IZMIR INSTITUTE OF TECHNOLOGY

DEPARTMENT OF PHYSICS

GENERAL PHYSICS I

LABORATORY MANUAL

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www.iyte.edu.tr/physics

CONTENTS

LABORATORY RULES

1 . Students may enter a laboratory only when a lecturer or demonstrator is present unless special permission has been granted.

2. Eating and drinking in any laboratory is prohibited.

3. Before starting an experiment;

- Check that all apparatus is present and has no obvious defect.

- Report to the person in charge any damaged or missing equipment.

4. During an experiment the student should report to the person in charge;

- any equipment that does not seem to be functioning properly.

- any accidents and breakages that occur.

- NEVER borrow equipment from another bench without permission.

5. Before leaving the laboratory,

- Switch off all power supplies and remove all AC/DC power plugs.

- Disconnect electrical circuits and collect the leads in a neat bundle.

- Ensure that the apparatus has been left tidily.

ANALYSIS OF MEASUREMENTS AND EXPERIMENTAL UNCERTAINTIES

1. RANDOM UNCERTAINTIES

The arithmetic mean $\bar{x}$ of a quantity obtained from a number (N) of readings x_i is the most probable value of that quantity. If the uncertainties are entirely random and is large, then $\bar{x}$ is close to the true value.

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$$

If the uncertainties of measurement are entirely random an estimate of the precision is given by the standard deviation

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

where $(x_i - \bar{x})$ is the deviation of a reading x_i from the mean $\bar{x}$.

The standard error (SE) of the mean $SE = (S/N)^{1/2}$ and the error at a 95% confidence level is $2SE$.

The significance of S can be seen by consideration of the distribution of a large collection of measurements, known as the normal or Gaussian distribution. It can be shown that for large N the probability of an individual reading differing from the mean by more than S is about 32%. $2S$ is about 5% and $3S$ is less than 1%.

In practice, when N **is less than 6 the statistical analysis is not appropriate** and an estimate of the uncertainty may be obtained from the range of values obtained.

2. PROPAGATION OF UNCERTAINTIES

Almost all experiments require calculations to be performed which involve manipulation of the measured uncertainties. In order to calculate the uncertainty in the final result it is necessary to know how the computed or estimated uncertainties in each quantity combine or propagate.

2.1 A General Approach

The easiest method of estimating the uncertainty is to substitute the extreme values of the quantities into the expression and calculate the result. The uncertainty is the difference between this value and the preferred value. e.g.

$$\lambda = \frac{d\sin\theta}{n}$$

Preferred value
$d = (1.00x10^{-6} \pm 0.05x10^{-6})m$
$\theta = 30.0^o \pm 0.5^o$, and $n = 1$
$\lambda = 10^{-6}xsin\ 30.0^o = 0.50\mu m$

Maximum value of λ is obtained with maximum value of d and maximum value of θ.

$\lambda_{max} = (1 + 0.05)x10^{-6}xsin(30 + 0.5) = 0.53\mu m$

$\lambda_{min} = (1 - 0.05)x10^{-6}xsin(30 - 0.5) = 0.47\mu m$

$\lambda = 0.50 \pm 0.03\mu m$

Note: The same method may be used for any uncertainty calculation e.g.

Density = mass/volume.

$Mass\ \ of\ \ object = (2.00 \pm 0.01)kg$
$Volume\ \ of\ \ object = (2.50 \pm 0.05)x10^{-3}m^3$
$Density(\rho) = 800kgm^{-3}$

Maximum value of ρ obtained using maximum mass and minimum volume

$$\rho_{max} = \frac{2.01kg}{2.45x10^{-3}m^3} = 820kgm^{-3}$$

Minimum value of ρ is obtained using minimum mass and maximum volume

$$\rho_{min} = \frac{1.99kg}{2.55x10^{-3}m^3} = 780kgm^{-3}$$

$\rho = 800 \pm 20kgm^{-3}$

2.2 Additions and Subtractions

It is usually fairly easy to write down the possible uncertainty in any single measurement. Thus suppose that in an experiment with a spring the length of the spring is measured with a metre scale. With care such a scale allows you to measure to about 1 mm. If you take a number of careful readings with the scale you should find that they do not differ among themselves by more than this. Thus for one particular reading you may be able to say:

$Length\ of\ spring = 302 \pm 1mm$

If additional masses are added and the spring is re-measured, you may find

$New\ length\ of\ spring = 488 \pm 1mm$

Now consider what you know about the change in length. According to our figures the change is equal to 186 mm. But each of the figures may have been wrong by 1 mm. If one of them happened to be too high by this amount while the other was too low, then the uncertainty in the difference would be 2 mm. **To be on the safe side we must assume that the worst has happened.** So we say

$Change\ in\ length = 186 \pm 2mm$

The same thing applies if we are concerned with adding the two lengths. The worst possible case will be when both figures were too high or both figures were too low. We assume the worst possiblee case and say

$Sums\ of\ lengths = 790 \pm 2mm.$

Thus if you are adding or subtracting two figures the actual uncertainty is the sum of the separate uncertainties.

2.3 Multiplications and Divisions

Now suppose that you are measuring the volume of a cylinder. You measure the diameter d and the length l and then calculate the volume from the equation

$$Volume = \frac{\pi d^2 l}{4}$$

In a case such as this the fractional uncertainty in the volume is the sum of the fractional uncertainty in the length plus twice the fractional uncertainty in the diameter. The fractional uncertainty in the diameter is doubled as a consequence of the fact that it is the square of the diameter that comes into the formula. If the formula had involved d^3, three times the fractional uncertainty would have been added and so on.

To take a very general case, suppose we are concerned with a formula of the type

$$x = \frac{k^a t^b}{m^c n^d}$$

In this case:

$$\frac{\triangle x}{x} = \frac{a \triangle k}{k} + \frac{b \triangle t}{t} + \frac{c \triangle m}{m} + \frac{d \triangle n}{n}$$

Fractional uncertainty in x=a(fractional uncertainty in k)+ b(fractional uncertainty in t) +c(fractional uncertainty in m) + d(fractional uncertainty in n)

This general rule can be proved, but the student is advised to accept the rule and leave the proof until later.

The rule is simple: if you are multiplying together or dividing a number of figures, the possible fractional uncertainty in the result is the sum of the separate fractional uncertainties

3.SIGNIFICANT FIGURES

In quoting a result only one uncertain figure should be retained; then the number of figures indicates the order of accuracy. For example, suppose the speed of light was calculated as $2.988x10^8ms^{-1}$ and is known to 1%. The possible uncertainty is then $0.03x10^8ms^{-1}$

This shows that the third and subsequent significant figures are unreliable, hence we retain only three figures and express the result in its neatest form as
$(2.99 \pm 0.03)x10^8ms^{-1}$

4. GRAPHICAL UNCERTAINTIES

In laboratory work a graph is often used to illustrate the behaviou of system; to assist in the calculation of a quantity or to determine the relationship between variables. It is essential that the graph displays the characteristics of the results and their uncertainties as clearly as possible. This involves the **proper selection of scale and the physical arrangement of the axis.**

The best way to indicate the uncertainties of the variables is to locate the point of the graph by a dot at the centre of bars indicating the range of uncertainty. A method of estimating the uncertainty in the gradient of a straight line is to draw lines of maximum and minimum gradient which are possible fits to the experimental points.The uncertainty in the gradient of the line of best fit is then one half the difference between the maximum and minimum gradients. A similar method can be used to estimate the uncertainty in an intercept. These techniques are illustrated on the graph in Figure 1.

5. THE SI SYSTEM OF UNITS

5.1 Classes of SI Units

There are three classes of SI units. These are:
Base units
Derived units
Supplementary units.

The base units are seven well-defined units: metre, kilogram, second, ampere, kelvin, candela and mole.

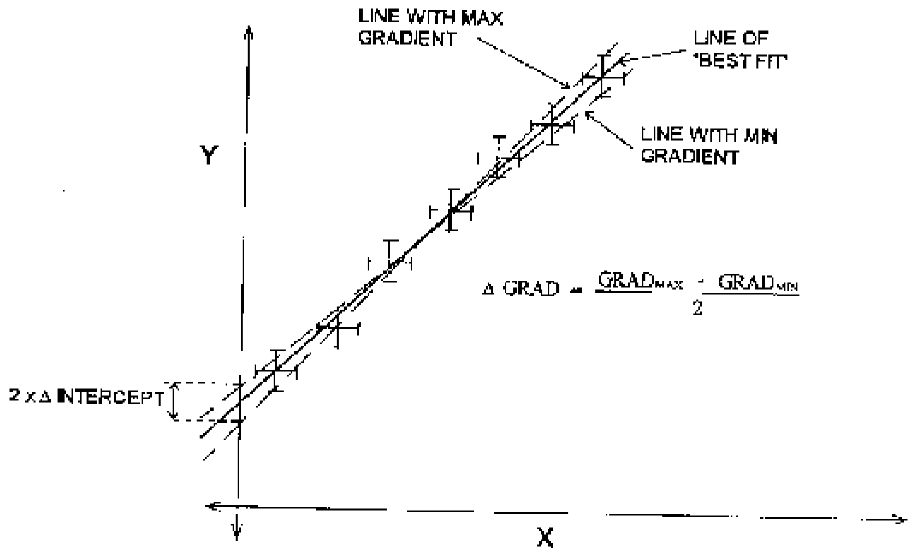

Figure 1:

The derived units are units which can be obtained by combining base units according to the algebraic relations linking the corresponding quantities.

