A Laboratory Manual of Physics

Fifth Edition SI Version

F. Tyler

A Laboratory Manual of Physics

Fifth Edition . SI Version

F. Tyler B.Sc., Ph.D., F.Inst.P.

Edward Arnold

© F. Tyler 1970
First published 1970
by Edward Arnold (Publishers) Limited,
25 Hill Street, London W1X 8LL
Reprinted 1971
Reprinted with amendments 1972
Reprinted 1974, 1975
Fifth edition 1977
Reprinted 1977

British Library Cataloguing in Publication Data

Tyler, Frank
A laboratory manual of physics. – 5th ed., SI version
1. Physics – Experiments
I. Title

530'.07'24 QC33

ISBN: 0 7131 0170 9

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means electronic, mechanical, photocopying, recording or otherwise, without the prior permission of Edward Arnold (Publishers) Limited.

Printed in Great Britain by
Fletcher & Son Ltd, Norwich

Preface

Changes of emphasis, as well as content, in modern courses necessitated a revision and updating of the *Laboratory Manual*. In this new edition the author has revised the text to conform to the latest publication of the Association for Science Education referring to signs, symbols and abbreviations for use in school science. This is particularly revealed in the 'result' headings and the labelling of graphical axes. Several sections of the book have been expanded to cover the demands of the new examination syllabuses particularly with regard to A.C. and electronics, the Hall effect and atomic physics. In other sections experiments which are no longer required have been removed.

Throughout stress is laid on the problems of errors in practical work. The importance of recognizing, and minimizing, personal and instrumental errors is emphasized—together with the estimation and validation of the reliability of the end results. Certainly teachers should draw attention to this most important aspect of an experimental course during their teaching sequence. Not enough attention, however, is given to the limitation imposed on the end result of an experiment of assuming the exact applicability of a theoretically derived formula used in the final calculation. In the current edition an estimate of errors likely to arise from this circumstance is given and suggestions made as to the most effective way in which theory and practice can be brought into the closest accord.

In compiling a series of experiments such as is given here one has to keep a considered balance between the creative activity of the teaching laboratory with its own resources on the one hand, and the availability (now considerably extended) of the new and sophisticated equipment commercially available for school use on the other. The facilities of the school workshop can be of inestimable use to the keen teacher and enterprising student who should be encouraged to make the fullest use of these facilities. Inevitably much of the complicated, high-precision equipment has to be obtained from the suppliers, but in the present volume many of the experiments depend on self generated units details of which will be found in the text.

Acknowledgments

The publishers would like to thank Mr E. J. Kay who, with the sudden death of Mr Tyler, took on the responsibility of reading the final proofs. Thanks are also due to the Schools Science Review for permission to include material on the multi-coil balance on p. 192 of the text.

Contents

此为试读，需要完整PDF请访问： www.ertongbook.com

Modern Physics

LIST OF ADDITIONAL EXPERIMENTS DESCRIBED IN THE TEXT

Mechanics and Properties of Matter

Light

Electricity and Modern Physics

Introduction

1. General

To a large extent, experimental Physics is concerned with the quantitative determination of physical constants, e.g. the specific heat capacity of a solid, coefficients of thermal expansivity, thermal conductivity, etc. Some experiments, however, are designed to investigate relationships between two or more quantities. In every case, accurate and methodical observations are necessary, and these should be taken with an intelligent realization of the capabilities of the apparatus provided. A course in practical Physics is designed to give the student the opportunity of acquiring the necessary skill and technique in the manipulation of apparatus, and the use and understanding of the instruments employed.

2. Records

A faithful record of all observations taken should be made in a book specially reserved for the purpose. This book should be at hand while carrying out the experiment, and full details of the results should be entered with relevant remarks where necessary. A book should also be available in which a full record of the experiment is kept, with diagrams and full practical details, in a manner similar to that followed in the pages of this book. If the book is not ruled for graphical work, a sheet of graph paper can be interleaved when necessary between the double page of the record.

