
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

Experiment	Page	Experiment	Page
Introduction	i	20 Refractive index of (a) glass and (b) a liquid, using a travelling microscope	42
Mechanics and Properties of Matter		21 Critical angle and the refractive index of a liquid by the air-cell method	43
1 Determination of the radius of gyration of a wheel and axle rolling down an inclined plane	5	22 Radius of curvature of a convex mirror using a spherometer	44
2 Moment of inertia		23 Refractive index of a liquid using a concave mirror	45
a using the bifilar suspension	8	24 Focal length of a concave mirror	46
b of a flywheel		25 Focal length of a convex mirror: (a) using a plane mirror (b) using a convex lens	48
3 Density of a liquid using a loaded test-tube	10	26 Focal length of a convex lens by the displacement method	50
4 Experiments with a spherical spring: (a) to verify Hooke's law, and to find the extension per gramme of added load; (b) to determine the acceleration of gravity and the effective mass (m) of the spring	12	27 Focal length and position of a lens mounted in an inaccessible position inside a tube	51
5 Acceleration due to gravity by means of a simple pendulum	14	28 Focal length of a convex lens by plotting the distance between the object and image against the object distance	52
6 Acceleration due to gravity by means of a compound pendulum	16	29 Radius of curvature of the surface of a convex lens, and the refractive index of the glass by Boys' method	54
7 Acceleration due to gravity by means of a Kater pendulum	18	30 Focal length of a convex lens by plotting magnification against image distance	56
8 Experiments with a ballistic balance: (a) comparison of masses; (b) determination of the coefficient of restitution	20	31 Refractive index of a liquid by a liquid lens method	57
9 Young's modulus for a wire	22	32 Focal length of a concave lens: (a) using a concave mirror (b) using a convex lens	58
10 Surface tension of water by rise in a capillary tube	24	33 Magnifying power of a telescope	60
11 Surface tension of a liquid using Jaeger's method	26	34 Magnifying power of a microscope	61
12 Surface tension of a soap film	28	35 Refractive index of a glass prism using a spectrometer	62
13 Surface tension by the method of direct pull	30	36 Adjustment of a spectrometer	64
14 Surface tension of soap solution from bubble measurements	31	37 Wavelength of sodium light using a Fresnel's biprism	65
15 Surface tension of a liquid by the drop-weight method	32	38 Thickness of paper by measurements on the interference fringes in an air wedge	66
16 Coefficient of viscosity for water by capillary flow	34	39 Diameter of a fine wire by interference fringe measurements	67
17 Coefficient of viscosity for glycerine by the falling-sphere viscosimeter	36	40 Wavelength of sodium light using a diffraction grating	68
18 Viscosity of air by deflating soap bubble method	38	41 Diameter of small particles by diffraction halo measurements	70
Light			
19 Percentage of light transmitted by a sheet of glass	40		

