LES KIRKUP

Experimental Methods for Science and Engineering Students

An Introduction to the Analysis and Presentation of Data

SECOND EDITION

7 Report Writing and Presentations

7.1 Overview

Progress in science and engineering relies not only on discoveries arising from experiments, but also on communication of those discoveries. In this chapter we focus on three modes of communication, because of their importance in college and university science and engineering courses and their prominence in the professional lives of scientists and engineers: reports, posters and oral presentations.

Where possible, a presentation should be planned with the background and interests of the audience in mind.[1] For example, a report written for someone with little background in science would differ from a report written for specialists with expert knowledge of the science being reported. Here we consider communicating the aims, methods and findings of experiments where the audience consists chiefly of science and/or engineering students and their instructors.

7.2 A Scientific or Technical Report

There is often a feeling of accomplishment combined with a sense of satisfaction when an experiment has been completed. The hard work is done, and it is time to relax. However, the background to the experiment, its aim, how it was performed and what was discovered may be known to only a few people at best. The laboratory notebook containing details of the experiment is probably only fully intelligible to its owner and therefore unlikely to provide an easily readable account of the experiment. In situations where all aspects of an experiment need to be communicated, a crucial stage of the work remains to be undertaken: the preparation of a written report.

It is unlikely that you would write a report on completion of every laboratory session you attend. In many situations, especially in the early years of study in

[1] It is acknowledged that there may be situations in which you are unaware of the background and interests of your audience, making presentation preparation a challenge.

science and engineering, keeping a laboratory notebook may be given more emphasis with respect to documenting and communicating work done in the laboratory. Nevertheless, it is not unusual to be required to write up one or more experiments in the form of a report in the first year of study at university or college.

As you progress through a course in science or engineering, more emphasis is generally placed on the communication of experimental results. Consequently, the assessment of reports is likely to constitute a significant proportion of marks awarded for experimental work you undertake. The communication may take the form of a report to an instructor or supervisor and be based on an extended experiment or a project.

Beyond this, we recognise that writing reports is a core activity practised by scientists and engineers everywhere. A thorough and well-written report enhances the reputation of the author(s) and can be a decisive factor when decisions are made about providing resources so that, for example, the scope of the work can be expanded.

The process of writing a report requires drawing together and organising the elements that make up a report, including:

- the aim of the experiment
- the background to the experiment
- the method and materials used
- the data gathered
- the analysis and discussion of the data
- the conclusions drawn from the data
- the references used to point the reader to similar work or to support what has been written.

The process of writing a report, which requires revisiting all aspects of an experiment, often rewards its author with a deeper understanding of the experiment. For these reasons, we concentrate first on report writing.

Writing good reports, like proficiency in performing experiments, requires practice, and first efforts can usually be improved upon. Actively looking for the strengths and shortcomings of reports written by others is a good way to identify what makes a competent report, but it is no real substitute for the experience gained through writing one.

A report should:

- be complete but concise
- have a logical structure
- be easy to read.

Some readers may have performed an experiment similar to that discussed in your report, and may wish to compare the experimental method you adopted with their own. For other readers, more general questions are likely to come to mind:

- What was the problem studied and what is its significance?
- What conclusions have been drawn, do they seem reasonable and are they supported by the data?

In addition to addressing these questions, many details must be considered in a report, from describing the background to the work to detailing the equipment used. Dealing with these matters requires a well-structured report.

7.2.1 Structure of a Report

The layout of the report impacts on its clarity, and it is usual for a report to be divided into the following sections.[2]

(i) Title
(ii) Abstract
(iii) Introduction
(iv) Background Theory
(v) Materials and Methods
(vi) Results
(vii) Discussion
(viii) Conclusion
(ix) Acknowledgements
(x) Appendices
(xi) References

There is no requirement that a report be written in the order given by these section headings. To give the writing of the report impetus, it is sometimes easier to begin with the Materials and Methods section. This section is usually straightforward to write, as many of the details are in the laboratory notebook used to document the experiment.

We will consider each section in turn, but first we begin by considering the use of English in report writing.

7.2.2 Use of English

It is unlikely anyone reads a scientific or technical report primarily to assess the correctness of the English. Nevertheless, if the use of English is poor, a reader may be forced to re-read passages several times to uncover what the writer is trying to say. In extreme cases the reader may give up in frustration.

There is flexibility in how the details of an experiment are reported. It is quite acceptable to write in the first person when describing an experiment. For example:

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[2] Where a report is short, it is reasonable to combine two or more sections under one heading. As examples, the Introduction may include background theory relevant to the experiment, or Results and Discussion may be combined into a single section. Some sections, such as Acknowledgements or Appendices, may not be applicable and may therefore be absent from the report.