In stating the final result of the experiment, it is important to remember that the statement is incomplete if unaccompanied by the units in terms of which the quantity is measured. Where there is no special name for the unit, it is usual to give the dimensions of the quantity in reference to the three fundamental units of mass, length, and time. In the SI system of units, these are the kilogramme, metre, and second respectively. Thus acceleration expressed in this system would be written as $m\ s^{-2}$ or metres per second squared; similarly, density would be written as $kg\ m^{-3}$ or kilogrammes per cubic metre.

If the quantity measured is very large or very small it is usual to give the measure with one significant figure before the decimal point, multiplied by a power of 10. Thus Young's modulus for aluminium would be given as $7{\cdot}0 \times 10^{10}$ newtons per square metre (pascals) and the wavelength of the D_1 line of sodium as $5{\cdot}896 \times 10^{-7}$ m.

3. Errors

(a) Types of error

In an experimental investigation there are three main types of error:

(i) *Instrumental errors.* These are errors inherent in the apparatus itself and in the measuring instruments used. It should be realized that not every piece of apparatus, especially in a teaching laboratory, is capable of giving measurements to a high degree of accuracy. The capabilities of each component used should be considered and the degree of accuracy in the final result will not be greater than that of the least reliable instrument used (see below).

(ii) *Observational or personal errors*, especially parallax reading errors and scale interpolation estimates. These errors can be minimized by obtaining several readings carefully and methodically and then taking their arithmetical mean. Manipulation errors as, for example, in the use of a micrometer screw gauge, come under this heading, and clearly it would be most injudicious to rely on only one reading of the gauge for the measurement of, say, the diameter of a wire. The error incidence here can be minimized by averaging several readings, taken spirally at points equidistant along the wire, to obtain the required mean diameter value. Examples of this, and of the necessity of evaluating the 'zero error' of screw and slide instruments, will be found in the experiments that follow in the main text.

(iii) *Adjustment or setting errors.* These, again, are essentially personal errors. A faultily aligned magnetometer, or a badly adjusted galvanometer scale, can introduce unnecessarily large errors in the final result. The need for care and precision in setting up equipment is obvious, although it should be noted in this context that methods which are based on the balancing of two effects will give a greater degree of accuracy than methods which rely on the explicit measurement of the effect. This is because certain errors—due to faulty alignment or setting up of the equipment, for example—tend to balance each other out, and also because, in a null method, positions of balance can be found more certainly and accurately than the direct measurement of a scale reading.

(*b*) *Percentage error*

It is frequently useful to express an estimated error as a percentage of the mean value of an observed quantit —thereby to obtain some idea of the relative magnitude of the error in the final evaluation. Thus, an object for which five consecutive readings of its length were recorded as 2·02, 2·03, 2·01, 2·03, 2·01 cm, may be stated as having a length of 2·02 cm subject to an error swing of $\pm 0{\cdot}01$ cm or of $\frac{0{\cdot}01}{2{\cdot}02} \times 100 = 0{\cdot}5\%$ approx. Again, in measuring a temperature rise using the usual simple laboratory mercury thermometer (which the student should be capable of reading to $\frac{1}{10}$°C accuracy), it should be realized that there will be an error of 0·1°C at either end of the temperature interval recorded. Thus a 5·0°C rise will have an error of ±0·2°C, or a percentage error of 4%. A temperature rise of 20·0°C will have the same (±0·2°C) actual error, but a percentage error of only 1%—hence the need for experimental arrangements (subject, of course, to the considerations of other aspects of the procedure) to yield as high a temperature range as possible.

It should be noted that where a measured quantity is used as a power in the final expression, the error in the final evaluation will be greater than the error in the original measurement. Thus, in determining the area of cross-section of a wire for which the diameter d has been measured as 1·02 mm with an error of 0·01 mm (i.e. 1% approx.), the values of the cross-sectional area (A) will be

$$\frac{\pi d^2}{4} = \frac{\pi}{4}(1{\cdot}02 \pm 0{\cdot}01)^2$$

$$= \frac{\pi}{4}\{(1{\cdot}02)^2 \pm 2 \times 1{\cdot}02 \times 0{\cdot}01\} \text{ approx.}$$

Hence, the percentage error in A is

$$\frac{2 \times 1{\cdot}02 \times 0{\cdot}01}{(1{\cdot}02)^2} \times \frac{100}{1} = 2\% \text{ approx.}$$

It is thus seen that a percentage error in a given quantity is *doubled* when that quantity appears to the power 2 in the final expression. Generally, if the quantity appears to the nth power the error contribution will be n times that of the directly measured quantity—as can be seen below.