Experiment	Page	Experiment	Page
42 Diffraction by gauze—determination of the wavelength of sodium light	72	Electricity and Electromagnetism	
43 Wavelength of sodium light by Newton's rings	74	64 Value of ϵ_0 and the stray capacitance of a parallel-plate capacitor	107
		65 Relative permittivity of a dielectric medium	109
Sound		66 Effect of a guard ring on a parallel-plate capacitor	110
44 Velocity of sound using a resonance tube	76	67 Capacitance using a Reed switch	111
45 Frequency of a tuning fork using a sonometer	78	68 Comparison of the e.m.f.s of two cells using a potentiometer	113
46 Velocity of sound in air using a Kundt's tube	80	69 Internal resistance of a cell using a potentiometer	115
47 Frequency of a tuning fork by the falling-plate method	82	70 Comparison of two resistances using a potentiometer	116
48 Frequency of a tuning fork using a stroboscopic disc	84	71 Measurement of current and calibration of an ammeter using a potentiometer	117
49 Frequency of the a.c. mains using a sonometer	85	72 Calibration of a voltmeter using a potentiometer	118
		73 Measurement of high e.m.f. using a potentiometer	119
Heat		74 Calibration of a thermocouple	120
50 Coefficient of linear expansivity of a metal tube using an optical lever	86	75 Temperature coefficient of resistance of a copper coil	123
51 Coefficient of cubic expansivity of a liquid using a pyknometer	87	76 Temperature determination using a platinum resistance thermometer	124
52 Atmospheric pressure using a Boyle's law apparatus	88	77 Determination of a low resistance	126
53 Atmospheric pressure from measurements of an entrapped air column	89	78 A simple method for determining the resistance of a voltmeter	127
54 Specific heat capacity of a liquid by the method of cooling	90	79 Determination of an unknown resistance using a Wheatstone bridge	128
55 Specific heat capacity of a bad conductor	92	80 End corrections for a wire bridge	129
56 Saturated vapour pressures of water at different temperatures	94	81 Resistivity of a wire using a Post Office box	130
57 Boiling point of water at different pressures and thus to ascertain the variation of the s.v.p. of water against temperature	95	82 Comparison of two nearly equal resistances by the Carey-Foster bridge	132
58 Thermal conductivity of copper by Searle's method	96	83 Determination of the specific charge of copper ions	133
59 Thermal conductivity of ebonite by Lees' disc method	98	84 Conductivity of an electrolyte by Kohlrausch's method.	135
60 Thermal conductivity of glass	100	85 Polarizing e.m.f. of acidulated water	137
61 Specific heat capacity of copper by Callendar's method	102	86 Specific heat capacity of a liquid by an electrical method	139
62 Boiling point of a liquid using a constant-volume gas thermometer	104	87 Specific heat capacity of water using a Callendar and Barnes continuous-flow calorimeter	141
63 Ratio of the specific heats of a gas by Clément and Desormes' method	105	88 Specific latent heat of vaporization of a liquid by an electrical method	143
		89 To investigate the relation between the current passing through a tungsten filament lamp and the potential applied across it	144

Experiment	Page	Experiment	Page
134 Counting and monitoring exercises using a Geiger-Muller tube and scaler	239	13 Focal length of a concave lens using an auxiliary convex lens in contact	59
135 Dead time of a Geiger-Muller tube	241	14 Refractive index of a liquid by Newton's rings	75
136 Efficiency of a Geiger-Muller tube for β counting	243	15 End correction of a resonance tube	77
137 Relative efficiency of a Geiger-Muller tube for β/γ counting	245	16 Verification of the laws of vibration of a stretched string	79
138 Absorption of β -rays	247	17 Density of a heavy object using a sonometer	79
139 To investigate the back scattering of β -particles	249	18 Young's modulus of a rod by Kundt's tube	81
140 Attenuation of γ -rays by matter	251	19 Coefficient of adiabatic elasticity by Kundt's tube	81
141 Verification of inverse square law for γ -rays	253	20 Coefficient of expansion of a powder (problem)	87
142 Experiments with a pulse electroscope	255	21 Verification of Newton's law of cooling	91
143 Determination of the range of α -particles in air (two methods)	258	22 Saturated vapour pressure of water vapour using a small flask	94
144 Absorption of α -rays by matter	260	23 Comparison of thermal conductivities of bad conductors by Lees' disc method	99
145 Measurement of the half-life of thorium emanation (thoron)	262	24 Thermal conductivity of rubber	101

LIST OF ADDITIONAL EXPERIMENTS DESCRIBED IN THE TEXT

Mechanics and Properties of Matter

1 Comparison of moments of inertia using a bifilar suspension	7
2 Moment of inertia of a flywheel by an oscillation method	9
3 'g' by vertical oscillations of a loaded test-tube	11
4 Comparison of densities of two liquids using a loaded test-tube	11
5 Empirical formula for a simple pendulum	15
6 Moment of inertia of a rigid body by measurement of the length of the simple equivalent pendulum	17
7 Variation of the surface tension of a liquid with temperature	27
8 Ferguson's method for the surface tension of a small quantity of liquid	27
9 Comparison of the surface tensions of two liquids by weighing drops	33
10 Interfacial surface tension of two liquids by the drop-weight method	33

