Preface

The purpose of the freshman physics laboratory is to explore, illustrate and clarify the physical concepts which are discussed in the didactic part of the freshman physics course. However, there are practical difficulties in keeping the laboratory course in phase with the lecture course. Further, in many instances, the instructor does not have sufficient time to dwell upon the details of the laboratory experiments in lecture/recitation or in the laboratory. The physics laboratory manuals for laboratory I and II have been designed to deal with this problem. The manuals present the basic theory and outlines of the procedure of each experiment, and the respective data sheets help the students in processing the data.

The laboratory experiments have been designed by the members of Physics discipline at York College. In nineteen-seventies, PHYSLABS - a set of interactive computer-assisted instruction programs was developed under the NSF CAUSE Grant. With the development of the new technology, PHYSLABS became obsolete and the CHAMP computer interface was introduced in three experiments. In view of these changes, the original manual needed major revision which has been accomplished under the present NASA Grant.

Acknowledgment

I am grateful to my colleagues, Prof. Samuel Borenstein, Prof. Eugene Levin, Prof. Frank Pomilla, Prof. Martin Spergel and Mr. Joel Gomez, for their cooperation and assistance. In particular, I appreciate the work of Prof. Borenstein in introducing the CHAMP interface under the support of NASA-NSF AMP Grant.

I would like to thank the 'York College Observatory Outreach Program' (YCOOP) under NASA Grant NAG 5 10152, for their support in preparing this edition, as well as the NSF CAUSE Grant Program (circa 1979) for the foundational edition of physics laboratory manual at York College, titled 'Physics 103 Laboratory Manual'.

- D. C. J.

Contents

INTRODUCTION

How To Make A Good Grade In A Lab Course Without Really Trying

A laboratory course may seem to involve a lot of work for too few credits. However, remembering the following points may help:

A. A laboratory course supplements the lecture course and helps the students grasp the basic concepts of the subject.

B. A laboratory course teaches the students to be systematic and organized.

C. A laboratory course helps the students realize the distinction between 'exact' theoretical concepts and limitations of 'physical reality' of experimental work.

A Few Simple Rules:

1. Learn the basic theory of the experiment, working of the various pieces of equipment used in the experiment and the procedure of the experiment. Read the experiment, become familiar with the data sheet and answer the pre-lab questionnaire before coming to the laboratory.

2. In the laboratory, follow the steps of the procedure as described in the laboratory manual and record the observations as they appear in the data sheet. The readings should be recorded correct to the least count of the instruments. In general, if estimation is to be done, it should be done correct to half of the value of the smallest division on the scale of the measuring device. Units must be entered where necessary.

3. It is a good practice to make a copy of the data sheet in the note book, perform the calculations and then transfer the data onto the data sheet. Use scientific notation where necessary and avoid non-significant figures.

4. Prepare the laboratory report as soon as possible and submit the report on time.

Physical Quantities and Units:

Scientific work involves dealing with physical quantities - quantities that can be measured. Examples of physical quantities are length, mass, time, velocity, force, momentum, energy, etc. Of these, length, mass and time are the fundamental physical quantities. Other physical quantities can be expressed as suitable combinations of length, mass and time. For example, the velocity of a glider can be obtained by measuring its displacement in a given time interval.

Systems of Units:

System	Length	Mass	Time
MKS system	meter (m)	kilogram (kg)	second (s or sec)
cgs system	centimeter (cm)	gram (g or gm)	second (s)
British system or FPS system	foot (ft)	pound (lb)*	second (s)

* In fact, pound is a unit of force. However, in everyday life, it is used as unit of mass, that is , quantity of matter whose weight is 1 pound. The proper unit of mass in FPS system is a slug, which is the mass in which the force of 1 pound produces an acceleration of 1 ft/s^2. 1 slug is equal to 14.59 kg.

The units must be consistent in all calculations.

The units of some physical quantities are presented in the following table:

Physical quantity	cgs unit	MKS unit	Definition
Volume	cm^3	m^3	volume = length x width x height
Density	gm/cm^3	kg/m^3	density = mass/volume
Velocity	cm/s	m/s	velocity = displacement/time
Acceleration	cm/s^2	m/s^2	acceleration = velocity/time
Momentum	gm.cm/s	kg.m/s	momentum = mass x velocity
Force*	dyne	newton	force = mass x acceleration
Energy	erg	joule	energy = work = force x displacement

* Sometimes, force is measured in gm-wt (gram-weight) which is the force of gravity of the earth on a mass of 1 gram.

In a given laboratory experiment, all data should be obtained and recorded either in MKS or cgs units.

Scientific Notation:

Very large and very small numbers are handled more conveniently in scientific notation. Thus numbers like 2570, 14300 and 0.00056 should be written as 2.57×10^3, 1.43×10^4 and 5.6×10^{-4}, respectively. As a rule, numbers larger than 1000 and smaller than 0.001 should be expressed in scientific notation.

Significant figures:

In a number, all nonzero digits and the zeros that are not used to define the position of the decimal point are significant. This is illustrated in the following table.

Number	Number of significant figures
1.27	3
420	2
420.	3
0.023	2
0.0403	3

Rules for determining the number of significant figures in the result:

(i) Conventionally, at most one more decimal digit can be retained than the certainty of the result.

(ii) In addition and subtraction, the sum or difference has significant figures only in the decimal places where the original numbers have significant figures. Thus

$$\begin{array}{r} 6.843 \\ +\ 0.002 \\ \hline 6.845 \end{array} \qquad \begin{array}{r} 500 \\ -\ 4 \\ \hline 500 \end{array} \qquad \begin{array}{r} 600. \\ +\ 7 \\ \hline 607 \end{array}$$

(iii) In multiplication and division, the result can not have more significant figures than the least accurately known numbers. Thus

$2.4 \times 5.8 = 14$; $2.413 \times 5.8 = 14$; $\frac{44}{7} = 6$; $\frac{44}{7.1} = 6.2$.

In intermediate steps of calculation, generally, an extra significant figure is carried.

Error Analysis: Standard Deviation and Standard Error:

Errors are part of physical reality. In most cases, an error-free result may be obtained accidentally due to cancellation of errors or due to negligence. Some errors are accountable such as errors caused due to inaccurate graduation of a scale. Other errors are unaccountable. These are random errors, mistakes in reading the scale and recording of values, etc.

To avoid mistakes, it is a good practice to take at least 2 readings independently, even though only one reading is to entered in the data sheet. If any reading is substantially different from the other readings, it should be discarded or replaced, if necessary.

If only a few (about 3) readings are taken, the probable error can be considered to be equal to the least count of the instrument (the smallest value of a physical quantity that can be measured by the instrument). Thus the length of a cylinder, obtained with a meter stick, will have a probable error of 0.1 cm, if the scale is graduated in mm. Such a reading can be recorded as 12.3 ± 0.1 cm, if the average of the readings of the length of the cylinder is 12.3 cm.

If a number of readings (about 6) are taken, standard deviation and standard error can be used.

Standard Deviation:

Let n readings $x_1, x_2, x_3, \ldots x_n$ be taken. Their arithmetic mean (average) is $\bar{x}$ is defined as

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots x_n}{n}.$$

Standard deviation is defined as

$$\sigma = \sqrt{\frac{(x_1-\bar{x})^2 + (x_2-\bar{x})^2 + (x_3-\bar{x})^2 + \ldots (x_n-\bar{x})^2}{n}}.$$

Finally, the standard error of the mean is defined as

$$\sigma_m = \frac{\sigma}{\sqrt{n-1}}.$$

An Example:

Two students, A and B, measure the length of an object with a meter stick and obtain the following values:

Number	Student A' s data		Student B's data	
	x, length (cm)	$x - \bar{x}$	x, length (cm)	$x - \bar{x}$
1	31.4	-0.07	31.5	0.03
2	31.5	0.03	31.7	0.23
3	31.5	0.03	31.3	-0.17
4	31.4	-0.07	31.9	0.43
5	31.5	0.03	31.1	-0.37
6	31.5	0.03	31.2	-0.27
7	31.5	0.03	31.6	0.13
8	31.4	-0.07	31.5	0.03
9	31.5	0.03	31.3	-0.17
10	31.5	0.03	31.6	0.13

Results	Student A's data	Student B's data
Mean $\bar{x}$	31.47 cm	31.47 cm
σ	0.046 cm	0.232 cm
σ_m	0.015 cm	0.078 cm
Probable percent error*	0.05 %	0.25 %

* Taking probable error equal to σ_m.

Note that although the mean value in both sets of data is 31.47 cm, the standard deviation and standard error in the first set are smaller than those in the second set. Thus the first set of data is better than the second set.

Percent Errors:

$$\text{Probable percent error} = \frac{\text{Probable error}}{\text{Experimental value}} \times 100\ \%.$$

If the standard value of the physical quantity is known, the percent error can be calculated by the formula

$$\text{Percent error} = \frac{(\text{Experimental value - standard value})}{\text{Standard value}} \times 100\ \%.$$

Propagation of Errors:

The final experimental value of a physical quantity is obtained by a series of steps of calculations. Thus errors in the experimental data lead to errors in the final result. The following rules are applied to determine the probable error in the result:

(i) In addition and subtraction, the probable error in the result is the sum of the absolute values of the probable errors in the individual quantities which are used in the addition or subtraction. For example,

17.9 ± 0.2	(probable % error = 1.1 %)	14.8 ± 0.5	(probable % error = 3.4 %)
$+ 24.3 \pm 0.1$	(probable % error = 0.4 %)	$- 7.9 \pm 0.2$	(probable % error = 2.5 %)
42.2 ± 0.3	(probable % error = 0.7%)	6.9 ± 0.7	(probable % error = 10 %)

Note that in subtraction, the probable percent error in the result is considerably larger than the probable percent error in the individual quantities.

(ii) In multiplication and division, the probable percent error in the result is equal to the sum of the probable percent errors in the individual quantities. For example, consider the following data:

Length of a cylinder, $\ell = 5.4 \pm 0.1$ cm (probable percent error = 2%)

Radius of the cylinder, $r = 1.24 \pm 0.05$ cm (probable percent error = 4%)

Volume of the cylinder,

$V = \pi r^2 \ell = \pi \times 1.24^2 \times 5.4 \text{ cm}^3$

$= 26.07154$ cm (as given by the calculator

Probable percent error in V = probable percent error in ℓ + 2x(probable percent error in r)

$= 2 + 2 \times 4 \% = 10\%$

Here r appears as r^2 in the formula for V. Thus the probable percent error in r has to be added twice in obtaining the probable percent error in V.

Note that the probable percent error in volume V is 10%. Thus the probable error in V is 2.6 cm^3. Accordingly, the volume should be reported as 26 cm^3 or at most 26.2 cm^3. All other digits given by the calculator are not significant.

Further remember that quantities like r in the above example, which are small and are raised to higher powers in the calculations must be measured more accurately.

Examples of Propagation of Errors:

The following examples illustrate propagation of errors:

Error in the sum of two numbers:

Let x = 17.9 ± 0.2 and y = 24.3 ± 0.1.

Maximum value of x + y = (17.9 + 0.2) + (24.3 + 0.1) = 42.2 + 0.3

Minimum value of x + y = (17.9 - 0.2) + (24.3 - 0.1) = 42.2 - 0.3

Thus the error in the sum = sum of the absolute values of errors = 0.2 + 0.1 = 0.3.

Error in the difference of two numbers:

Let p = 14.8 ± 0.5 and q = 7.9 ± 0.2.

Maximum value of p - q = (14.8 + 0.5) - (7.9 - 0.2) = 6.9 + 0.7

Minimum value of p - q = (14.8 - 0.5) - (7.9 + 0.2) = 6.9 - 0.7

Thus the error in the difference = sum of the absolute values of errors in p and q = 0.5 + 0.2 = 0.7

Errors in the results of multiplication and division:

Let x = 5.4 ± 0.2 (% error = 3.7 %) and y = 3.0 ± 0.1 (% error = 3.3 %).

Value of the product xy = 5.4 x 3.0 = 16.2.

Maximum value of xy = (5.4 + 0.2)(3.0 + 0.1) = 17.36 = 16.2 + 1.16.

Percent error in the maximum value of xy = 7.2 %.

Minimum value of xy = (5.4 - 0.2)(3.0 - 0.1) = 15.08 = 16.2 - 1.12.

Percent error in the minimum value of xy = 6.9 %.

Value of $\frac{x}{y} = \frac{5.4}{3.0} = 1.8.$

Maximum value of $\frac{x}{y} = \frac{5.4 + 0.2}{3.0 - 0.1} = 1.93 = 1.8 + 0.13.$

Percent error = 7.2 %

Minimum value of $\frac{x}{y} = \frac{5.4 - 0.2}{3.0 + 0.1} = 1.68 = 1.8 - 0.12.$

Percent error = 6.7 %

Note that in each case, the percent error in the result is nearly equal to the sum of the percent errors in x and y.

GRAPH - An Example

Given the data:

t (sec)	0	5	8	12	17
v (cm/sec)	17	22	26	31	38

We note that t is the independent variable. Thus t should be plotted along the x-axis, and v, along the y-axis.

Suppose the graph paper has 70 divisions along the x-axis and 100 divisions along the y-axis. (Remember that this is just an example.)

First, we choose (x_o, y_o), where x_o is the minimum value of t to be represented and y_o is the minimum value of v to be represented. In the present example, $x_o = 0$ and $y_o = 17$ cm/sec, but for convenience, we will choose $y_o = 10$ cm/sec.

The maximum values of t and v are 17 sec and 38 cm/sec, respectively.

Thus, along the x-axis, (17 - 0) sec are to be represented by 70 divisions.

Or 1 sec can be represented by 70/17 = 4.11 divisions.

For convenience, we will represent 1 sec by 4 divisions.

Along the y-axis, (38 - 10) cm/sec are to be represented by 100 divisions.

Or 1 cm/sec can be represented by 100/28 = 3.57 divisions.

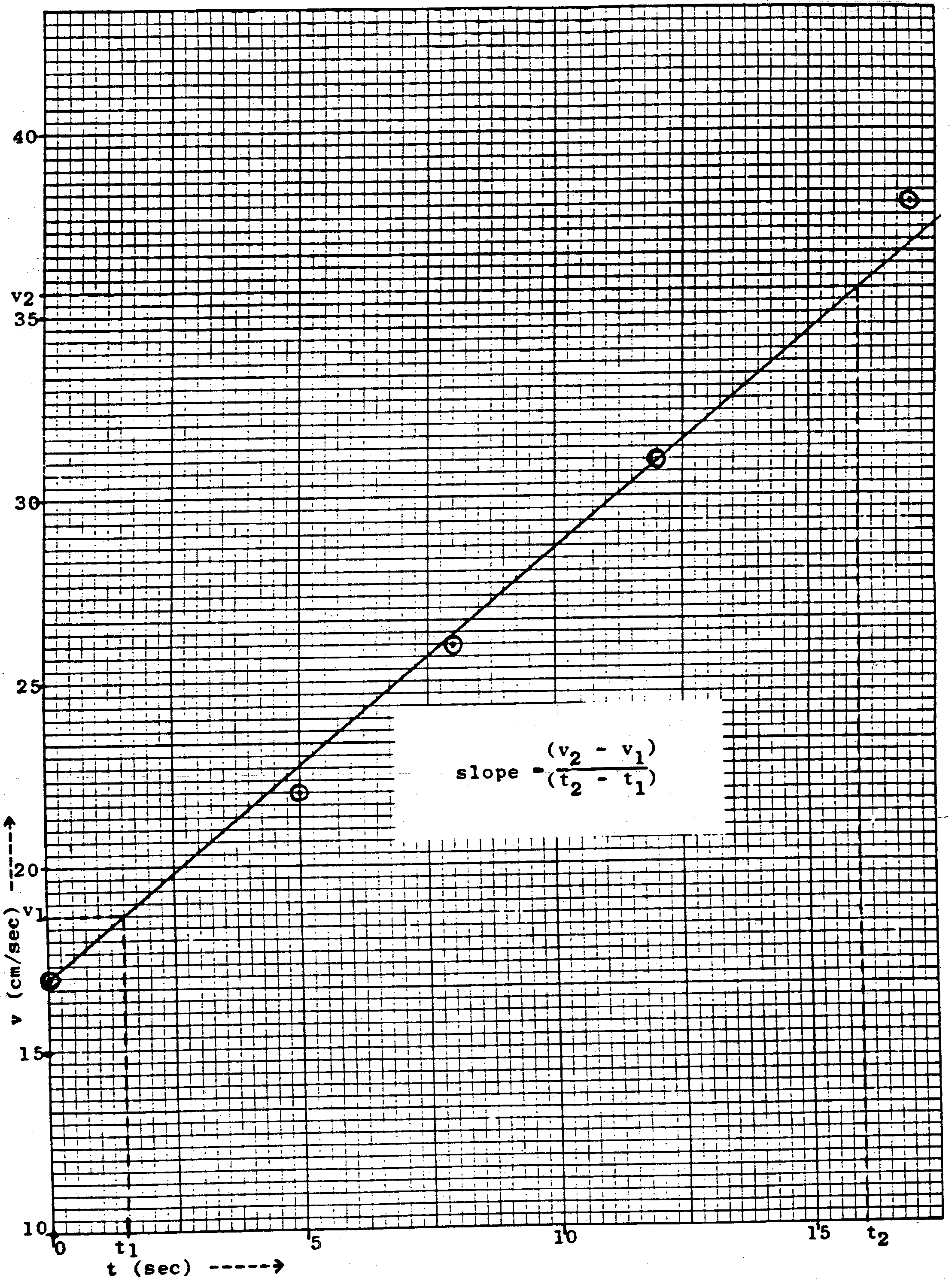
For convenience, we shall represent 1 cm/sec by 3 divisions.

