Introductory Physics Experiments for Undergraduates

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内 容 简 介

本书是为电子科技大学中外合作办学机构格拉斯哥学院编写的基础物理实验英文教材. 主要内容包括实验前的一些相关基础知识与要求，测量与不确定度的评定、数据处理方法，涵盖电学、力学、光学、磁学、声学的15个基本物理实验. 附录提供了英文物理实验报告的撰写要点，基本物理常数，以及配套本书的考卷样本和参考答案.

本书可作为中外合作办学项目理工科专业的基础物理实验教材或参考书，也可作为全国各高校理工科专业物理实验双语课程的教材或参考书.

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Preface

Physical laboratory experiments are an essential complement to the study of physics and engineering. Most theoretical principles are confirmed or otherwise disputed by experimental work. On the other hand, experimental results are important basis for understanding the theoretical model of a physical system. It is therefore very important to take accurate measurements and to properly carry out experiments to avoid misleading results. This book is thus focused on the fundamentals of good laboratory practices necessary for personal safety and minimizing experimental error to the bearers minimum.

The book has three chapters with a total of fifteen experiments. Chapter one is the introduction which presents in detail the safety measures to be taken in the laboratory, equipment maintenance and care and how to concisely present and discuss the obtained results in the form of a standard laboratory report. In Chapter two, how to accurately read various measurements during an experiment and the processes of uncertainty estimations are well covered. The final chapter has fifteen experiments with specific instructions to guide students through their practical execution in the laboratory.

It is very important to read through and understand Chapters one and two before attempting any experiments in Chapter three.

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1. INTRODUCTION

You are advised to read the entire introduction very carefully. References to it will be made in many sections of this book.

1.1 Safety

The most important thing in the laboratory is your safety and that of others. Experiments are designed to be done safely, and as such proper caution must always be exercised. A major potential danger arises from the lack of knowledge of the equipment used and the required procedure. Upon entering the physics laboratory at the first instance, you will probably find the equipment for the experiment on the laboratory bench. Restrain your curiosity and do not play with the equipment. You may hurt yourself and/or damage the equipment. A good general rule is:

Do not touch or turn on laboratory equipment until its use and/or setup has been properly explained and understood and authorized by the instructor to do so.

Certain items used in various experiments can be particularly dangerous, for example, hot objects, electricity, mercury lamps, and radioactive sources. In some instances, such as with hot objects and electricity, basic common sense and knowledge are required.

However, in other instances, such as with mercury lamps and radioactive sources, you may not be aware of the possible dangers. Mercury lamps may emit ultraviolet radiation that can be harmful to your eyes. Consequently, some sources need to be properly shielded. Some radioactive sources are solids and are encapsulated to prevent direct contact. Others are in liquid form and are transferred during an experiment, so care must be taken to avoid spillage or to reduce the danger of spillage to the barest minimum. Proper handling is therefore important.

In general, necessary precautions will be given in the experiment descriptions. *Note them well.* As pointed out earlier, experiments are designed to be carried out safely. Yet a common kitchen match can be dangerous if used improperly. You should take extra care to follow the procedure carefully and adhere to the precautions prescribed. Another good rule for the laboratory is:

If you have any questions about the safety of a procedure, ask your instructor for clarification before proceeding with the experiment.

The physics laboratory is a place to learn and practice safety.

1.2 Laboratory Objectives

The laboratory is a workshop for students and the place where they get firsthand knowledge of physical principles and experimental methods through the handling of apparatus designed to demonstrate the meaning and application of specific theories. Some of the more specific objectives are:

a. To acquire training in scientific methods of observation and recording of data.

b. To acquire techniques in the handling and adjustment of equipment.

c. To gain an understanding of the limitations and strengths of experimentation.

d. To obtain experience in the use of graphical representation.

e. To collect data and to develop confidence in one's ability to compute reliable answers or to determine valid relation.

By developing the skill of computing the required results from experimental data for comparison with known values of the desired quantities, the student acquires the necessary confidence needed to perform an experiment and to determine some quantity or relationship which was previously unknown.