The supplementary units, the **radian** and **steradian** (symbol, rad and sr respectively) are dimensionless quantities used when defining derived units for quantities such as angular frequency.

5.2 Definition of Base Units

metre (unit of length, symbol m)

The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. Note that the metre is defined in terms of the speed of light.

kilogram (unit of mass, symbol kg)

The kilogram is equal to the mass of the international prototype of the kilogram. Once the mass of a litre of water, it may soon be redefined as the mass of a number of carbon-12 atoms.

second (unit of time, symbol s)

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom. This is a highly monochromatic **microwave** emission.

ampere (unit of electric current symbol A)

The ampere is that **constant current** which, if maintained in two straight parallel conductors of **negligible circular cross-section**, placed one metre apart **in vacuum**, would produce beetwen these conductors a force equal to $2x10^{-7}$ Newton per metre of length.

Earlier metric systems used the coulomb as the base unit, but it was too hard to measure with sufficient precision.

Kelvin (unit of thermodynamic temperature, symbol K)

The Kelvin is the fraction 1/273.15 of the thermodynamic temperature of the triple point of water. The Kelvin is used to express an interval or a difference in temperature, so it tends to appear in the denominator of derived units.

(Celsius temperature, symbol T, is defined by the expression $T = K - 273.15$)

candela (unit of luminous intensity, symbol cd)

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540x10^{12}$ Hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. This unit is used when the instrument of comparison is the human eye. Its use is in decline.

mole (unit of amount of substance, symbol mol)

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 12 g of carbon-12. When the mole is used, the elementary entities must be specified. It is properly used as a number, but is often used as a mass.

5.3 Writing of Symbols

Roman lower case is used for symbols of units unless the symbols are derived from proper names, when capital roman type is used for the first letter. These symbols are not followed by a stop.

Unit names and symbols do not change in the plural, even though we often add an "s" in common speech. ($2K$ reads as two degree Kelvins.)

5.4 Derived Units, Special Names

Several derived units have been given special names and may be used to obtain further derived units. This is much simpler than expressing all units in terms of base units. e.g. $1Pa = 1Nm^{-2}$

Table 1 Derived units which have been given special names

PHYSICAL QUANTITY	UNIT	SYMBOL	IN TERMS OF BASE UNITS
activity	becquerel	Bq	s^{-1}
capacitance	farad	F	$m^{-2}kg^{-1}s^4A^2$
conductance	siemens	S	$m^{-2}kg^{-1}s^3A^2$
dose absorbed	gray	Gy	m^2s^{-2}
dose equivalent	sievert	Sv	m^2s^{-2}
electric charge	coulomb	C	s A
electric potential	volt	V	$m^2kgs^{-3}A^{-1}$
electric resistance	ohm	Ω	$m^2kgs^{-3}A^{-2}$
energy, work, heat	joule	J	m^2kgs^{-2}
force	newton	N	$mkgs^{-2}$
frequency	hertz	Hz	s^{-1}
illuminance	lux	lx	$m^{-2}cdsr$
inductance	henry	H	$m^{-2}kgs^{-2}A^{-2}$
luminous flux	lumen	lm	$cdsr$
magnetic flux	weber	Wb	$m^2kgs^{-2}A^{-1}$
magnetic induction	tesla	T	$kgs^{-2}A^{-1}$
power, radiant flux	watt	W	m^2kgs^{-3}
pressure	pascal	Pa	$m^{-1}kgs^{-2}$

5.5 Recommendations for Use of Units

(i) It is **preferable** to indicate the product of **two units with a dot** when there is a risk of confusion with another symbol. When **no dot is used a space should be left between the symbols** for the two units.

(ii) A negative power, horizontal line, or a solidus (/), may be used to express a derived unit obtained from two other units by division.

(iii) The solidus must not be repeated unless parentheses are used to avoid ambiguity.

5.6 Number Notation

The decimal point should be expressed by a dot placed on the line. Then multiplication should be indicated by an "x". If a dot half-high is used for this purpose, the decimal point must be a comma. **A number should never commence with a decimal point.**

Long numbers should be arranged in groups of three with a space, not a comma, separating them. The grouping should start at the decimal point.

A space should be left between the number and the unit.

5.7 Multiples and Sub-multiples

Table 2

FACTOR	PREFIX	SYMBOL	FACTOR	PREFIX	SYMBOL
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a

The prefixes hecto, deca, deci and centi are still legal but should be avoided in technical work. An exponent attached to a symbol containing a prefix indicates that the multiple, or submultiple, of the unit is raised to the power of the exponent: e.g. a sand grain of 2 mg has a volume of about $1mm^3$. (The metre is cubed and so is the milli). A **prefix should not appear in the denominator of a derived unit**: e.g. thus the sand grain has a density of about $2Mgm^{-3}$

NOTE: The kilogram is the only base unit containing a prefix, retained for historical reasons. It may appear in the denominator: e.g. a specific activity of $1.5kBqkg^{-1}$, not $1.5Bqg^{-1}$.

5.8 Units which are not within the SI

Some units, not within the SI are in widespread use. They should be converted to SI units before calculations. These are:

minute (min)	tonne (t) (1 Mg)
hour (h)	degree (o)
day (d)	minute (’)
year (a)	second (”)
litre (l,L)	

Jargon survives in all disciplines despite a general willingness to conform (to SI) for the general good. In physics, the following non-SI units have survived:

electronvolt (eV)

The energy acquired by an electron when moved through a potential difference of one volt.
(6 eV = 1 aJ approx; 6 MeV = 1 pJ approx)

atomic mass unit (u)

1/12 of the mass of one ^{12}C atom. An energy of 149 pJ or 931 MeV has approximately 1 u of mass. Atomic masses are expressed in u.

light year (ly)

The distance light travels in a year. (1 ly = 10 Pm, approx).

curie (Ci)

An activity of 37 GBq. This number is similar to the number of events per second in a gram of radium.

Other jargon units will be encountered in specialist areas; their conversion factors will be found in the references below.

Other disciplines have their jargon units, too. For instance - engineering has rpm (1 Hz = 60 rpm), geophysics has milligals ($1mgal = 10\mu ms^{-2}$) and surveying has hectares ($1ha = 10^4 m^2$, $1km^2 = 100ha$).

6. UNITS, ERRORS AND DIGITS

When an experimental value is to be reported, it must be put into the standard form. Here is how to do it:

Take a fresh page. Lay out the value to be processed. Rewrite it as you make each of the following corrections:

1. Reduce the units' denominator to base units: (DENOM)
2. Reduce the units' numerator to an appropriate unit: (NUM)
3 . Choose a 10^{3N} prefix which brings the main value to between 1 and 999 (PREFIX)
4. Express the error in the same units as the value: (SAME UNITS)
5. Round the error to one or two significant figures: (SIG. FIG.)
6. Round the main value and error to the same decimal place: (D.P.)
7. Check the spaces and cases: (FORMAT)

A difficult example: $605.643 calories/gK \pm 1.567\%$

=$605643 calorieskg^{-1}K^{-1} \pm 1.567\%$	DENOM
=$2537648.Jkg^{-1}K^{-1} \pm 1.567\%$	NUM
=$2.537648MJkg^{-l}K^{-1} \pm 1.567\%$	PREFIX
=$2.537648 \pm 0.039765MJkg^{-1}K^{-1}$	SAME UNIT
=$2.537648 \pm 0.04MJkg^{-1}K^{-1}$	SIG. FIGS.
=$2.54 \pm 0.04MJkg^{-1}K^{-1}$	D.P.
=$2.54 \pm 0.04MJkg^{-1}K^{-1}$	FORMAT

Practice the following, using pencil, eraser and scratch paper

$2.3 \pm 0.37Jg^{-1}$

$6.71 \pm 0.022Bqcm^{-2}$

$1191300GJ \pm 15TJ$

$171 \pm 9.666666 N/mm^2$
$1050.3 \pm 18.33 hectopascals$
$55 tonnes\ km^{-3} \pm 2\%$
$1.2345x10^{-7} g \pm 75875 fg$
$\sim 6 miles, \sim 6 ft, \sim 17 min., \sim 3 kWh, \sim 100 light\ years$
$\sim 60 MeV, \sim 10^{-5} kgs^{-2} A^{-2}$ (magnetic unit)

7. USE OF GRAPHS

This session is designed to give an understanding of the use of graphs. For those who are good at mathematics it will serve as revision, for the rest of you please use the time to master the following:

- Knowledge and understanding of the equation of a straight line.
- Ability to write an equation for a straight line given the graph.
- Ability to draw the graph given the equation without plotting out all the points.
- Understanding of "directly proportional".
- Ability to use a graphical method to show direct proportion in a variety of situations.
- Understanding of the term "inversely proportional".
- Ability to use a graphical method to show inverse proportionality.
- Ability to check equations using log graphs.

7.1 Gradient of a Stright Line

The straight line shown in Figure 2 has a constant gradient. In other words, as point P moves along the line in the direction of x increasing (i.e. from A to B) y changes at a constant rate, and in this case it is a simple matter to find the gradient.

7.1.1 Calculation of Gradient

In moving from A to B the x-coordinate has increased by 10 (from 0 to 10) while the y-coordinate has increased by 5 (from 2 to 7).

$$Gradient = \frac{increase\ in\ y}{increase\ in\ x} = \frac{5}{10} = \frac{1}{2}$$

The gradient is positive as y is increasing as x increases. So we say that the gradient of the line in Figure 2 is 1/2 or 0.5. In fact to find the gradient of the line we can take any two points on the line; e.g. we could have considered the points C add D with co-ordinates (4,4) and (8,6) respectively. To obtain the most accurate answer choose points which are as far apart as is convenient.