Now we form the following table:

t (sec)	v (cm/sec)	$x = t - x_o$ sec	$y = v - v_o$ cm/sec	4*x divisions	3*y divisions
0	17	0	7	0	21
5	22	5	12	20	36
8	26	8	16	32	48
12	31	12	21	48	63
17	38	17	28	68	84

Now plot the graph as follows:

1. Mark the origin. Mark a few equidistant points along the x- and y-axes.
2. Write the physical quantities and the units along the x- and y-axes.
3. Plot the points by using the values in the last two columns of the above table.
4. Draw the 'best' curve such that it passes through as many points as possible, and, nearly as many points are above the curve as below it.


40
v2
35
30
25
20
v1
15
10
0
t1
5
10
15
t2
v (cm/sec)
t (sec)
slope = (v2 - v1)/(t2 - t1)

Instructions For Plotting A Graph By Using Microsoft EXCEL

Select the data for plotting the graph (values of x and y), for example, the values of V and I in the table for verification of Ohm's law.

Click on Chart Wizard in the first line of the menu bar.

Select chart type XY (scatter).

Press and hold to view sample.

Click on Finish.

Pull down Chart menu and click on location. Select sheet 3. The chart will be seen on sheet 3.

Pull down Chart menu, select chart options and type in Chart title 'Ohm's Law Verification'.

Pull down Chart menu and click on chart options and select major and minor grid lines for X as well as Y.

Double click on X-axis to see Format axis. Click on scale and enter minimum, maximum, major unit, minor unit and 'value of (Y) axis crosses at' (enter minimum of X). Major unit should be (maximum-minimum)/5 and minor unit should be major unit/5.

Double click on Y-axis to see Format axis. Click on scale and enter minimum, maximum, major unit, minor unit and 'value of (X) axis crosses at' (enter minimum of Y). Major unit should be (maximum-minimum)/5 and minor unit should be major unit/5.

Pull down the File menu, select Print preview and print the graph.

Draw the 'best' straight line, select two points on the graph and perform the necessary calculations.

Experiment 1a. Density

It may look small but it is massive because of its density.

Objective:

To determine the density of an irregular solid.

Apparatus:

An irregular solid, a balance, a graduated cylinder.

Theory:

$$\text{Density, } \rho = \frac{\text{mass}}{\text{volume}}$$

Procedure:

1. Find the least count of the balance. The least count of an instrument is the smallest value of the physical quantity that can be accurately measured with that instrument. For example, on a meter stick, one centimeter is divided into ten equal parts (millimeters). Thus the least count of a meter stick is 0.1 cm.
2. Take two readings of the mass of the solid.
3. Find the least count of the graduated cylinder.
4. Pour some water into the graduated cylinder and take the reading of the water level. Remember that the lowest point of the meniscus is read if the meniscus is concave.
5. Gently lower the irregular solid by means of the thread into the graduated cylinder and read the position of the water level again.
6. Take one more set of readings by changing the quantity of water in the graduated cylinder.

Use cgs units in this experiment.

The cgs unit of volume is cubic cm (cm^3). 1 mL (milliliter) = 1 cm^3.

Record the observations with appropriate units.

Experiment 1b. Scattering

Ever wondered how the 'size' of an atom is estimated!

Objective:

To determine the diameter of a marble by scattering method.

Apparatus:

Two wooden boards (one with nails), marbles, a meter stick.

Theory:

Let a marble A (Fig. 1) of radius r approach another marble T of the same radius. The marble A will hit the marble T if the path of its center lies between the points G and H. It is evident from the figure that GH = 4r = 2D, where D is the diameter of each marble. Thus each target marble presents a 'collision cross-section' of 2D. Now if n marbles are arranged on the target board J, the total collision cross-section presented by n target marbles is 2Dn. Further, if w is the width of the target board, then the probability of a collision is given by

$$P = \frac{2Dn}{w}. \qquad (1)$$

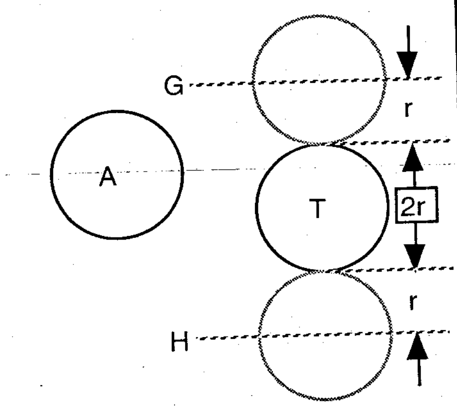


Fig. 1

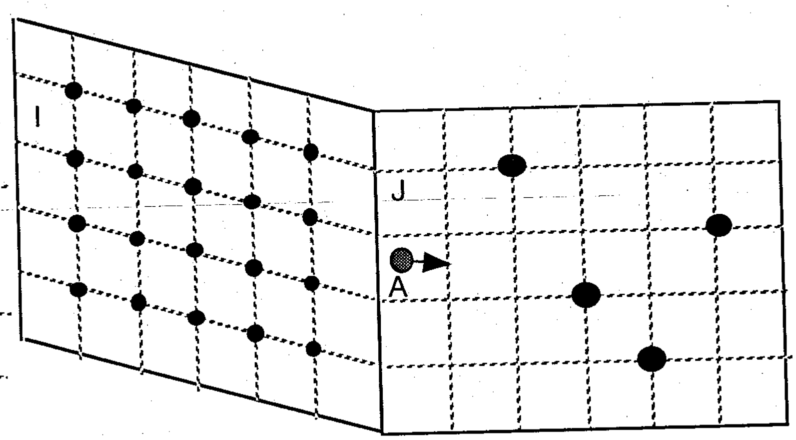


Fig. 2

To determine the collision probability, a number of target marbles are arranged on the target plane J (Fig. 2) such that no two marbles are on the same line. A marble A is rolled down a number of times from different points near the top of the inclined plane I. The inclined plane has a number of nails to randomize the motion of the marble being rolled down. If the marble A hits any target marble, the trial is counted as one with a hit. Now if s is the total number of trials and h is the number of trials with a hit, then the collision probability is given by

$$P = \frac{h}{s}. \qquad (2)$$

By equating the right hand sides of Eqs. (1) and (2), we get

$$\frac{2Dn}{w} = \frac{h}{s}.$$

$$\text{Or } D = \frac{hw}{2sn} \qquad (3)$$

Procedure:

1. Arrange 8 target marbles on the target board. Marbles should be placed at the points of intersections of the lines on the board. No two marbles should be placed on the same line on the board.
2. Let a marble roll down the plane I. If this marble hits one or more target marbles, count this trial as one with a hit. Repeat the procedure 100 times, releasing the marble from different points at the top of the inclined plane I.
3. Measure the width (w) of the target board.
4. Measure the length of a string of 10 marbles, arranged in a straight line along a meter stick and thus find the diameter of a single marble.
5. This procedure is followed by each team of 2 students of the class. The data of all the teams is accumulated and used by each student.

Use cgs units in this experiment.

Experiment 1a. Density

It may look small but it is massive because of its density.

Objective:

To determine the density of an irregular solid.

Apparatus:

An irregular solid, a balance, a graduated cylinder.

Theory:

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Procedure:

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4. Pour some water into the graduated cylinder and take the reading of the water level. Remember that the lowest point of the meniscus is read if the meniscus is concave.
5. Gently lower the irregular solid by means of the thread into the graduated cylinder and read the position of the water level again.
6. Take one more set of readings by changing the quantity of water in the graduated cylinder.

Use cgs units in this experiment.

The cgs unit of volume is cubic cm (cm^3). 1 mL (milliliter) = 1 cm^3.

Record the observations with appropriate units.

Experiment 1b. Scattering

Ever wondered how the 'size' of an atom is estimated!

Objective:

To determine the diameter of a marble by scattering method.

Apparatus:

Two wooden boards (one with nails), marbles, a meter stick.

Theory:

Let a marble A (Fig. 1) of radius r approach another marble T of the same radius. The marble A will hit the marble T if the path of its center lies between the points G and H. It is evident from the figure that GH = 4r = 2D, where D is the diameter of each marble. Thus each target marble presents a 'collision cross-section' of 2D. Now if n marbles are arranged on the target board J, the total collision cross-section presented by n target marbles is 2Dn. Further, if w is the width of the target board, then the probability of a collision is given by

$$P = \frac{2Dn}{w}. \qquad (1)$$

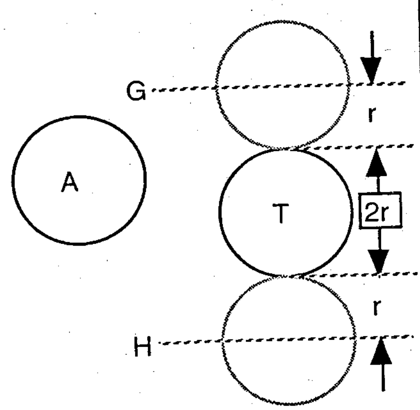

Fig. 1

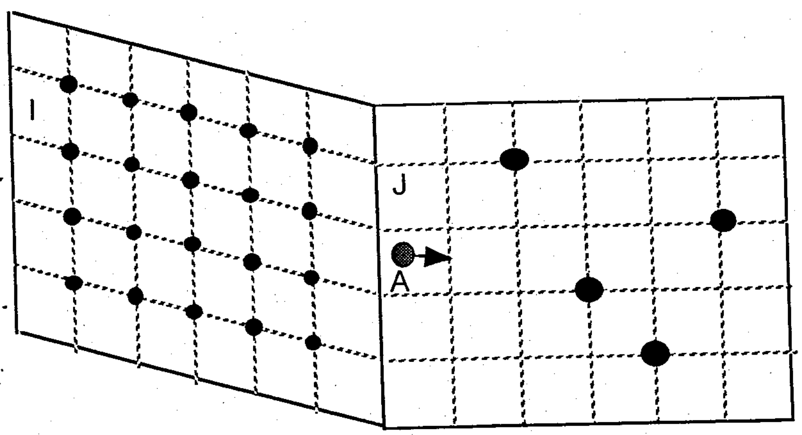

Fig. 2

To determine the collision probability, a number of target marbles are arranged on the target plane J (Fig. 2) such that no two marbles are on the same line. A marble A is rolled down a number of times from different points near the top of the inclined plane I. The inclined plane has a number of nails to randomize the motion of the marble being rolled down. If the marble A hits any target marble, the trial is counted as one with a hit. Now if s is the total number of trials and h is the number of trials with a hit, then the collision probability is given by

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2. Let a marble roll down the plane I. If this marble hits one or more target marbles, count this trial as one with a hit. Repeat the procedure 100 times, releasing the marble from different points at the top of the inclined plane I.
3. Measure the width (w) of the target board.
4. Measure the length of a string of 10 marbles, arranged in a straight line along a meter stick and thus find the diameter of a single marble.
5. This procedure is followed by each team of 2 students of the class. The data of all the teams is accumulated and used by each student.

Use cgs units in this experiment.

Experiment No. 1

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

a. Determination of the density of an irregular solid:

Least count of the balance =

Mass of the irregular solid:

Reading 1 =

Reading 2 =

Least count of the graduated cylinder =

No.	Initial reading of water level	Final reading of water level	Volume

Calculations:

Average mass of the solid =

Average volume of the solid =

Density of the solid = $\frac{\text{Mass}}{\text{Volume}}$ =

Standard value of the density of the solid =

Percent error in the experimental value of density =

Probable errors:

Probable error in the mass of the solid = least count of the balance =

Probable error in the volume of the solid

= least count of the graduated cylinder[1] =

Probable percent error in the mass of the solid =

Probable percent error in the volume of the solid =

Probable percent error in the density of the solid

= probable percent error in mass + probable percent error in volume

=

1 In fact, the probable error in volume = sum of the probable errors in the initial and final readings of water level.

b. Determination of diameter of a marble:

Width of the board, $w =$; Number of target marbles, $n =$

Team No.	1	2	3	4	5	6	7	8	9	10
No. of trials with hits										
Total No. of trials										

Length of the string of 10 marbles, $L =$

Calculations:

Total number of trials for all the teams, $s =$

Total number of trials for all the teams with hits, $h =$

$$D = \frac{hw}{2sn}$$

Total number of trials for team numbers 3 and 6, $s_1 =$

Total number of trials for team numbers 3 and 6 with hits, $h_1 =$

$$D_1 = \frac{h_1 w}{2 s_1 n}$$

Diameter of one marble (from direct measurement), $D_t = \frac{L}{10} =$

Taking D_t as the standard value,

Percent error in $D =$

Percent error in $D_1 =$

Questions

1. What is the main source of error in the determination of density?

2. Do the results by using a larger sample demonstrate the advantage of having a larger sample in the scattering experiment? Explain.

Experiment 2a. Vernier Caliper

Can you divide a millimeter into 20 equal parts?
Essentially, a vernier does that exactly.

Objective:

To measure the length and diameter of a cylinder, determine its mass, and calculate its volume and density.

Apparatus:

Vernier caliper, a cylinder and a balance.

Theory:

Least count of a vernier caliper, the smallest length that can be accurately measured with it, is equal to the length of the smallest main scale division divided by the number of divisions on the vernier scale.

Procedure:

1. Find s, the length of the smallest division of the main scale of the vernier caliper.

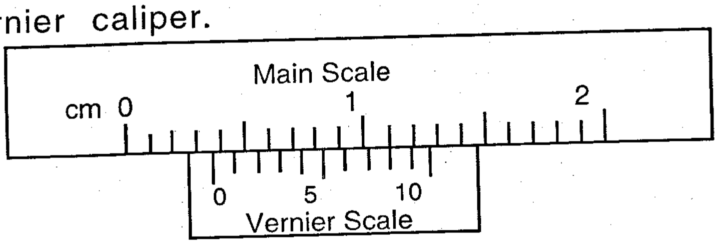


Figure 1

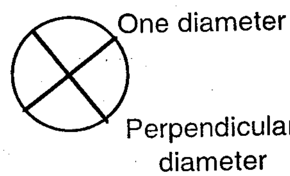


Figure 2

2. Count n, the number of divisions on the vernier scale of the caliper.
3. Note that a length equal to n-1 divisions of the main scale is divided into n equal parts. Thus the least count of the vernier, $\ell.c. = s/n$.
4. Learn to read the vernier caliper. The reading of any length taken with a vernier caliper consists of two parts:
   (a) Main scale reading which is the reading of the main scale division just to the left of (or coinciding with) the vernier zero. In the above diagram, the main scale reading, m = 0.3 cm.
   (b) Vernier scale reading which is the number of division of the vernier scale that coincides with some main scale division. In the above diagram, the vernier scale reading, v = 8.

The reading of length (being measured with a vernier caliper)
= main scale reading + vernier reading x least count

$= m + v \times \ell.c.$

$= 0.3 + 8 \times 0.01$ (where $\ell.c. = 0.01$ cm)

$= 0.38$ cm

5. Bring the 'jaws' of the vernier caliper together. If the zero of vernier scale coincides with the zero of the main scale , there is no zero error in the instrument. However if the zero of the vernier scale does not coincide with the zero of the main scale, there is zero error. To find the zero error, take the vernier reading (p). Now if the vernier zero is on the right of the zero of the main scale, the zero error is positive and its value is + p x $\ell.c.$ If the vernier zero is on the left of the zero of the main scale, the zero error is negative and its value is - (n-p)x $\ell.c.$ Remember that the zero error is always subtracted algebraically from the readings.
6. Take six readings for the length of the cylinder.
7. Take 4 pairs of readings for the diameter of the cylinder. To obtain a pair of readings for diameter, measure one diameter, rotate the cylinder through 90^{o} and then measure the perpendicular diameter (Fig. 2).
8. Find the least count of the balance and take two readings for the mass of the cylinder.

Note that a vernier and a micrometer enable us to measure lengths correct to some fraction of the smallest main scale division without actually subdividing the smallest main scale divisions into a number of equal parts.