Let the error in a measured length l be δl, then the error in the quantity $l^n = \delta l^n = nl^{n-1}\delta l$, or a percentage error of

$$\frac{nl^{n-1}\delta l}{l^n} \times \frac{100}{1} = n\left(\frac{\delta l}{l}\right) \times 100$$

$$= n \times \text{percentage error in } l$$

(*c*) *Compounding errors*

When a number of quantities are involved in the final formulation the errors of all the measured quantities will, of course, affect the end result. The manner in which these individual errors are compounded is illustrated by the following examples:

(i) *Volume of a right cylinder*. This is given by the expression $V = \pi r^2 h = \frac{\pi}{4} d^2 h$ d being the measured diameter, and h the measured height. If δd and δh represent the errors in the measurement of these two quantities the final error δV in V can best be found by taking logs of the original expression, thus

$$\log V = \log \frac{\pi}{4} + 2 \log d + \log h$$

and then differentiating the expression so obtained. In this case this gives,

$$\frac{\delta V}{V} = 2\frac{\delta d}{d} + \frac{\delta h}{h}$$

Now since the errors in d and h can be both positive and negative, it follows that the relative error in V is given by

$$\frac{\delta V}{V} = \pm 2\frac{\delta d}{d} \pm \frac{\delta h}{h}$$

(The *percentage* error in V is, of course,

$$\frac{\delta V}{V} \times 100).$$

(ii) *Measurement of the resistivity of a wire*. The formula here is

$$\rho = \frac{RA}{l} = \frac{R\pi d^2}{4l}$$

The final error in the resistivity ρ will be compounded of the errors of measurement in the resistance R, the diameter d, and the length l of the wire. If these are, respectively, δR, δd, and δl, then, proceeding as above we get

$$\log \rho = \log \frac{\pi}{4} + \log R + 2 \log d - \log l$$

此为试读，需要完整PDF请访问： www.ertongbook.com

from which the relative error $\left(\frac{\delta\rho}{\rho}\right)$ in the resistivity is given by

$$\frac{\delta\rho}{\rho} = \pm\frac{\delta R}{R} \pm 2\frac{\delta d}{d} \mp \frac{\delta l}{l}$$

The ***maximum*** percentage error in this case is obtained by *adding* the percentage error in l to that of R and twice that of d.

(iii) *Acceleration of gravity by simple pendulum experiment.* The time period T of the simple pendulum is given by $T = 2\pi\sqrt{\frac{l}{g}}$ from which $g = \frac{4\pi^2 l}{T^2}$. The final error in the determined value of g is thus the composition of the errors in determining the time of oscillation T and measuring the oscillating length l. Proceeding as before we get

$$\log g = \log 4\pi^2 + \log l - 2\log T$$

from which

$$\frac{\delta g}{g} = \pm\frac{\delta l}{l} \mp 2\frac{\delta T}{T}$$

The ***maximum*** percentage error in the final value of g is thus

$$\frac{\delta g}{g} \times 100 = \frac{\delta l}{l} \times 100 + 2\frac{\delta T}{T} \times 100$$

(*d*) *Degree of accuracy*

In giving final numerical evaluation to an experimental result, it should be the custom to indicate the limits of error, or degree of accuracy, to which it is confined. The manner in which this is done may be illustrated by the reference to the experiment immediately above for determining a value for the acceleration of gravity from measurements with a simple pendulum. Let us suppose that in a given experiment the following measurements were recorded:

Length (l) of pendulum = 0·500 m (measured to 1 mm accuracy using a metre rule).

Time for 20 complete oscillations = 28·4 s (measured to 0·1 s accuracy on a $\frac{1}{10}$ s stopwatch).

Thus, time (T) of 1 oscillation = 1·42 s.

