大学物理实验

Laboratory Experiments In College Physics

主编◎王丽香　吕　春
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内 容 提 要

本书是根据国家教育部《高等工业学校物理实验课程教学基本要求》，充分借鉴国外英文原版物理实验教材的编写风格，并结合国内高校物理实验教学的实际情况及在北京工业大学所进行的普通物理实验双语教学实践，经过多次修改编写而成的教材。

本书的绪论部分介绍了实验误差和不确定度的概念，以及实验数据处理方法；常规实验部分包括38个力学、热学、电磁学、光学和综合性实验；另外还有23个设计性实验项目和12个PASCO实验项目；附录部分包括常用物理学常数和SI单位制简介等。

本教材适用于高校理工科物理专业学生的物理实验双语课程。

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主　　编：王丽香　吕　春
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PREFACE

This textbook is intended for use with a bilingual teaching course of laboratory physics in universities for the students majoring in physics. It contains thirty-eight fundamental physics experiments, twenty-three projects and twelve PASCO experiments. The textbook provides more than sufficient experiments for a full three semester program, allowing the instructor to choose experiments consistent with their preference and available equipment.

The experiments are designed for a three hour laboratory period. Each experiment contains a complete list of required apparatus, a statement of the objectives of the experiment, a brief description of the theory, and directions for the experimental procedures. A description of the operation and use of the apparatus is included in most of the experiments. The questions that follow each experiment are designed to aid the students in making more careful observations and interpret the results. Forms on which the data and results may be recorded are included with most of the experiments. The instructor may choose to have the students make their own data forms and not use the ones provided. Vocabulary is attached to help the Chinese students to clearly understand the corresponding Chinese meanings of the scientific terminology.

As the primary instructional resource for the students, the textbook naturally plays a great role, and a central goal of this textbook and the bilingual teaching course is to help students develop practical skills as well as improve their professional English ability. Although this textbook is as much as possible in keeping with the content of the original Chinese textbook《大学物理实验》, we try our best to imitate the style of the original English edition to make the content easy to understand by using simple and fluent English. In some parts of the textbook, we even copy from the original English materials to avoid our Chinglish. We believe that it will not be too difficult for Chinese students to use as a textbook.

Of course, our work is never done. We hope to continue to receive comments and suggestions from our readers so that we can improve the textbook and correct any errors. If you find any errors or have any suggestions for improvements in the textbook, please send us a note at wanglixiang@ bjut. edu. cn, or contact the author directly who is responsible for the specific experiment (See Table 1).

Table 1 Detailed information of the authors

Author	Email	Contents
Wang Lixiang	wanglixiang@ bjut. edu. cn	Introduction, 1.1, 1.2, 1.7, 1.8, 1.10, 1.11, 1.12, 2.0, 2.3, 2.4, 2.6, 2.7, 2.12, 2.13, 2.14, 2.15, 2.16, 3.1, 3.2, 3.3, 3.4, 3.5, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.4, 4.7, 4.8, 4.10~4.19, 4.21, 4.22, 4.23, Appendix
Lv Chun	spring@ bjut. edu. cn	1.5, 1.6, 1.9, 2.1, 2.2, 2.5, 2.6, 4.3, 4.5, 4.6, 4.9
Cui Min	mcui@ bjut. edu. cn	2.8, 2.9, 2.11
Yuan Anjuan	yuananjuan@ bjut. edu. cn	1.3, 2.17, 3.6, 4.20, 5.1, 5.3, 5.4, 5.5, 5.9, 5.10
Duan Ping	duanping@ bjut. edu. cn	1.3, 1.4, 1.7
Liu Liying	liuliying@ bjut. edu. cn	2.10, 5.2, 5.6, 5.7, 5.8, 5.11, 5.12

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前　言

本书的编写是为了用于高校应用物理专业学生的物理实验双语教学课程。它包括38个基础物理实验、23个设计性实验和12个PASCO实验。这些实验项目要多于三个学期的实验课程内容，以便教师能够根据教学需求和实验设备的情况适当进行取舍。