We measured the gas pressure every 30 s. This is certainly easy to read. However, writing in the first person places the emphasis on the person or persons who carried out the activity, rather than on the activity itself.

A more commonly used style in science and engineering is to write in the third person, with the emphasis placed on what was done rather than on who did it. As an example: *The gas pressure was measured every 30 s.* Writing in this manner might leave the reader wondering who did the things described in the report, especially if the report has more than one author. However, this detail is usually of little long-term interest or importance to the reader.

Several other points can be made which should help in the task of report writing.

Choice of Tense

The report is generally written in the past tense when giving details of what was done during the experiment. Occasional use is made of the present tense, especially when giving details of the background to the work or when inferring relationships from the data. For example:

> *Measurements **were** made of the length of the copper rod as a function of temperature. The graph of the data shown in* Figure 1 ***indicates** that the increase in length of the rod **was** directly proportional to the temperature rise.*

Sentence Length

Keep sentences short, especially when the content is highly technical or specialised vocabulary is used. The sentence

> *The decay of photocurrent in a sintered cadmium sulfide photoconductor was measured by illuminating the photoconductor with monochromatic light of wavelength 585 nm for a period of 60 ms, then converting the decaying photocurrent to a voltage using an operational amplifier whose output was connected to a PC-based data acquisition system.*

is easier to absorb if it is written as

> *A cadmium sulfide photoconductor was illuminated with monochromatic light of wavelength 585 nm for a period of 60 ms. The resulting photocurrent was converted to a voltage using an operational amplifier. The decay of the photocurrent was measured by sampling the output of the amplifier using a PC-based data acquisition system.*

Acronyms

It is possible that the analysis technique, instrument or device used during the experiment is commonly referred to by an acronym, such as AFM for Atomic Force Microscope or LVDT for Linear Variable Differential Transformer. Though such acronyms may be familiar to some readers of the report, to others they will be new and incomprehensible, which in turn will affect the readability of the whole report. Each acronym should be explained the first time it is used in a report.

7.2.3 Sections of a Report

We will now consider the sections that make up a typical report.

Title and Author

The title of the report should be brief (say between 5 and 15 words), informative and followed immediately by the author's name and their affiliation. Consider the following two titles:

A study of the insulating properties of some materials

Petra Jones, University of the Southern States

and

A comparison of the thermal insulating properties of Styrofoam and fibreglass

Petra Jones, University of the Southern States

The first title is too vague. In the second we are made aware that it is the *thermal* insulating properties that are compared (as opposed to, say, the electrical or sound insulating properties), and specific mention is made of the materials being compared.

Abstract

This is an overview of the experiment and its findings. It should be brief (typically 50 to 200 words) and should avoid the detail that the reader will encounter in later sections. The goal is to get straight to the heart of the matter by communicating what was done, why it is significant and what the major findings are. Writing a good abstract can be quite challenging, and often requires several revisions. Consequently, many people prefer to draw up a plan of the whole report, write a draft of the report and then return to the abstract later.

Consider two alternative abstracts. Abstract A reads:

The cathodoluminescence of a ceramic material is discussed in this report. Cathodoluminescence is the emission of light from a material when it is struck with fast moving electrons. The light emitted from the ceramic was analysed, permitting the identification of a compound formed at the surface. It is possible to relate the existence of the compound to the difficulties some workers have found in making good electrical connections to the ceramic.

Abstract B reads:

Advances in the applications of the superconducting ceramic $YBa_2Cu_3O_{7-\delta}$ *have been constrained, partly because of the difficulty of making electrical connections to this material. Cathodoluminescence, used to analyse the surface of the ceramic, revealed that barium carbonate forms at the surface when the ceramic is exposed to air. The barium carbonate forms an electrically insulating layer detrimental to the formation of good electrical connections.*

Abstract A focuses on the analysis technique used in the investigation (cathodoluminescence) rather than on the main purpose of the experiment, which was to find out *why* it is difficult to make good electrical connections to the ceramic material. The abstract goes into details of the technique: *Cathodoluminescence is the emission of...* It is important these details be given, but it is preferable that they appear in the Materials and Methods section of the report. Finally, there is a vague statement to the effect that a compound discovered using the technique can help to explain the electrical connection problem. If the author has identified the compound, and the likely relationship between the compound and the problem of making good electrical connections, then this information should be stated concisely in the abstract.

Abstract B is an improvement on abstract A. It states:

- the reason for the investigation
- the type of ceramic material studied
- the technique used
- what that technique revealed
- how the results can be used to explain why electrical connections are difficult to make to the ceramic material.