Now $$T = 2\pi\sqrt{\frac{l}{g}}$$

giving $$g = \frac{4\pi^2 l}{T^2}$$

$$= \frac{4\pi^2 \times 0{\cdot}500}{(1{\cdot}42)^2}$$

$$= 9{\cdot}788 \text{ m s}^{-2} \text{ (using 4-figure logs).}$$

Now the errors of measurement are (*a*) $\frac{0{\cdot}001}{0{\cdot}500}$ or 0·2% in l, and (*b*) $\frac{0{\cdot}1}{28{\cdot}4}$ or (approx.) 0·35% in T. Hence the total percentage error swing due to measurements is 0·2 + 2 × 0·35 (see (*c*) (iii) above) = 0·9%, or just under 1%. It is clear, therefore, that the final figure behind the decimal point in the answer for g above has no significance and thus can be disregarded by stating the value of g as 9·79 m s^{-2}. Even so, the figure in the second decimal place here has no firm significance and the extent by which it can vary may be estimated by taking 0·9% (the total measuremental error swing) of 9·79, i.e. 0·09 on either side of the calculated value. That is to say, the value of g obtained from this particular experiment may be stated as lying somewhere between the estimated limits 9·88 and 9·70 m s^{-2} or g = 9·79 ± 9 m s^{-2}. The student should endeavour to assess in this way the margin of fallibility, or factor of reliability, by estimating the limits of error in any quantity derived from experimental measurements.

It will be clear that the results of an experiment should be calculated only to within the degree of accuracy merited by the observations taken. Generally, 4-figure mathematical tables (accuracy of about 1 in 2500) will be more than adequate, but where sensitive apparatus is used, as for example in experiments with a good spectrometer, it may be necessary to use 5-figure, or even 7-figure, logarithms to obtain the necessary degree of accuracy. Slide rules (10 inch) cannot, in general, be relied upon to a greater degree than about 1 in 500. In the final statement of the result no more significant figures should be given than is justified by the observations, and also by the extent to which the theory is applicable in the particular circumstances.

4. Graphs

Wherever possible, the results of an experiment should be presented in graphical form. Not only does a graph provide the best means of averaging a set of observations but the dependence between the quantities is clearly shown. In plotting the results, the dependent variable should be plotted as ordinates on the y-axis, and the independent variable as abscissae on the x-axis. The scale used should be a convenient one for arithmetical work, and should be sufficiently extensive for the graph to occupy a wide sweep of the space available. On the other hand, too large a scale will tend to accentuate the errors of observation, and obscure the relationship between the two quantities. Each point on the graph is an actual observation, and should be made to stand out by surrounding it with a small circle. The departure of the point from the final curve is a measure of the experimental error in that observation.

Wherever possible the straight-line graph should be used. This is more accurately drawn, and deductions from such a graph more reliable, than with curved graphs. If the relationship between the two quantities is not a simple linear one it is usually possible to obtain the straight-line form by plotting powers of one or other (or both) of the quantities. For example, in the case of the simple pendulum, a plot of t against l results in a parabolic graph, but t^2 against l becomes a straight line; and in the bifilar suspension, t against l produces a rectangular hyperbola, which can be converted into the straight-line form by plotting t against $\frac{1}{l}$. The use of logarithmic scales is another means of obtaining the straight-line form in many cases. This method can often be used to obtain the empirical relation between two quantities.

Observations should be taken over as wide a range as possible, and the graph confined to the limits of the observations. In taking gradients, the full range of the graph (if a straight line) should be used; and for extrapolated values, the graph is continued as a broken line, and the result qualified by the statement 'extrapolated value', indicating that it is outside the limits of actual observation.