1.3 Development of Character and Sense of Responsibility

Prospective employers and placement offices frequently request information from physics instructors on the character, attitude, honesty, and dependability of students. The instructor makes an evaluation of these traits from observations of the student's performance in class and in the laboratory. It is therefore important to take laboratory experiment seriously. The laboratory is a place for serious thought and investigation, and the following suggestions should help you to develop the above-mentioned traits:

a. Be prompt in arriving at your work station and be well prepared concerning the principles of the experiment. If, for some good reason, you are late or absent, report the matter to the instructor.

b. Work quietly and attempt to make the most careful observations possible by adjusting the equipment to perform at its best.

c. Be honest in making and recording observations. Record data as indicated by your equipment and not as you thought they were supposed to be, if they differ. Do not copy data, conclusions, or computations from any other source. If your results seem to be outside the limits predicted by the experimental uncertainties, recheck your measurements and computations. If this does not give the answer, provide the best possible explanation for the discrepancy.

d. Have the entire procedure well in mind and perform the various steps in the order that will make the best use of your time. Cooperate with your partner, if allowed, so that each of you gets experience in manipulating the equipment. However, you should compute your results independently and compare to check on the accuracy of your work.

e. Always remain at your assigned station and do not disturb other people in the laboratory concerning any part of the experiment. Do not fidget with other equipment in the laboratory that is not part of your assigned experiment.

f. Always abide by any precautions that your instructor may have given you regarding the proper handling of the equipment. Delicate equipment may be easily damaged.

››› 1.4 Preparation for the Actual Laboratory Work

The efficiency of performance in the laboratory depends largely on the preparation made before the experimental work begins. The entire experiment should be read in detail before any measurements are made. It is also advisable for the student to review sections in the class textbooks that deal with the principles under investigation.

Laboratory experiments are usually intended to give students the opportunity to discover for themselves what may not be obvious at the start of the experiment, so they should not be concerned if they do not know the expected results at the beginning. At the start of the laboratory period the instructor will discuss any required special instructions needed for the apparatus being used, including precautions and perhaps some special techniques which should be used to get the best results. The instructor may also choose to discuss the underlying theory at the start of the laboratory period and/or discuss the results at the end of the laboratory period. The details of how to perform the experiment can be found in the—Experimental Procedure—section of each experiment.

1.5 Equipment Care

The equipment provided for the laboratory experiments are often expensive and in some cases quite delicate. If used improperly, certain pieces of apparatus can be damaged. The general rules given above concerning personal safety also apply to equipment care.

Even after familiarizing oneself with the equipment, it is often advisable or required to have an experimental setup checked and approved by the instructor before putting it into operation. This is particularly true for electrical experiments. Applying power to improperly wired circuits can cause serious damage to meters and other apparatus.

If a piece of equipment is broken or does not function properly, it should be reported to the laboratory instructor. Disassemble the experimental setup after you complete an experiment and leave the bench neatly as found, unless you are otherwise instructed.

If you accidentally break some equipment or the equipment stops working properly during an experiment, *report it to your instructor.* Otherwise, the next time the equipment is used, a great deal of time may be wasted trying to get good results.

1.6 Materials to Be Provided by the Student

Tools and other materials which are not considered as general laboratory apparatus will be needed at various times. These items include graph paper, straight edge, protractor, data entry sheet and a hand calculator. You should always have your related textbook available for reference.

1.7 Performance of the Experiment

Before beginning the experimental work always read the entire procedure to get a general idea of what is to be done. You should always arrange and adjust the apparatus to give the best performance possible and then make and record readings as precisely as the apparatus will permit. Always estimate one significant figure beyond the smallest graduation on the instrument being read.

Data should never be recorded on scrap paper and then transferred to your record form. If, after you have recorded a reading, you decide that it is in error and should be discarded, mark through it and record the corrected reading below it. Always record the proper unit beside the measured value or at the heading of a column when a whole column of readings use the same unit.

Do not hesitate to discuss any details of the experiment with the laboratory instructor during the laboratory session. You may want to question certain procedures or suggest improvements in the method. A good question may be more important than a good answer.

1.8 Experimental Report

The form of the report required will be designated by the instructor in the course. In any case, the original data should be presented in a neat form, such as that suggested for each experiment in this book. The data should be followed by sample calculations showing the method of obtaining the results. If the experiment requires several computations of the same type, only one of each type need be shown in the report.

