Laboratory Physics

SECOND EDITION

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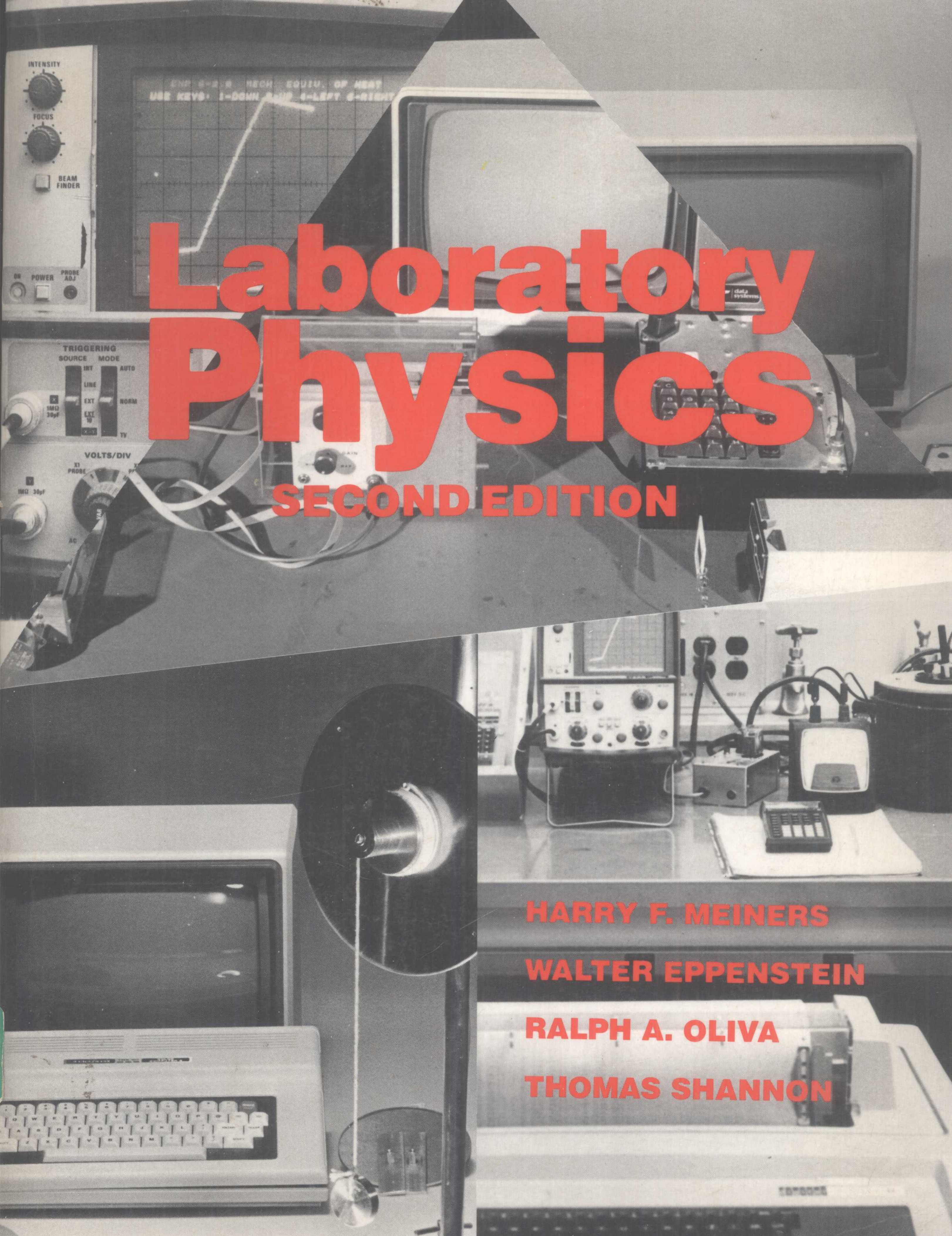

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PREFACE

Laboratory Physics is intended to be a laboratory guide for a calculus based introductory physics course taught primarily to science and engineering students. We believe that the laboratory is an important part of such a course and that very often the experiment bridges the gap between the idealized situations presented in the usual physics text and the real world of the laboratory.