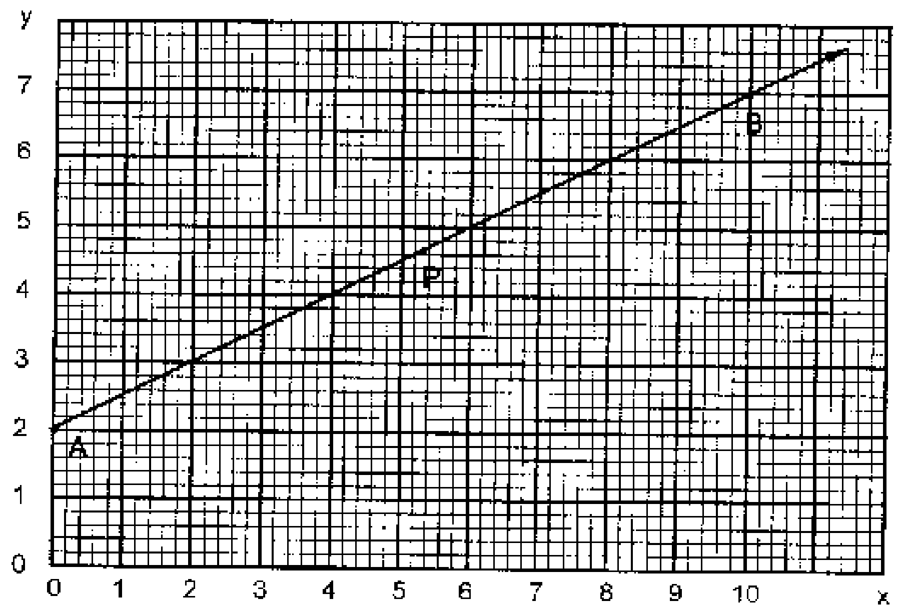

Figure 2:

7.1.2 Equation of a Straight Line

Consider the line shown in Figure 3. What is its gradient? Answer is 2. Now look at the points marked and write down their coordinates. Answer:

A : (0,1)
B : (1,3)
C : (2,5)
D : (3,7)
E : (4,9)

You might like to add a few more points of your own. Can you now find a connection between the y and x coordinates?

The first thing to notice is that the x-coordinate increases by 1 at each step as you go from A to E, and as we would expect the y-coordinate increases by 2 each time, since 2 is the gradient of the line (remember gradient is the change in y for an increase of 1 in x). Can you find the rule which connects y with x? The answer is that to get the y-coordinate you double the x-coordinate and add 1. Since the y-coordinate is referred to simply as 'y' and the x-coordinate as 'x':

$y = 2x + 1,\quad$ (gradient)x + (intercept on y axis)

or in general terms $y = mx + c$

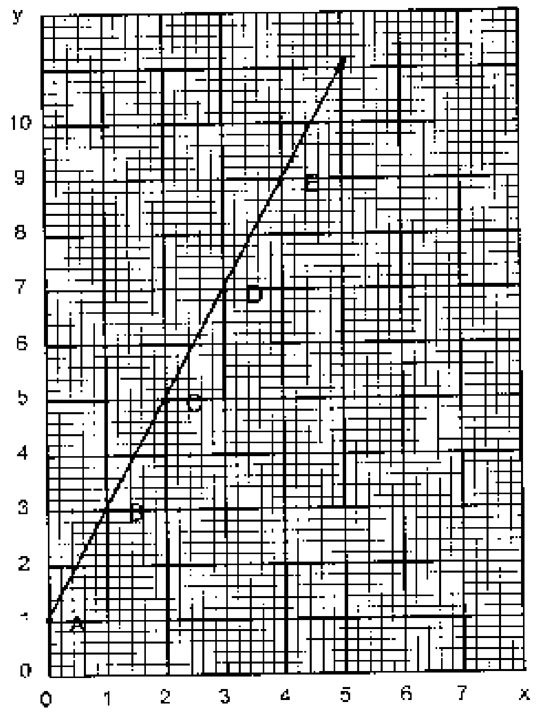

Figure 3:

7.2 Direct Proportion

Imagine you go shopping and buy items at \$3 each. If you tabulated the cost then you would get:

Number of items	cost
1	\$3
2	\$6
3	\$9
.	.
.	.
.	.
10	\$30

Draw a graph of cost on y-axis against number of items on the x-axis. The graph represents a graph of two quantities which are proportional.

$y \propto x$ or $y = kx$

The two main features of a graph showing that two quantities are directly proportional are:
1. the graph is a straight line

2. the graph passes through the point (0,0).

If you added the cost of the journey to the shop then the cost would no longer be directly proportional to the number of items. (If you bought twice the number of items it would cost less than twice as much). The graph would still be a straight line but it would not pass through (0,0), i.e. a **straight line alone is not sufficient proof of direct proportionality**.

Choose a value for the cost of the journey and plot the graph.

Write down the equation of the line. It should be
Cost = \$3 x number of items + cost of journey

Another shopping example, this time the cost of tiling a square room at \$10 a square metre.

side of room	area of room	cost
lm	$1m^2$	\$10
2m	$4m^2$	\$40
3m	$9m^2$	\$90
4m	$16m^2$	\$160

Question

Draw a graph of cost against side of room and of cost against $(side\ of\ room)^2$. What do you find?

Which graph enables you to deduce the relationship between cost and the length of the side of the room?

7.3 Inverse Proportion

The term inverse proportion is often wrongly used. It has a very precise meaning and refers to the situation where doubling one quantity halves the other, trebling one causes the other to be a third etc.

$y \propto \frac{1}{x}$ or $xy = constant$

Question

Which of the following sets of pairs of numbers are inversely proportional?

a	b		c	d		e	f
1	24		1	20		1	144
2	12		2	16		2	48
3	8		3	12		3	32
4	6		4	8		4	16
5	4.8		5	4		5	8
6	4		6	0		6	6

Draw a graph of each. What do you notice?

What graph can you draw to establish without doubt that the two quantities are inversely proportional?

Note: You need a straight line graph before you can be sure about the relationship between two variables.

7.4 Linear Graph from Non-linear Equations

The aim of many experiments is to find an equation relating two variables. If the graph obtained by plotting these two variables is a straight line, it is an easy matter to measure the slope and intercept and write out an equation in the form $y = mx + c$. If the graph is a curve, the solution is not so simple but it is often possible to choose the variables so that a straight line is obtained. Here are distances moved by a trolley from rest after various times.

Time, t	Distance, s
0.7	0.141
1.3	0.372
1.9	0.794
2.3	1.113
2.9	1.850

If s is plotted against t the graph will not be a straight line since s increases much more rapidly than t because the trolley is accelerating.

For an object travelling with constant acceleration from rest, the equation relating acceleration (a), distance (s) and time (t) is

$s = (1/2)at^2$

comparing this with $y = mx + c$ shows that a graph of s against t^2 should be a straight line passing through (0,0) and having a gradient of $(1/2)a$.

Question

How would you check graphically whether experimental results fit the following equations?

1. $F = k/r^2$, where k is constant.
2. $E = (1/2)mv^2$, where m is constant,
3. $V = RE/(R + r)$, when E and r are constant.

7.5 Log Graphs

Sometimes, two variables are related by an equation of the form

$y = Ax^n$

where A and n are unknown constants.
You can use trial and error to try to find n but this would involve graphing;

y against x
y against x^2
y against $1/x$

etc. until you obtained a straight line and, in the end, you might give up without getting a solution. However, if

$y = Ax^n$ then
$log\ y = log(Ax^n)$
$log\ y = logA + log\ x^n$
$log\ y = logA + nlog\ x$

(compare this with) $y = mx + c$.

The graph of $logy$ against $logx$ would be a straight line. The constant n is the gradient and the intercept is $logA$. From this graph we would be able to find both A and n.

Question

Under certain conditions (when heat cannot flow into or out of the gas) the pressure p and volume V are related by the equation

$pV^\gamma = k$

where γ and k are constants.

If you obtained experimental data under these conditions, what graph would you plot to find the values of γ and k and how would you find the values of γ and k?

Question

Theory suggests that the power P dissipated in a heated filament of resistance R is given by an equation of the form

$P = kR^n$

where k and n are constants.
Plot a suitable graph of the following data so that the values of n and k can be found.

P(W)	R(Ω)
4.41	0.91
8.11	1.11
12.59	1.27
17.70	1.41
23.88	1.51

7.6 Use of Graphs-Assignment

1. A 100 watt heater and a thermometer were immersed in a copper calorimeter containing water. The following readings were obtained:

temperature (^oC)	22	36	40	45	49	54	58
time (minutes)	3	4	5	6	7	8	9

Plot a graph of temperature against time (reminder: this means that time should be on the x axis).

The relevant equation is: *power x time = heat capacity x temperature rise*
Compare this equation with the equation of a straight line: $y = mx + c$

From your graph determine the initial temperature of the water and the heat capacity of the calorimeter + water.

2. The tension of a vibrating string is kept constant and its length varied to tune it to a series of tuning forks. The necessary lengths are given below:

Tuning Fork	C	D	E	F	G
frequency of tuning fork (Hz)	256	288	320	384	512

length of string (cm)	117	104	94	78	59

Plot a graph of length against frequency. What possible relationship is there between the frequency of vibration and the length of the string? Draw a suitable graph to confirm this.