Each experiment has a stated "purpose". Use this as a guide to your investigations. Your report should include a separate section in which you clearly and concisely state your results and conclusions. This section should respond to the question: "To what extent was the experiment's purpose accomplished?" This discussion should stick to the facts, and all conclusions should be supported by reference to your data and observations. Avoid idle, unsupported speculation.

Many of the questions at the end of each experiment are intended to stimulate thought and to guide the student in drawing conclusions concerning the results. These questions are to be answered in a discussion style and the answers so worded that the reader can ascertain the question from the answer. The sheet containing the questions may be removed from a lab manual if the instructor prefers that both questions and answers be a part of the report and has instructed so.

1.9 Proficiency in the Laboratory

The factors that will be used to measure your proficiency in the laboratory fall into two general categories as defined below.

General laboratory performance including:

a. Conduct in the laboratory.

b. Care and technique in operating the equipment.

c. Ability to grasp the fundamental principles demonstrated.

Presentation of experimental results including:

a. Neatness and orderly arrangement of recorded data and computations.

b. Interpretation of experimental data and conclusions drawn from it.

c. Answers to the assigned questions.

d. Answers to quiz questions if given.

⋙ 1.10 Use of the Origin Software

In laboratory experiments you will often need to plot graphs of your results. There are many software applications for data processing, such as Excel, Matlab, etc. However, in this book, the *Origin* software is recommended. This software also provides a multitude of data analysis tools. Here you will need to use a relatively small number of its features but it is advised that you familiarize yourself with its features as many will be required in your lab work during the year.

2. EXPERIMENTAL UNCERTAINTY AND DATA ANALYSIS

2.1 Measurement

Laboratory work in physics involves the use of apparatus to make measurement which can be used for one of two purposes; either to make a definite determination, such as the elementary electric charge, the wavelengths of lights, the refractive index of air, etc. or to investigate the validity of a law. In both cases, the observations must be faithfully recorded and should be as reliable as possible.

In the classical definition, *measurement* is the determination or estimation of ratios of quantities. It is the assignment of a number to a characteristic of an object or an event, which can be compared with other objects or events. A measurement tells us about a property of something. It might tell us how heavy an object is, or how hot, or how long it is. It gives a number to that property. Measurements are always made using an instrument of some kind. Rulers, stopwatches, weighing scales, and thermometers are all measuring instruments. The result of a measurement is normally in two parts: a number and a unit of measurement, e. g. "How long is it? ··· 2 metres. "Quantities frequently measured include time, length, area, volume, pressure, mass, force, and energy.

There are some processes that might seem to be measurements, but are not. For example, comparing two pieces of string to see which is longer is not really a measurement. Counting is not normally viewed as a measurement. Often, a test is not a measurement: tests normally lead to a "yes/no" answer or a "pass/fail" result.

Measurements are classified into ***direct*** and ***indirect***. Direct measurement means measuring exactly the quantity of interest with a given instrument without need for further manipulations. In physics, there are some quantities that are very easy to measure directly. These include mass, distance, temperature, time and electric current. So to measure how long a piece of wood is one would just measure its length using a tape measure. To determine the temperature of a cup of water, all one needs is just a thermometer. Indirect measurement refers to determining the value of the quantity in question by measuring some other quantities for manipulation. For example, the most obvious way to find the velocity v of an object is to measure the distance traveled, d, and the time taken, t, and then to calculate v as $v = d/t$. It is worth noting that you can measure one quantity by using direct or indirect measurement. For example, you can measure the magnetic field by measuring the voltages and currents based on the Hall effect. It is indirect measurement. However, if you have a teslameter you can read the magnetic field directly.

When doing a direct measurement, we must read an instrument. There are three parts that must be reported. The first is the reading itself, called the nominal value of the measurement. The second is the unit of the measurement. The third part is to estimate the uncertainty of the reading.

Important points to remember:

a. A measurement without units is meaningless.

b. A measurement without an estimated range of uncertainty is also meaningless.

Let us consider an example that illustrates more clearly the crucial importance of knowing how big the uncertainties are.