The first six chapters give an introduction to laboratory procedures and instrumentation. How these chapters are used is entirely up to the faculty or staff teaching the course; some of the material may be assigned as reading whereas other topics may be completely left out.

The first chapter presents some of the objectives of the laboratory and makes suggestions for laboratory operations. The second chapter on errors should be studied in detail and at some time during the first physics course the material should be assigned in a formal manner. The ideas of Chapter 3 on graphing will be applied throughout the experiments and should be referred to at the appropriate time. Chapter 4 includes a very brief description of some important pieces of equipment, and students should read these sections before handling the apparatus involved.

Chapters 5 and 6 give a general introduction to the use of calculators and computers in the laboratory as well as some of the principles of digital integrated circuits. This information, usually not found in an introductory laboratory manual, has been included for the benefit of interested instructors and students. A study of these two chapters is not a prerequisite for the experiments in this text.

The rest of the text presents more than 70 experiments, arranged by topic and not by level of difficulty. This gives the instructor a wide choice depending on interest, equipment available, level of difficulty, and the like. Some of the experiments contain detailed instructions while others are - on purpose - rather vague, leaving the details up to the student. The experiments differ greatly in difficulty as well as in length. Some use very simple equipment whereas others use rather sophisticated apparatus. Most of the experiments have several different parts, and the students are not necessarily expected to finish all parts; very often they may have a choice.

This laboratory text should not be regarded as an instruction book that is to be followed word by word; it is meant to be a general guide to various experiments in introductory physics. It is hoped that the instructor and the student will deviate from the directions given and will add their own parts to the experiments. Student creativeness and initiative are stressed by suggesting various projects without going into details. Some experiments suggest further work. In some cases the equipment can be used for "free" experiments not described in this text; examples are the low-friction devices discussed in Chapter 8, the oscilloscope with accessories, the microwave apparatus, and the laser.

Report writing has traditionally been a very time-consuming activity in connection with physics laboratories. We do not want to minimize the importance of well presented experimental results, but this can be accomplished without too much busy work. How the laboratory should be organized and what type of reports, if any, the student should present is left up to the instructor in charge of the course. Generally, students should be encouraged to record all data, including qualitative observations, in a laboratory notebook.

Although this book is based on the text Analytical Laboratory Physics, which was published by Meiners, Eppenstein, Moore, and Nickol in 1956, a great many experiments have been added. Most of the old experiments have been changed so that they are less formal, include more optional parts, and make use of newly available instrumentation. In 1956, for instance, inexpensive air tracks and air tables did not exist, the laser had not yet been invented, and microcomputers were unheard of. All of these relatively recent innovations are now standard equipment in most introductory physics laboratories.

We are grateful to Gerald Luecke of the Texas Instruments Teaching Center for writing Chapter 6 on integrated circuits and to M. Dean Lamont of Texas Instruments for his critical review of Chapter 2. We are indebted to Volker Paedelt of Rensselaer Polytechnic Institute for producing most of the art work.

We express our appreciation to the thousands of freshmen and sophomore students at Rensselaer Polytechnic Institute who have tried out all of the experiments and have helped us greatly by their constructive criticism. We acknowledge the many comments we have received from the graduate assistants teaching in our introductory laboratories as well as from faculty members. We express our thanks to the manufacturers of scientific equipment who have supplied us with photographs and literature relating to their products.

June, 1986
Troy, New York

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Chapter 1

THE LABORATORY

1.1 Introduction

Recent technological advances in all fields of science and engineering have emphasized the microscopic world, the world of the atom and its parts. This emphasis requires every embryo engineer and scientist to develop an individual initiative to see, to question and, if possible, to find out why. This cannot be done quickly but requires a gradual, directed introduction to the fundamental methods of analysis.

The objectives of the physics laboratory are not, as is often imagined, simple or easy to define. They cannot be generalized in a single sentence. The object of the physics laboratory of today should not be the verification of a known law and the blind substitution of data into a formula with the consequent "cranking out" of an answer. The physics laboratory should help to bridge the gap between the idealized laws and postulates discussed in the textbook and the real world. The laboratory is not a separate course in physics. It is an integral part of the study of physics and must be considered as such.