每个实验的计划学时为3学时。每个实验都列出了实验仪器、实验目的、实验原理和实验步骤。大部分的实验对实验的操作方法和仪器使用进行了阐述。每个实验后面的思考题可以帮助学生更好地观察实验现象和分析实验结果。大部分的实验都提供了用来记录实验数据和结果的表格。教师可以要求学生自己设计表格，而不是使用书中的表格。词汇表可以帮助中国学生准确地了解专业术语所对应的中文含义。

作为学生最首要的教学资源，教材无疑具有重要的地位和作用。在物理实验课程中进行双语教学的主要目的就是要帮助学生在提高实践能力的同时提高专业英语水平。尽管本书在实验内容上尽量与原来的中文教材《大学物理实验》保持一致，我们还是尽可能多地模仿英文原版材料的风格，使用简单流利的英文以便于学生理解教材内容。在书中某些部分，我们甚至照搬原始英文材料，以尽量避免出现中国式英语。我们相信，对于中国学生来说，这本书作为教材使用将不太难理解。

当然，我们做得还远远不够好。我们希望能不断收到读者的批评意见和建议，以便改进本书并改正其中的错误。如果您发现本书中有错误，或者有哪些改进意见，请发送邮件至 wanglixiang@ bjut. edu. cn，或者与负责特定实验项目的编者联系（见表1）。

表1　编者信息

编者	电子邮箱	内容
王丽香	wanglixiang@ bjut. edu. cn	绪论，1.1，1.2，1.7，1.8，1.10，1.11，1.12，2.0，2.3，2.4，2.6，2.7，2.12，2.13，2.14，2.15，2.16，3.1，3.2，3.3，3.4，3.5，3.7，3.8，3.9，4.0，4.1，4.2，4.4，4.7，4.8，4.10～4.19，4.21，4.22，4.23，附录
吕春	spring@ bjut. edu. cn	1.5，1.6，1.9，2.1，2.2，2.5，2.6，4.3，4.5，4.6，4.9
崔敏	mcui@ bjut. edu. cn	2.8，2.9，2.11
原安娟	yuananjuan@ bjut. edu. cn	1.3，2.17，3.6，4.20，5.1，5.3，5.4，5.5，5.9，5.10
段苹	duanping@ bjut. edu. cn	1.3，1.4，1.7
刘立英	liuliying@ bjut. edu. cn	2.10，5.2，5.6，5.7，5.8，5.11，5.12

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CONTENTS

INTRODUCTION

The student should read the entire introduction very carefully since references to it will be made in many sections of this book.

0.1 General Laboratory Instructions

0.1.1 Purpose of the Physics Laboratory

Physics is an experimental science. The theoretical concepts and relationships introduced in the lecture part of the course describe the general nature and behavior of real phenomena. They were discovered by careful observation and thoughtful analysis of actual experiments. *Genuine*（真正的）understanding *entails*（需要）being able to relate the abstract ideas to the particular facts to which they correspond.

The *premise*（前提）of the scientific method is that nature is the ultimate judge of the truth of any physical theory. Indeed, experiments designed to prove certain ideas have often ended up showing them to be wrong. Consequently, all physical concepts must be verified experimentally if they are to be accepted as representing laws of nature.

Accordingly, the introductory physics laboratories have the following purposes and goals:

(1) To provide an experimental foundation for the theoretical concepts introduced in the lectures. It is important that students have an opportunity to verify some of the ideas for themselves.

(2) To familiarize students with experimental *apparatus*（仪器）, the scientific method, and methods of data analysis so that they will have some idea of the inductive process by which the ideas were originated. To teach how to make careful experimental observations, how to think about and draw conclusions from such data.

(3) To introduce the methods used for estimating and dealing with experimental *uncertainties*（不确定度）, including simple ideas in *probability theory*（概率论）and the distinctions between random（statistical）and systematic "errors". This is essential in understanding what valid conclusions can be deduced from experimental data and

that, properly obtained, these conclusions are valid, *notwithstanding*（尽管） the uncertainty of the data.

(4) To learn how to write a technical report which communicates scientific information in a clear and *concise*（简洁） manner.

(5) To introduce new concepts and techniques which have a wide application in experimental science, but have not been introduced in the standard courses. These may require that the student consult additional textbooks.