Abstract B could be improved by including a key quantitative finding, such as the thickness of the layer of barium carbonate.

Introduction

The abstract of the report acts as a summary for the reader. The next stage is to describe the background to the experiment and the goals of the experiment or set of experiments being reported. A reader will 'switch off' if too much detail is given and be confused if there is too little. If the work has followed on from that done by someone else, then that work should be referred to in a manner that will allow the reader to track down details of that work (see the later discussion of the References section).

The introduction should include a description of the background to the work, and outline the specific problem being investigated. The length of the introduction depends on the type of report, but it is unlikely that it would exceed 20% of the whole report. A short report (say 800–1000 words) might have an introduction of about half a page. A good introduction leaves the reader with the sense that the author has a firm grasp of the science or engineering underlying the experiment being reported.

An example is given below of an introduction to a short report. Note how it sets the scene, gives some background to the work and includes references which can be consulted by a reader who wishes to know more.

An electrochromic film changes colour when a voltage is applied across the film. When deposited on glass used for windows, such films can be used to control the amount of light entering a room. Consequently, the films have potential for energy efficiency gains when *used in industrial or domestic environments. Established methods for depositing the films include evaporation (Durey et al., 2000) and sputtering (Playfair et al., 2002). A third and possibly more cost-effective method of depositing electrochromic films is to use the sol-gel technique (Rowley et al., 2005). The method requires inexpensive equipment and can be scaled up to provide large area coatings of commercial viability. The technique does have some disadvantages, however. Retention of carbon within films may have a detrimental effect on their optical properties (Harbottle, 2006). This report deals with the deposition of sol-gel films and compares the quality of the films with those prepared using more established techniques. The report focuses on the conditions necessary to produce good films and discusses what improvements are required before the preparation of electrochromic films by the sol-gel deposition technique can be made fully viable.*

At the core of many experiments is a hypothesis that is being tested. For example, in an experiment in which the tensile strength of materials is compared, the hypothesis may be expressed as 'the tensile strength of material A is greater than that of material B'. A suitable location for the hypothesis is near the end of the introduction.

Background Theory

If the physical principles underpinning the experiment are well understood and can be summarised by one or two equations, then these may be included in the introduction, with one or more references to sources of further information. The equations may then be referred to, and applied, in the Results section of the report. If the theory is likely to be unfamiliar to the reader, or a short derivation is required, then a separate Theory section can be included within the report.

Materials and Methods

This is a description of how the experiment was performed and how the materials, samples and/or components were used. All important details need to be included in this section of the report. Carefully drawn and labelled diagrams are useful to a reader wishing to visualise the experimental set-up employed.

If a standard experimental technique or protocol has been used, it should be described in a few words. Alternatively, a reference should be given to where full details of the technique can be found.

If you have devised the experimental method yourself or modified an existing method, then include sufficient details so that the experiment can be repeated by someone else. However, this does not mean that the Method section of the report should be presented as a series of instructions such as those found in a laboratory manual. For example, you should avoid writing in a report:

(1) *Connect a 1000 Ω resistor into the circuit as shown in Figure 1.*
(2) *Measure the voltage across the resistor with a digital voltmeter.*

Instead, write:

> *A 1000 Ω resistor was connected to the circuit as shown in* **Figure 1**. *The voltage across the resistor was measured with a digital voltmeter.*

Results

It is usually not necessary or desirable to include all the data obtained in the experiment in this section of the report. Doing so may overwhelm the reader with table after table of data. Sufficient representative data should be included so that any discussion that follows or conclusions drawn can be seen to be well supported by the data. Graphs are an excellent way to present large quantities of data, and are likely to be examined before, and more carefully than, data in tabular form.

A graph containing several sets of data aids the reader when data comparison is required. This is preferred to the option of having separate but similar graphs spread over several pages, requiring the reader to switch back and forth between pages to carry out the comparison.

Tables are very useful when summarising values that emerge from the analysis of data. For example, if least-squares fitting has been performed on several sets of x–y data, a table is a compact way to present the parameter estimates, for example of the slope and intercept of the best line and their uncertainties.

Where calculations are presented, attention must be paid to the impact that errors in the ‘raw’ data have on the calculated values. The subsequent discussion and conclusion will have more credibility if sources of error have been identified and quantified through the inclusion of a statement of the uncertainty in values obtained.

Discussion

The Discussion section deals with the interpretation of the results that have been presented. An experiment is likely to contain many details, both major and minor. Unless the discussion focuses on the important points, a reader is likely to become lost in a mass of unnecessary detail. Where limitations have been identified in the experimental method, these should be discussed. If data from the experiment do not lend strong support to a particular idea or hypothesis at the core of the experiment, then this should be acknowledged. At a minimum, the experiment should provide for a better insight into the problem being studied, and indicate other means of approaching the problem.