Suppose we are faced with a problem like the one said to have been solved by Archimedes. We are asked to find out whether a crown is made of pure gold, as claimed, or a cheaper alloy. Following Archimedes, we decide to test the crown's density ρ knowing that the densities of 18-karat gold and the suspected alloy are

$$\rho_{\text{gold}} = 19.3 \text{ g/cm}^3$$

and

$$\rho_{alloy} = 17.8 \text{ g/cm}^3$$

If we can measure the density of the crown, we should be able to decide whether the crown is really gold by comparing ρ with the known densities ρ_{gold} and ρ_{alloy}.

Suppose we summon two experts in the measurement of density. The first expert, Muller, might make a quick measurement of ρ and report that his best estimate for ρ is 19.0 g/cm^3 and that it almost certainly lies between 17.5 and 20.5 g/cm^3. Our second expert, Halberstam, might take a little longer and then report a best estimate of 17.9 g/cm^3 and a probable range from 17.7 to 18.1 g/cm^3. The findings of our two experts are summarized in Fig. 2-1.

The first point to notice about these results is that although Halberstam's measurement is much more precise, Muller's measurement is probably also correct. Each expert states a range within which he is confident ρ lies, and these ranges overlap; so it is perfectly possible (and even probable) that both statements are correct.

Note next that the uncertainty in Muller's measurement is so large that his results are of no use. The densities of pure gold and of the alloy both lie within his range, from 17.5 to 19.5 g/cm^3. So no conclusion can be drawn from Muller's measurements. On the other hand, Halberstam's measurements indicate clearly that the crown is not genuine; the density of the suspected alloy, 17.9 g/cm^3, lies comfortably inside Halberstam's estimated range of 17.7 to 18.1 g/cm^3, but that of pure gold, 19.3 g/cm^3, is far outside it. Evidently, if the measurements are to allow a conclusion, the experimental uncertainties must not be too large. The uncertainties do not need to be extremely small, however. In this respect, our example is typical of many scientific measurements, for which uncertainties have to be reasonably small (perhaps a few percent of the measured value) but for which extreme precision is often unnecessary.

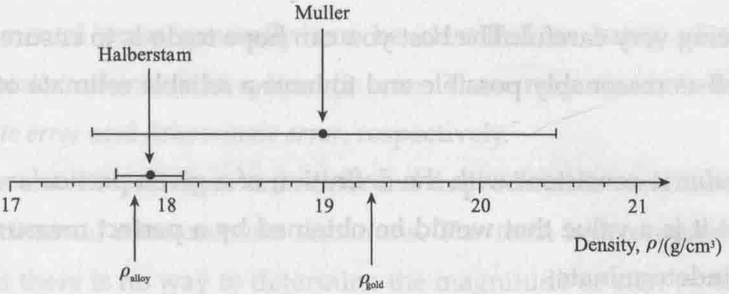

Fig.2-1 Two measurements of the density of a supposedly gold crown. The two dots show Muller's and Halberstam's best estimates for the density. The two horizontal error bars show their margins of error, the ranges within which they believe the density probably lies. Muller's uncertainty is so large that both gold and the suspected alloy fall within his margins of error. Therefore, his measurement does not determine which metal was used. Halberstam's uncertainty is appreciably smaller, and his measurement shows clearly that the crown is not made of gold

The most important point about the two experts' measurements is that, like most scientific measurements, they would both have been useless if they had not included reliable statements of their uncertainties. In fact, if we knew only the two best estimates (19.0 g/cm^3 for Muller and 17.9 g/cm^3 for Halberstam), not only would we have been unable to draw a valid conclusion, but we could actually have been misled, because Muller's result (19.0 g/cm^3) seems to suggest the crown is genuine.

2.2 Types of Errors

Error is defined as the result of a measurement minus the true value of the measurand. It is sometimes called *absolute error*. Measurand is a particular quantity subject to measurement.

$$\textit{error} = \textit{result of measurement} - \textit{true value} \tag{2.1}$$

It should be noted that *absolute error* can be positive or negative and should not be confused with *absolute value of error*, which is the modulus of the error.

In science, the word error does not carry the usual connotations of the terms mistake or blunder. Errors are not mistakes and you cannot eliminate