The laboratory is not a contest whose object is to get the "right answer". The purpose is to learn how to gain knowledge by looking at reality, not an attempt to make reality conform to *preconceptions*（预想）. The important thing is to learn how to be *observant*（善于观察的）, to really see what happens, and to deal with this information with the strictest *integrity*（诚实）. And to understand, or learn to understand, the meaning of what happens. Even if you get results totally *at variance with*（和……不符） theory（as may happen due to a mistake, or a systematic uncertainty） you will get a high grade if you report it honestly and demonstrate that you understand what you did and how your results occurred. (If you have trouble interpreting your results, contact your *instructor*（教师）for help.) On the other hand, if you get perfect agreement with theory by *falsifying*（伪造） your data you will fail.

0.1.2 Instructions

The *instructions*（指导书） for each experiment include some basic theory on the phenomenon to be investigated and a description of the *procedure*（步骤） to be used. You should study these carefully before coming to the laboratory to avoid waste of valuable laboratory time figuring out what should be done. You will be told well in advance which experiments are to be *performed*（完成） and the date for which each is *scheduled*（预定） so that there will be time for preparation.

The instructions for each experiment include a list of the required *equipment*（设备）, and the necessary equipment will be laid out at each assigned place in the laboratory. You should check this list against the items on the *workbench*（工作台） to make sure everything necessary is there and in good condition. Anything missing or broken should be reported to the instructor or *assistant*（助教） at once. At the end of the period, check the apparatus again and leave it neatly arranged. Do not disturb other equipment that may be in the room but is not a part of your present experiment. Always *abide by*（遵守） any *precautions*（警告） that your instructor may have given you regarding the proper *handling*（操作） of the equipment. *Delicate*（精密的） equipment may be easily damaged.

Before beginning the experimental work always read the entire procedure to get a general idea of what is to be done. Work quietly and attempt to make the most careful observations

possible by *adjusting*(调节) the equipment so that it will give its best possible *performance*(性能). 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*(基本原理) at the start of the laboratory period and discuss the results at the end of the laboratory period.

Record all the observations and data directly in the blank tables provided for this purpose in each experiment. **Do not use pencil or *correction fluid*(修正液), and the record must not be erased.** If a mistake is made, draw a line through the *measurement*(测量值) and place the corrected value above. Do not use "*scratch*"(草稿) data sheets from which data are to be *transcribed*(誊写) onto the blank ones. Very neat data sheets can be made out this way, but mistakes can also *creep in*(悄悄混进). The instructor is interested in an *original data record*(原始数据记录) and is willing to *put up with*(忍受) a certain amount of *sloppy*(潦草的) *penmanship*(书写) in order to see the direct recording of the actual data taken in the laboratory. Be honest in making and recording observations. Record data as indicated by your equipment and not as you thought they were supposed to be. **Copy no data, conclusions, or computations from any source.** If your results seem to be outside the limits predicted by the experimental uncertainties, *recheck*(再核对) your measurements and computations. If this does not give the answer, make the best possible explanation for the *discrepancy*(差异). **The original data record must be presented to the instructor to be checked and *initialed*(签名) before you leave the lab.** This permits obvious errors to be found. The copy of the original data record is to be included with your lab report.

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

The data should be followed by sample calculations showing the method of obtaining the results. Each set of calculations should be headed by the *pertinent*(有关的) equation so that anyone reading the report can see what *mathematical operations*(数学运算) are being performed and why. State all *formulas*(公式). Identify all symbols. *Substitute*(替代) one set of data into each different formula. When stating results, express answers with proper units and the range of uncertainty if the experiment requires *precision analysis*(精度分析). Watch your number of *significant figures*(有效数字). Number the steps followed so that your approach may be easily understood by the instructor. An *electronic calculator*(电子计算器) of your own may and indeed should be used, but be careful. *Erroneous*(错误的) entries produce erroneous results, and all numbers should be looked at to be sure no careless mistake has crept in. A quick *order-of-magnitude*(数量级) check by hand is sometimes useful.

When reporting graphical results, show carefully *slope*(斜率) calculations and the values obtained from the axes of the graphs. List the numerical results as found in the computation

outline. If the results are *qualitative*(定性的), describe briefly.