EXPERIMENT 1

MEASUREMENT

Purpose

- To introduce the concept of measurement uncertainties using a metre ruler, vernier calipers, micrometer, and balance.
- To determine the density of the given samples based on the measured quantities.
- To assess the influence of measurement uncertainties on the accuracy and reliability of the calculated results.

Introduction

In physics, it is essential to recognize the limitations of any measuring instrument and to estimate the uncertainty associated with every measurement. This uncertainty is often referred to as the *error of the reading*, although the term can be misleading, as it implies that the experimenter has made a mistake. In reality, uncertainty is inherent in every measurement, regardless of the care and skill of the experimenter or the precision of the instrument.

What is measurement?

Measurement is the process of determining the size, length, mass, or other physical quantity of an object using a suitable instrument. Every measurement involves some degree of uncertainty, which must be considered when analyzing results.

Formulae Required:

- ***Density***

$$\rho = \frac{\mathrm{m}}{\mathrm{V}}$$

where ρ is the density, m is the mass, and V is the volume.

- ***Volume of a Cylinder***

$$\mathrm{V} = \pi r^2 h$$

where r is the radius of the base and h is the height (length) of the cylinder.

- ***Volume of a Sphere***

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

where r is the radius of the sphere.

- ***Volume of a Hexagonal-Based Object***

$$V = \frac{3}{2}hd^2$$

where h is the height (length) of the object and d is the distance across opposite edges of the hexagonal base.

Densities of Materials

- Aluminium: $\rho = 2.70\ \mathrm{g/cm^3}$
- Brass: $\rho = 8.75\ \mathrm{g/cm^3}$
- Copper: $\rho = 8.96\ \mathrm{g/cm^3}$
- Steel: $\rho = 7.85\ \mathrm{g/cm^3}$

Equipments

- A ruler
- Vernier calipers
- A micrometer
- A balance
- Brass, copper, aluminum, and steel objects

Procedure

1) Record the smallest scale division of each measuring instrument in Table 1.1.

2) Estimate the reading uncertainty for each instrument and record it in Table 1.1.

3) For each object, measure every relevant dimension three times at different points to obtain a reliable average value. Use each measuring instrument as appropriate and record the data in Table 1.2.

4) Calculate the densities of the objects using the recorded measurements and enter the results in Table 1.3.

REPORT SHEET

EXPERIMENT 1: MEASUREMENT

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Table 1.1: The smallest scale divisions of the measuring instruments and the corresponding reasonable estimates of reading uncertainty.

Instrument	Size of the smallest division on the scale	Reasonable estimate of reading uncertainty
Ruler		
Vernier		
Balance		

Table 1.2: Measurements of sample dimensions using different instruments, including individual readings, mean values, and the best estimates of uncertainty.

Object	Instrument	Quantity measured	Readings			Mean	Best estimate of uncertainty
	Ruler						
	Ruler						
	Vernier						
	Vernier						

Table 1.3: Mass, volume, and calculated density of the measured objects.

Object	Mass (g)	Volume (cm^3)	Density (g/cm^3)

Questions

1. Is there any *zero error* present in your measuring instruments? If so, how would you correct your measurements to account for this error?

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2. How do the results obtained from different measuring instruments compare with one another? Are the values consistent within the combined uncertainty estimates? If they are not, what does this indicate about the accuracy or reliability of the measurements?

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3. What is the most accurate instrument?

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4. Based on all the measurements obtained, what are the best estimates for the mass, length, and diameter of the objects?

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5. Would you consider the uncertainties you obtained to be random, where the probability of a reading being too high is the same as it being too low, or systematic, where the error consistently has the same sign and may result from an incorrectly calibrated instrument or a zero error?

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6. How may random uncertainties be reduced?

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7. How may systematic errors be detected and then eliminated or reduced?

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8. What are the volumes of the objects? How accurate are your answers?

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9. What are the densities of the specimens? How accurate are your results, and which units have you used: g/cm^3 or kg/m^3?

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10. In measuring the density of each object, is there any instrument that contributes significantly more to the overall uncertainty in the density?

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11. If you needed to improve the precision of your density measurements for each object, what would be your first step?

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EXPERIMENT 2

INSTANTANEOUS VERSUS AVERAGE VELOCITY

Purpose

To understand the distinction between average velocity and instantaneous velocity, and to identify the appropriate contexts in which each should be applied.

Introduction

The **average velocity** of a motion is defined as the total displacement divided by the total time elapsed from the beginning of the motion. In contrast, the **instantaneous velocity** corresponds to the displacement over such a small time interval that the start and end of the motion cannot be distinguished, as if the entire motion occurred in a single instant. Mathematically, it is expressed as: $v = dx/dt$, where dx is an infinitesimal displacement and dt is an infinitesimal time interval.

Both average and instantaneous velocities have their proper applications. For example, in the famous parable of the race between the hare and the tortoise, it is the average velocity that enables the slow tortoise to win. The hare, who rests for most of the race (having nearly zero instantaneous velocity) but sprints at the end (achieving a very high instantaneous velocity), loses because his average velocity is lower than that of the tortoise. On the other hand, a karate master can break a wooden block because he is trained to produce an immensely high instantaneous velocity (and thus momentum) with his hand at the moment of impact.

In this experiment, you will investigate the relationship between instantaneous and average velocities and explore how a sequence of average velocities can be used to approximate an instantaneous velocity.

Equipments

- Photogate Timer
- Accessory Photogate
- Air Track System with one glider
- Air Supply

Procedure

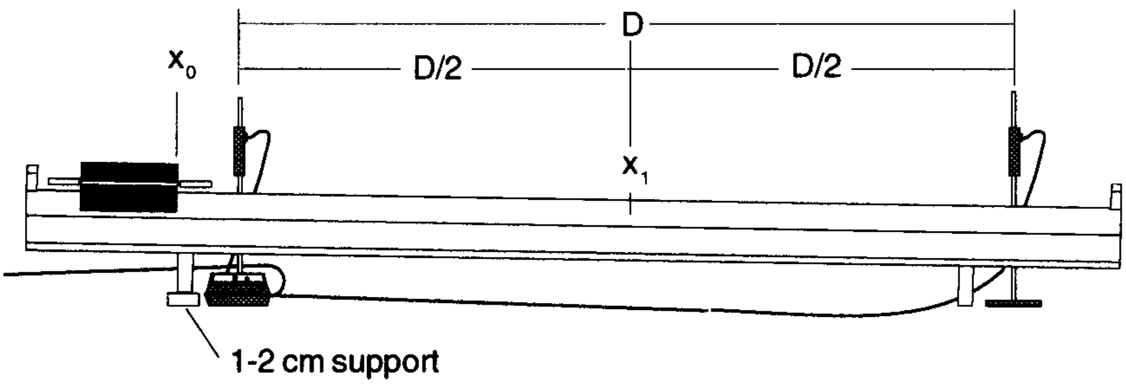

Figure 2.1: Experimental setup for measuring average and instantaneous velocities using a glider on an air track. The distances x_0, x_1, and D represent measurement points along the motion, with the track supported by a 1-2 cm elevation.

1. Set up the air track as shown in Figure 2.1, elevating one end of the track with a 1-2 cm support.
2. Choose a point x_1 near the center of the track. Measure the position of x_1 on the air track metric scale and record this value in Table 2.1.
3. Choose a starting point, x_0, for the glider, near the upper end of the track. With a pencil, carefully mark this spot on the air track so you can always start the glider from the same point.
4. Place the Photogate Timer and Accessory Photogate at points equidistant from x_1, as shown in the figure. Record the distance between the photogates as *D* in Table 2.1.
5. Set the slide switch on the Photogate Timer to PULSE.
6. Press the RESET button.
7. Hold the glider steady at x_o, then release it. Record time t_1, the time displayed after the glider has passed through both photogates.
8. Repeat steps 6 and 7 at least two more times, recording the times as t_2 through t_3.
9. Now repeat steps 4 through 9, decreasing *D* by approximately 10 cm.
10. Continue decreasing *D* in 10 cm increments. At each value of *D*, repeat steps 4-8.

REPORT SHEET

EXPERIMENT 2: INSTANTANEOUS VERSUS AVERAGE VELOCITY

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Table 2.1: Measured times for the glider passing through the photogates at different distances D, along with the average time and corresponding average velocity.

D (cm)	t_1 (s)	t_2 (s)	t_3 (s)	t_{avg} (s)	v_{avg} (m/s)
80					
70					
60					
50					
40					
30					
20					
10					

1. For each value of D, calculate the average of t_1 through t_3. Record this value as t_{avg}.
2. Calculate $v_{avg}=D/t_{avg}$. This is the average velocity of the glider in going between the two photogates.
3. Plot a graph of v_{avg} versus D with D on the x-axis.

Questions

1. Which of the measured average velocities provides the closest approximation to the instantaneous velocity of the glider at point x_1?

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2. Can you extrapolate your collected data to obtain a closer approximation of the instantaneous velocity of the glider at point x_1? Based on your data, estimate the maximum error expected in this value.

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3. When attempting to determine an instantaneous velocity, what factors, such as timer accuracy, the characteristics of the object being timed, and the type of motion, influence the accuracy of the measurement? Discuss how each of these factors affects the result.

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4. Can you think of one or more methods to measure instantaneous velocity directly, or must it always be inferred from average velocity measurements?