Use cgs units in this experiment.

Experiment 2b. Micrometer

A step ahead of the vernier - a micrometer can essentially divide a millimeter into 100 equal parts.

Objective:

To determine the diameter of a wire with a micrometer.

Apparatus:

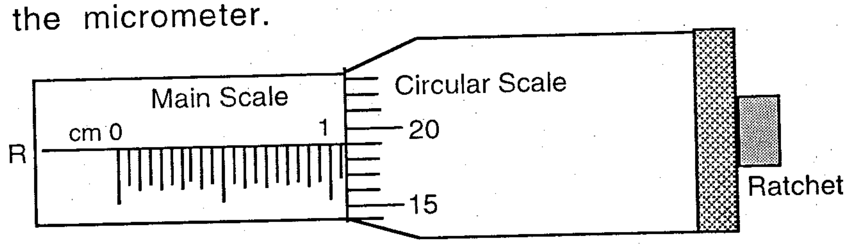
A micrometer, a piece of wire.

Theory:

The pitch of a screw is defined as the length traversed by the screw when it is given one complete rotation. The least count of a micrometer, the smallest length that can be accurately measured with it, is equal to the pitch of its screw divided by the number of divisions on its circular scale.

Procedure:

1. Find the length of the smallest division of the main scale of the micrometer. Count the total number of divisions (n) on the circular scale of the micrometer.



2. Make the edge of the thimble (on which the circular scale is engraved) coincide with some division of the main scale by rotating the thimble and record the main scale reading. Take the reading of the circular scale division which is closet to the reference line R (along which the main scale is engraved). Give 4 complete revolutions to the micrometer screw and again take the main scale reading. Find d, the difference between the two main scale readings. This is the distance through which the edge of the thimble (micrometer screw) moves in 4 complete rotations, and thus the pitch of the micrometer screw, p = d/4.
3. The least count of the micrometer is found by dividing the pitch by the number of divisions on the circular scale. Thus

Least count of the micrometer $= \frac{p}{n}$.

Calculate the least count ($\ell.c.$) of the micrometer.

4. Learn to read the micrometer. A micrometer reading consists of two parts:
   (a) Main scale reading which is the reading of the main scale division just to the left of (or coinciding with) the edge of the thimble. In the above diagram, the main scale reading, m = 1.05 cm.
   (b) Circular scale reading which is the number of circular scale division that is closest to the reference line. In the above diagram, the circular scale reading, c = 19.

   The reading of length (being measured with a micrometer)
   = main scale reading + circular scale reading x least count
   $= m + c \times \ell.c.$
   $= 1.05 + 19 \times 0.001$ (where $\ell.c. = 0.001$ cm)
   = 1.069 cm

5. Find the zero error. Bring the plane ends of the micrometer in contact and take the circular scale reading. If the edge of the thimble is at the zero of the main scale and the circular scale reading is zero, there is no zero error in the instrument. If the circular scale reading is c and the edge of the thimble is to the right of the zero of the main scale, the zero error is positive and it is equal to $c \times \ell.c.$ Otherwise, the zero error is negative and its value is $(c-n) \times \ell.c.$
   Remember that zero error is always subtracted algebraically to obtain the correct length.

6. Take 4 pairs of readings for the diameter of the wire. In each case, take the reading for one diameter, rotate the wire through 90^o and then measure the perpendicular diameter (Fig. 2).

Note that most micrometers have a ratchet which is used to tighten up the object being held between the plane ends of the instrument with the same force each time. Application of an unnecessarily large force is also avoided by this arrangement.

Use cgs units in this experiment.

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York College of The City University of New York

Physics I

Name:

Experiment No. 2: Pre-Lab Questionnaire

1. In the measurement of length of a cylinder, the main scale reading of a vernier caliper is 1.5 cm, the vernier reading is 6, and the least count of the vernier is 0.01 cm. Find the reading of the length of the cylinder.

2. The edge of the thimble of a micrometer moves a distance of 0.2 cm when it is given four complete revolutions. (a) Find the pitch of the micrometer. (b) If the number of divisions on the circular scale are 50, calculate the least count of the micrometer.

3. Using a vernier caliper of least count 0.01 cm, the length of a cylinder measured to be 3.76 cm, and its diameter, 1.28 cm. (a) Find the volume of the cylinder. (b) Calculate the probable percent error in the length. (c) Calculate the probable percent error in the radius. (d) Calculate the probable percent error in the volume.

Experiment No. 2

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

a. Vernier Caliper:

Length of the smallest division on the main scale, s =

Number of divisions on the vernier scale, n =

Least count of the vernier caliper, *l.c.* =]

Zero error =

Readings for the length of the cylinder:

No.	Length L_i	$L_i - L_{avg}$	$(L_i - L_{avg})^2$

Average length, L_{avg} =

Standard deviation in L, σ =

Standard error in L, σ_m =

Probable percent error in L =

Readings for the diameter of the cylinder:

No.	One diameter	Perpendicular diameter	Average reading

Average reading for the diameter =

Diameter of the cylinder, corrected for zero error =
Probable percent error in the diameter of the cylinder =
Mass of the cylinder:

Least count of the balance =

Reading 1 =

Reading 2 =

Average mass of the cylinder =

Probable percent error in the mass of the cylinder =

Calculations:

Volume of the cylinder =

Density of the cylinder = $\frac{\text{Mass}}{\text{Volume}}$ =

Standard value of the density of the cylinder =

Percent error in the experimental value of density =

Probable errors:

Probable error in the volume of the cylinder

= probable percent error in length

+ 2(probable percent error in diameter)

=

Probable percent error in the density of the cylinder

= probable percent error in mass + probable percent error in volume

=

b. Micrometer:

Length of the smallest main scale division of the micrometer

=

Distance traveled by the micrometer screw in 4 rotations =

Pitch of the micrometer screw =

Number of divisions on the circular scale of the micrometer =

Least count of the micrometer =

Zero error = divisions = cm

Readings for the diameter of the wire:

For thin wires, it may be more convenient to take the circular scale reading with the wire between the plane ends and the circular scale reading with the plane ends in contact. The product of the difference between the two readings and the least count gives the diameter. In this case, the correction for zero error is not necessary.

No.	One diameter	Perpendicular diameter	Average reading

Average reading for the diameter =
Diameter of the wire, corrected for zero error =

Experiment No. 2: Questions

1. Why are several readings taken for each physical quantity?

2. A single reading taken with a meter stick for the length of a cylinder is 5.5 cm. What is the probable percent error in the reading?

3. The following readings were taken with a meter stick for the length of a cylinder: 5.5 cm, 5.3 cm, 5.4 cm, 5.5 cm and 5.6 cm. Calculate the standard deviation of the mean, the stand error and the probable percent error.

4. How many significant figures should be given in reporting the length of the cylinder in question 3?

5. If the radius of the cylinder in question 2 is 2.4±0.2 cm and its mass is 32.6±0.5 gm, what will be the probable percent error in the density of the cylinder? What will be the probable error in density? How many significant figures should be given in reporting the density?

Experiment 3. Equilibrium

Addition of vectors - two forces, $F_1 = 80$ newton and $F_2 = 60$ newton can balance a force, $F_3 = 100$ newton.

Objective:

(a) To study the equilibrium of a point mass. (b) To study the equilibrium of an extended object.

Apparatus:

The apparatus consists of an vertical board having two small pulleys attached at the two top corners of the board. A thin string carrying two weights at its ends passes over the pulleys (Fig. 1). Another string which carries a third weight is tied to the first string. To study the equilibrium of an extended object, an arrangement similar to that shown in Fig, 3 is used.

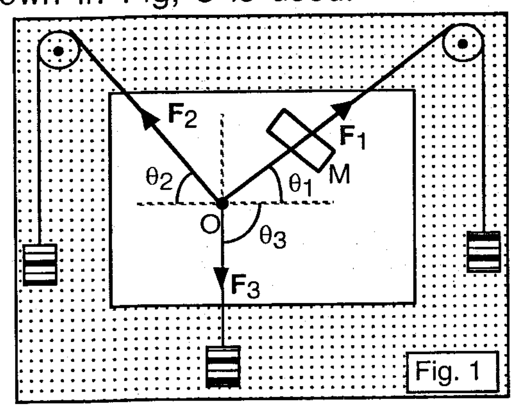

Fig. 1

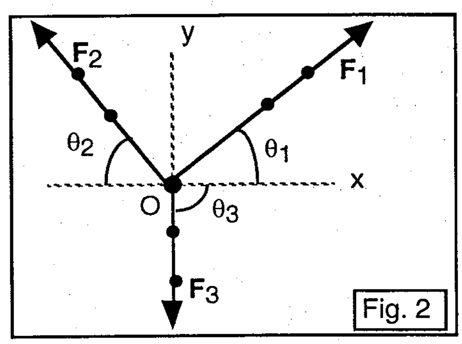

Fig. 2

Theory:

A body is said to be in equilibrium if there is no change in its translational motion or rotational motion. In other words, equilibrium entails that the body should not have translational or rotational acceleration. External forces and torques produce or tend to produce a translational and angular accelerations in a body. Thus forces and torques change or tend to change the state of equilibrium of a body. Obviously, if the resultant of external forces and the resultant of external torques are zero, the body will remain in equilibrium. Thus the conditions for equilibrium are:

I. If a number of forces, $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., keep a body in equilibrium, the resultant of the forces $\Sigma\mathbf{F} = 0$. In other words,
the sum of the x-components of the forces $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma F_x = 0$, and
the sum of the y-components of the forces $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma F_y = 0$.

II. The algebraic sum of the torques of $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma\tau = 0$

Components of a force:

If a force $\mathbf{F}_1$ = 80 gm-wt makes an angle $\theta_1 = 30^o$ with the x-axis (Fig. 2),

x-component of $\mathbf{F}_1$, $Fx = F_1 \cos\theta_1 = 80 \cos 30^o$ gm-wt = 69.3 gm-wt and

y-component of $\mathbf{F}_1$, $Fy = F_1 \sin\theta_1 = 80 \sin 30^o$ gm-wt = 40 gm-wt.

Note that angles θ_1 and θ_2 are the acute angles made with the +x-axis or -x-axis. If the component points toward the +x-axis (or +y-axis), it is positive, and if it points toward the -x-axis (or -y-axis), it is negative.

Torque (moment) of a force:

Torque of a force is a measure of the capability of the force to produce angular acceleration and thereby changing the rotational motion of a body. The torque depends on the magnitude of the force and on the position of its point of application (including the direction) relative to the axis of rotation (or of intended rotation). The torque of a force can be counter-clockwise (positive) or clockwise (negative).

The torque of a force is calculated by using the formula

torque τ = force x lever arm (or moment arm),

where lever arm p = perpendicular distance of the axis of rotation from the line of action of the force.

For example (Fig. 4), if force $\mathbf{F}_1$ = 100 gm-wt, distance AT = 17 cm and $\theta_1 = 38^o$,

lever arm $AP_1 = 17 \sin 38^o$ cm = 10.5 cm,

and torque τ_1 = 100x10.5 cm-gm-wt = 1050 cm-gm-wt.

Procedure:

(a) Equilibrium of a point object:

1. Arrange the strings and weights as shown in Fig. 1. Attach a sheet of paper on the board such that the knot is nearly in the center. Hold a mirror strip M (Fig. 1) gently on the paper behind a section of the string. Mark two fine dots on the paper with a pencil such that the dots are hidden behind the string when the image of the string is hidden behind the string (see Fig. 2). Similarly, mark two pairs of dots for the other two sections of the string as well. Do not try to mark the position of the knot. The procedure using the mirror strip eliminates errors due to parallax. (What is parallax?)
2. Remove the paper from the board. check to see that the lines of action of the three forces acting on the knot meet at one point as shown in Fig. 2. If they do not meet at one point, discard the sheet of paper and repeat the procedure.

3. Extend the line of action of force $\mathbf{F}_3$ to obtain the y-axis. Then draw the x-axis as shown in Fig. 2. Record the forces including the weights of the hangers. Measure angles θ_1 and θ_2. Note that θ_3 is -90^o.
4. Repeat the procedure by using different combinations of weights.

(b) Equilibrium of an extended object:

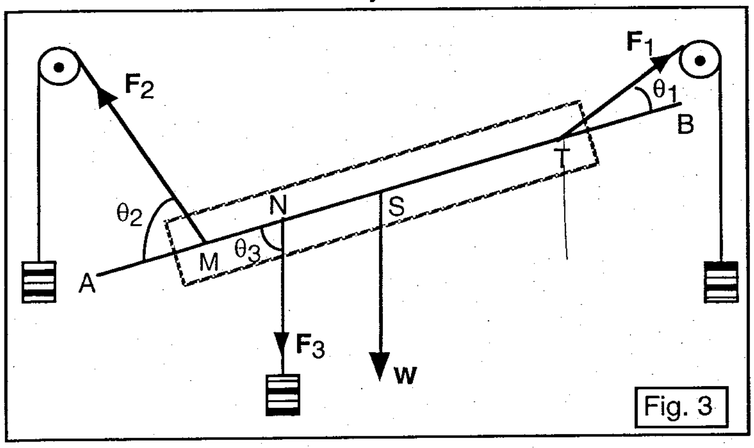

Fig. 3

5. Arrange the strings and weights as shown in Fig. 3 attaching a sheet of paper on the board. Using the mirror strip, mark the lines of action of forces $\mathbf{F}_1$, $\mathbf{F}_2$ and $\mathbf{F}_3$, and the corners of the plastic strip (for finding the central axis AB).

Calculation of torques:

Torque = force x lever arm

Lever arms:

Length AP_1
$= AT \sin\theta_1 = d_1 \sin\theta_1$

Length AP_2
$= AM \sin\theta_2 = d_2 \sin\theta_2$

Length AP_3
$= AN \sin\theta_3 = d_3 \sin\theta_3$

Length AP_4
$= AS \sin\theta_3 = d_4 \sin\theta_3$

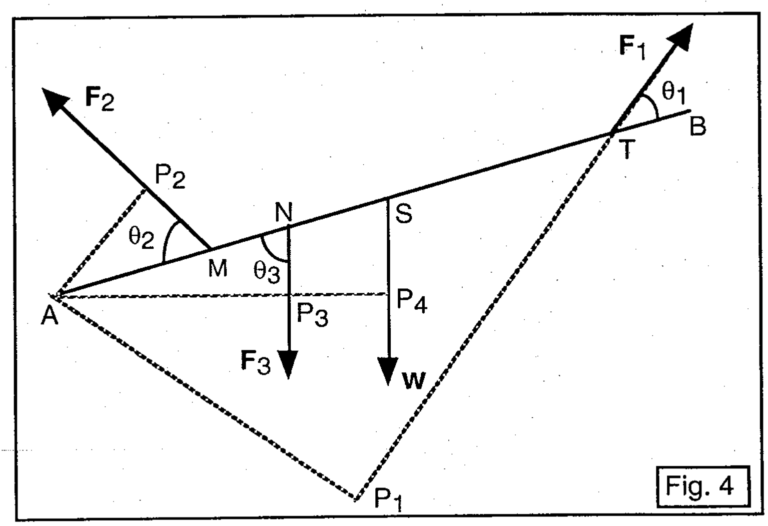

Fig. 4

6. Remove the sheet of paper, draw the lines of action of the forces $\mathbf{F}_1$, $\mathbf{F}_2$ and $\mathbf{F}_3$, and draw the line AB. Record the weights and the weight of the plastic strip. Note that the weight of the strip acts through S, the geometric center of the strip and makes an angle equal to θ_3. Here point A is chosen arbitrarily and AB is taken to be the x-axis for convenience.
7. Measure the angles and the distances d_1 = AT, d_2 = AM, d_3 = AN, d_4 = AS.
8. Take one more set of data, if time permits.

Use gm-wt as the unit of weight and cm as the unit of length in this experiment.

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York College of The City University of New York

Physics I   Name:

Experiment No. 3: Pre-Lab Questionnaire

1. In Fig. 1, let $\mathbf{F_1}$ = 120 gm-wt, $\mathbf{F_2}$ = 195 gm-wt, $\theta_1 = 35^o$ and $\theta_2 = 60^o$.
   (a) Determine $\mathbf{F_3}$. (b) Calculate ΣFx.

2. In Figs. 3 and 4, let length AM = 6.5 cm, $\mathbf{F_2}$ = 120 gm-wt, angle $\theta_2 = 60^o$. Calculate the torque of $\mathbf{F_2}$ about A.

3. In Figs. 3 and 4, let length AN = 16.5 cm, $\mathbf{F_3}$ = 85 gm-wt, angle $\theta_3 = 80^o$. Calculate the torque of $\mathbf{F_3}$ about A.