Even if the experimental method used could have been improved, we must take care not to be too dismissive of data that were obtained in an experiment. Perhaps better equipment *could* have been used, or more time *could* have been spent collecting data. The question is, what can be usefully said with the data that were gathered, despite any shortcomings?

Conclusion

Here we refer back to the purpose of the experiment. What was the aim of the experiment and was it achieved? If others have undertaken a similar investigation, then it is usual to include a comparison of findings.

It is possible that the value of a quantity has been determined through your experiment which is sufficiently well known that it appears in a data book or textbook. In such a case, a comparison of values should be included along with a reference to the source of the published value. For example, as part of a conclusion to an experiment in which the surface tension of a liquid was investigated, we might write:

An analysis of the data obtained in this work gives a value of $(5.8 \pm 0.2) \times 10^{-2}$ *N/m for the surface tension of glycerol at* $20\,^{\circ}$*C. This value compares with that published elsewhere of* 6.3×10^{-2} *N/m (Johnston, 2017).*

Acknowledgements

Experiments in science and engineering are generally collaborative activities. There are situations in which we rely on someone for instruction in the operation of an instrument, for preparation of a sample or for some other form of technical assistance. Perhaps you have discussed the data with someone to clarify your ideas and that person has assisted in improving your understanding, and hence the report. Those who have contributed to the work deserve to be acknowledged. If no mention is made of their help, it would not be surprising to find them less than enthusiastic the next time they are called on for assistance.

Keep acknowledgements brief; for example:

The author gratefully acknowledges Ms J. Sutherland for assisting with sample preparation.

References

References are an important part of a report. They point the reader to relevant information including the background to the work, details of experimental techniques adopted by others who have carried out similar studies, and results obtained by other experimenters. If the experiment is in an area where there have been many previous publications, it will not be possible or desirable to include references to all those publications in the report. Selectivity is the key. If a reference is included to provide general background to the experiment, then a recent book or review article which offers an overview of the subject area is a good option. Such a book or article is likely to have other references which the reader can seek out.

A widespread method of citing references is to include the surname of the author or authors and the year of publication at an appropriate point in the text. For example:

The tunnelling of electrons in semiconductors was first reported in the late 1950s (Esaki, 1958).

The references appearing the References section of the report are given in a standard form.[3] For example:

Esaki, L. (1958) 'New Phenomenon in Narrow Germanium p—n Junctions', Physical Review, 109, pp. 603–604.

It includes

- the name(s) of the author(s)
- the year of publication
- the title of the article
- the journal title
- the volume number, (in this example, the volume number is 109)
- the page numbers.

Another method of referencing is to add a superscript number close to the point at which the reference is relevant. For example:

The tunnelling of electrons in semiconductors was first reported in the late 1950s.[1]

A consecutive list of numbers appears in the References section of the report. Adjacent to each number is the appropriate reference. For example:

[1] *Esaki L 1958 New Phenomenon in Narrow Germanium p—n Junctions Phys. Rev. 109: 603–604.*

An advantage of the first approach, in which the name of the author appears in the citation, over numbering the references is that if another reference needs to be added to the report, it can be inserted without requiring that the remaining references be renumbered.

As well as papers that appear in journals, it is likely that you will want to include references to other sources of information.[4] Useful information may be found, for example:

- in books, including electronic books (e-books)
- on the Internet
- in publications by national or international organisations
- in the proceedings of science or engineering conferences.

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[3] This is a popular referencing style, known as the Harvard referencing style. There are other, similar, styles in use.

[4] See Pears and Shields (2016) for assistance with referencing, or go to websites such as http://www.citethisforme.com/

Including trustworthy references enhances the authority of a report. For example, including a reference to an article which has been through a refereeing process in which other scientists have reviewed the article (a requirement of most scientific journals) is regarded much more highly than those found, for example, on a general website where the correctness of the content cannot be assured.

Appendices

In a report, some material may need to be included which would affect its readability, such as a lengthy derivation of an equation. If no adequate reference to the derivation can be found, the derivation can be included in an appendix. The listing of a computer program written to assist in the analysis of data or an electronic circuit diagram are other examples of items often placed in an appendix.

7.2.4 Preparation Aids

Figure 7.1 illustrates an approach to writing a report, consisting of four stages.

(i) **The plan of the report**. A good plan is one which eases the writing process. Section 7.2.5 describes one approach to planning a report, which involves creating a map of the report.