Light

11 Reflecting power of a surface	41
12 Refractive index of a lens by locating a flare spot	55

Electricity and Modern Physics

25 Recovery rate of a polarized Leclanché cell	114
26 Melting point of a solid using a thermocouple	122
27 Galvanometer resistance by Kelvin's method	131
28 Verification of Faraday's laws of electrolysis	134
29 Calibration of an ammeter using a copper voltameter	134
30 Galvanometer resistance from sensitivity measurements	150
31 Adjustment tables and correction graphs for ballistic galvanometers	154
32 Comparison of capacitances using a ballistic galvanometer	156
33 Calibration of a ballistic galvanometer by the aid of a scaler counting unit	159
34 To explore the axial field of a solenoidal coil by the aid of a cathode-ray indicator	167
35 To obtain the coefficient of coupling for a mutual inductor	171
36 Direction of the magnetic meridian using an earth inductor	178
37 Evaluation of hysteresis cyclic energy losses	186

Experiment	Page	Experiment	Page
38 Relative permeability for a magnetic specimen	186	43 Linear and mass absorption coefficients for γ -rays	252
39 Remanence and coercivity measurements for a magnetic specimen	187	44 Comparison of radioactive source intensities	252
40 Factors affecting the inter-pole flux of an electromagnet by current balance measurements	191	45 Characteristics of an ionization chamber	256
41 Measurement of magnetic field strength by the Hall effect	222	46 Estimation of initial energy rating of α -rays	260
42 Estimation of maximum energy of a β -ray stream	248		

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 7.0×10^{10}

newtons per square metre (pascals) and the wavelength of the D_1 line of sodium as $5.896 \times 10^{-7} \text{ m}$.

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 quantity—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 ± 0.01 cm or of $\frac{0.01}{2.02} \times 100 = 0.5\%$

approx. Again, in measuring a temperature rise using the usual simple laboratory mercury thermometer (which the student should be capable of reading to $\frac{1}{10}^{\circ}\text{C}$ 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 $\pm 0.2^{\circ}\text{C}$, or a percentage error of 4% . A temperature rise of 20.0°C will have the same ($\pm 0.2^{\circ}\text{C}$) 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

$$\begin{aligned}\frac{\pi d^2}{4} &= \frac{\pi}{4} (1.02 \pm 0.01)^2 \\ &= \frac{\pi}{4} \{ (1.02)^2 \pm 2 \times 1.02 \times 0.01 \} \text{ approx.}\end{aligned}$$

Hence, the percentage error in A is

$$\frac{2 \times 1.02 \times 0.01}{(1.02)^2} \times \frac{100}{1} = 2\% \text{ approx.}$$

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 n th 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 $l^n = \delta l^n = n l^{n-1} \delta l$, or a percentage error of

$$\begin{aligned}\frac{n l^{n-1} \delta l}{l^n} \times \frac{100}{1} &= n \left(\frac{\delta l}{l} \right) \times 100 \\ &= n \times \text{percentage error in } l\end{aligned}$$

(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

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

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

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

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 stop-watch).

Thus, time (T) of 1 oscillation = 1.42 s.

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

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

$$= \frac{4\pi^2 \times 0.500}{(1.42)^2}$$

$$= 9.788 \text{ m s}^{-2} \text{ (using 4-figure logs).}$$

Now the errors of measurement are (a) $\frac{0.001}{0.500}$ or

0.2% in l , and (b) $\frac{0.1}{28.4}$ or (approx.) 0.35% in T .

Hence the total percentage error swing due to measurements is $0.2 + 2 \times 0.35$ (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 measurement 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 $g = 9.79 \pm 0.09 \text{ m s}^{-2}$. 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

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ can be rewritten } \frac{v}{u} = \frac{v}{f} - 1. \text{ Thus,}$$

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

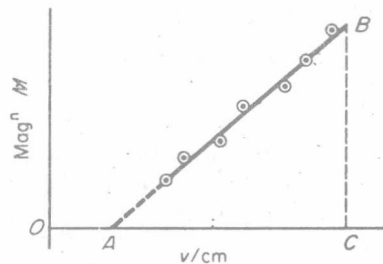


FIG. A

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.

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

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

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

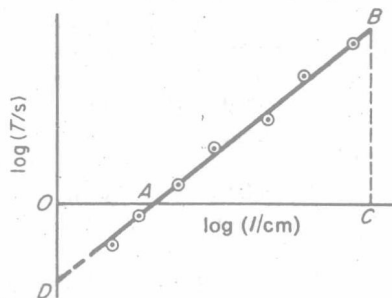


FIG. B

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, $k = \text{antilog of } OD$.