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EXPERIMENT 3

NEWTON'S SECOND LAW

Purpose

To verify Newton's Second Law by demonstrating that acceleration is directly proportional to the applied force and inversely proportional to the mass.

Introduction

Newton's Second Law states that a change in the velocity of an object with constant mass requires an external force. According to this law, the acceleration a produced is proportional to the net force F and inversely proportional to the mass m of the object:

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

In this experiment, this relationship will be verified by examining the motion of an air track glider subjected to a constant force. The force is provided by a hanging mass attached to the glider. By varying the mass of the glider and the hanging weight, and measuring the resulting acceleration, the predictions of Newton's Second Law will be tested.

Equipments

- Photogate Timer
- Accessory Photogate
- Air Track System with one glider
- Pulley and masses

Procedure

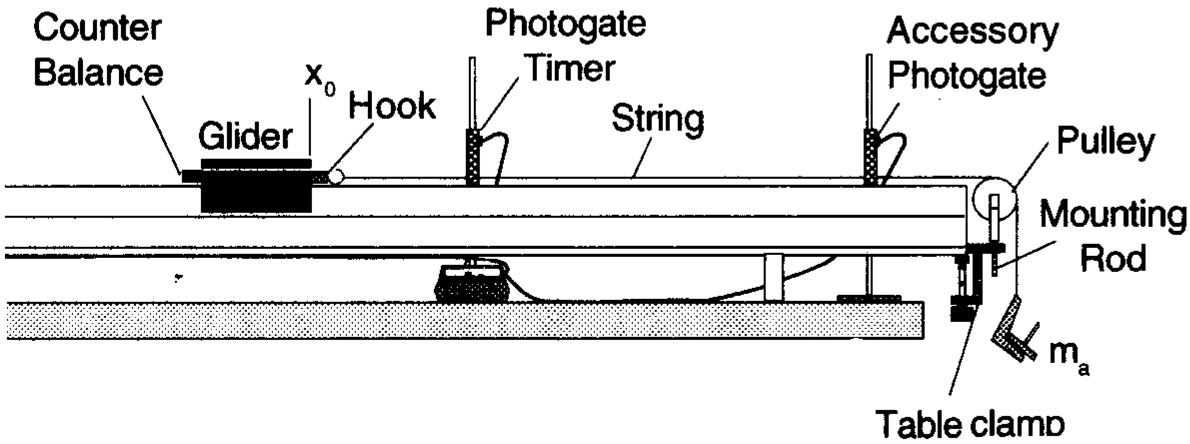

Figure 3.1: Schematic of the experimental setup

1. Set up the air track as shown in Figure 3.1. The glider should sit on the track without moving in either direction. You may adjust the leveling feet to ensure that the track is horizontal.
2. Mount the hook into the bottom hole of the glider. To counterbalance its weight, add a piece of similar weight on the opposite end as shown on Figure 3.1.
3. Add 60 g of mass to the glider using 10 g or 20 g weights. Make sure the masses are placed symmetrically so the glider remains balanced. Determine the total mass of the glider with the added weights and record it as *m* in Table 3.1.
4. Place a mass of 5 grams on the mass hanger. Record the total mass (hanger plus added mass) as m_a.
5. Choose a starting point x_o for the glider, near the end of the track. Mark this point with a pencil so that you can always start the glider from this same point.
6. Set the Photogate Timer to GATE mode and turn ON the memory function.

   Note: The Memory function of the photogate timer is used to measure two time intervals. Turn the MEMORY switch to ON, then press RESET. Run the experiment. When the first time t_1 is measured, it will appear on the display immediately. The timer will automatically measure the second time t_2, but it will not be shown yet.

   Record t_1, then switch MEMORY to READ. The display will now show the total time, $t_1 + t_2$. Subtract t_1 from this value to find t_2.

7. Press the RESET button.

8. Hold the glider steady at x_o, then release it. Note t_1, the time it takes for the glider to pass through the first photogate, and t_2, the time it takes to pass through the second photogate. Repeat this measurement two more times. Calculate the averages of your measured $t_1$and $t_2$values, and record these averages as $t_1$and $t_2$in Table 3.1.
9. Set the Photogate Timer to PULSE mode.
10. Press the RESET button.
11. Again, release the glider from x_o. This time, measure and record t_3, the time it takes the glider to travel between the two photogates. Repeat this measurement two more times and calculate the average of the three $t_3$values, and record this average as $t_3$in Table 3.1.
12. Vary the mass of the hanger, m_a, by transferring masses from the glider to the hanger, while keeping the total mass $(m + m_a)$constant. Record both m and m_a, and then repeat Steps 6 –11. Perform this procedure for at least four different values of m_a.
13. Next, keep m_a fixed at one of the previously used values. Vary the glider mass m by adding or removing masses from the glider. Repeat Steps 6–11 for each configuration. Obtain data for at least four different values of m.

REPORT SHEET

EXPERIMENT 3: NEWTON'S SECOND LAW

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Flag length, L = 10 cm

Mass of the unloaded glider = 210 g

Table 3.1

m	m_a	t_1	t_2	t_3	v_1	v_2	a	F_a
(210 + 60) g	10 g							
(210+ 40) g	30 g							
(210 +20) g	50 g							
210 g	70 g							
(210 + 60) g	10 g							
(210 + 40) g	10 g							
(210 +20) g	10 g							
210 g	10 g							

1. Use the length L of the glider and the average times obtained from your measurements to calculate the average velocities of the glider as it passes through each photogate. The velocity at the first photogate is given by $v_1 = L/t_1$, and the velocity at the second photogate is given by $v_2 = L/t_2$. These values represent the average speeds of the glider while it interrupts each photogate beam. Record $v_1$and v_2.
2. The average acceleration of the glider as it moves between the two photogates is calculated from the change in velocity divided by the time taken, using the expression $a = (v_2 - v_1)/t_3$. Calculate and record the resulting acceleration.

3. Determine the force applied to the glider by the hanging mass using the expression $F_a = m_a g$, where $m_a$is the mass of the hanger and $g = 9.8\ m/s^2$ is the gravitational acceleration.
4. Draw a graph of average acceleration versus the applied force, F_a.
5. Draw another graph of average acceleration versus the glider mass, m, keeping m_a constant.
6. Examine your graphs carefully and note whether they form straight lines. Use the data to determine how the applied force, the mass of the glider, and the average acceleration are related for the air track glider.

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7. In this experiment, only the average acceleration of the glider between the two photogates was measured. Consider whether these results are likely to reflect the instantaneous acceleration as well. Explain your reasoning, and suggest additional measurements or experiments that could be performed to determine the instantaneous acceleration of the glider.

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EXPERIMENT 4

THE FORCE OF GRAVITY

Purpose

To measure the force exerted on an object by the Earth's gravitational field by using Newton's Second Law.

Introduction

In this experiment, we will use Newton's Second Law ($F = ma$) to measure the gravitational force on an object by observing its acceleration as it slides down an inclined plane. This method allows precise determination of the force while illustrating the relationship between force, mass, and acceleration.

The gravitational force F_g can be resolved into two components: one perpendicular and one parallel to the motion of the glider. Only the parallel component contributes to the glider's acceleration; the perpendicular component is balanced by the air cushion of the track. From the diagram (Figure 4.1), the accelerating force is given by

$$F = F_g \sin\ \theta,$$

where F_g is the total gravitational force and F is the component along the direction of motion. By measuring the glider's acceleration, F can be determined, allowing calculation of the total gravitational force F_g.

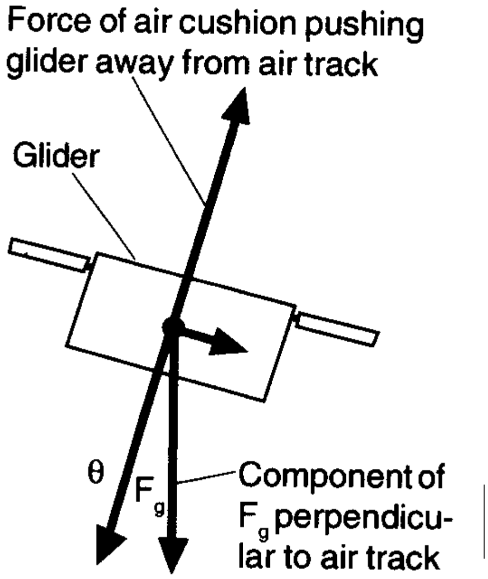

Figure 4.1

Equipments

- Photogate Timer
- Accessory Photogate
- Air Track System with one glider
- A block of known thickness
- Masses

Procedure

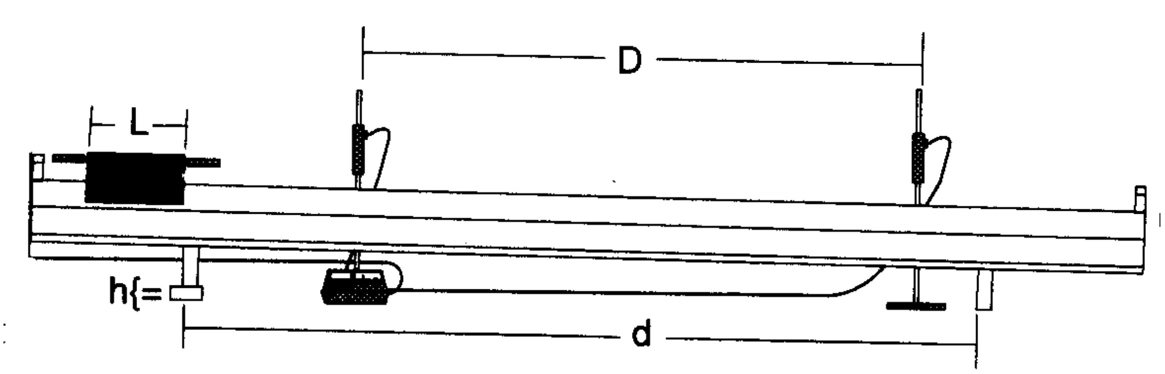

Figure 4.2

1. Set up the air track as shown in Figure 4.2.

2. Measure *d*, the distance between the air track support legs. Record this distance.

3. Place a block of thickness *h* under the support leg of the track. Measure *h* with calipers and record it.

4. Measure and record *D*, the distance the glider moves on the air track from where it triggers the first photogate to where it triggers the second photogate.