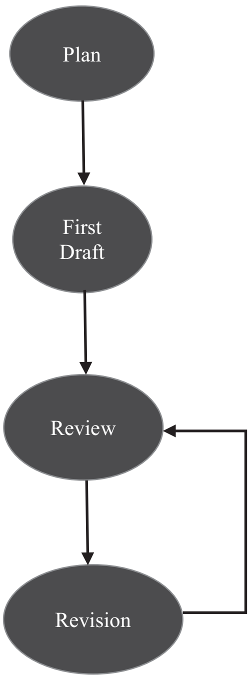

Figure 7.1 Stages of report writing.

(ii) **The first draft**. This is often written quickly with the goal of setting down essential information in each section, and with less consideration given to matters such as correct punctuation or consistent use of tense. Typically, the first draft contains incomplete sections which are returned to later.

(iii) **Reviewing what has been written.** It is valuable to ask someone who might be able to offer you some feedback or suggestions for improvement to review the first draft. If you do the review yourself, then allowing a day or two between writing the draft and reviewing it, if possible, will assist you to examine the draft with a 'fresh eye' and detect mistakes or omissions that you would have otherwise overlooked.

(iv) **Revising the draft.** The draft is revised following the review. It is common for the new draft to be reviewed before the content is settled and the report made available to others.

When you have completed the report, it can be helpful to read it aloud. This will assist in uncovering small mistakes, such as missing words or poor grammar, that may have been there since the first draft but were not discovered during the review and revision process.

7.2.5 The Plan: A Map to Aid Report Preparation

A one-page diagram or map containing the essential features of a report can be a useful aid when planning a report. The map[5] can:

- assist in organising the contents of the report
- trigger ideas about what else to include
- emphasise relationships between the contents of each section of the report
- alert the author to details that have been overlooked or need more attention
- include key facts and figures to be included in the report.

As report writing proceeds, the map is revisited and modified if necessary. Figure 7.2 shows part of a map created to assist in writing a report on an experiment carried out on a helical spring. The map consists of shapes (often hand-drawn circles or rectangles) containing text, symbols and equations. The shapes are linked with lines indicating a relationship between each shape. The part of the map shown in Figure 7.2 is a summary of the Materials and Methods section of the report.

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[5] This is sometimes referred to as a 'mind map' or a 'cognitive map'.

Figure 7.2 Section of a map created to assist in writing a report on the properties of a helical spring.

Computer-generated maps can be created in several ways, including using the SmartArt tool in Microsoft Word.[6] However, a hand-drawn map can generally be constructed more quickly, especially if equations are to be included on the map. A map can be conveniently located in the laboratory notebook used to document the experiment (and might cover two pages, if the map is large). Figure 7.3 shows a map used in the preparation of a report on an experiment which investigated the electrical resistivity of graphite.

It is convenient to place the theme of the report – expressed, say, by a provisional title – near the centre of the map. Lines are drawn radiating from the central circle to others containing many of the headings appearing in Section 7.2.1. Within most circles is some key content to be included and expanded upon in the report. Some

[6] https://mindmapsunleashed.com/learn-to-create-a-mind-map-in-word-heres-how

Figure 7.3 Map of a report on an experiment to measure the resistivity of graphite.

circles, such as the one representing the discussion, are likely to contain several ideas that might be included in the report. In such a case, further sub-branching lines are incorporated, leading to other circles containing those ideas. More branches and circles are added as the map grows.

As a map is an intermediate step in preparing a report, there is little need to be concerned about its neatness or elegance. If the map is meaningful to its creator, it will be of value as report writing proceeds. Reports have quite a rigid structure and are prepared for distribution to, and examination by, others. By contrast, a map is primarily an aid to the author and unlikely to be inspected by anyone else.

Having the whole report represented as a map on a single sheet of paper can bring emphasis to essential features of the report, such as what should be in each section and how sections link together. I reflect that, as I have become more experienced as an experimenter, I use maps regularly when preparing reports (as well as when preparing posters and oral presentations). However, not everyone finds maps useful when preparing a report. Some authors prefer to begin their report by simply typing the section headings appearing in Section 7.2.1 and then populating those sections with words, figures, charts and tables.

Exercise A

An experiment is carried out in which two methods for measuring the spring constant of a helical spring are compared. The report based on the experiment, given next, is laid out in the manner described in this chapter. Sections of the report can be improved. Read the report, then focus on each section and address the following questions:

(i) What is good about the section?
(ii) How could the section be improved?