Experiment No. 3

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

a. Equilibrium of a point object:

No.	Force	Angle	x-component	y-component
1.	$\mathbf{F}_1$	θ_1		
	$\mathbf{F}_2$	θ_2		
	$\mathbf{F}_3$	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$
2.	$\mathbf{F}_1$	θ_1		
	$\mathbf{F}_2$	θ_2		
	$\mathbf{F}_3$	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$

b. Equilibrium of an extended object:

Weight of the plastic strip =

No.	Force	Angle	x-component	y-component
1.	$\mathbf{F}_1$	θ_1		
2.	$\mathbf{F}_2$	θ_2		
3.	$\mathbf{F}_3$	θ_3		
4.	w	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$

No.	Distance of point of application	Lever arm	Torque
1.	$AT = d_1 =$		
2.	$AM = d_2 =$		
3.	$AN = d_3 =$		
4.	$AS = d_4 =$		
			$\Sigma\tau =$

Make similar tables if you have more observations.

Conclusions

Experiment No. 3: Questions

1. Define force and torque. Does the torque depend on the point of application of the force? Explain.

2. What are the conditions of equilibrium?

3. A rain drop falling toward the ground was observed to have a constant velocity. Was the rain drop in equilibrium? Explain.

Experiment 4. Inclined Plane

Galileo's experiments that revealed important secrets of nature performed with modern technology

Objective: To study the motion of a glider along an inclined plane and to determine the acceleration due to gravity.

Apparatus: An air track, a glider with a flag, photogates, CHAMP interface and a personal computer.

In a photogate (Fig. 1), a beam of infrared light emitted by a light emitting diode (LED) is sent to a solid state infrared detector. Changes in the light level at the detector change the voltage levels in the control circuits which turn the timers in the computer on and off.

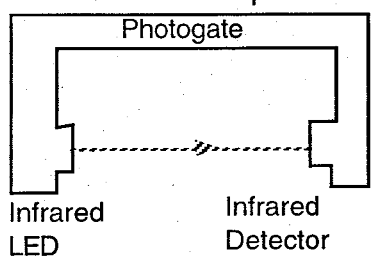

Fig. 1

In the double gate (B) mode, when an object such as a flag on the glider passes through gate 1 and through gate 2 (Fig. 5), time t_1 is the time during which gate 1 is blocked, time t_2 is the time taken by the object in going from gate 1 to gate 2 and time t_3 is the time during which gate 2 is blocked.

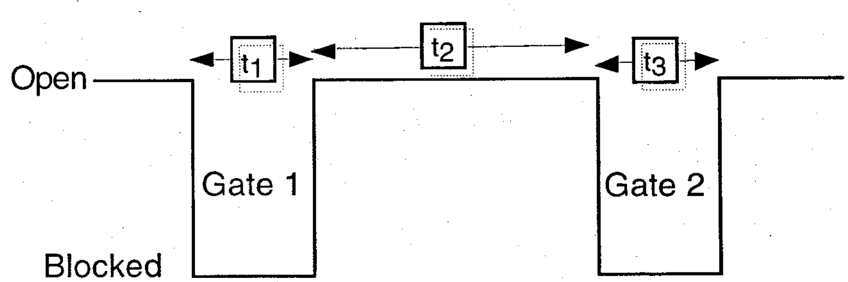

Fig. 2

Theory:

Consider a glider on a smooth inclined plane (shown in Fig. 3). The cart glides on a cushion of air and so friction is minimized. Thus the external forces acting on the block are its weight mg and the normal force F_N applied by the plane. The component of the weight perpendicular to the plane is mg cos θ, which balances the normal force F_N. Thus the resultant force on the glider is equal to the component of mg along the plane, that is mg sin θ. Finally, according to Newton's second law, the acceleration of the glider along the plane is given by

$$a = \frac{mg \sin \theta}{m} = g \sin \theta. \qquad (1)$$

Thus by determining the acceleration 'a' and angle θ, the acceleration due to gravity g can be calculated.

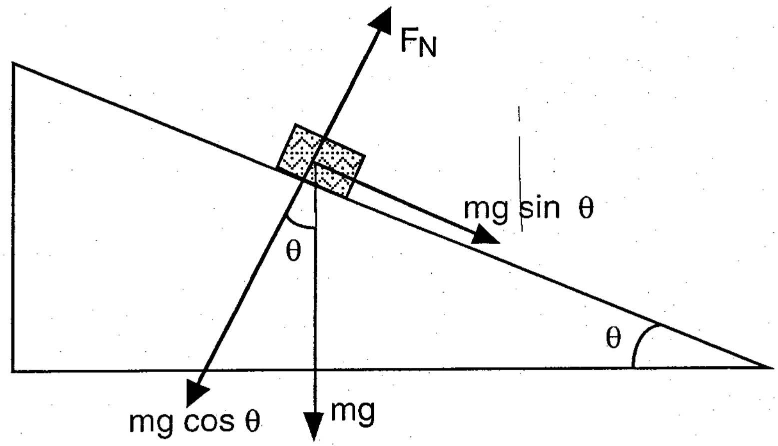

Fig. 3

Now let the velocity of the glider at gate 1 = v_1
and the velocity of the glider at gate 2 = v_2
Further let the separation between the gates = s
Then the third kinematic equation gives

$$v_2^2 = v_1^2 + 2\,a\,s. \qquad (2)$$

By measuring v_2, v_1 and s, one can calculate the acceleration 'a'.

Procedure:

1. Measure the height (h) and length (ℓ) of the inclined plane at two points.

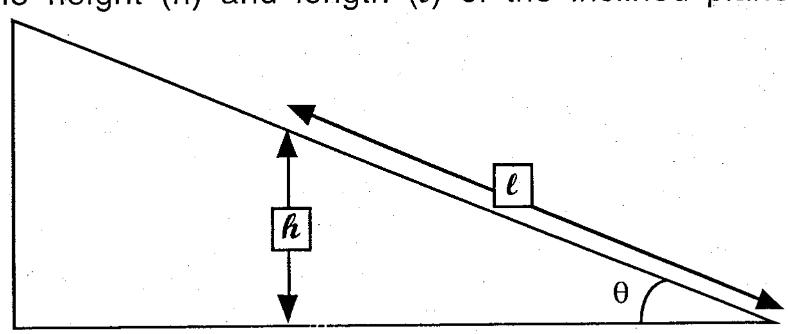

Fig. 4

2. Measure the length of the flag twice.
   Place the two photogates at suitable positions. Place gate 1 at a convenient position near the top of the inclined plane and gate 2 about 25 cm down the plane from gate 1.
3. Turn on the CHAMP and then the computer.

(Always make sure that CHAMP interface is connected and turned on before switching on the computer. Also the computer should be switched off before turning off the CHAMP.)

At the prompt

C:TPACK>

enter TP

You will see 'TIMEPACK' on the screen among other things.

Press any key and you will see

You will see 'HIT ENTER TO ACCEPT', etc. on the screen.

Press the enter key.

You will see 'PLEASE ENTER PASSWORD'.

Enter PASS as the password.

4. You will see the menu containing:

A: Single gate timer	H: Frequency Timer
B: Double gate timer	- - - - -
C: Time between gates	- - - - -
D: Pendulum timer	- - - - -
E: Motion timer	L: Data Analysis
F: Collision timer	M: Test photogates
- - - - -	N: Exit Timepack

Enter M

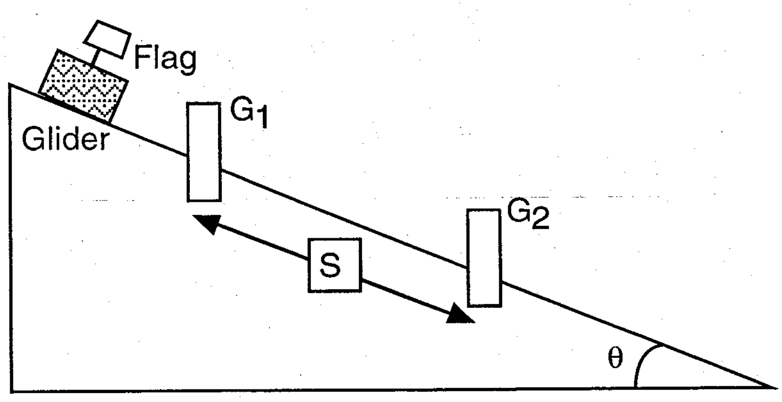

Fig. 5

Move the glider until photogate 1 changes from open to blocked. This gives the position of gate 1. Record the position of gate 1 in meters. Now move the glider until photogate 2 changes. This gives the position of gate 2. Record the position of gate 2 in meters.

The difference between the positions of the two gates gives s.

Press any key to return to the main menu.

5. To measure times, select "B: Double gate timer"
   Turn on the air flow.
   Release the glider five times. Make sure that the glider is released from the same point each time. Make sure that the glider does not bounce up along the plane up to the second gate.
   Now press any key to terminate data collection.
   A table containing
   Run # Time #1 Time #2 Time #3
   and their averages (AVG) and standard deviations (STD) will be displayed on the screen. Examine the data for consistency.
6. To analyze the data, press any key to go to data analysis menu.
   You will see the menu containing:

A: Display Data Table	E: Edit Timing Data
B: Print Data Table	- - - - -
C: Analyze Timing Data	H: Repeat Experiment
D: Graph Timing Data	I: Return To Main Menu

   Enter C to select "C: Analyze Timing Data"
   Enter length of flag in m (meter).
7. A table containing velocity #1 velocity #2 acceleration
   and their averages will be displayed on the screen.
   Examine the data for consistency.
   If all five trials have consistent values, you need not edit the data.
   If all five trials have inconsistent values, you should repeat steps 5, 6 and 7.
   If one or two trials contain inconsistent values, edit the data.
8. To edit, press any key to return to the previous menu (Data Analysis Menu). Enter E: EDIT TIMING DATA
   The screen will give directions to edit the data. Move the cursor to the line which contains the data to be deleted and press enter. An asterisk (*) will appear next to the data to be omitted. Press ESC and follow the directions on the screen to return to the data analysis menu. Copy average values of the velocities and acceleration.
9. Repeat steps 4-8 by changing the positions of the photogates and take 5 or 6 sets of readings with different values of s. Move photogate 1 down by about 2 cm and photogate 2 by about 7 or 8 cm.
10. Plot a graph between s and $(v_2^2 - v_1^2)$ and find 'a' from the slope of the graph.
    Use mks units in this experiment.

York College of The City University of New York

Physics I

Name:

Experiment No. 4: Pre-Lab Questionnaire

1. Briefly explain the working of a photogate.

2. If in Fig. 2, ℓ = 86 cm and h = 17 cm, find the value of sin θ. If the value of 'a' given by the CHAMP is 1.93 m/s^2, calculate g.

3. If the CHAMP gives v_1 = 1.2 m/s, v_2 = 1.7 m/s and the separation between the two gates is 0.4 m, find 'a'.

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Experiment No. 4

Name:	Marks:
Partner:	Remarks:
Section:	
Date Submitted:	

Title:

Objective:

Theory/Formulas:

Data Sheet

Measure all lengths in meters.

Determination of sin θ:

Height (h)		
Length (ℓ)		
$\sin \theta$		

Average sin θ =

Length of the flag: Reading 1 = ; Reading 2 =

Average length of the flag, L =

Caution: Release the glider from the same point in each reading.

Readings for acceleration:

No.	Position of gate 1 r_1	Position of gate 2 r_2	s= r2-r1	Average			a [formula (2)]
				v_1	v_2	a(CHAMP)	

Average 'a' (CHAMP) = g =

Average 'a' (formula) = g =

Data for graph:

No.	$s = r_2 - r_1$	$v_2^2 - v_1^2$

Plot a graph between s and $v_2^2 - v_1^2$ and find 'a' from the slope of the graph.

'a' (graph) = g =

Conclusions & Remarks:

Experiment No. 4: Questions

1. What is the advantage of determining 'g' by using the inclined plane rather than by free fall?

2. Does the acceleration of the glider depend on the angle of inclination of the plane? Does the value of 'g' depend on the angle of inclination of the plane? Explain.

3. Is the velocity of the glider at the second photogate greater than that at the first photogate? What about the acceleration?

4. How will the results of the experiment change if a heavier glider is used?

Experiment 5. Simple Pendulum

A pendulum isn't just for keeping time. One can also study gravity with it.

Objective:

(a) To verify that the time period of a simple pendulum is proportional to the square root of its length, if the amplitude is small, and to determine the value of g, the acceleration due to gravity.

(b) To show that the period oscillation is independent of its amplitude for small amplitudes only.

Apparatus:

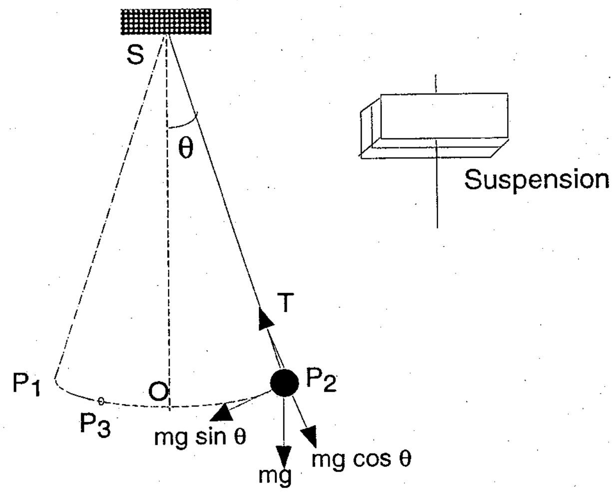
A simple pendulum, a meter stick, photogate, CHAMP interface and a personal computer.

Theory:

A simple pendulum consists of a small spherical metal bob suspended from a fixed support by means of a light inextensible string. The length of the pendulum ℓ is defined as the distance between the point of suspension S and point of oscillation O.

Thus ℓ = length of the string (including the hook) + radius of the bob.

When the pendulum is oscillating, one round trip is defined as one oscillation. In the figure below, one oscillation is from O to P_2 to P_1 and back to O. The round trip from P_3 to P_1 to P_2 and back to P_3 is also one oscillation.



The period or time period T of a pendulum is defined as the time for one complete oscillation.

The amplitude of oscillation is defined as the maximum displacement of the center of the bob from the equilibrium position O.

Thus amplitude is $OP_1 = OP_2$.

The amplitude can also be measured in terms of the maximum value of angle θ.

If the amplitude of oscillation is small (maximum value of $\theta \leq 0.05$ radian, that is, $OP_1 = OP_2 \leq 5$ cm for about 100 cm long pendulum), the time period of a simple pendulum is almost independent of the amplitude of oscillation. Further, in such a case, the motion of the pendulum is simple harmonic, and the time period is given by

$$T = 2\pi\sqrt{\frac{\ell}{g}} \qquad (1)$$

where g is the acceleration due to gravity (which is the acceleration of an object falling freely under gravity).

Squaring equation (1), we get

$$T^2 = 4\pi^2\frac{\ell}{g} = \left(\frac{4\pi^2}{g}\right)\ell \qquad (2)$$

The acceleration due gravity g is constant at a given place. Thus T^2 is directly proportional to ℓ. Therefore, a plot of T^2 vs. ℓ gives a straight line.

By choosing two points with coordinates $(T_1{}^2, \ell_1)$ and $(T_2{}^2, \ell_2)$ on the straight line graph, we get

$$T_1^2 = \left(\frac{4\pi^2}{g}\right)\ell_1 \quad \text{and} \quad T_2^2 = \left(\frac{4\pi^2}{g}\right)\ell_2$$

By subtracting and some mathematical manipulation, we get

$$g = 4\pi^2\left(\frac{\ell_2 - \ell_1}{T_2^2 - T_1^2}\right) \qquad (3)$$

Eq. (2) gives $g = 4\pi^2\left(\frac{\ell}{T^2}\right)$.

Hence the average value of g can also be calculated by using the average value of $\frac{\ell}{T^2}$.

Procedure:

1. Set up the pendulum and measure the diameter of the bob.
2. Turn on the CHAMP and then the computer.
   At the prompt
   C:TPACK>

enter TP
Follow the directions on the screen.
Use PASS as the password.
Select "M" to test the photogate.
The CHAMP determines the period by measuring the time between every other interruption of the photogate.

3. Measure the length of the string.
   Press any key to return to the main menu. To study the period of oscillation of the pendulum, select "D: Pendulum Timer."
   At the pendulum timer screen, start the oscillations. Keep the amplitude small. When the pendulum is at one extreme, press 'ENTER'.
   Accumulate data for about 10 full swings of the pendulum.
   Press any key to terminate the data collection.
   You will see a table of time periods.
   To edit the time periods that are not consistent, press any key to get the data analysis menu.
   Select E to edit the timing data.
   The screen will give directions to edit the data. Move the cursor to the line which contains the data to be deleted and press enter. An asterisk (*) will appear next to the data to be omitted. Press ESC and follow the directions on the screen to return to the data analysis menu.
   Now select A to display the data again. Record average T.
   Select C to analyze the timing data.
   While entering the length of the pendulum, remember to add the radius of the bob to the length of the string. Enter the length in meters.
   Record the value of 'g' calculated by the computer.
4. By selecting H, repeat step 3 with 5 different lengths of the string by changing the length by about 8 cm each time.
5. Tabulate the data, plot a graph between length and T^2 and determine 'g' from the slope of the graph.
6. Keeping the length of the string fixed at about 70 cm, determine the periods of oscillations for 3 different amplitudes (about 5 cm, 10 cm and 40 cm).
   Use mks units in this experiment.