Before the student can see, question and find out why, he or she must master the fundamental tools (or techniques) necessary for the ultimate satisfaction of his or her curiosity. The degree of mastery depends on the attitude of the student toward the laboratory work.

The objectives of this laboratory are:

1. To introduce the student to the significance of the experimental approach through actual experimentation.
2. To apply the theory of the textbook and the recitation class to real-life problems to develop a better understanding of the fundamentals of classical and modern physics.
3. To introduce the student to the methods of data analysis used throughout science and engineering.

4. To develop an "error conscience" so that the engineer and scientist will at least be aware of the relative worth of all measurements, whatever their type. The method of "precision analysis" presented here should not be thought of as the only way of determining a measurement's relative worth. Precision analysis appears in various guises in all branches of business, government and science. The student should become familiar with its many facets and realize that while learning a fundamental technique, he or she is also becoming more proficient in applying calculus.
5. To familiarize the student, by direct contact, with a great many basic instruments and their applications.
6. To make the student realize that such tools as graphing, difference analysis, the use of calculus, etc., are of fundamental importance.
7. To impress on the student that even an experiment which is apparently unimportant to his or her professional future may contribute directly to the student's mental development because of the analytics and mathematics involved.
8. To improve the student's ability of self expression through report presentation.
9. To give the student direct contact with the instructor, and thus the advantages of close direction and personal discussion of ideas and methods.

1.2 Laboratory Operation

1. ASSIGNMENTS

At the first laboratory meeting, working teams of two members will be made up, each team being assigned a number. All assignments will be made in terms of these numbers.

Each laboratory assignment requires the performance of an experiment in the laboratory and the presentation of the data, computations, etc., must be completely worked out in the laboratory notebook. Most of the writeup should be completed in the laboratory on the day the experiment is performed. If not finished, the report in final form must be turned in for inspection and grading AT THE NEXT SCHEDULED LABORATORY MEETING FOLLOWING THE PERFORMANCE OF THE EXPERIMENT.

Although many experiments will be preceded by the necessary theory in the recitation class, this will not always be the case. This should be no disadvantage, however, since laboratory work is usually the forerunner of theory. The student will be expected, in these instances, to study the theory concerned in his theory text, and check thoroughly the content of the experiment.

Each student is expected to prepare in advance for each experiment. He or she should be able, before beginning the experiment, to answer questions based on the general content of the experiment.

2. DATA CHECK

At the completion of the experiment, the laboratory notebooks are to be presented to the instructor to be checked, stamped, and initialed. This permits obvious errors to be found.

3. STUDENT'S RESPONSIBILITIES TOWARD EQUIPMENT

Apparatus is to be treated with respect. Most of the equipment is sensitive and expensive. Damage over and above normal depreciation will be charged to the team involved.

Students must leave their tables and apparatus in good order: i.e., weights put away, instruments returned to cases, water emptied, scrap paper picked up, etc.

1.3 The Report

In most experimental work, records of the work done, data taken, and observations made in the laboratory are kept in a data book. When important research projects are underway, such a book is usually assigned to each team, and the people associated with the project record in it all the data in complete and careful detail. All matters having any conceivable bearing on the problem are carefully recorded and every effort is made to preserve a complete picture of what is going on. All work is carefully dated and signed. Very often, when new effects are noted, the books are signed by witnesses (for possible patent purposes). Progress or final reports are abstracted from such databooks for publication or for presentation to the head of the laboratory or other officials. The completeness or detail of abstracted reports is determined, of course, by the use to which they will be put. In our physics laboratories, all data is to be taken and all work done in laboratory notebooks.

The laboratory report has generally the following eight parts:

1. Purpose of the experiment and preliminary discussion
2. Sketch
3. List of Apparatus
4. Procedure
5. Data
6. Computation Outline
7. Graphs and Results
8. Discussion (or conclusion)

1. PURPOSE

A short statement of the object or objectives should be made. The object may be not only to find an unknown, to establish the linearity of a function, or to verify a known law, but also - more subjectively - to apply a fundamental technique.

The PRELIMINARY DISCUSSION is not a statement of procedure, but an explanation of any special features of the experiment: for example, that it involves the use of precision analysis, or the development of an empirical equation, or the application or fundamental laws to a field problem.