Two Methods Compared for Determining the Spring Constant of a Helical Spring

D DUREY

Abstract

Springs are widely used in domestic and industrial situations. The spring constant is an important characteristic of a spring. In this study the spring constant of a helical spring was established by two methods, one static and the other

dynamic. The degree of mutual consistency for the spring constant determined using both methods was good, with a value of (13.07 ± 0.04) N/m obtained using the static method and a value of (13.42 ± 0.08) N/m for the dynamic method. Owing to the ease of the method, and the smaller measurement uncertainty it yields, the static method is preferred for determining the spring constant.

Introduction

Springs have many applications, including isolating buildings from the effect of earthquakes, in automobile suspensions to improve the comfort of the ride for passengers and in spring balances used to measure forces (Bankes et al., 1998; Parvin and Ma, 2001; Yamada, 2007). An important characteristic of a spring is its spring constant. The aim of this study was to compare two methods for determining the spring constant of a small helical spring.

The spring constant, k, can be found by applying a force, F_{app}, to a spring and measuring the extension, x, that the force produces. The relationship between F_{app} and x is (Walker et al., 2014)

$$F_{\text{app}} = kx. \tag{1}$$

Rearranging equation (1) gives

$$x = \frac{F_{\text{app}}}{k}. \tag{2}$$

The spring constant may be found by measuring x as F_{app} is varied.

An alternative approach to determining the spring constant is to analyse the oscillation of a mass attached to the end of the spring. When the mass on the end of a spring undergoes simple harmonic motion, the period T of the motion is given by (Serway and Vuille, 2015)

$$T = 2\pi\sqrt{\frac{m}{k}}, \tag{3}$$

where m is the mass attached to the spring.

Squaring both sides of equation (3) gives

$$T^2 = 4\pi^2\frac{m}{k}. \tag{4}$$

By varying m and measuring T, equation (4) can be used to determine the spring constant.

Materials and Methods

Method A considers the extension produced by an applied force and Method B the period of oscillation as a function of mass added to the spring. Method A and Method B were applied to the same spring.

Method A

A small spring of length 20 cm was suspended vertically from a rigid point. A mass holder was attached to the free end of the spring and a ruler positioned adjacent to the spring, as shown in Figure 1, to allow the extension of the spring to be measured. A pointer was used to indicate the position of the end of the spring. Standard 50 g slotted masses were added, one at a time, to the holder and the new position of the pointer recorded after each mass was added. This allowed the extension of the spring to be established for a range of force applied to the spring.

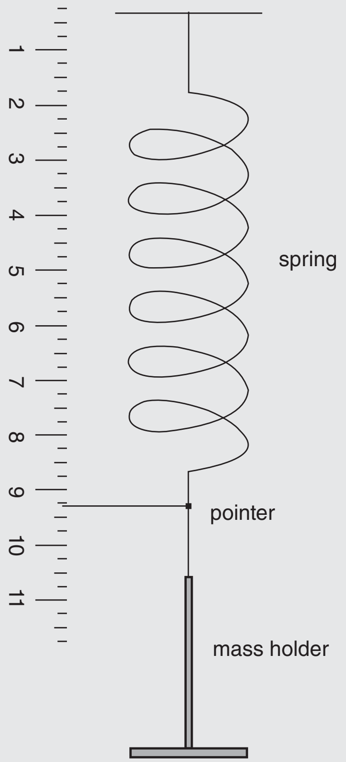

Figure 1 Experimental arrangement.

Method B

A standard 50 g mass was added to the mass holder in Figure 1 and allowed to move down to a new equilibrium position. The mass holder was pulled down one centimetre and then released. The time was recorded for 20 complete oscillations of the mass holder. To check for repeatability of measured values, and to improve precision of the measurement, the timing of 20 oscillations was repeated twice.

Further 50 g masses were attached to the holder, one at a time, and the procedure repeated.

Results

The spring constant obtained using Method A is written k_A and that obtained using Method B is written k_B.

Method A

The relationship $F = mg$, with $g = 9.81$ m/s, was used to calculate the force exerted by the loaded mass holder on the spring. Table 1 shows the extension–force data for applied forces between approximately 0.5 N and 3.5 N.

The uncertainty in reading the metre ruler was taken as 1 mm. The uncertainty in the standard masses was taken to be negligible.

Figure 2 shows a graph of extension versus applied force for the spring. Error bars which would represent the uncertainty in each measurement of extension are too small to plot on this graph.

