Chapter 1: HOW TO KEEP A LAB NOTEBOOK

> "'But perhaps I keep no journal.'
> 'Perhaps you are not sitting in this room, and I am not sitting by you. These are points in which a doubt is equally possible. Not keep a journal!'"
> **--** *Northanger Abbey*

1.1 INTRODUCTION

Keeping a lab notebook seems like a simple and obvious task, but it requires more care and thought than most people think. It is an important skill to learn since virtually every practicing scientist keeps a lab notebook of some type. Your lab notebook is your written record of everything you did in the lab. Hence it includes not only your tables of data, but notes on your procedure and at least some of your data analysis as well. You want all this information in one place for two main reasons, which continue to apply even after you leave the introductory physics laboratory. First, your lab notebook contains the information you will need to write a convincing report on your work, whether that report is for a grade in a course or a journal article. Second, your notebook is the source to which you turn in case someone questions the validity of your results. (You may be aware of the famous David Baltimore case of alleged scientific fraud, in which the lab notebook of one of Baltimore's collaborators was the subject of careful scrutiny. While the scientist in question was eventually exonerated, she spent an uncomfortable couple of years having others second-guess her lab records.)

Your notebook therefore serves somewhat contradictory purposes. On the one hand, you need a complete and accurate record of your work in the lab, so you should write things down *as they occur* and before you have a chance to forget them. On the other hand, your notebook needs to be reasonably neat and well-organized, partly so you can find things later and partly so that if anyone questions your results, not only will they be able to find things, but the clarity of your notes will suggest that you investigated the problem carefully and systematically. However, it is hard to be completely organized when you are writing things down as you go. The purpose of this chapter is to suggest ways to balance these needs.

1.2 USE EVERY OTHER PAGE

As mentioned, a basic problem with taking notes on the fly is that it is hard to keep them organized. As the experiment progresses, you will be reminded of things you should have described in an earlier section, find that you should have taken a few more pieces of data, or discover mistakes in material you have already written. If you were simply to write your thoughts sequentially, you would never be able to find important bits of information later; no one's "stream of consciousness" is sufficiently organized.

Therefore, the cardinal rule of keeping a lab notebook is: *give yourself plenty of space*. Doing so makes extending tables or descriptions of procedure easy, and typically also makes your notebook easier to read. The best trick we have found for observing this rule is to use only one of the two facing notebook pages (probably the right page if you're right-handed, the left page if you're left-handed). If you have to go back later and add explanations, corrections, calculations, or even new tables of data, you have a whole blank page available to record these things right next to the material you are supplementing or correcting. You can also use this blank page to record calculations as you reduce data (which allows you to look at the raw and reduced data at the same time), or to graph the data on the facing page.

Give yourself plenty of space *on* the page, too; leave some blank space between explanations and around lists of equipment, sketches, and tables of data. This not only makes your notebook easier to read, it leaves you space to add short comments and/or corrections.

The point is that initially using only every other page and leaving yourself plenty of space on the page provides you with the flexibility to go back and supplement or correct earlier material, without disturbing the organization and flow of your thinking in lab. Even if your “stream of consciousness” may not be organized, your lab notes can be if you give yourself this flexibility.

1.3 DIVIDE YOUR NOTES INTO LABELED SECTIONS

Anyone reading your lab notebook (including you, later on) will find following it much easier if you organize your presentation into clearly labeled sections. For most labs, the sequence of headings listed below works well. Each of these sections will be discussed in more detail later on.

(Title)
Purpose
Equipment
Procedure
Data
Analysis

Any section heading listed above may be omitted or renamed if appropriate, and in some cases you may want to add other sections; you should consider this a “default” list that you start with, but modify if you have good reasons to do so. (If you compare this list to the outline for a lab report in Chapter 3, you will notice some remarkable similarities. This is not an accident. A well-organized lab notebook can really speed up writing a lab report later on.)

1.3.1 (Title)

This item should appear at the beginning of every lab description. You should begin each new experiment on a fresh page in your notebook, and start with a brief title for the experiment -- just enough to remind you what that section of your notebook is about. You should also record the name of your partner and the date you did the experiment. In fact, it's good practice to record the date at the top of each page and follow it with a page number for that experiment.

1.3.2 Purpose

This section can often be implied or even omitted, but you should always take a minute at the beginning of each lab to think about exactly what you are trying to measure in this lab and why. If this takes more than a little thought, write something down here. This helps you to work through your thoughts clearly and completely, and if later in the lab you need to remind yourself of what you set out to do, you can refer back to this section.

1.3.3 Equipment

In this section, you should list and perhaps describe the equipment you use in the lab. This is particularly important if your apparatus differs from that described in the lab manual or from that used by other students. Any differences should be described carefully, in case this turns out to be relevant when comparing your results with those of other groups.

In your equipment list, identify large pieces of equipment with manufacturer's name, the model, and serial number. (The definition of a “large” piece of equipment is “a piece of equipment large enough to have a serial number.”) Usually the serial number, if present, is marked on a small metal plate along with the model number on the front or the back of the unit. Smaller pieces of equipment and equipment made in-house will generally have a station number (1 through 12). With this information, you can repeat the experiment with the identical equipment if for some reason you are interrupted and have to return to the equipment much later. Furthermore, scientific equipment gets out of calibration. For example, a stopwatch could, in principle, run too fast or too slow; if you suspect that your time measurements are in error, you can check your stopwatch against another clock if you know which stopwatch you used! Identifying any pieces of equipment whose failure or misadjustment might influence your results is essential if you are to be able to track down possible sources of error.

