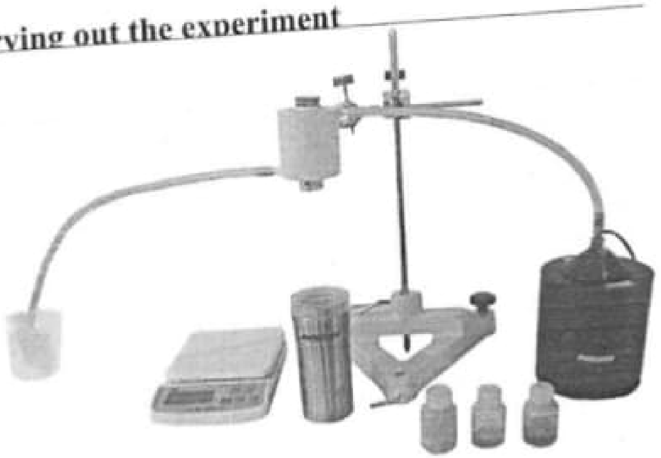
$$m_{pb} c_1 (t_s - t_f) = (M_w + W)(t_f - t_i) C_\omega \quad \text{------------------ (6)}$$

Water équivalent is the mass of water which absorb the be same amount of heat as absorbed by flask to its raise temp. by 1° C.

We assume that the mixing can be done without loss of heat by the hot specimen to the surroundings.

We will consider a metal specimen heated to a high temperature is dropped into water contained in a calorimeter (Dewar flask) at a lower temperature. If this system is thermally insulated from the surroundings, the specific heat of the specimen can be determined by equating the heat lost by the metal to the heat gained by both the calorimeter cup and the water contained in it.

Setup and carrying out the experiment



1. The experiment setup is shown in the adjacent figure
2. Open the top of steam generator by turning it anticlockwise and add sufficient water so that heater element is well dipped into water.
3. Connect the heating chamber to the steam generator using silicon tube as shown in figure.
4. Attach silicone tubing to the bottom hose connection of the heating chamber(steam outlet), and hang the other end in the beaker. See to it that the silicone tubing is securely seated at all connections.
5. Fill the sample chamber of the heating chamber with a weighed quantity of laed shots and seal it with the stopper.
6. Switch ON the steam generator to generate steam and heat the shots for about 20-30 minutes in the heating chamber.

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Step – 1 Determination of water equivalent of dewar flask.

1. Mass of flask (M_1) = 292.8g
2. M_2 (mass of cold water (M_c) + mass of flask (M_1)) = 396.8g
3. Mass of cold water (M_c) = M_2 - M_1 = 104g
4. Temp. of cold water (T_c) = 30°C
5. Temp. of hot water (T_h) = 77°C
6. M_3 (cold water + flask + hot water) = 545.6g
7. Mass of hot water = M_h = M_3 - M_2 = 148.8g
8. Temp. Of mixture T_m = 53.2 °C (ie. mixture of temperature of cold water & hot water)

Heat lost = Heat gained

$$M_h(T_h - T_m) = M_c(T_m - T_c) + w(T_m - T_c)$$

148.8 (77-53.2) = 104 (53.2-30) + W (53.2-30)

We get W = 48.7g

Step – 2. To determine the specific heat:

1. Empty the dewar flask and place in water so that it regain its normal temperature.
2. Open the cover of the dewar vessel and shift below the heat chamber and drop the shots at 100 °C into the dewar flask.
3. Stir the mixture gently by rotating the flask clockwise and anti-clock wise with hand
4. Read the temperature of the mixture when the temperature of the water stop rising and use *eqn*-6 to find specific heat.
5. Repeat the experiment with copper and glass shots.

Sample result for lead:-

initial temperature of water (T_2) = 28.3°C

final(mixing) temperature of water (T_f) = 29.2°C

mass of lead shots, m_{pb}= 83g

M_w= 144.2g (Mass of water in flask in which lead shots added)

water equivalent of water (w) = 48.7g

t_s= temp. of steam = 100 °C

use formula:

$$m_{pb} c_1 (t_s - t_f) = (M_w + W)(t_f - t_2) C_w \text{------------} \quad (6)$$

$$\frac{83}{1000}(100-29.2) C_{Pb} = \frac{(144.2+48.7) 4.19 (29.2-28.3)}{1000}$$

$$= 0.123 \ \frac{kJ}{K_g K} \quad (\text{ 1 cal} = 4.19 \text{ Joules})$$

Literature value = 0.129 $kJK^{-1}Kg^{-1}$

Similarly, the specific heat for copper and glass can be calculated.
Thus we find that specific heat of lead is less then that of water.

Note:
To heat the water up to about 60°C for finding the water, equivalent of DEWAR FLASK use your own heater, (i.e make your own arrangement).