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 discussion style. Use proper English so that communication between you and a reader will not be *impeded*(阻止).

0.1.3 Lab Logbooks

One of the vital skills of a scientist is the ability to keep a good record of his or her work. The skill is hard to develop, but eventually it becomes a good habit. Your bound logbook is a permanent record of all the work you do during and after the lab. It is much more than a simple collection of numbers—it should also show the setup for each experiment, describe briefly the procedure, list all your measurements, show the steps in your analysis, and answer the assigned questions, etc. Additional material such as computer generated graphs, photos, and copies of shared data may be pasted into the logbook as necessary. At the conclusion of any experiment, it should be possible to extract a written lab report easily from the notebook.

The instructions below should be followed for *lab logbook*(实验工作记录本) write up:

(1) Use a bound notebook with numbered pages. Don't use loose sheets of paper. Extra material, such as computer printout, photographs, etc., may be pasted or taped into the book.

(2) Skip the first page or two to use for a Table of *Contents*(目录).

(3) Each new lab should start on a fresh right-hand page. The name of the experiment, the date, and your lab partner's name(if any) should be clearly visible at the top of the first page of each experiment's entry.

(4) Enter the following information at the beginning of each experiment: a) the purpose of the experiment; b) the apparatus used; c) the theory of the experiment. Generally a few words in the logbook describing what you intend to do should precede the actual data set at each stage of the experiment.

(5) *Literally*(逐字地) writing down what you are doing in as *succinct*(简洁的) a manner as possible. Full sentences and good grammar are not necessary. It also is not necessary to reproduce in detail the procedure described in the experiment write-up, but just summarize each step as you go through it. It is insufficient, however, to have a page splattered with numbers, calculations, and tables. Those numbers and calculations must be embedded in a "verbal" context so that it's clear what each entry is. Note the relevant experimental conditions and record any unusual events that might affect the experimental data, like someone accidentally turning on a light when your experiment was supposed to be done in a darkened room.

(6) The data should be *tabulated*(列表) as it is taken, whenever possible. Then, if a good result is to be obtained, the quality of the data should be determined before leaving the laboratory. The data should be checked for consistency, by repeating a portion of the measurement. Any important graphs, calculations, or estimates of uncertainties should be done before finishing the experiment to ensure that the data is "good" and sufficient.

(7) The log book should be written in ink, since penciled writing can be erased or lost. If you want to delete something, cross it out such that it can still be read rather than erasing it. You may find out later that you want to know this information after all. You should never tear out pages from your logbook!

(8) Each student must keep an individual logbook though you will sometimes work in pairs.

(9) The logbook for each experiment has to be *signed off*(签字结束) at the end of each session. This signature will serve to confirm that the work has been completely satisfactorily. Marks will be *deducted*(扣除) if it is found that you have altered your original data record outside of laboratory hours. The logbook must be presented for grading one week after you complete the experiment. Because of the grading schedule, you will need to buy **two** logbooks dedicated to this course alone. You will be working in one while the instructor is grading the other.

(10) Do **not** use red pen in your lab logbook, because the instructor will use red pen to grade.

The crucial test of a good logbook is that it provides you (not the instructor!) with a complete record of everything that you have done so that long afterwards you can recall all relevant facts. The technique of keeping a good lab logbook is a very useful skill to develop. Professional scientists and engineers routinely maintain detailed logbooks of their experiments. In industry, these records are used as *legal documents*(合法证明) to substantiate claims of original discoveries and subsequent *patent rights*(专利权). In the research lab, many a *Nobel Prize*(诺贝尔奖) has been won based on unexpected findings that were first recorded in a logbook as an *oddball*(古怪的) observation and later found to be important. The results in this class probably won't get you a trip to *Stockholm*(斯德哥尔摩), but we are going to get you into the habit of keeping a good experimental logbook so you will be ready when that "*eureka*"(希腊语"找到了") moment arrives.

0.1.4 The Report

The following elements should be included in a formal lab report:

1. **Title and authors.**
2. **The purpose of the experiment.** Give an extremely short (only a few sentences)