Examples of linear graphical forms of experimental relationships:

(i) *Measurement of linear magnification of real images formed by a convex lens.* The lens formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ can be rewritten $\frac{v}{u}=\frac{v}{f}-1$. Thus, writing M for the magnification $\frac{v}{u}$, we get

$$M=\left(\frac{1}{f}\right)v-1$$

By plotting M (on the y-axis) against v (on the x-axis) a straight-line plot is obtained (Fig. A). In standard notation this is $y = mx + c$, where

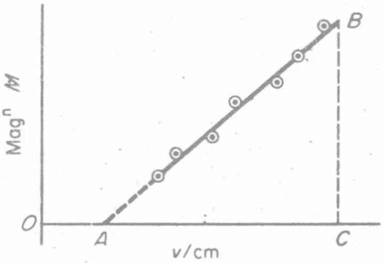

FIG. A

m is the slope of the line and c its intercept on the y-axis. In this case a value for the focal length (f) of the lens used can be obtained from the gradient.

Thus, $\frac{BC}{AC}=\frac{1}{f}$ (BC and AC measured in scale units)

or $f=\frac{AC}{BC}$

Note also that when $M = 0$, $v = f$. Hence f is also equal to the intercept OA on the v-axis.

(ii) *Empirical formula for a simple pendulum.* This may be expressed as $T = kl^n$, the object of the experiment being to evaluate k and n and so obtain the empirical relationship between the time of oscillation T and the length l of the pendulum. By taking logs we get

$$\log T = n \log l + \log k$$

hence a log–log plot with log T on the y-axis, and log l on the x-axis, will yield a straight-line plot as indicated in Fig. B. The slope of this

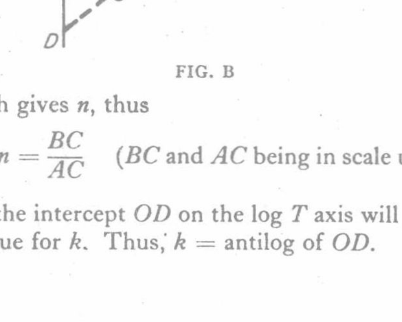

FIG. B

graph gives n, thus

$$n=\frac{BC}{AC} \quad (BC \text{ and } AC \text{ being in scale units})$$

and the intercept OD on the log T axis will yield a value for k. Thus, k = antilog of OD.

Experiment 1

Determination of the radius of gyration of a wheel and axle rolling down an inclined plane

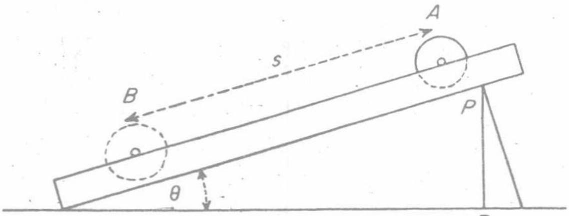

FIG. 1.1

APPARATUS

Long, narrow, open wooden box, the top edges of which serve as rails over which the wheel and axle rolls. Wheel and axle consisting of a metal disc through the centre of which is passed a cylindrical rod. Wedge of wood, stop-watch, screw gauge, metre rule.

METHOD The wedge is placed under one end of the box and the sine of the angle of inclination measured from the lengths *PR* and *PQ*. The wheel is held at rest with the axle on the marked position *A*, and the time taken for it to reach the mark *B*, a measured distance *s* down the plane, is taken. This is repeated three times, and the acceleration *a* down the plane is obtained, using the mean of these times. The experiment is then repeated, using different inclinations of the box, and a graph of *a* against sin θ is drawn. The diameter of the axle is accurately taken, and from the radius of the axle and the slope of the graph, the radius of gyration *k* of the wheel and axle is found.

THEORY Let the radius of the axle be r and let the mass of the wheel and axle be M and its moment of inertia I. Then on rolling from A to B, a distance s down the slope inclined at an angle θ to the horizontal, the potential energy lost $= Mgs \sin \theta$.

If the linear velocity of the wheel at B is v and its angular velocity w, the kinetic energy gained $= \frac{1}{2}Mv^2 + \frac{1}{2}Iw^2$.

$$\therefore \quad Mgs \sin \theta = \tfrac{1}{2}Mv^2 + \tfrac{1}{2}Iw^2 \text{ (since p.e. lost = k.e. gained)}$$

$$= \frac{v^2}{2}\left(M + \frac{I}{r^2}\right)\left(\text{since } w = \frac{v}{r}\right)$$