5. Measure and record *L*, the effective length of the glider.

6. Measure and record *m*, the mass of the glider.

7. Set the Photogate Timer to GATE mode and press the RESET button.

8. Hold the glider steady near the top of the air track, then release it so it glides freely through the photogates. Record t_1, the time during which the glider blocks the first photogate, and t_2, the time during which it blocks the second photogate.

Note: Use the memory function of the timer to measure the two times. Turn the MEMORY switch to ON. Press RESET. Run the experiment. When the first time t_1 is measured, it will be immediately displayed. The second time t_2 will be automatically measured by the timer, but it will not be shown on the display. Record t_1, then push the MEMORY switch to READ. The display will now show the TOTAL time, $t_1 + t_2$. Subtract t_1 from the displayed time to determine t_2.

9. Repeat the measurement several times and record your data in Table 5.1. You needn't release the glider from the same point on the air track for each trial, but it must be gliding freely and smoothly as it passes through the photogates.

10. Change the mass of the glider by adding weights and repeat steps 6 through 8. Do this for at least five different masses, recording the mass *m* for each set of measurements.

REPORT SHEET

EXPERIMENT 4: THE FORCE OF GRAVITY

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

$d \approx 100$ cm

$h = 1$ cm

$D = 50$ cm

$L = 10$ cm

$\theta =$ ________

m (mass of the glider with the flag) = 190 g

Table 5.1

m	t_1	t_2	v_1	v_2	a	F	F_g
190 g							
200 g							
210 g							
220 g							
230 g							
240 g							

$a_{avg} =$ ________

1. Calculate θ, the angle of incline for the air track, using the equation $\theta = \arctan(h/d)$.
2. For each set of time measurements, calculate the velocities of the glider as it passed through the two photogates. Namely, divide L by t_1 and t_2 to determine v_1 and v_2 respectively.
3. For each set of time measurements, calculate the acceleration of the glider using the kinematic equation for constant acceleration:

$$v_2^2 - v_1^2 = 2a\text{D},$$

where v_1 and v_2 are the initial and final velocities over the distance $\text{D} = x_2 - x_1$ between photogates. Solve for a to determine the glider's acceleration.
4. For each glider mass used, calculate the average of your measured accelerations and record it as a_{avg}.
5. For each of your average accelerations, calculate the force acting on the glider along its line of motion ($F = m\,a_{avg}$).
6. For each measured value of F, use the equation $F = F_g \sin\theta$ to determine F_g.
7. Construct a graph of F_g versus m, with m as the independent variable (x-axis).
8. Examine your graph of F_g versus m to determine whether it shows a linear relationship and whether the line passes through the origin. Record your observations.

Verify whether the gravitational force acting on the mass is proportional to the mass. If it is, the relationship can be expressed as $F_g = mg$, where g is a constant. Determine the slope of your graph to calculate the value of g.

Questions

1. In this experiment, it was assumed that the acceleration of the glider was constant. Was this a reasonable assumption to make? How would you test this?

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2. The equation $v_2^2 - v_1^2 = 2a(x_2 - x_1)$was used to calculate the acceleration. Under what conditions is this equation valid, and are those conditions satisfied in this experiment?

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EXPERIMENT 5

ELASTIC-KINETIC ENERGY

Purpose

To investigate how kinetic energy can be stored in a spring and transferred to an object, illustrating the concept of elastic potential energy.

Introduction

A spring exerts a force that obeys Hooke's Law,

$$F = -kx,$$

where k is the spring constant and x is the displacement from the spring's natural length. Because this force is conservative, the work done in stretching or compressing the spring is stored as elastic potential energy. For a displacement x, the stored energy is

$$U_{\text{spring}} = \frac{1}{2}kx^2.$$

When the spring is released, this energy can accelerate an object, converting the stored energy into the object's kinetic energy

$$E_{\text{kinetic}} = \frac{1}{2}mv^2.$$

In this experiment, you will investigate the relationship between the energy stored in a spring and the kinetic energy imparted to an object, testing the principle of energy conservation for elastic systems.

Equipments

- Photogate Timer
- Air Track with one glider
- Mass hanger with masses
- Spring (with a low spring constant)

Procedure

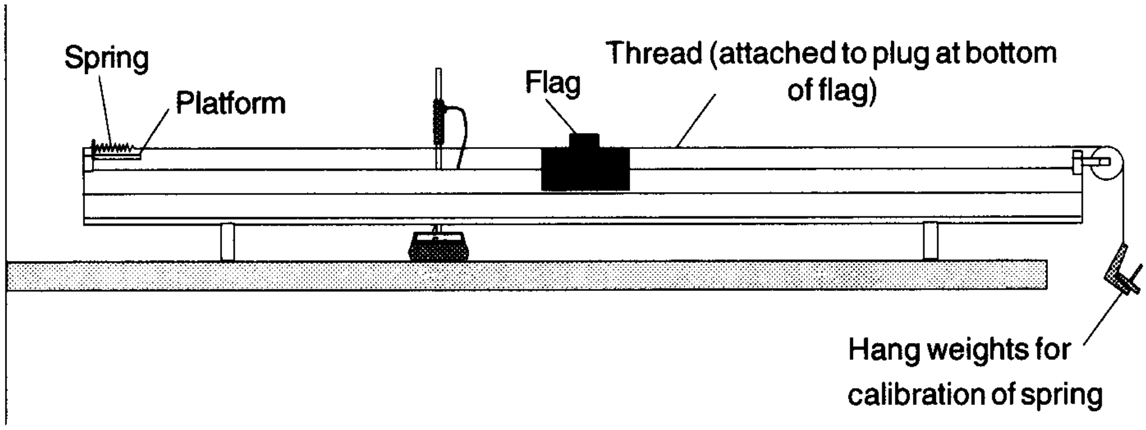

Figure 5.1

1. Set up the equipment as shown in Figure 5.1:
   Attach a cardboard flag to the glider. Construct a horizontal platform to hold the spring so it does not sag, and secure the platform to the end of the air track. Connect the spring to the glider using a piece of thread, positioning the glider near the middle of the track with the spring unstretched. Run another piece of thread from the glider over the pulley at the end of the track and attach it to a hanger
2. Position the glider so that the spring exerts no force on it, while keeping the thread taut (not sagging). Record this glider position as x_0 .
3. With the air flow turned on, add masses to the hanger and measure how far the spring stretches using the metric scale on the side of the air track. Use the glider's position to monitor the extension of the spring. Record the added masses and corresponding glider positions in Table 5.1. After completing the measurements, remove the hanger and thread.
4. Move the glider slowly through the photogate, noting the glider's position when the LED first turns on and when it turns off. The distance between these two points, Δd, represents the effective width of the flag. Record this value.
5. Position the glider at $x_0$and set up the photogate between the glider and the spring so that the glider passes cleanly through it when released.
6. Pull the glider 5 cm away from the equilibrium position x_0.

7. Set the Photogate Timer to GATE mode and press the RESET button.
8. Hold the glider steady while turning on the air flow. Release the glider, allowing it to pass through the photogate, and catch it before it collides with the spring platform. Record the measured time as t_1 in Table 5.2.
9. Repeat steps 6–9 two more times. Record the measured times as t_1, t_2, and t_3 in Table 5.2. Calculate the average of these three times and record it as t_{avg}.
10. Repeat steps 6–9 for various spring stretches, up to 20 cm.

REPORT SHEET

EXPERIMENT 5: ELASTIC-KINETIC ENERGY

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Table 5.1 Determining the spring constant

Hanging Mass	Applied Force, (mg)	Spring Stretch, (x)
5 g		
10 g		
15 g		
20 g		
25 g		

Determine the spring constant k by plotting the applied force ($F = mg$) versus the spring stretch x. Place the stretch values on the x-axis and the corresponding forces on the y-axis. The slope of the resulting line gives the spring constant k. Make sure the value of k is expressed in units of newtons per meter (N/m).

k = ________

Table 5.2

Flag width, Δd = _______

Glider mass, m = 190 g

Stretch, x	t_1	t_2	t_3	t_{avg}
5 cm				
10 cm				
15 cm				
20 cm				

v_{avg}	$E_{Kinetic}$	U_{Spring}	% Difference

1. For each set of trials with a given spring stretch and glider mass, calculate the average velocity of the glider as it passed through the photogate:
$$v_{\text{avg}} = \frac{\Delta d}{t_{\text{avg}}}.$$
2. Then compute the final kinetic energy of the glider:
$$E_{\text{kinetic}} = \frac{1}{2} m v_{\text{avg}}^2.$$
3. Calculate the elastic potential energy stored in the spring for each case:
$$U_{\text{spring}} = \frac{1}{2} k x^2,$$
where $k$is the spring constant and $x$is the spring stretch.
4. Determine the percentage difference between the elastic potential energy stored in the spring and the final kinetic energy of the glider for each trial:

$$\text{Percentage difference} = \frac{|\ U_{\text{spring}} - E_{\text{kinetic}}\ |}{U_{\text{spring}}} \times 100\%.$$

EXPERIMENT 6

CONSERVATION OF MECHANICAL ENERGY

Purpose

To demonstrate that the sum total of potential and kinetic energies is another conserved quantity in elastic collisions and mechanically isolated objects that are subjected to gravity only.