2. SKETCH

A line sketch of the experimental equipment (wiring diagram for electrical experiments) should be made with a straight edge. This need not be an artist's sketch or be drawn to scale. Do not include standard items such as micrometers, meter sticks, stands, timeclocks, clamps, etc. Label with a letter and identify under the list of apparatus.

3. LIST OF APPARATUS

Identify all measuring apparatus. Omit stands, clamps, etc. List:

a) Name of apparatus and manufacturer; Model number and serial number (if available).
b) Range of values covered; Least Count of scale; Instrumental Limit of Error, as guaranteed by the manufacturer or by laboratory tests.

4. PROCEDURE

It is not necessary to copy the detailed instructions of most of the experiments. List the procedure only for those experiments lacking complete instructions.

5. DATA

All measurements must be recorded directly into the laboratory notebook. Data must not be taken on scrap paper and recopied into the report. It must not be erased. If a mistake is made, draw a line through the measurement and place the corrected value above. Data should be presented in a table whenever possible. Place the units of the quantities being measured at the top of the data columns. A typical data table is shown in Fig. 1-1.

6. COMPUTATION OUTLINE

State all formulas. Identify all symbols. Substitute <u>one</u> set of data into each different formula. When stating results, express answers in powers of ten, with proper units and the range of error if the experiment requires precision analysis. Watch your number of significant figures. Number the steps followed so that your approach may be easily understood by the instructor.

7. GRAPHS AND RESULTS

When reporting graphical results, show carefully slope 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, describe briefly.

Graphical Method:

Mass (gm)	Scale Readings (cm)				mean Scale Readings	Elongation [Y] (cm)
	Run 1	Run 2	Run 3	Run 4		
0	39.28	39.29	39.29	39.28	39.285	
50.0	44.89	44.88	44.88	44.89	44.885	5.600
100.0	50.49	50.48	50.49	50.50	50.490	11.205
150.0	56.10	56.08	56.09	56.10	56.093	16.808
200.0	61.69	61.70	61.68	61.69	61.690	22.405
250.0	62.27	67.26	67.28	67.28	67.273	27.988
300.0	72.85	72.86	72.88	72.89	72.870	33.585
350.0	78.41	78.42	78.43	78.44	78.425	39.140
400.0	83.98	84.00	84.02	84.01	84.003	44.718

Tabular Difference Method:

Mass (gm) $\Delta\omega = 50$ gms	Elongation Y (cm)	ΔY (cm)	$\Delta^2 Y$ (cm)
0			
50.0	5.600	5.600	
100.0	11.205	5.605	+.005
150.0	16.808	5.603	-.002
200.0	22.405	5.597	-.006
250.0	27.988	5.583	-.014
300.0	33.585	5.597	+.014
350.0	39.140	5.555	-.042
400.0	44.718	5.578	+.023

∴ mean value of ΔY = 5.589 (Sig. Fig.)

Fig. 1-1 Data table from an actual student report.