Now if a is the acceleration down the plane, $v^2 = 2as$, and writing $I = Mk^2$ we have

$$Mgs \sin \theta = \frac{2as}{2} M \left(1 + \frac{k^2}{r^2}\right) \quad \text{or} \quad a = \frac{g}{\left(1 + \frac{k^2}{r^2}\right)} \sin \theta$$

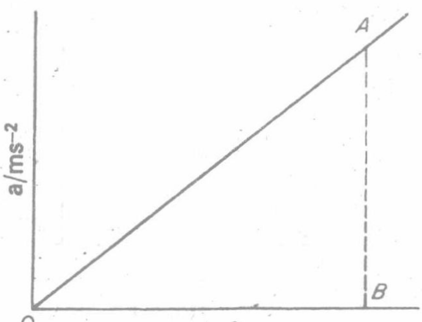

FIG. 1.2

If t is the time taken to roll the distance s down the plane the acceleration can be determined from

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

By plotting a against $\sin \theta$, a straight-line graph is obtained whose slope is

$$\frac{g}{1 + \frac{k^2}{r^2}} = \frac{AB}{OB}$$

from which k can be obtained.

NOTE Rolling friction can be allowed for by finding the angle α at which the plane has to be inclined in order that the wheel and axle may roll down with constant velocity. Then it can be shown that to a first approximation

$$a = \frac{g}{\left(1 + \frac{k^2}{r^2}\right)} \sin (\theta - \alpha)$$

Experiment 2

Determination of moment of inertia

a. USING THE BIFILAR SUSPENSION

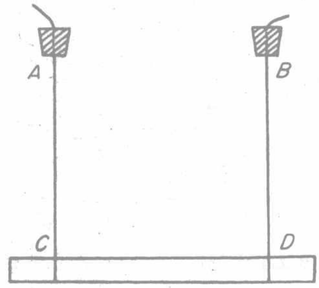

FIG. 2.1

APPARATUS Two heavy stands and clamps, two threaded corks, metre rule, brass rod, stop-watch.

METHOD Pass the brass rod through two loops made on the ends of the two lengths of cotton passing through the corks. Firmly clamp the corks in two heavy stands. Arrange the threads at some distance d apart, and adjust the lengths of the threads to some suitable length l. Tie off the loose ends of the threads on the clamp, and give the rod a small angular displacement about a vertical axis. Find the periodic time (T) by timing 20 vibrations. Repeat with the threads at varying distances apart, and plot a graph of T against $\frac{1}{d}$ (Fig. 2.2) from which to obtain an average value of Td. Measure l and find the mass M of the rod by weighing.

RESULTS

$M =$ kg

$l =$ m

d/m	Time for 50 vibrations/s	T/s

from the graph

$$Td = \frac{AB}{OB}$$

$$\therefore I = \frac{Mg}{16\pi^2 l} \cdot (Td)^2$$

$$= \frac{Mg}{16\pi^2 l}\left(\frac{AB}{OB}\right)^2 \_\_\_\_\_\_ \text{ kg m}^2$$

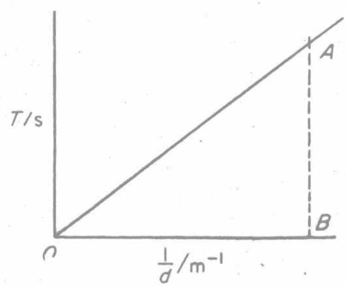

FIG. 2.2

THEORY Let a body of mass M and moment of inertia I be suspended by two parallel threads AC and BD of length l and distance d apart. Then the tension in each of these will be $\frac{Mg}{2}$. Give the system a