Introduction

Though conservation of energy is one of the most powerful laws of physics, it is not an easy principle to verify. If a boulder is rolling down a hill, for example, it is constantly converting gravitational potential energy into kinetic energy (linear and rotational), and into heat energy due to the friction between it and the hillside. It also loses energy as it strikes other objects along theway, imparting to them a certain portion of its kinetic energy. Measuring all these energy changes is no simple task.

This kind of difficulty exists throughout physics, and physicists meet this problem by creating simplified situations in which they can focus on a particular aspect of the problem. In this experiment you will examine the transformation of energy that occurs as an air track glider slides down an inclined track. Since there are no objects to interfere with the motion and there is minimal friction between the track and glider, the loss in gravitational potential energy as the glider slides down the track should be very nearly equal to the gain in kinetic energy. Stated mathematically:

$$\Delta E_k = \Delta(mgh) = mg\Delta h,$$

where ΔE_k is the change in kinetic energy of the glider ($\Delta E_k = (1/2)mv_2^2 - (1/2)mv_1^2$) and $\Delta(mgh)$ is the change in its gravitational potential energy (m is the mass of the glider, g is the acceleration of gravity and Δh is the change in the vertical position of the glider).

Equipments

- Photogate Timer
- Accessory Photogate
- Air track system with one glider
- A block of known thickness

Procedure

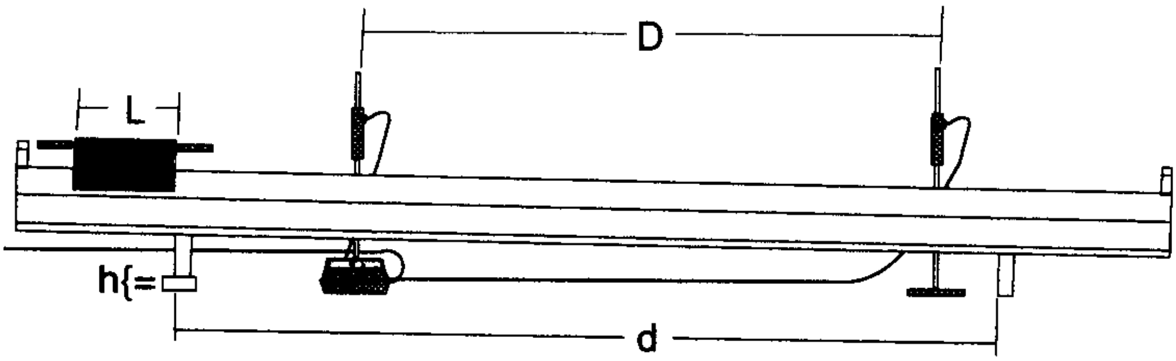

Figure 6.1:

1. Level the air track as accurately as possible.
2. Measure d, the distance between the air track support legs. Record this distance in Table 6.1
3. Place a block of known thickness under the support leg of the track. For best accuracy, the thickness of the block should be measured with calipers. Record the thickness of the block as h in Table 6.1.
4. Setup the Photogate Timer and Accessory Photogate as shown in Figure 6.1.
5. Measure and record D, the distance the glider moves on the air track from where it first triggers the first photogate to where it first triggers the second photogate. (You can tell when the photogates are triggered by watching the LED on top of each photogate. When the LED lights up, the photogate has been triggered.)
6. Measure and record L, the effective length of the glider. (The best technique is to move the glider slowly through one of the photogates and measure the distance it travels from where the LED first lights up to where it just goes off.)
7. Measure and record m, the mass of the glider.

8. Set the Photogate Timer to GATE mode and press the RESET button.
9. Holdtheglider steady near the top of the air track, then release it so it glides freely through the photogates. Record t_1, the time during which the glider blocks the first photogate, and t_2, the time during which it blocks the second photogate. (The memory function of the Photogate Timer will make it easier to measure the two times.)
10. Repeat the measurement several times and record your data in Table 6.1. You needn't release the glider from the same point on the air track for each trial, but it must be gliding freely and smoothly (minimum wobble) as it passes through the photogates.
11. Changethemass of thegliderby adding weights and repeat steps 7 through 10. Do this for at least five different masses, recording the mass m for each set of measurements.

REPORT SHEET

EXPERIMENT 6: CONSERVATION OF MECHANICAL ENERGY

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

$d \approx 100$ cm

$D = 50$ cm

$h = 1$ cm

$L = 10$ cm

$m = 190$ gr

Table 6.1

m	θ	t_1	t_2	v_1	v_2	E_{k1}	E_{k2}	ΔE_k	$\Delta(mgh)$
190									
200									
210									
220									
230									
240									

1. Calculate θ, the angle of incline for the air track, using the equation $\theta = \arctan(h/d)$.

For each set of time measurements:

2. Divide L by t_1 and t_2 to determine v_1 and v_2, the velocity of the glider as it passed through each photogate.

3. Use the equation $E_k = (1/2)mv^2$ to calculate the kinetic energy of the glider as it passed through each photogate.

4. Calculate the change in kinetic energy, $\Delta E_k = E_{k2} - E_{k1}$.

5. Calculate Δh, the distance through which the glider dropped in passing between the two photogates ($\Delta h = D \sin\theta$).

6. Compare the kinetic energy gained with the loss in gravitational potential energy. Was mechanical energy conserved in the motion of the glider?

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EXPERIMENT 7

CONSERVATION OF LINEAR MOMENTUM

Purpose

- To demonstrate that linear momentum is conserved in every collision that is free from any other force except that is due to the collision itself
- To demonstrate that if collision is elastic and horizontal, the total kinetic energy of the system is a conserved quantity, ie, a constant throughout the act.

Introduction

When objects collide, whether locomotives, shopping carts or your foot and the sidewalk, the results can be complicated. Yet even in the most chaotic of collisions, as long as there are no external forces acting on the colliding objects, one principle always holds and provides an excellent tool for understanding the dynamics of the collision. That principle is called *the conservation of momentum*. For a two-object collision, momentum conservation is easily stated mathematically by the equation:

$$p_i = m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} = p_f,$$

where m_1 and m_2 are the masses of the two objects, v_{1i} and v_{2i} are the initial velocities of the objects (before the collision), v_{1f} and v_{2f} are the final velocities of the objects (after the collision), and p_i and p_f are the combined momentums of the objects, before and after the collision. In this experiment, you will verify the conservation of momentum in a collision of two air track gliders.

Momentum is always conserved in collisions that are isolated from external forces. Energy is also always conserved, but energy conservation is much harder to demonstrate since the energy can change forms: energy of motion (kinetic energy) may be changed into heat energy, gravitational potential energy, or even chemical potential energy. In the air track glider collisions you'll be investigating, the total energy before the collision is simply the kinetic energy of the gliders:

$$E_{ki} = (1/2)m_1 v_{1i}^2 + (1/2)m_2 v_{2i}^2$$

After the collision, the total kinetic energy of the system is:

$$E_{kf} = (1/2)m_1 v_{1f}^2 + (1/2)m_2 v_{2f}^2$$

In this experiment you'll examine the kinetic energy before and after a collision to determine if kinetic energy is conserved in air track collisions.

Equipments

- Two Photogate Timers
- Air Track System with two gliders

Procedure

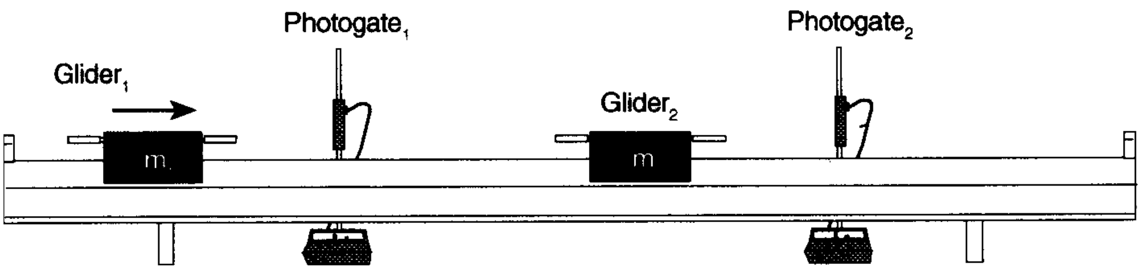

Figure 7.1

1. Set up the air track and photogates as shown in Figure 7.1, using bumpers on the gliders to provide an elastic collision. Carefully level the track.

2. Measure m_1 and m_2, the masses of the two gliders to be used in the collision. Record your results in Table 7.1.

3. Measure and record L_1 and L_2 the length of the gliders. (e.g., push glider through photogate and measure the distance it travels from where the LED comes on to where it goes off again.)