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Physics I Name:

Experiment No. 5: Pre-Lab Questionnaire

1. What is a simple pendulum? Define time period and amplitude of a simple pendulum.

2. A student obtained ℓ_1 = 0.564 m, T_1^2 = 2.26 s^2; ℓ_2 = 0.823 m, T_2^2 = 3.30 s^2 from the graph between ℓ and T^2. Calculate 'g'.

Experiment No. 5

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

N
^

Data Sheet

Diameter of the bob: Reading 1 = Reading 2 =

Average diameter = Radius =

No.	Length of string	Length of pendulum	T	g (CHAMP)	T^2	$\frac{\ell}{T^2}$

Average $\frac{\ell}{T^2}$ =

From the average $\frac{\ell}{T^2}$, g = Percent error =

Average 'g' (CHAMP) = Percent error =

From the graph, T_1^2= ; ℓ_1 = ; T_2^2= ; ℓ_2 =

'g' (graph) = Percent error =

Dependence of T on amplitude

No.	Amplitude	T
1		
2		
3		

Remarks and conclusions about study of dependence of T on amplitude:

Experiment No. 5: Questions

1. Why should the amplitude of oscillation of the pendulum should be kept small?

2. What will happen if a rubber string is used instead of an inextensible string to suspend the bob?

3. Will the time period of a pendulum increase or decrease if it is taken from the earth to the moon? Explain.

4. The time period of a simple pendulum is 0.8 second. If its length is made four times the original length, what will be its new period?

Experiment 6. Atwood Machine

Diluting gravity so that the time of fall can be measured more accurately.

Objective:

To study motion under gravity and to determine the value of g, the acceleration due to gravity by using an Atwood machine.

Apparatus:

An Atwood machine (Fig. 2), a timer, weights.

Theory:

Consider the two masses M_1 and M_2, attached to the ends of a light string passing over the light smooth pulleys as shown in Fig. 1. Mass M_1 is greater than M_2. When the masses are released, M_1 will descend with an acceleration 'a' and M_2 will ascend with the same acceleration 'a'. The tension T in the string is the same throughout its length.

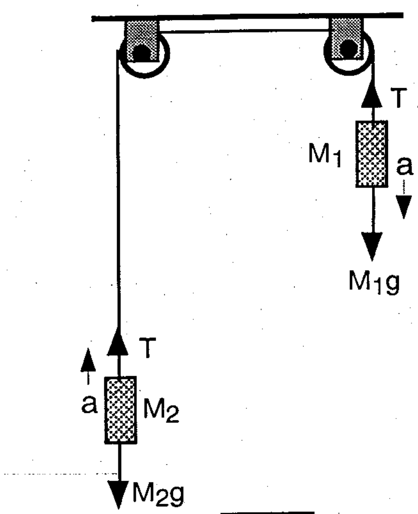

Fig. 1

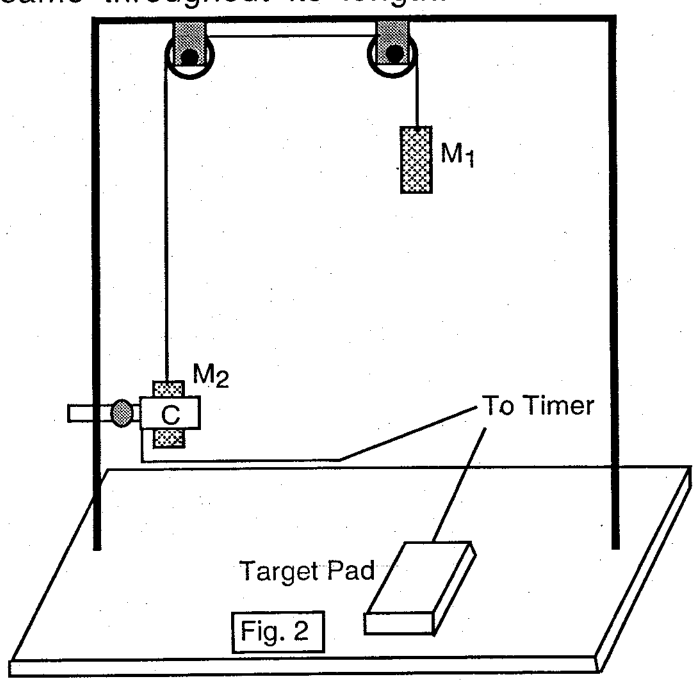

Fig. 2

By applying Newton's second law of motion to mass M_1,

Resultant of external forces acting on M_1 = (Mass M_1)(acceleration of M_1).

Or $T - M_1 g = - M_1 a$ (1)

Note that the acceleration of M_1 is downward and hence the negative sign.

Similarly, for the motion of M_1,

$T - M_2 g = M_2 a$ (2)

By subtracting Eq. (1) from Eq. (2),

$$M_1 g - M_2 g = M_1 a + M_2 a.$$

Or $$a = \frac{M_1 - M_2}{M_1 + M_2} g = \frac{\Delta M}{\Sigma M} g \qquad (3)$$

Here $\Delta M = M_1 - M_2$ = difference between the masses, and

$\Sigma M = M_1 + M_2$ = sum of the masses.

Note that the weights of the hangers must be considered in calculating ΔM and ΣM.

Eq. (3) indicates that if ΣM is kept constant,

$a \propto \Delta M$.

Thus a graph between a and ΔM will be a straight line and the value of g can be computed from the graph.

Further, Eq. (3) indicates that if ΔM is kept constant,

$a \propto \frac{1}{\Sigma M}$.

Thus a graph between a and $\frac{1}{\Sigma M}$ will be a straight line.

The value of g can be computed from the slope of the a versus $\frac{1}{\Sigma M}$ graph.

Procedure:

1. Study the working of the Atwood machine apparatus (Fig. 2) carefully. The masses M_1 and M_2 are tied at the ends of a light string passing over two smooth light pulleys. The lighter mass M_2 is held by a clamp C while the heavier mass M_1 hangs free. The timer should be reset before releasing the mass M_2. As soon as the mass M_2 is released, the timer starts. Mass M_2 rises and mass M_1 falls. When mass M_1 hits the target pad, the timer stops. Thus the time of fall of M_1 is measured.
2. Practice operating the apparatus a few times. Clamp mass M_2 such that its bottom is in level with the lower edge of the clamp C. Reset the timer and release the system so that mass M_1 falls on the target pad. Record the time of fall. Repeat the process a few times until you get consistent values of the time of fall.
3. Clamp mass M_2 such that its bottom is in level with the lower edge of the clamp C. Hold the meter stick vertically such that its one end rests on the target pad and read the position of the bottom of mass M_1. Thus

determine the distance of fall which is the height of the bottom of mass M_1 above the target pad.

4. Keeping ΣM constant, find the times of fall for five or six different values of ΔM. Measure the time of fall three times for each value of ΔM.
5. Keeping ΔM constant, find the times of fall for five or six different values of ΣM. Measure the time of fall three times for each value of ΣM.

Sample set of masses to be clamped on the left and right cylinders for the two pars of the experiment are given below:

Note that masses M_1 and M_2 consist of masses clamped on the left and right cylinders.

Let mass of the right cylinder $= C_1$
mass clamped on the right cylinder $= m_1$
mass of the left cylinder $= C_2$
mass clamped on the left cylinder $= m_2$
Thus mass $M_1 = m_1 + C_1$
and mass $M_2 = m_2 + C_2$

ΣM = constant		
No.	m_1 (kg)	m_2 (kg)
1	0.095	0
2	0.085	0.01
3	0.075	0.02
4	0.065	0.03
5	0.055	0.04

ΔM = constant		
No.	m_1 (kg)	m_2 (kg)
1	0.02	0
2	0.03	0.01
3	0.04	0.02
4	0.05	0.03
5	0.06	0.04

Make tables similar to the above examples with suitable values of m_1 and m_2 for use in steps 4 and 5 of the procedure.

Use mks units in this experiment.

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Physics I Name:

Experiment No. 6: Pre-Lab Questionnaire

The following data were obtained in an Atwood machine experiment:

Distance of fall = 0.455 m

M_1	M_2	Time of fall (sec)		
		R_1	R_2	R_3
0.20 kg	0.10 kg	0.535	0.539	0.932

1. Explain why the third reading R_3 should be discarded or repeated?

2. On repeating the experiment, R_3 was found to be 0.531 sec. Find the average value of time of fall.

3. Find the value of acceleration 'a' from the above data.

4. Calculate the value of 'g' from the above data.

Experiment No. 6

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

Mass of the right cylinder, C_1 =

Mass of the left cylinder, C_2 =

Distance of fall, D =

Least count of the timer =

ΣM = constant:

Note that small m's (m_1 and m_2) represent masses on the cylinders.

$\Sigma M = m_1 + C_1 + m_2 + C_2 =$

In the following table, $\Delta M = m_1 + C_1 - m_2 - C_2$.

No.	m_1 (kg)	m_2 (kg)	ΔM (kg)	Time of fall, T (second)			Average T	$a = \frac{2D}{T^2}$
				R_1	R_2	R_3		

Plot a graph between ΔM and a. Choose 2 points on the graph, find the values of ΔM and a for the 2 points and calculate the value of g from the slope of the graph by applying Eq. (3).

Percent error in the experimental value of g =

ΔM = constant:

Note that small m's (m_1 and m_2) represent masses on the cylinders.

$\Delta M = m_1 + C_1 - m_2 - C_2 =$

In the following table, $\Sigma M = m_1 + C_1 + m_2 + C_2$.

No.	m_1 (kg)	m_2 (kg)	ΣM (kg)	$\frac{1}{\Sigma M}$	Time of fall, T (second)			Average T	$a = \frac{2D}{T^2}$
					R_1	R_2	R_3		

Plot a graph between $\frac{1}{\Sigma M}$ and a.

Choose 2 points on the graph, find the values of $\frac{1}{\Sigma M}$ and a for the 2 points and calculate the value of g from the slope of the graph by applying Eq. (3).

Percent error in the experimental value of g =

Experiment No. 6: Questions

1. Draw the free body diagrams of M_1 and M_2, indicating the forces acting on them.

2. What is the resultant force acting on M_1 in observation number 2 of the first table?

3. Is the magnitude of the resultant force acting on M_1 equal to the magnitude of the resultant force acting on M_2? Explain your answer.

Experiment 7. Inelastic Collisions

> Nature works in mysterious ways!
> Total kinetic energy may change but momentum is always conserved.

Objective:

To study inelastic collisions and to verify that in an inelastic collision, momentum is conserved and that kinetic energy is not conserved.

Apparatus:

An air track, gliders, a glider with a flag, photogates, a meter stick, photogate, CHAMP interface and a personal computer.

Theory:

Let a glider of mass M_1, moving with an initial velocity $\vec{u}$, strike and stick to another glider of mass M_2, initially at rest. Further, let the combination move with a velocity $\vec{v}$ after the collision. If the resultant of the external forces acting on the two gliders is zero, then their total momentum will be conserved.

Before Collision   After Collision

Thus

initial momentum of the gliders $\vec{P}_i$ = final momentum of the gliders $\vec{P}_f$.

Or $$M_1\vec{u} = (M_1+M_2)\vec{v} \tag{1}$$

The initial kinetic energy E_i and final kinetic energy, E_f are given by

$$K_i = \frac{1}{2} M_1u^2 \; ; \; K_f = \frac{1}{2}(M_1 + M_2)v^2.$$

Thus $$\frac{K_f}{K_i} = \frac{(M_1 + M_2)v^2}{M_1u^2} = \left(\frac{M_1 + M_2}{M_1}\right)\left(\frac{v}{u}\right)^2$$

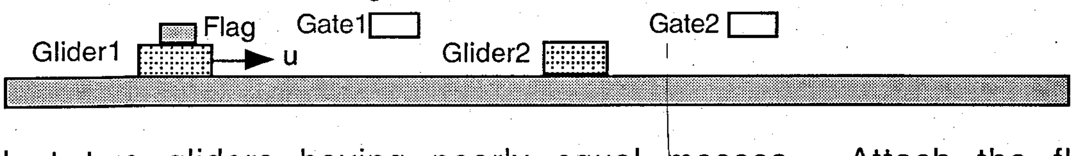
Now by Eq.(1), $$\frac{v}{u} = \frac{M_1}{M_1 + M_2}.$$

Thus $$\frac{K_f}{K_i} = \left(\frac{M_1 + M_2}{M_1}\right)\left(\frac{v}{u}\right)^2 = \left(\frac{M_1 + M_2}{M_1}\right)\left(\frac{M_1}{M_1 + M_2}\right)^2 = \frac{M_1}{M_1 + M_2}.$$

Procedure:

1. Measure the length of the flag twice.
2. Place the two photogates at suitable positions. Place gate 1 at a convenient position near the left end of the air track and gate 2 at a

suitable distance from the other end of the air track. Remember that the first glider is given an initial velocity u which is measured by gate 1 when it passes through it. Then glider 1 collides and sticks to glider 2. The final velocity of the combination is measured when it passes through gate 2. Make sure that the gliders do not bounce back to gate 2. After each run, lift the gliders off the track.



3. Select two gliders having nearly equal masses. Attach the flag to glider 1 and find their masses.
4. Turn on the CHAMP and then the computer.
   (Always make sure that CHAMP interface is connected and turned on before switching on the computer. Also the computer should be switched off before turning off the CHAMP.)
   At the prompt
   C:TPACK>
   enter TP
   You will see 'TIMEPACK' on the screen among other things.
   Press any key and you will see
   You will see 'HIT ENTER TO ACCEPT', etc. on the screen.
   Press the enter key.
   You will see 'PLEASE ENTER PASSWORD'.
   Enter PASS as the password.
5. You will see the menu containing:

A: Single gate timer	H: Frequency Timer
B: Double gate timer	- - - - -
C: Time between gates	- - - - -
D: Pendulum timer	- - - - -
E: Motion timer	L: Data Analysis
F: Collision timer	M: Test photogates
- - - - -	N: Exit Timepack

Select "M" to test the photogate. Press any key to return to the main menu.

6. To measure times, select "F: Collision timer"
7. Turn on the air flow.
   Make sure that the air track is level. Place a glider on the air track. If the track is horizontal, the glider will not move appreciably.
   Place glider 1 on the left of gate 1 and give it a gentle push keeping glider 2 between the two gates. Repeat the process three times.
8. Now select two gliders such that $M_1 > M_2$. Attach the flag to glider 1 and find their masses. Repeat step 7.
9. Finally select two gliders such that $M_1 < M_2$. Attach the flag to glider 1 and find their masses. Repeat step 7.
10. Now press any key to terminate data collection.
    You will see the menu containing:

A: Display Data Table	E: Edit Timing Data
B: Print Data Table	- - - - -
C: Analyze Timing Data	H: Repeat Experiment
D: Graph Timing Data	I: Return To Main Menu

11. Enter C to select "C: Analyze Timing Data"
    Enter length of flag in m (meter).
    A table containing velocity #1 velocity #2 will be displayed.
    Copy velocities in the appropriate tables and complete the calculations.
    Use mks units in this experiment.

York College of The City University of New York

Physics I

Name:

Experiment No. 7: Pre-Lab Questionnaire

1. What is the theoretical value of p_f/p_i? If $M_1 = 0.56$ kg and $M_2 = 0.82$ kg, what will be the theoretical value of K_f/K_i?

2. Glider A of mass $M_1 = 0.56$ kg, moving with a velocity of 2.1 m/s, strikes and sticks to glider B of mass $M_2 = 0.82$ kg. After the collision, the two move with a velocity of 0.85 m/s. (a) Find the experimental value of p_f/p_i. (b) Find the experimental value of K_f/K_i.