Experiment 1

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

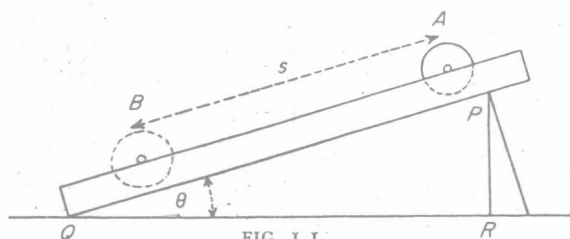


FIG. 1.1

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 $\sin \theta$ 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 ω , the kinetic energy gained = $\frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$.

$$\begin{aligned} \therefore Mgs \sin \theta &= \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 \quad (\text{since p.e. lost} = \text{k.e. gained}) \\ &= \frac{v^2}{2} \left(M + \frac{I}{r^2} \right) \quad (\text{since } \omega = \frac{v}{r}) \end{aligned}$$

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

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

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.

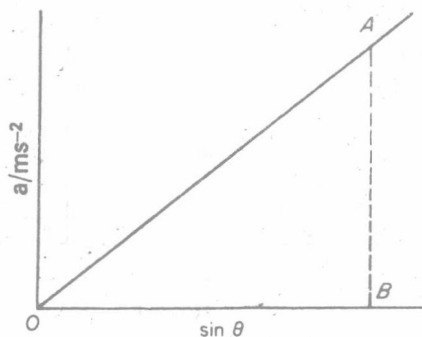


FIG. 1.2

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

APPARATUS

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

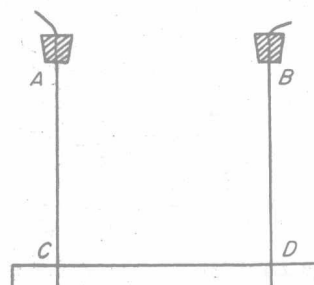


FIG. 2.1

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

$$M = \quad \text{kg}$$

$$l = \quad \text{m}$$

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

from the graph

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

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

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

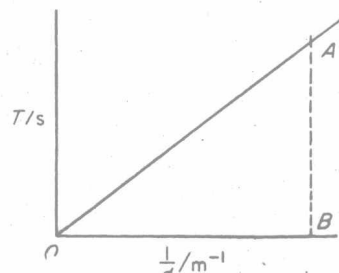


FIG. 2.2

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

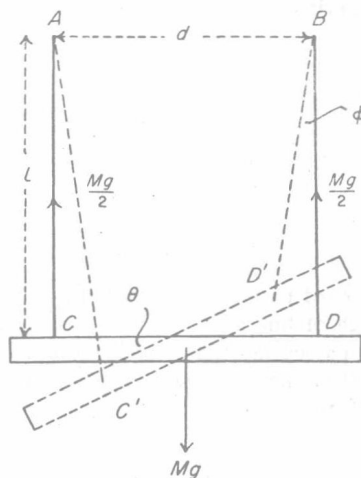


FIG. 2.3

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

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

the motion is thus simple harmonic or periodic time

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

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

$$T = 2\pi \sqrt{\frac{4Il}{Mgd_1 d_2}}$$

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

$$\frac{I_1}{I_2} = \frac{M_1 T_1^2}{M_2 T_2^2}$$

b. OF A FLYWHEEL

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.

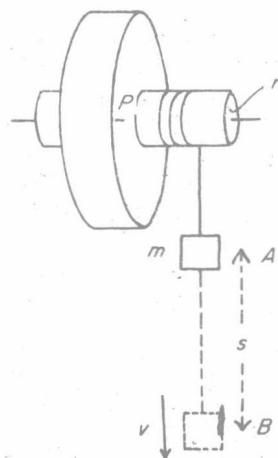


FIG. 2.4

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
$n =$,	rev
$N =$,	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 $= \frac{1}{2}I\omega^2$ (where $v = r\omega$).

Then by the principle of the conservation of energy

$$mgs = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + \text{the work done against friction}$$