4. Set both Photogate Timers to GATE mode, and press the RESET buttons.

5. Place $glider_2$ at rest between the photogates. Give $glider_1$ a push toward it. Record four time measurements in Table 7.1 as follows:

t_{1i} = the time that $glider_1$ blocks $photogate_1$before the collision.

t_{2i} = the time that $glider_2$ blocks $photogate_2$before the collision. (In this case, there is no t_{2i} since $glider_2$ begins at rest.)

t_{1f} = the time that $glider_1$ blocks $photogate_1$ after the collision.

t_{2f} = the time that $glider_2$ blocks $photogate_2$ after the collision.

6. Repeat the experiment several times, varying the mass of one or both gliders and varying the initial velocity of $glider_1$.

7. Try collisions in which the initial velocity of $glider_2$ is not zero. You may need to practice a bit to coordinate the gliders so the collision takes place completely between the photogates.

REPORT SHEET

EXPERIMENT 7: CONSERVATION OF LINEAR MOMENTUM

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Table 7.1

$L_1 = 10$ cm, $L_2 = 10$ cm

$m_1(g)$	$m_2(g)$	$t_{1i}(s)$	$t_{2i}(s)$	$t_{1f}(s)$	$t_{2f}(s)$
210	210				
230	210				
210	210				
230	210				

$v_{1i}(m/s)$	$v_{2i}(m/s)$	$v_{1f}(m/s)$	$v_{2f}(m/s)$	$p_i(kg \times m/s)$	$p_f(kg \times m/s)$	$E_{ki}(J)$	$E_{kf}(J)$

1. For each time that you measured, calculate the corresponding glider velocity (e.g., $v_{1i} = \pm L_1/t_{1i}$, where the velocity is positive when the glider moves to the right and negative when it moves to the left). Record your results in the table.

2. Use your measured values to calculate p_i and p_f, the combined momentum of the gliders before and after the collision. Record your results in the table.

3. Use your measured values to calculate E_{ki} and E_{kf} the combined kinetic energy of the gliders before and after the collision. Record your results in the table.

Questions

1. Was momentum conserved in each of your collisions? If not, try to explain any discrepancies.

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2. If a glider collides with the end of the air track and rebounds, it will have nearly the same momentum it had before it collided, but in the opposite direction. Is momentum conserved in such a collision? Explain.

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3. Suppose the air track was tilted during the experiment. Would momentum be conserved in the collision? Why or why not?

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4. Was kinetic energy conserved in each of your collisions?

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5. If there were one or more collisions in which kinetic energy was not conserved, where did it go?

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EXPERIMENT 8

CONSERVATION OF ANGULAR MOMENTUM

Purpose

To determine that if the angular momentum of rotating objects is conserved in acollision as like their linear momentum.

Introduction

Suppose that our rotating body is at angular position θ_1 at time t_1 and at angular position θ_2 at time t_2. We define the average angular velocity of the body in the time interval Δt from t_1 to t_2 to be

$$\omega_{avg} = \frac{\theta_2 - \theta_1}{t_2 - t_1} = \frac{\Delta\theta}{\Delta t}$$

in which $\Delta\theta$ is the angular displacement that occurs during Δt.

The *(instantenous) angular velocity* ω is the limit of the ratio in equation above as Δt approaches zero. Thus,

$$\omega \ (\lim \Delta t \longrightarrow 0) = \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt}$$

If we know $\theta(t)$, we can find the angular velocity ω by differentiation.

The angular velocity ω of a rotating rigid body is either positive or negative, depending on whether the body is rotating counterclockwise (positive) or clocwise (negative).

If the angular velocity of a rotating body is not constant then the body has an angular acceleration. Let ω_2 and ω_1 be its angular velocities at times t_2 and t_1, respectively. The average angular acceleration of the rotating body in the interval from t_1 to t_2 is defined as:

$$\alpha_{avg} = \frac{\omega_2 - \omega_1}{t_2 - t_1} = \frac{\Delta\omega}{\Delta t}$$

in which $\Delta\omega$ is the angular displacement that occurs during the time interval Δt.

The *(intantaneous) angular acceleration* α is the limit of this quantity as Δt approaches zero. Thus,

$$\alpha\ (\lim \Delta t \longrightarrow 0) = \frac{\Delta\omega}{\Delta t} = \frac{d\omega}{dt}$$

If the motion of an object undergoing constant acceleration, then the average acceleration is equal to the instantaneous acceleration.

Angular momentum of a system of particles that form a rigid body that rotates about a fixed axis with constant angular speed ω, can be written as $L = I\omega$. I in that equation is the rotational inertia about that same axis. The law of conservation of angular momentum can be written as

$$L_i = L_f \qquad \text{(isolated system)}$$

We can apply this law to a isolated body which rotates around a fixed axis. Suppose that the initially rigid body somehow redistributes its mass relative to that rotation axis, changing its rotational inertia about that axis. The law of conservation states that the angular momentum of the body cannot change. So we write this conservation law as

$$I_i\omega_i = I_f\omega_f$$

Here the subscripts refer to the values of the rotational inertia I and angular speed ω before and after the redistribution of mass.

In this experiment you will use the Rotational Dynamics Apparatus. The optical readers of the apparatus count the number of black bars that pass by them in one second. This is the number that is displayed. R is the reading in *bars/second*. So you can use this information to convert the measurement to *radians/second.*

$$\omega = \kappa R$$

where κ is the rotation of the disk in radians for each bar detected by the optical reader.

Equipments

- Rotational Dynamics Apparatus
- Air Pump

Procedure

1. Set up the equipment as in Figure 8.1. Use the steel disks as the top and bottom disks.
2. Insert one valve pin in the bottom disk valve and the other in the hole in the center of the top disk. Spin the disks. They should rotate smoothly and independently.
3. Set the display switch so that the display monitors the motion of the upper disk.

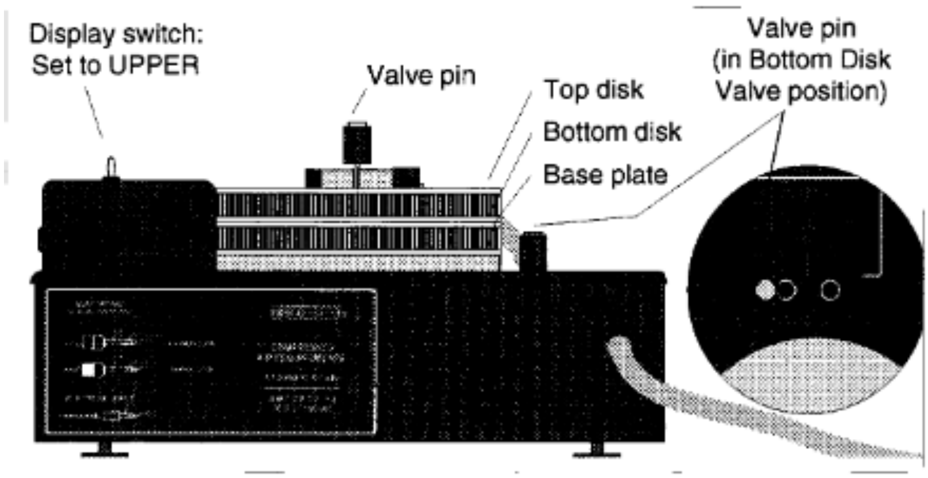

Figure 8.1

REPORT SHEET

EXPERIMENT 8: CONSERVATION OF ANGULAR MOMENTUM

Student's Name:

Experiment Date:

Group Member Name(s):

Laboratory Bench Number:

Assistant's Name and Signature:

Data and Calculations

Table 8.1

ω_{bot}	ω_{top}	R_{top}	R_{bot}	R_{final}
0	$\neq 0$			
0	$\neq 0$			
0	$\neq 0$			
$\neq 0$ (cw)	$\neq 0$ (cw)			
$\neq 0$ (cw)	$\neq 0$ (cw)			
$\neq 0$ (cw)	$\neq 0$ (cw)			
$\neq 0$ (ccw)	$\neq 0$ (cw)			
$\neq 0$ (ccw)	$\neq 0$ (cw)			
$\neq 0$ (ccw)	$\neq 0$ (cw)			

1. Hold the bottom disk stationary and give the top disk a spin, so that the display reads approximately 300-400 counts/s. Wait several seconds, then record the display reading for the top disk as R_{top} in Table 8.1. (The initial reading for the bottom disk, R_{top}, is zero, since it was held stationary.)

2. Immediately after recording the reading, pull the valve pin from the top disk so that the top disk falls onto the bottom disk. Wait a full two seconds, then record the reading, on the display as R_{final} in the data table.

3. Repeat the experiment with both disks spinning initially in the same direction, and also with both disks spinning initially in opposite directions. (When both disks are spinning initially, you will need to flip the display switch to measure both R_{top} and R_{bot}, before removing the drop pin. Each time you flip the switch or pull the pin, be sure to wait a full two seconds before recording the new display reading. Also be sure to record the direction in which each disk spins, cw or ccw.)

4. Use the law of conservation of angular momentum for each experiment to see the relations between the readings R_{top}, R_{bot}, and R_{final}. Check if these relations are provided with the observed readings in the data table.

Questions

1. Within the limits of your experimental error, was angular momentum conserved in your collisions. Discuss any discrepancies.

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2. Discuss the role of friction in the experiment. How might you change the apparatus and/or the design of the experiment, to compensate for frictional effects?

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3. Suppose you performed the experiment without the valve pin in the bottom disk valve, so that the bottom disk was sitting firmly on the base plate. The initial angular momentum would be that of the top disk. The final angular momentum would be zero. Would momentum be conserved? Explain your answer.

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