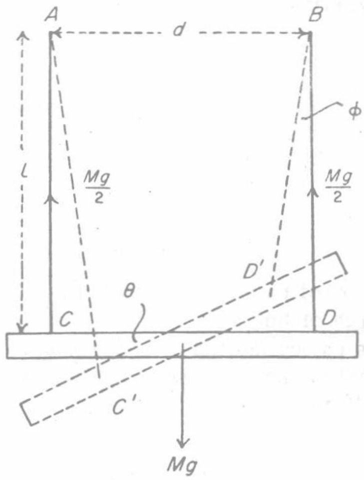

FIG. 2.3

small angular displacement θ about a central axis, and let ϕ be the corresponding inclination of the strings to the vertical. Since both angles are small,

$$l\phi = \frac{d}{2}\theta$$

The components of the tensions in the strings producing restoring forces at C' and D' are of magnitude $\frac{Mg}{2}\sin\phi = \frac{Mg}{2}\phi$ (since ϕ is small)

$$= \frac{Mgd\theta}{4l}$$

The restoring couple on the rod is thus

$$-\frac{Mgd}{4l}\theta \cdot d$$

and the equation of motion of the rod is

$$I\ddot{\theta} = -\frac{Mgd^2}{4l}\cdot\theta \qquad \text{or} \qquad \ddot{\theta} + \frac{Mgd^2}{4Il}\cdot\theta = 0$$

the motion is thus simple harmonic or periodic time

$$T = 2\pi\sqrt{\frac{4Il}{Mgd^2}}. \qquad \therefore \quad I = \frac{Mgd^2T^2}{16\pi^2 l}$$

NOTES

1. Additionally, the value of I may be obtained by keeping d constant and varying l. The student should repeat the experiment under these conditions, and obtain the value of I from the slope of the graph resulting from plotting T^2 as ordinates against l as abscissae.

2. If the threads are not parallel, but with distances between them of d_1 and d_2 at the ends, an analysis similar to the above shows that

$$T = 2\pi\sqrt{\frac{4Il}{Mgd_1d_2}}$$

3. If two bodies of masses M_1 and M_2, and moments of inertia I_1 and I_2, have periodic times of T_1 and T_2 when suspended in turn by the same strings,

then
$$\frac{I_1}{I_2} = \frac{M_1T_1^2}{M_2T_2^2}$$

b. OF A FLYWHEEL

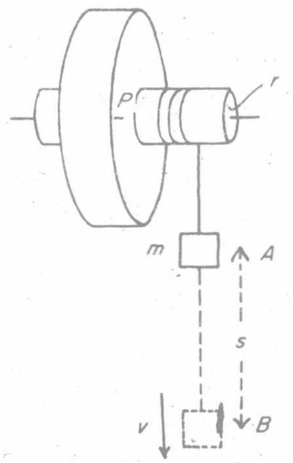

FIG. 2.4

APPARATUS Flywheel of standard pattern supplied with wall support. A mass attached to a length of fine cord which is wrapped round the axle, the free end being passed through a hole in the axle. The length of cord is adjusted so that when the attached mass reaches the ground, the cord detaches itself from the axle. Callipers, stop-watch, metre rule.

METHOD The mass m is allowed to fall through a measured distance (s) to the ground, and the time of descent (t) is taken by a stop-watch. The number of revolutions (n) of the wheel during this time is taken by observing a mark made on the circumference of the wheel at P. The further revolutions (N) made by the wheel before coming to rest after m is detached are also counted by reference to the mark P. The experiment is repeated two or three times for the same distance s and average values of n, t, and N are taken. The value of m is obtained and the radius r of the axle found by using callipers.

RESULTS

Radius of axle (r) = m
Mass (m) = kg
Distance (s) = m

$t =$	,	,	s	Average t =		s
$n =$	,	,	rev	Average n =		rev
$N =$	,	,	rev	Average N =		rev

$\therefore\ I =$ ________ kg m^2

NOTE The cord should be of small diameter compared with the axle, otherwise the value of r used above must be taken as the sum of the radii of axle and cord.

THEORY Let the mass of the suspended load be m, and let the moment of inertia of the flywheel be I and the radius of the axle r. Then when the mass descends a distance $AB = s$ it loses potential energy $= mgs$, and during the same time it acquires kinetic energy $= \frac{1}{2}mv^2$ due to its velocity v at B, and the wheel acquires kinetic energy $= \frac{1}{2}Iw^2$ (where $v = rw$).

Then by the principle of the conservation of energy

$$mgs = \tfrac{1}{2}mv^2 + \tfrac{1}{2}Iw^2 + \text{the work done against friction}$$

此为试读,需要完整PDF请访问: www.ertongbook.com