A straight line was fitted to the data shown in Figure 2 using the LINEST function in Excel.[7] Applying the tool gives the slope of the line through data

Table 1 Extension–force data for helical spring

Mass added, m (kg)	Applied force, F_{app} (N)	Extension, x (m) ($\pm$0.001) m
0.050	0.491	0.033
0.100	0.981	0.071
0.150	1.472	0.108
0.200	1.962	0.147
0.250	2.453	0.184
0.300	2.943	0.221
0.350	3.434	0.258

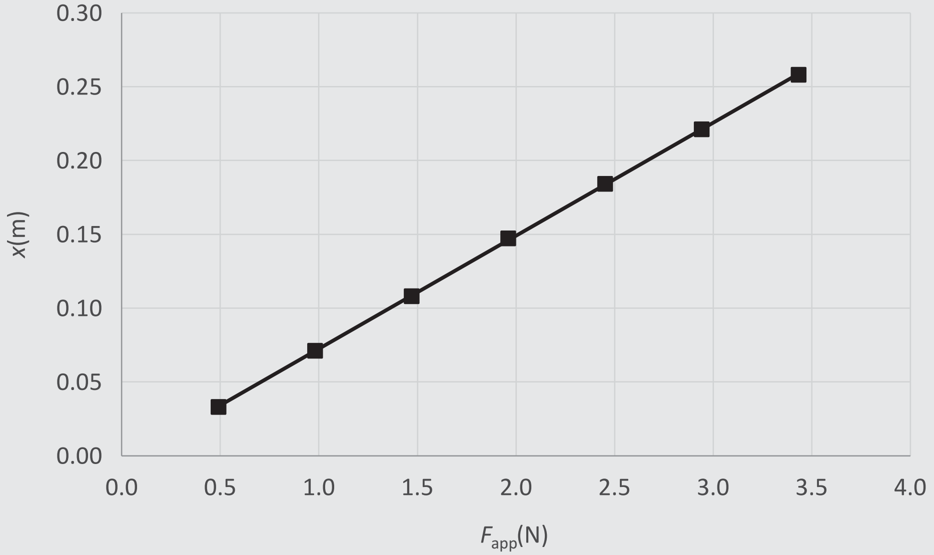

Figure 2 Plot of extension–force data shown in Table 1.

and the standard error in the slope. With reference to equation (1) the slope, b, of the line in Figure 2 is

$$b = \frac{\Delta x}{\Delta F_{\text{app}}} = \frac{1}{k_{\text{A}}} = 0.07653 \ \text{m/N}.$$

The standard error in the slope is $s_b = 2.46 \times 10^{-4}$ m/N.

It follows that

$$k_{\text{A}} = \frac{1}{b} = 13.068 \ \text{N/m}.$$

The standard error in k_{A} is

$$s_{k_{\text{A}}} = \left|\frac{\partial k_{\text{A}}}{\partial b}\right| s_b = \frac{1}{b^2} s_b = \frac{1}{13.068^2} \times 2.46 \times 10^{-4} \ \text{N/m} = 0.0421 \ \text{N/m}.$$

So, $k_{\text{A}} = (13.07 \pm 0.04)$ N/m.

[7] Note: Excel's LINEST function is discussed in Section 8.3.2.

Method B

Table 2 shows the mean time for 20 oscillations of the spring for masses in the range 0.05 kg to 0.35 kg added to the mass holder. Timing was carried out by hand using a stopwatch with a resolution of 0.01 s.

Error bars representing the uncertainty in T^2 are too small to plot on this figure. A straight line was fitted to the data shown in Figure 3 using the LINEST function in Excel. With reference to equation (4) the slope, b, of the line in Figure 3 is

$$b = \frac{\Delta T^2}{\Delta m} = \frac{4\pi^2}{k_B} = 2.9424 \ \ s^2/kg.$$

The standard error in the slope is $s_b = 1.848 \times 10^{-2}\,s^2/kg$.

It follows that

$$k_B = \frac{4\pi^2}{2.9424} = 13.417\ kg/s^2 \equiv 13.417 \ \ N/m.$$

The standard error in k_B is

$$s_{k_B} = \left|\frac{\partial k_B}{\partial b}\right| s_b = \frac{4\pi^2}{b^2} s_b = \frac{4\pi^2}{2.943^2} \times 1.750 \times 10^{-2} N/m = 0.080\ N/m.$$

So, $k_B = (13.42 \pm 0.08)$ N/m.

Table 2 Variation of time for 20 oscillations of the spring as a function of mass. Also shown are the calculated values for the period, (period)^2 and the uncertainty in each of these.