Experiment No. 7

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

Length of the flag: Reading 1 = ; Reading 2 =

Average length of the flag, L =

A. M_1 nearly equal to M_2:

Mass of glider 1, M_1 = ; Mass of glider 2, M_2 =

No	$u = v_1$	$v = v_2$	p_i	p_f	p_f/p_i	K_i	K_f	K_f/K_i

Average p_f/p_i (experimental) =

p_f/p_i (theoretical) =

Average K_f/K_i (experimental) =

K_f/K_i (theoretical) =

Comments:

B. $M_1 > M_2$

Mass of glider 1, M_1 = ; Mass of glider 2, M_2 =

No	$u = v_1$	$v = v_2$	p_i	p_f	p_f/p_i	K_i	K_f	K_f/K_i

Average p_f/p_i (experimental) =

p_f/p_i (theoretical) =

Average K_f/K_i (experimental) =

K_f/K_i (theoretical) =

Comments:

C. $M_1 < M_2$

Mass of glider 1, M_1 = ; Mass of glider 2, M_2 =

No	$u = v_1$	$v = v_2$	p_i	p_f	p_f/p_i	K_i	K_f	K_f/K_i

Average p_f/p_i (experimental) =

p_f/p_i (theoretical) =

Average K_f/K_i (experimental) =

K_f/K_i (theoretical) =

Comments:

Experiment No. 7: Questions

1. Is momentum conserved in inelastic collisions?

2. If an external force is acting on the system, will the final momentum be equal to the initial momentum? If the air track is not horizontal, will momentum will be conserved? Explain.

3. How will you check that the air track is level?

4. How is friction between the glider and air track minimized?

Experiment 8. Moment of Inertia of a Flywheel

Flywheel is a device for storing large quantities of energy. Can you think of its practical applications?

Objective:

To determine the moment of inertia of a flywheel.

Apparatus:

A flywheel, a timer, a meter stick, a hanger and weights.

Theory:

According to Newton's law, F = Ma, where F is the resultant of the external forces acting on the body, 'a' is the linear acceleration of the body and M is its mass. The analogous relation for rotational acceleration is

$$\Sigma\tau = I\alpha. \tag{1}$$

Here $\Sigma\tau$ is the resultant of external torques acting on the body about the axis of rotation, α is the angular acceleration and I is the moment of inertia of the body about the axis of rotation. The kinetic energy of a mass M having a linear velocity v is given by

$$K = \frac{1}{2}mv^2. \tag{2}$$

In an analogous manner, the kinetic energy of a body of moment of inertia I and having an angular acceleration ω is given by

$$K = \frac{1}{2}I\omega^2. \tag{3}$$

Thus, in rotational motion, the moment of inertia plays a role which is analogous to the role of mass M in linear motion. The cgs unit of moment of inertia is $gm.cm^2$. The moment of inertia of a body depends on the axis of rotation and the distribution of mass about the axis of rotation.

Equation (3) indicates that a rotating body having a large moment of inertia, like a flywheel, can be used to store large amounts of kinetic energy.

Let a mass m be attached to the free end of a string wound around the axle of a flywheel as shown in Fig. 1. Further, let r be the radius of the axle and T, the tension in the string. If the linear acceleration of mass m is 'a' downward, then by Newton's second law of motion,

$$T - mg = - m a,$$

or $T = m(g - a)$. (4)

The torque acting on the flywheel due to tension T in the string is given by

$$\tau = r T \quad (5)$$

Now if τ' is the torque due to the frictional forces acting on the flywheel and if α is the angular acceleration of the flywheel, then Eq. (1) yields

$$\tau - \tau' = I \alpha \quad (6)$$

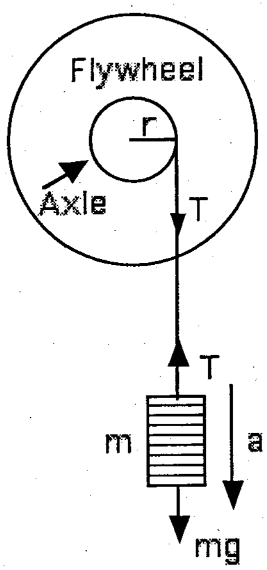


Fig. 1

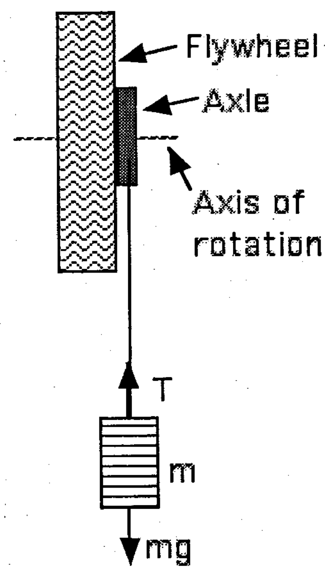


Fig. 2

The linear acceleration 'a' can be determined by measuring the time taken by the mass m to fall from rest through a distance d. In such case,

$d = \frac{1}{2} at^2$, because the initial velocity is zero.

Thus $a = \frac{2d}{t^2}$. (7)

The torque τ can be determined by using Eqs. (4) and (5), and α can be calculated by $a = r\,\alpha$.

By determining a number of pairs of values of τ and α (for different values of m), and by plotting a graph between τ and α , we shall get a straight line graph according to Eq. (6). Here τ' is assumed to be constant. If (τ_1, α_1) and (τ_2, α_2) are the coordinates of two points on this graph, then

$\tau_1 - \tau' = I\,\alpha_1$ and $\tau_2 - \tau' = I\,\alpha_2$.

By subtracting, we get $\tau_2 - \tau_1 = I(\alpha_2 - \alpha_1)$.

$$\text{Or} \quad I = \frac{\tau_2 - \tau_1}{\alpha_2 - \alpha_1}. \qquad (8)$$

If the flywheel is a circular disk of mass M and radius R_1, the theoretical value of its moment of inertia is given by

$$I = \frac{1}{2} M R_1^2. \qquad (9)$$

The radius of gyration (k) of a body of moment of inertia I and mass M is defined by the relation $I = Mk^2$.

$$\text{Thus} \quad k = \sqrt{\frac{I}{M}}. \qquad (10)$$

A particle of mass M placed at a distance k from the axis of rotation will have the same moment of inertia as that of the flywheel.

Procedure:

1. Determine d, the distance of fall of mass m by measuring the length of the string (including the height of the hanger). Record the mass of the hanger.
2. Place a suitable mass on the hanger, wind the string around the axle (the black disk attached to the side of the flywheel) and place the hanger on the small circular platform under the flywheel. Trip the platform and simultaneously start the timer. Stop the timer as soon as the string gets detached from the small peg on the axle.
3. Repeat step 2 by changing the mass on the hanger 4 or 5 times.
4. Measure the diameter of the axle. Record the radius and mass of the flywheel.

York College of The City University of New York

Physics I Name:

Experiment No. 8: Pre-Lab Questionnaire

1. In an experiment, a mass m = 40 gm, attached to a string wrapped around the axle of a flywheel and starting from rest, falls through a distance of 147 cm in 3.5 s. The diameter of the axle of the flywheel is 12 cm What is the acceleration of the mass and the angular acceleration of the flywheel?

2. Find the tension in the string.

3. Find the torque due to the tension acting on the flywheel.

4. Assuming that the torque due to friction is negligible, find the moment of inertia of the flywheel.

6

Experiment No. 8

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

Readings of the diameter of the axle:

Reading 1 =

Reading 2 =

Average diameter of the axle =

Radius of the axle, r =

Readings of the distance of fall:

Reading 1 =

Reading 2 =

Average distance of fall d =

Mass of the flywheel, M_1 =

Radius of the flywheel, r_1 =

Readings of time of fall:

Reading No.	Falling mass m (including the mass of the hanger)	Time of fall			
		Time t_1	Time t_2	Time t_3	Average (t)
1					
2					
3					
4					
5					
6					

Calculations:

Reading No.	Mass m	Average t	Linear accln. 'a'	Angular accln. α	Tension T	Torque τ

Plot a graph between τ and α.

Find the moment of inertia from the slope of the graph.

$\tau_1 =$ $\alpha_1 =$

$\tau_2 =$ $\alpha_2 =$

Experimental value of moment of inertia,

$I_{exp} =$

Theoretical value of moment of inertia,

$I_{th} =$

Percent error =

Radius of gyration of the flywheel,

k =

Experiment No. 8: Questions

1. What is meant by moment of inertia?

2. Name the forces acting on the descending mass.

3. Name the torques acting on the flywheel when the mass is descending. Do these torques remain constant during the fall of the mass?

4. What happens to the potential energy lost by the falling mass?

5. Describe a practical application of flywheel.

Experiment 9. Spring Constant

> Is rubber more elastic than steel?
> The answer lies in the concept of elasticity.

Objective:

To determine the spring constant of a spring by
(a) static method, and (b) dynamic method.

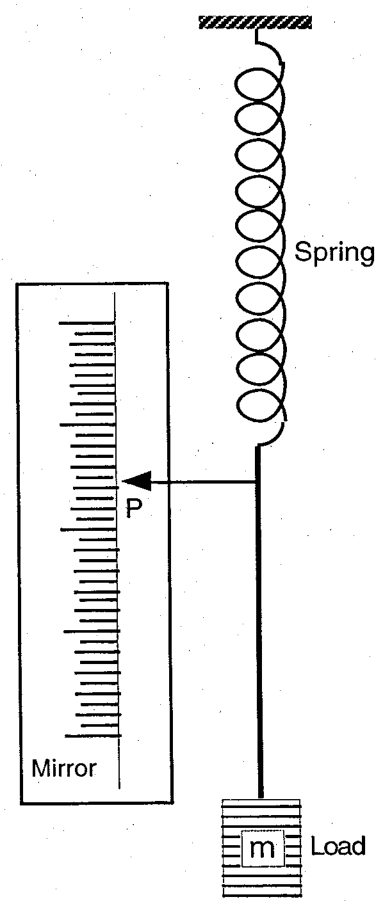
Apparatus:

A spring, a hanger with a light aluminium pointer, a small scale etched on a plane mirror strip, weights, a timer.

Theory:

(a) Static method:

Consider a spring hanging from a rigid support. When a load m is suspended from the free end of the spring, an external, F_{ext}, acts on the spring in the downward direction. The support applies an equal force in the upward direction. Thus the spring has a balanced system of forces acting on it and it is in equilibrium. The length of the string increases and an internal (restoring) force F_{int} is developed in the spring due to the elasticity of the spring. This internal force tends to bring the spring back to its original length when the external forces are withdrawn. Note that F_{int} and F_{ext} are equal in magnitude.



According to Hooke's law,

F_{int} is directly proportional to x, the change in the length of the spring.

Thus $F_{int} = - k x$ (1)

Here k is the constant of proportionality, known as the spring constant or force constant. The minus (-) sign indicates that F_{int} and x are in opposite directions.

Obviously,

$$F_{ext} = k\,x. \qquad (2)$$

Eqs. (1) and (2) indicate that the spring constant k is numerically equal to the force required to change the length of the spring by 1 unit.

If the load on the spring is M and M_p is the sum of the mass of the hanger and the effective mass of the spring, $F_{ext} = (M+M_p)g$. In this experiment, values of x for a number of values of F_{ext} are determined by changing M. Then a graph of M vs. x is plotted and k is determined from the slope of the graph.

(b) Dynamic method:

If a mass M is suspended from a spring of spring constant k and the system is made to oscillate, then for small amplitudes of oscillations (that is, within elastic limit) along the length of the spring, the motion of the system is simple harmonic. In this case, the time period T of the system is given by

$$T = 2\pi\sqrt{\frac{M + M_p}{k}}, \qquad (3)$$

where M_p is the effective mass of the spring which is approximately equal to 1/3 the mass of the spring (Reference: Vibrations and Waves by A. P. French, pages 60-61).

In this experiment, M_p is eliminated in the following manner:

Eq. (3) gives $T^2 = \frac{4\pi^2}{k}M + \frac{4\pi^2}{k}M_p$.

Thus if we plot T^2 vs. M, then for a given spring (k and M_p constant), the graph will be a straight line. By choosing two points (M_1, T_1^2) and (M_2, T_2^2) on the graph, we get

$$T_1^2 = \frac{4\pi^2}{k}M_1 + \frac{4\pi^2}{k}M_p \text{ and } T_2^2 = \frac{4\pi^2}{k}M_2 + \frac{4\pi^2}{k}M_p.$$

By subtracting one equation from the other, we get

$$T_2^2 - T_1^2 = \frac{4\pi^2}{k}(M_2 - M_1),$$

$$\text{or} \quad k = 4\pi^2\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right). \qquad (4)$$

Procedure:

(a) Static method:

1. Arrange the apparatus as shown in the figure. Make sure that the aluminum pointer is close to the mirror on which the scale is etched but it does not touch the mirror.

2. Read the position of the pointer on the scale. Avoid the parallax error. This is done by reading the position of the pointer on the scale when the image of the pointer is hidden behind the pointer. (Remember the procedure of the experiment on equilibrium.)
3. Increase the load on the spring in equal steps and read the position of the pointer each time. Thus fill out the first two columns of the first table of the data sheet.
4. Now gently pull the load down through about 0.5 cm. Release it gently and let it come to rest. Take the reading of the position of the pointer and enter it in the last row of column 3 of the table. Gently decrease the load in equal steps and thus fill out the rest of column 3 of the table.

(a) Dynamic method:

5. Place a suitable load on the hanger and start the oscillations of the system. Make sure that the oscillations are along the length of the spring and the amplitude is small. Find the time for 40 (or 50) oscillations 3 times.
6. Repeat the procedure by changing the load on the spring in equal steps.

York College of The City University of New York

Physics I Name:

Experiment No. 9: Pre-Lab Questionnaire

1. A student finds the following values from a graph between M and x in the static method of determining the spring constant k:

   x_1 = 0.5 cm; x_2 = 7.8 cm; M_1 = 120 gm; M_2 = 300 gm.

   Calculate the value of k.

2. Consider the following data for an experiment to study the spring constant by dynamic method:

   Number of oscillations, N = 25

   Load M_1 = 120 gm; average time for N oscillations = 11.0 seconds

   Load M_2 = 280 gm; average time for N oscillations = 16.9 seconds

   Calculate the spring constant k.

   (Note that the mass of the hanger is not given.)

h
b

Experiment No. 9

Name:	Marks:
Partner:	Remarks:
Section:	
Date Submitted:	

Title:

Objective:

Theory/Formulas:

Data Sheet

(a) Static method:

No.	Load M on the hanger	Position of the pointer (x)		Average x
		Load increasing	Load decreasing	
1				
2				
3				
4				
5				
6				

Plot a graph between M and average x.
From the graph,
M_1 = ; x_1 = ; M_2 = ; x_2 =

k =

(b) Dynamic method:
Number of oscillations, N =

No.	Load M	Time for N oscillations				Period T	T^2
		R_1	R_2	R_3	Average R		
1							
2							
3							
4							
5							
6							

Plot a graph between M and T^2.
From the graph,
M_1 = ; T_1^2 = ; M_2 = ; T_2^2 =

k =

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Experiment No. 9: Questions

1. State Hooke's law.

2. What is meant by the spring constant of a spring? (Remember, it is also known as force constant.)

3. Under what conditions the period of oscillations of a mass on a spring is given by

$$T = 2\pi\sqrt{\frac{M}{k}}\ ?$$

4. Why is it not necessary to use the mass of the hanger in the calculations of the load on the spring?

5. If the load M on the spring is made 4 times its previous value, will the time period then become exactly double its previous value? Explain your answer.

Experiment 10. Young's Modulus

Is rubber more elastic than steel? The answer lies in the concept of elasticity.

Objective:

To determine the Young's modulus of the material of a wire.

Apparatus:

Young's modulus apparatus, a micrometer, a vernier caliper, a meter stick.

Theory:

If a balanced system of forces is applied to a body, the shape and/or size of the body change and the body is said to have developed strain. Due to this, internal forces are produced within the body which tend to bring the body back to its original shape and size when the external forces are withdrawn. This property of matter to develop these internal forces (of stress) is known as elasticity.

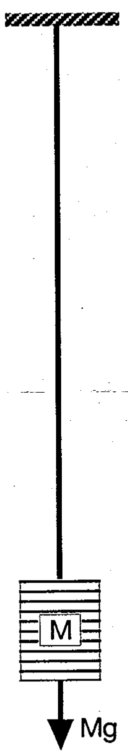

Fig. 1

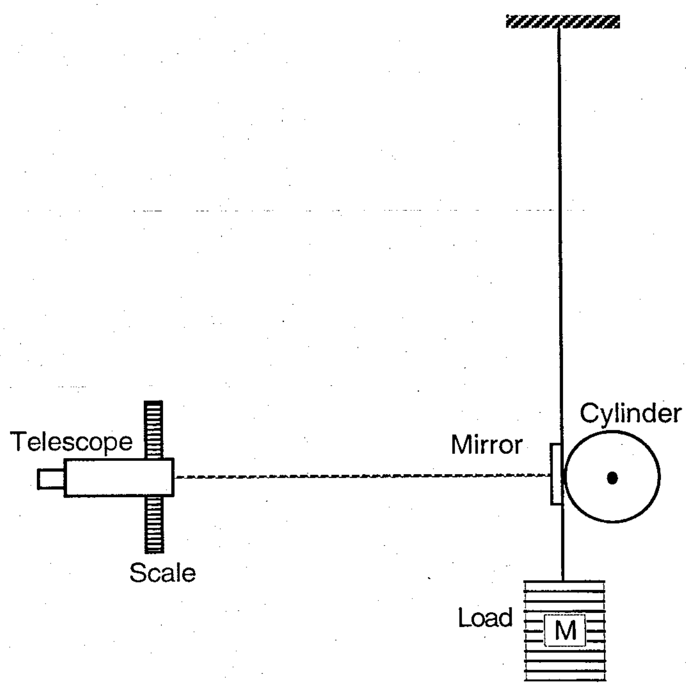

Fig. 2. Schematic Diagram of Young's Modulus Apparatus

If one end of a wire (Fig. 1) is fixed and a mass M is suspended from the other end of the wire, equal and opposite forces of magnitude Mg are applied to the wire by the mass M and by the support at the top. Due to this, the length of the wire increases. (There is also a slight change in other dimensions of the wire but we will not consider them.) If the increase in the length of the wire is ΔL and the original length of the wire is L, then

longitudinal strain or tensile strain = $\Delta L/L$.