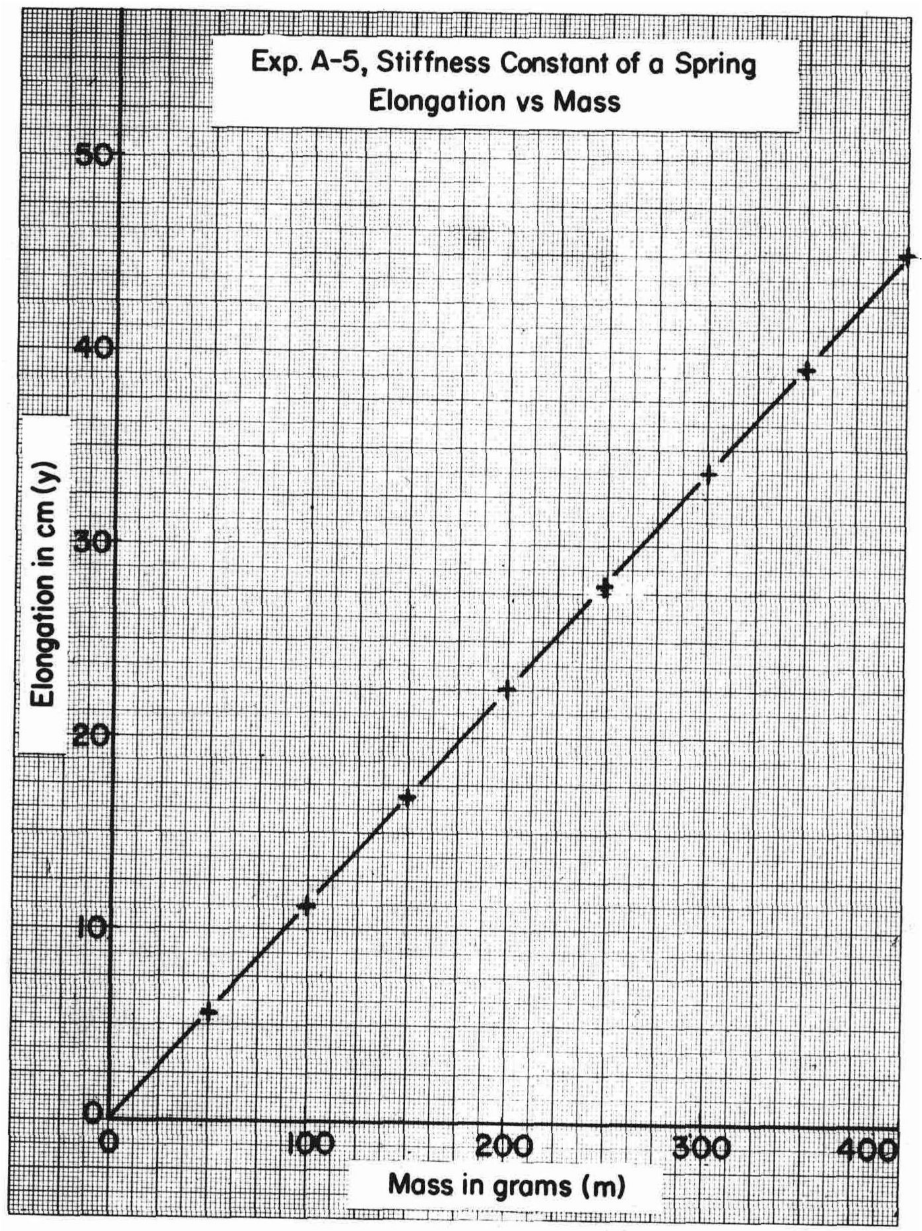

Fig. 1-2 Typical graph from an actual student report.

8. DISCUSSION (or CONCLUSION)

If several methods are used, summarize the worth of the experiment by describing the benefits of a particular analytical approach as compared to another. If only one approach is used, discuss the significance. Discuss the value of a particular result as indicated by the error analysis. Try to determine why the experiment was performed. Discuss the meaning of your graphical results.

The discussion (or conclusion) is the individual's job. No team partner should copy the other member's work. The discussion should be concise and to the point. Do not use over half a page. This, obviously, indicates that the student must think and use judgment before presenting the discussion.

The impossible is not requested of the student in the preparation of a discussion. The suggestions given are designed to help the student to observe, and, as the course progresses, he or she will find this section of the report increasingly easier. The student should, if in trouble, contact the instructor and request help.

1.4 Summary

The report is the individual's responsibility. Data may be secured by a group (or team), but under no circumstances may a student use data which belongs to some different group. Reports which are copied completely or in part from other students' work will receive an "F". An absent student may not copy the partner's data, but must arrange to perform the experiment at the convenience of the instructor.

The average time required to take the data varies greatly, but is usually less than one hour. The balance of the laboratory period must be spent toward completing the report.

A complete report has the seven or eight divisions described above. In special cases, where the taking of data requires an unusually long time, only three divisions are necessary: Data, Computation Outline, and Discussion. Unless the directions for an experiment specify that only three divisions are necessary, a complete report must be submitted.

In requiring adherence to this standard report form, the laboratory is preparing the student for future professional work: almost all industrial and research units have fairly rigid specifications for reports of different types, and engineers and scientists are expected to obey the ground rules.