Mass added, m (kg)	Mean time for 20 oscillations (s)	Uncertainty in mean time (s)	Period, T (s)	Uncertainty in T (s)	Period^2, T^2 (s^2)	Uncertainty in T^2 (s^2)
0.05	11.38	0.16	0.569	0.0080	0.324	0.009
0.10	13.79	0.19	0.690	0.0095	0.476	0.013
0.15	15.81	0.16	0.791	0.0080	0.626	0.013
0.20	17.51	0.25	0.876	0.0125	0.767	0.022
0.25	19.23	0.10	0.962	0.0050	0.925	0.010
0.30	20.60	0.12	1.030	0.0060	1.061	0.012
0.35	21.97	0.06	1.099	0.0030	1.208	0.007

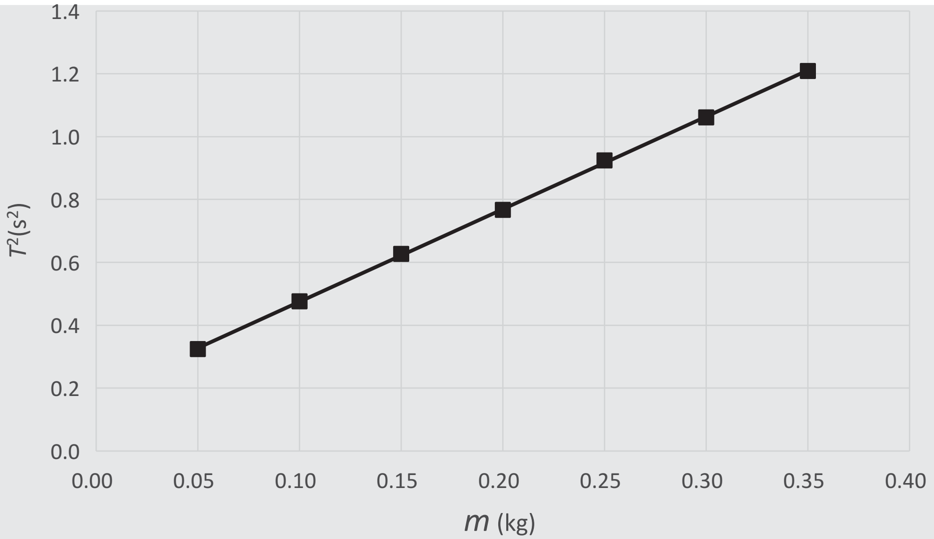

Figure 3 Plot of T^2 versus m data given in Table 2.

Discussion

Equations 2 and 4 predict linear relationships between the dependent and independent variables. The prediction is supported by the graphs in Figure 2 and Figure 3.

Being a static measurement, the extension versus applied force experiment was easier to perform than the dynamic experiment in which the time for 20 oscillations was measured. This is possibly the main reason for the smaller value for the uncertainty in the spring constant arising from the static experiment. More specifically, the standard error in the spring constant using Method B is twice that of Method A. For small mass added to the spring, the period of the oscillation was small, requiring careful concentration to count 20 oscillations. Further, hand timing 20 oscillations required synchronising the starting and stopping of the stopwatch with the release of the mass and the completion of 20 oscillations, respectively. It was difficult to judge when the last of the 20 oscillations had been completed.

The values for the spring constant using the two methods differ from each other by 2.7%. This difference cannot be attributed solely to the random errors arising using methods A and B; the standard errors in k estimated using each method are quite small, such that the 95% confidence intervals do not overlap. This implies that the true values for the spring constant obtained using each method are not the same. This suggests that there are systematic errors that arise when employing Method A and/or B that have not been accounted for, or that equations 1 and/or 3 do not completely account for the behaviour of the spring.

A possible systematic error could be due to starting and stopping the stopwatch. As an example, stopping the stopwatch consistently belatedly could have led to the time for 20 oscillations being too large. This in turn would have led to a smaller value for the spring constant. Investigation of possible sources of systemic error is recommended, including replacing hand timing with an electronic-based system.

Conclusion

Methods adopted in this experiment produced values for the spring constant of a helical spring that mutually agreed to better than 3%. Method A, which used the extension of a spring as the force on the spring is increased, gave a value for the spring constant of (13.07 ± 0.04) N/m. Method B, which involved measuring the period of oscillation of the spring as a function of mass attached to the spring, gave a value for the spring constant of (13.42 ± 0.08) N/m. Method A is preferred as it is easier to perform, leading to smaller uncertainty in the value for the spring constant.

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7.3 Posters

Posters are widely used for communicating the aims, methods and findings of experiments in colleges and universities, as well as in professional settings such as meetings, conferences and other gatherings of scientists and engineers. A poster offers scope for creativity and imagination while at the same time being a clear, concise and accurate description of an experiment, its findings and conclusions.

Posters share common features with reports but are more succinct descriptions of experiments and their findings. Well-crafted posters are clear and concise, display technical proficiency and demonstrate understanding of the science or technology being presented. Posters offer the opportunity for creativity on the part of the author(s). This could come in the form of an eye-catching layout or the imaginative use of images.