Further, the internal forces over any cross-section of the wire are equal to the external force Mg. Thus

longitudinal stress or tensile stress = $Mg/\pi r^2$.

Here r is the radius of the wire.

According to Hooke's law, within elastic limits, stress is directly proportional to strain.

Thus tensile stress = Y (tensile strain), where Y is called the Young's modulus or modulus of longitudinal elasticity or stretch modulus of the material of the wire.

$$\text{Thus } Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{Mg/\pi r^2}{\Delta L/L} = \frac{MgL}{\pi r^2 \Delta L} \quad (1)$$

The wire whose Young's modulus is to be determined passes over a small cylinder which is free to rotate about a horizontal axis (Fig. 2). When the length of the wire increases by an amount ΔL, the cylinder of radius r_1 rotates through an angle θ which is given by

$$\theta = \frac{\Delta L}{r_1} \quad (2)$$

There is a small plane mirror attached to the cylinder which rotates along with the cylinder. The increase in length ΔL and thus angle θ are very small and so an optical lever (an arrangement of scale, mirror and telescope shown in Figs. 2) is used to determine θ and ΔL.

The image of a vertical scale formed by the mirror is observed through the telescope. When the mirror is in the vertical position MP (Fig. 3), the image of point N of the scale is seen through the telescope. When the cylinder and mirror rotate through an angle θ and is in position M_1P_1, the

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image of point Q is seen through the telescope. In both cases, the reflected ray is ON while NO is the incident ray when the mirror is position MP and QO is the incident ray when the mirror is in position M_1P_1. It easy to see that when the mirror rotates through an angle θ, the incident ray rotates through an angle 2θ. Angle θ is small. Thus angle 2θ (in radian) is nearly equal to tan 2θ = x/D, where x = distance NQ and D = distance NO.

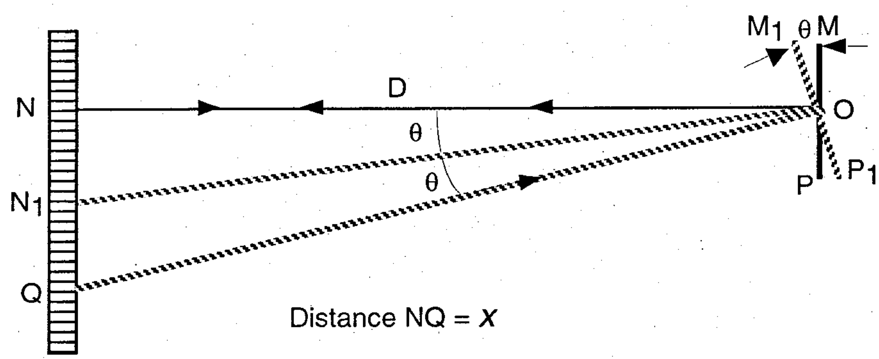

Fig. 3

$$\theta = \frac{x}{2D} = \frac{\Delta L}{r_1}\text{, by Eq. (2).}$$

Hence $\Delta L = \dfrac{x\ r_1}{2D}$.

Finally, by substituting the value of ΔL into Eq. (1), we get

$$Y = \frac{MgL}{\pi r^2 \Delta L} = \frac{2MgLD}{\pi r^2 x\ r_1}. \qquad (3)$$

Procedure:

1. Make sure that the apparatus is arranged as shown in Fig. 2. Do not disturb the setup or try to make any adjustments. Do not take off the initial load placed on the hanger.
2. Look through the telescope and read the position of the cross wires on the scale. Record load on the hanger as zero along with this reading in the first row and second and third columns of Table I.
3. Increase the load and take the reading of the position of the cross wires. Record the load on the hanger and this reading in the next row of Table I.

4. Increase the load on the hanger in equal steps and repeat step 3. Thus fill out the second and third columns of Table I.
5. Increase the load on the hanger by 250 gm. Gently take off this weight and take the reading of the cross wires. Record this reading in the last row of the fourth column of Table I.
6. Decrease the load on the hanger in equal steps (by the same amount as it was increased), take the readings of the cross wires and thus fill out the rest of the fourth column of Table I. Note that this column is filled out from last row to the first row as the load is decreased in equal steps. If the color of the graduations of the scale changes from red to black (or from black to red), change the sign (from + to -) of the readings.
7. Find the least count of the micrometer and take 8 readings of the diameter of the wire, measuring one diameter and then perpendicular diameter at four different points.
8. Measure the length of the wire twice.
9. Measure the distance between the mirror and the scale twice.
10. Take two readings of the diameter of the cylinder.

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Physics I Name:

Experiment No. 10: Pre-Lab Questionnaire

1. Briefly describe how an optical lever works.

2. Calculate Young's modulus from the following data:

Load on the hanger (gm)	Readings of the scale (cm)			Change in the reading of the scale when the load is increased by M = _____ gm
	when the load is		Average s	
	increased (s_i)	decreased (s_d)		
100	8.4	8.5		
300	6.2	6.3		$s_4 - s_1 = x_1 =$
500	3.9	4.0		$s_5 - s_2 = x_2 =$
700	1.7	1.8		$s_6 - s_3 = x_3 =$
900	-0.5	-0.4		
1100	-2.7	-2.6		Average x =

Average diameter of the wire = 0.036 cm

Average length of the wire = 96.7 cm

Average diameter of the cylinder = 1.24 cm

Average distance between the mirror and the scale = 84.6 cm

Experiment No. 10

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

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Data Sheet

Table I

Readings for the determination of ΔL:
Change the load on the hanger in equal steps.
Number of sets of readings must be even.

No.	Load on the hanger (gm)	Positions of the cross wires (cm)			Change in the position of cross wires when load is changed by M = gm
		Load increasing (S_i)	Load decreasing (S_d)	Average (S)	
1					$S_5 - S_1 = x_1 =$
2					
3					$S_6 - S_2 = x_2 =$
4					
5					$S_7 - S_3 = x_3 =$
6					
7					$S_8 - S_4 = x_4 =$
8					

Average x =

Table II

Readings for the diameter of the wire:

Least count of the micrometer = ; Zero error =

No.	1	2	3	4	Average
One diameter					
Perpendicular diameter					

Average diameter of the wire =

Diameter of the wire corrected for zero error =

Radius of the wire, r =

Length of the wire (reading 1) =

Length of the wire (reading 2) =

Average length of the wire, L =

Distance between mirror and the scale (reading 1) =
Distance between mirror and the scale (reading 2) =
Average distance between mirror and the scale, D =
Diameter of the cylinder (reading 1) =
Diameter of the cylinder (reading 2) =
Average diameter of the cylinder =
Radius of the cylinder, r_1 =

Calculations:

Calculate Y by using the values of M and *x*. Determine the percent error.

Plot a graph between M and average S. Determine Y from the slope of the graph. Again calculate the percent error in Y.

Experiment No. 10: Questions

1. Using your data, find the increase in the strain in the wire when the load is increased by 400 gm.

2. Using your data, find the increase in the stress in the wire when the load is increased by 400 gm.

3. What is Hooke's law? How does the straight line graph of M and S (the readings of the scale) verify Hooke's law?

4. Is rubber more elastic than steel? Explain your answer.

Experiment 11. Archimedes' Principle

An application of Archimedes' principle - a piece of iron sinks while a steel cup of the same weight floats on water.

Objective:

(a) To determine the specific gravity of a liquid by using a hydrometer.

(b) the specific gravity of a solid heavier than water, the specific gravity of a liquid and the specific gravity of a solid lighter than water by applying Archimedes' principle.

Apparatus:

A balance, a solid heavier than water, a wooden cylinder, a hydrometer, alcohol and distilled water

Theory:

According to Archimedes' principle, when a body is immersed in a fluid (Fig. 1), either wholly or partially, the fluid exerts a buoyant force B on it. This buoyant force is equal to the weight of the fluid displaced by the body. Thus the apparent weight of the body is less than its actual weight, the loss of weight being equal to the buoyant force.

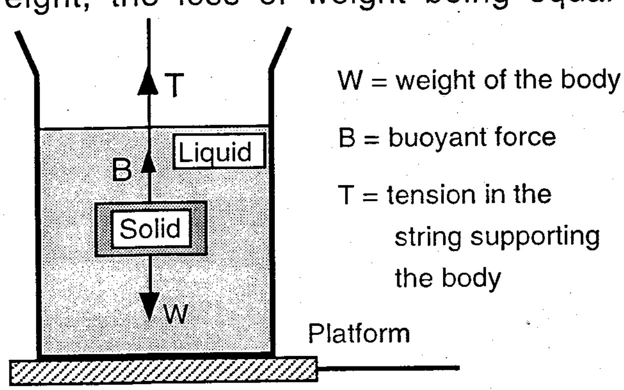


Fig. 1

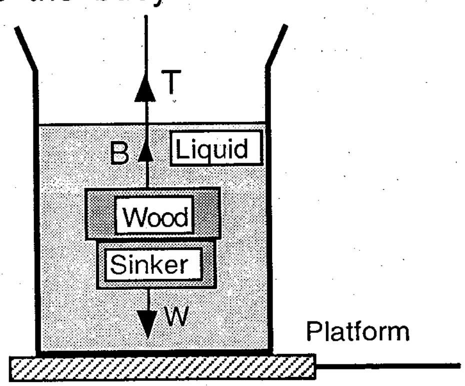


Fig. 2

Consider the following problem:

Weight of the body in air (actual weight of the body),	$w = 600$ gm-wt
Volume of the body,	$V = 80\ cm^3$
Density of the liquid,	$\rho = 1.2\ gm/cm^3$
Volume of the liquid displaced = volume of the body	$V_\ell = 80\ cm^3$
Weight of the liquid displaced,	$w_\ell = V_\ell \times \rho = 96$ gm-wt
Buoyant force,	$B = 96$ gm-wt
Apparent weight of the body,	$w_a = 600 - 96$ gm-wt
	$= 504$ gm-wt

Note that the apparent loss of weight of the body is equal to the buoyant force of the fluid acting on the body, which, in turn, is equal to

the weight of the fluid displaced by the body. Thus,
the buoyant force = apparent loss of weight,
or, $B = w - w_a = w_\ell$ = weight of fluid displaced (1)
Remember, if the body is completely immersed in the fluid, the weight of the fluid displaced by it is equal to the weight of the fluid whose volume is the same as the volume of the body.
Archimedes' principle provides a convenient method of determining specific gravities of substances.

(a) Principle of a hydrometer:

A hydrometer is an instrument for determining the specific gravities of liquids. When a hydrometer is floating in equilibrium in any liquid, the buoyant force (the weight of the liquid displaced by it) is equal to the weight of the hydrometer. Let

Weight of the hydrometer = 600 gm-wt
Volume of the hydrometer under water = 600/1 = 600 cm^3
(when floating in water of density 1 gm/cm^3)
Volume of the hydrometer under the liquid = 600/1.2 = 500 cm^3
(when floating in a liquid of density 1.2 gm/cm^3)

Thus the volume of the hydrometer under a liquid depends on the density of the liquid. In general, hydrometers are calibrated so that the specific gravities can be read off directly.

(b) Specific gravity of a solid heavier than water:

Specific gravity (sp. gr.) is defined as

$$\text{sp. gr.} = \frac{\rho}{\rho_\ell}, \text{ where } \rho = \text{density of the substance}$$

and ρ_ℓ = density of water at 4 °C

$$\text{or sp. gr.} = \frac{M/V}{M_\ell/V_\ell}, \text{ where } M = \text{mass of the body, } V = \text{volume of the body,}$$

M_ℓ = mass of water, and V_ℓ = volume of water.

Now if volume of water (V_ℓ) is made equal to the volume of the body (V),

$$\text{sp. gr.} = \frac{M}{M_\ell} = \frac{Mg}{M_\ell g} = \frac{W}{W_\ell},$$

where W = weight of the body, an(
W_ℓ = weight of water whose volume is equal to the volume of the bo(
According to Eq. (1), $W_\ell = W - W_a$, where W_a = apparent weight of the body. Thus

$$\text{sp. gr.} = \frac{W}{W_\ell} = \frac{W}{W - W_a} \qquad (2)$$

(c) Specific gravity of a liquid:

Let W = weight of a solid in air

W_b = apparent weight of the solid completely immersed in a liquid, and

W_a = apparent weight of the solid completely immersed in water.

Thus, by Eq. (1),

$W - W_b$ = weight of the liquid whose volume equals the volume of the solid

and $W - W_a$ = weight of water whose volume equals the volume of the solid.

Therefore, specific gravity of the liquid is given by

$$\text{sp. gr.} = \frac{W - W_b}{W - W_a} \qquad (3)$$

(d) Specific gravity of a solid lighter than water:

To determine the sp. gr. of a solid lighter than water, a sinker is used to immerse the solid completely in water. In this case, the denominator of Eq. (2) can be written as

$W - W_a = W + W_s - (W_s + W_a)$, where W_s is the weight of the sinker in water.

In this experiment, the solid used in part (b) is used as a sinker.

Procedure:

(a) Sp. gr. of alcohol by using a hydrometer:

1. Find the least count of the hydrometer.
2. Carefully float the hydrometer in the alcohol filled in the cylindrical jar and read the specific gravity of the liquid.

(b) Sp. gr. of the solid:

3. Find the least count of the balance and measure the weight of the metal cylinder in air.
4. Find the apparent weight of the metal cylinder by immersing it completely in water.

(c) Sp. gr. of alcohol:

5. Find the apparent weight of the metal cylinder [used in part (b)] by completely immersing it in alcohol.

(d) Sp. gr. of wood:

6. Weigh the wooden cylinder in air.
7. Tie the wooden cylinder and metal cylinder together and suspend them in water as shown in Fig. 2. Thus find the total apparent weight of the wooden cylinder and metal cylinder when they are completely immersed in water.

Use gm-wt as the unit of weight in this experiment.

York College of The City University of New York

Physics I   Name:

Experiment No. 11: Pre-Lab Questionnaire

1. Calculate the specific gravity of liquid from the following data:

Mass of a metal cylinder in air	= 56.8 gm
Apparent mass of the metal cylinder in water	= 50.3 gm
Apparent mass of the metal cylinder in liquid	= 48.7 gm

2. Determine the specific gravity of the wooden cylinder from the following data: (The metal cylinder of question 1 was used as the sinker.)

Mass of a wooden cylinder in air	= 6.9 gm
Apparent mass of the metal cylinder and wooden cylinder in water	= 45.8 gm

Experiment No. 11

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

(100)

Data Sheet

(a) Sp. gr. of alcohol by using a hydrometer:

Least count of the hydrometer =

Specific gravity of alcohol =

(b) Sp. gr. of a metal cylinder:

Least count of the balance =

Weight of the metal cylinder in air =

Apparent weight of the metal cylinder in water =

(c) Sp. gr. of alcohol:

Apparent weight of the metal cylinder in alcohol

(d) Sp. gr. of wooden cylinder:

Weight of the wooden cylinder in air =

Total weight of both, wooden cylinder and metal cylinder,

in water =

Calculations:

Show substitutions in all calculations.

(a) Percent error in the experimental value of the alcohol =

(b) Apparent loss of weight of the metal cylinder in water =

Buoyant force on the metal cylinder in water =

Weight of water whose volume equals the volume of the metal cylinder

=

Sp. gr. of the metal =

Percent error in the sp. gr. of the metal =

(c) Weight of alcohol whose volume equals the volume of the metal cylinder =

Weight of water whose volume equals the volume the metal cylinder =

Sp. gr. of alcohol =

Percent error in the experimental value of the alcohol =

(d) Apparent loss of weight of the wooden cylinder in water =

Sp. gr. of wooden cylinder =

Experiment No. 11: Questions

1. State Archimedes' principle.

2. Explain the working principle of a hydrometer.

3. Why is the apparent loss of weight of the wooden cylinder larger than its weight in air?

4. Draw a neat diagram showing the forces acting on a solid immersed in a fluid.

Experiment 12. Joule's Constant

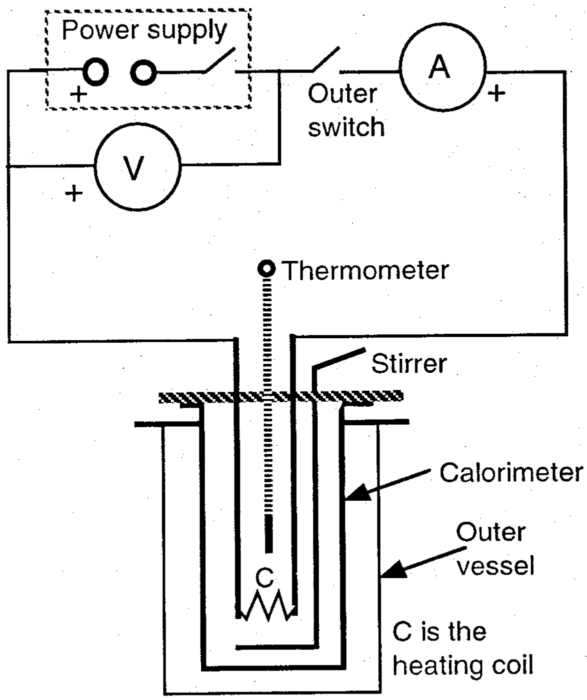
Joule, while on his honeymoon, found that the water at the bottom of a fall is warmer than the water at the top of the fall, and established the equivalence between mechanical work and heat.

Objective:

To determine Joule's constant (J) or the mechanical equivalent of heat by electrical method.

Apparatus:

An electrical calorimeter, a thermometer, a balance, a power supply, an ammeter and a voltmeter.



Schematic Diagram of Electrical Calorimeter

Theory:

According to the first law of thermodynamics, the amount of work converted into heat (W) is directly proportional to the quantity of heat generated (H).

Thus $W = J H$,

where J is called the mechanical equivalent of heat or Joule's constant.

Therefore, $J = W/H$.

If W is measured in joules and H is measured in calories, the unit of J will be joule/calorie.

In this experiment, electrical energy (W) is converted into heat. If a voltage V (in volts) is applied across a resistor and thus a current I (in amperes) is maintained for a time t (in seconds), the electric power is given by

$P = V\,I$,

and the electrical energy converted into heat is given by

$W = V\,I\,t$.

The electrical energy supplied to the heating coil is converted into heat. This heat is taken up by the calorimeter (including the stirrer, heating coil, etc.) and the water in the calorimeter. If the temperature of the system rises from T_1 ^oC to T_2 ^oC, the heat generated is given by

$H = (m_1 s + m_2 + m_3)(T_2 - T_1)$,

where m_1 = mass of the calorimeter,

s = specific heat capacity of the calorimeter,

m_2 = mass of water in the calorimeter,

m_3 = water equivalent of the heating coil, stirrer, etc. (that is, the mass of water whose heat capacity is equal to the heat capacity of the heating coil, stirrer, etc.)

Procedure:

1. Make the electrical connections as shown in the schematic diagram of the electrical calorimeter. Keep the outer switch open.
2. Find the least counts of the voltmeter, ammeter and thermometer. Read the room temperature. Record specific heat capacity [$s = 0.22$ calories/(gm C^o)] of the calorimeter and the water equivalent of the heating coil, stirrer, etc. [$m_3 = 2.5$ gm].
3. Weigh the empty dry calorimeter correct up to 0.1 gm.
4. Mix some hot and cold water such that the temperature in the calorimeter is about 3 ^oC below the room temperature. Fill the calorimeter about 2/3 with water. Wipe any drops of water sticking to the sides of the calorimeter.
5. Weigh the calorimeter plus water correct up to 0.1 gm.
6. Wind the timer and set it to zero. Keeping the outer switch off, switch on the power supply. Adjust the voltage to a bit less than 6 volts. (Use the 6-volt range.)

7. Read the temperature of water in the calorimeter correct up to the least count of the thermometer. This is the temperature at time zero and it is also the initial temperature of the system (T_1).
8. Close the outer switch and simultaneously start the timer. Read the voltmeter and ammeter. Enter these in the first row of the table on the data sheet.
9. Take the readings of the voltage, current and temperature at regular intervals of 2 (or 3) minutes. Keep stirring the water in the calorimeter carefully.
10. Switch off the current at the end of N intervals of time. The number N should be chosen such that the final temperature is about as many degrees above the room temperature as the initial temperature was below. For example, if the room temperature was 26 ^oC and the initial temperature T_1 = 23 ^oC, then the final temperature should be about 29 ^oC.
11. Keep stirring and record the highest temperature attained by the system. This is the final temperature T_2.
12. Perform the calculations and repeat the experiment if the result does not have the desired accuracy.

Note that if the voltage V is in volts and current I is in amperes, then the power P (=V I) will be in watts, and the energy W (= V I t) will be in joules.

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Physics I Name:

Experiment No. 12: Pre-Lab Questionnaire

Complete the following data sheet:

Specific heat of the material of the calorimeter, s = 0.093 cal/(gm.C^o)

Water equivalent of the heating coil, stirrer, etc., m_3 = 6.8 gm

Mass of the empty dry calorimeter, m_1 = 123.4 gm

Mass of calorimeter plus water, m = 280.1 gm

Mass of water in the calorimeter, m_2 =

No.	Time (min)	Temperature (C^o)	Voltage (V)	Current (A)	Power (watt)
1	0	22.6	5.2	1.1	
2	3	24.1	5.1	1.1	
3	6	25.4	5.2	1.2	
4	9	26.8	5.0	1.0	
5	12	27.8	5.2	1.1	

Interval No.	Time interval (min)	Average Power (watt)
1	0 - 3	
2	3 -6	
3	6 - 9	
4	9 -12	

Length of a time interval, t =

Total average power, P =

Total electrical energy supplied, W =

Initial temperature, T_1 = 22.6 ^oC

Final temperature, T_2 = 28.2 ^oC

Amount of heat generated in calories, H =

Joule's constant, J =

Percent error in J =

Experiment No. 12

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

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Data Sheet

Least count of the voltmeter =

Least count of the ammeter =

Least count of the thermometer =

Room temperature =

Specific heat of the material of the calorimeter =

Water equivalent of the heating coil, stirrer, etc., m_3 =

Mass of empty dry calorimeter, m_1 =

Mass of calorimeter and water, m =

Mass of water in the calorimeter, m_2 =

Initial temperature of water in the calorimeter, T_1 =

Readings for determining the total electrical power:

Take the readings at intervals of 2 or 3 minutes.

Start reckoning time from the time the current is switched on.

Keep stirring the water in the calorimeter carefully.

The first reading is taken at time t = 0.

Switch off the current at the end of the time interval when the final temperature is nearly as many degrees above the room temperature as the initial temperature was below.

No.	Time (min)	Temperature (C^o)	Voltage (V)	Current (A)	Power (watt)

On switching off the current, continue stirring the water in the calorimeter and record the highest temperature attained. This is the final temperature.

Final temperature of water in the calorimeter, T_2 =

Calculations:

Calculation of total electrical power:

Interval No.	Time interval (min)	Average Power (watt)
1		
2		
3		
4		
5		
6		
7		
8		
9		

Total power (sum of the last column of the above table), P =

Length of each time interval in seconds, Δt =

Total energy in joules, $W = P\ \Delta t$ =

Total heat generated, $H = (m_1 s + m_2 + m_3)(T_2 - T_1)$ =

$J = W/H$

Percent error in the experimental value of J =

Experiment No. 12: Questions

1. What is meant by J?

2. Why should the final temperature be approximately as many degrees above the room temperature as the initial temperature was below?

3. What is the purpose of measuring the voltage and current at regular intervals during the course of the experiment? Briefly explain the method of determining W.

Experiment 13. Ohm's Law

Relationship between voltage and current

Objective:

(a) To verify Ohm's law.

(b) To verify the rules of combination of resistances in series and parallel.

Apparatus:

A power supply, resistors, an ammeter, a voltmeter and a personal computer.

Theory:

Ohm's law:

According to Ohm's law, the electrical current in a metallic conductor is directly proportional to the potential difference between the ends of the conductor. Thus, if V (in volts) is the potential difference between the ends of the conductor PQ and the current in the conductor is I amperes, then

$$V = R\,I, \qquad (1)$$

where R (in ohms) is the constant of proportionality, known as the resistance of the conductor. Note that the resistance of a conductor depends on its temperature. As a conductor offers some resistance to the current, it is known as a resistor.

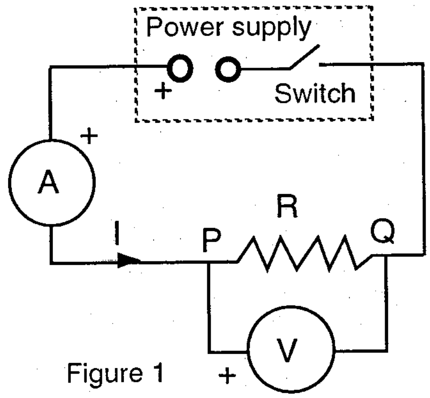

Figure 1

Equation (1) indicates that the resistance of a resistor can be determined by measuring the potential difference V and the current I. An ammeter is used to measure the current in a resistor and it is connected in series with the resistor PQ. The current must enter through the terminal marked + of the ammeter. A voltmeter is used for measuring the potential difference V applied to the resistor and thus the terminals of the voltmeter are connected to the two ends of the resistor. The end P of the resistor through which the current enters is at a higher potential than the end Q. The terminal of the voltmeter marked + must be connected to the end of the resistor which is at a higher potential.

Laws of resistors in series and parallel:

When two (or more) resistors are connected in series as shown in Fig. 2, their equivalent resistance is given by

$$R_s = R_1 + R_2 \qquad (2)$$

When two (or more) resistors are connected in parallel as shown in Fig. 3, their equivalent resistance is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (3)$$

Equations (2) and (3) can be extended to the cases of more than two resistors as well. Equations (2) and (3) represent the rules of combinations of resistors in series and parallel, respectively.

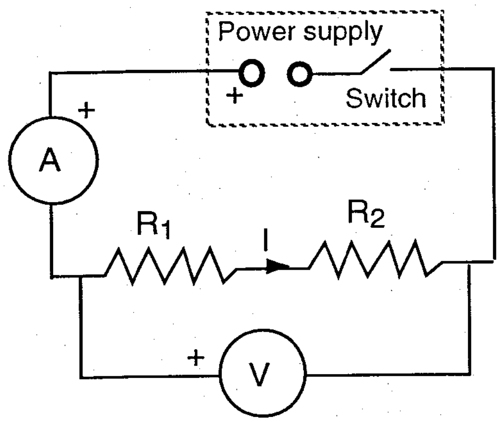

Figure 2

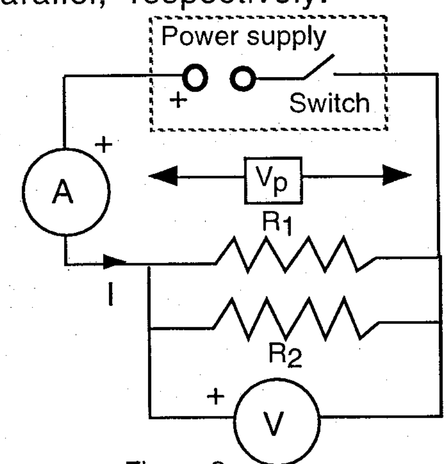

Figure 3

Note that the current in the resistors in series is the same and the potential differences across them are not equal unless the resistors have the same resistance.

In the case of a parallel combination, the potential difference across the resistors is the same, while the currents in the resistors are not equal unless the resistors have the same resistance. In any case, the sum of currents in the resistors R_1 and R_2 is equal to the total current I which is measured by the ammeter (Fig. 3).

Procedure:

1. Find the resistance of 4 resistors by using the color code.

In general, there are four bands of different colors painted on the

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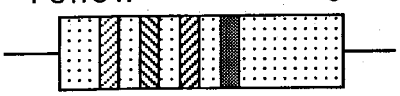
resistors. The color of the first band D_1 (which is nearest to an end of the resistor), gives the first digit of the resistance of the resistor. The color of the second band D_2 gives the second digit of the resistance of the resistor. The color of the third band E gives the exponent of 10 by which the number obtained by by using the colors of D_1 and D_2 should to be multiplied to obtain the resistance of the resistor. The color of the fourth band T gives the tolerance of the resistor which is a measure of the accuracy of the resistance of the resistor.

The color code is:

0 - -Black	5 - -Green	Tolerance:
1 - -Brown	6 - -Blue	Gold - - 5%
2 - -Red	7 - -Violet	Silver - -10%
3 - -Orange	8 - -Gray	No color - -20%
4 - -Yellow	9 - -White	



D_1 -- red (2) E -- orange (3)
D_2 -- green (5) T -- silver (10%)

The resistance of the resistor shown in the above diagram is 25×10^3 ohm (25000 ohm) and the tolerance is 10%.

2. Find the least counts for the different ranges of the voltmeter and ammeter.
3. Make the connections as shown in Fig. 1 including one of the resistors in the circuit. Use the highest ranges of the ammeter and voltmeter. Keep the voltage less than 6 volts. Switch on the circuit and take the readings of the voltmeter (V) and ammeter (I). While taking readings, use the ranges of the ammeter and voltmeter that give the values of V and I to the same degree of accuracy. Change the value of V and take the readings of V and i again. Thus take about six pairs of values of V and i and enter the data into Table III.
4. Choose 2 resistors and determine their individual resistances. Connect them in series (Fig. 2) and determine the series resistance. Then connect them in parallel (Fig. 3) and determine the parallel resistance.

The units of voltage, current and resistance are volt, ampere and ohm, respectively.

Use the computer program EXCEL and file ohmform to prepare the lab report.

York College of The City University of New York

Physics I

Name:

Experiment No. 13: Pre-Lab Questionnaire

1. How is an ammeter connected in the circuit?

2. How is a voltmeter connected in the circuit?

3. The following four bands are painted on a resistor:
   D_1 - orange; D_2 - yellow; D_3 - red; D_4 - silver.
   What is the resistance of the resistor? What is the tolerance?

4. Consider the following data and fill out the blanks:

Resistor(s)	V in volts	I in mA	R in ohms
R_1	3.4	7.1	$R_1 =$
R_2	3.5	6.7	$R_2 =$
R_1 and R_2 in series	3.8	3.7	$R_{se} =$
R_1 and R_2 in parallel	3.2	12.7	$R_{pe} =$

Using the values of R_1 and R_2 from the above table, calculate R_s.

Using the values of R_1 and R_2 from the above table, calculate R_p.

Percent difference between R_{se} and R_s =

Percent difference between R_{pe} and R_p =

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Experiment No. 13

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

Table I

Determination of resistance by color code:

Resistor No.	Color of band number				Resistance	Tolerance
	1	2	3	4		

Table II

Least counts:

No.	Voltmeter		Ammeter	
	Range	Least count	Range	Least count
1				
2				
3				

Table III

Verification of Ohm's law:

Resistor No.:

(Choose a resistor whose resistance is less than 1000 ohm.)

No.	V in volts	I in milliamps	R in ohms
1			
2			
3			
4			
5			
6			

Table IV

Verification of laws of resistances in series and parallel:
(Choose R_1 and R_2 such that their resistances are a few hundred ohms.)

Resistance(s)	Reading No.	V in volts	I in milliamps	R in ohms
R_1				
	Average R_1 =			
R_2				
	Average R_2 =			
R_{se} (R_1 and R_2 in series)				
	Average R_{se} =			
R_{pe} (R_1 and R_2 in parallel)				
	Average R_{pe} =			

By using the computer program EXCEL and the file ohmform, plot a graph between I and V (Table III). Determine R from the slope of the graph.

Calculate R_S by using Eq. (2) and the values of R_1 and R_2 from Table IV. Find the percent difference between the theoretical and experimental values of R_S.

Calculate R_p by using Eq. (3) and the values of R_1 and R_2 from Table IV. Find the percent difference between the theoretical and experimental values of R_p.

Experiment No. 13: Questions

1. State Ohm's law.

2. What will be the equivalent resistance of two 10-ohm resistors if they are connected in (a) series, (b) parallel? Show your calculations.

Appendix

Standard Values of Some Physical Quantities

Densities in gm/cm^3

Aluminum	2.70
Brass	8.44
Copper	8.87
Iron	7.87
Lead	11.37
Wood	0.4 - 0.8
Alcohol	0.79

Young's Modulus in 10^{11} $dyne/cm^2$

Brass	9.0 - 10.2
Steel	19.5 - 20.6
India rubber	0.05

$g = 980\ cm/s^2$

$= 9.8\ m/s^2$

J = 4.186 joule/calorie

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