Also make a quick sketch of the setup, and/or a schematic diagram if appropriate. It is often easier to write notes about your procedure if you can refer to a sketch. Such a sketch is also an essential part of a formal written lab report, so a good sketch in your notebook can make writing the formal report easier. A sketch can also be useful for tracking down problems with your procedure or analysis. For example, suppose that you are doing an experiment with a simple pendulum (a ball swinging from the end of a string), and you draw a sketch of the pendulum that shows how you defined its length. If you find strange results when you analyze your data, you could refer to the sketch to determine if your original definition of the pendulum's length was the correct one.

1.3.4 Procedure

This section is *very important,* because most experimental errors can be traced to incorrect or inadequate experimental procedures. This section is especially important in labs in which you develop much of your procedure yourself. Start by writing a short paragraph or two outlining how you expect to carry out your measurements. This should not be too detailed, since you will probably modify your procedure as you go along, but this opening paragraph will help you settle in your own mind what you do to get started. Be sure to leave yourself *plenty* of space, because you will find yourself modifying your initial procedure, discovering additional variables that should be recorded, and revising your approach.

Describe your procedure in complete sentences and complete paragraphs. Single words or phrases become mysterious very quickly as time passes. Start with a sentence or two about what you're measuring, such as the period of the pendulum as a function of length. Give more details where necessary, if (for example) the lab manual does not give a more detailed procedure or if you find you need to depart from the procedure in the manual.

We expect that people will get results consistent with physics as it is currently understood, since we will be dealing with well-explored physical principles. Poor results usually imply poor technique; your lab notebook is the place to start in establishing that your technique is good.

1.3.5 Data

In this section, record quantities that you measure directly, in an orderly table. Give each data table a title, unless its nature is clear from anything written immediately before it, and clearly label the rows and columns. It's also good to have an extra column, usually at the right-hand edge of the page, labeled “Remarks.” That way, if you make a measurement and decide that you didn't quite carry out your procedure correctly or you observe something unexpected, you can make a note to that effect in the “Remarks” column. For example, suppose that you realize in measuring the period of a pendulum that one of your measurements must have timed only nine swings instead of ten. If you indicate that with, say, “9 swings?” you could justify to a suspicious reader your decision to omit that point from your analysis. If you have room left on the page, you may also want to leave some room on one side or the other for data reduction later on.

You will often be performing experiments in which you have two independent variables. Usually in such experiments you fix the value of one independent variable and make a series of measurements working through several values of the other variable. Then you change the value of the first variable and run through the measurements with the other variable again; then you change the first independent variable again, make another set of measurements, and so on. It's usually easier to set up this sort of sequence in your notebook as a series of two-column tables (or three columns, if you add “Remarks”) rather than a big rectangular grid. Label each table with the value of the independent variable that you're holding fixed, and keep the format of all the tables the same.

1.3.6 Analysis

This section should consist of notes regarding the processing of your data, “low-level” graphs (see Chapter 2) of your processed data, and conclusions you draw from your data and its analysis. In very simple labs, this section might be combined with the *Data* section, but in more complicated labs it's often better to keep them distinct.

1.4 WORK IN PENCIL (if you like) BUT DON’T ERASE DATA

We have heard of science labs in which students are required to record everything in ink, to make changing data impossible. We think this restriction is needlessly coercive. In this lab, then, use pencil if you prefer, and feel free to erase any short statements or blank tables and rewrite them to make things neater. (Entire paragraphs should simply be X’d out, though.) Use a pencil with a dark lead, though, so that your notebook is easy to read.

It is unwise, though, to erase any raw measurement data, since a measured value that seems to be in error at first may turn out to be correct when the analysis is completed. If something comes out screwy in your analysis, it is helpful to have a complete and absolutely honest record of all your raw data, to simplify tracking down the problem. Therefore, if you believe that a data point is in error, don't erase it. Instead, cross it out with a single line (so that it's still readable) and write the replacement above it or next to it.

1.5 A SAMPLE LAB NOTEBOOK

As an example, we give you some pages photocopied from a notebook Dr. Zook keeps for trying out possible experiments for the introductory lab. (Dr. Zook is the main author of this section, which is the reason she's allowing her lab notebook to be held up to public scrutiny for possible humiliation.) This experiment was suggested by a standard gee-whiz demonstration, in which you put a small ball like a superball on top of a more massive ball (a basketball is good) and drop them simultaneously, so the small ball winds up colliding with the larger ball immediately after the large ball has collided with the earth. If you drop the two balls right, the small ball bounces surprisingly high. You can see that, although her penmanship leaves something to be desired (a typed transcription follows) and she keeps her lab book in ink, she does follow the guidelines we gave earlier: there's a short title, a list of apparatus and a couple of sketches. (The sketches are especially important because the apparatus is a home-built unit rather than a commercial one.) Then there's some quantitative information about the two "superballs" used in the experiment and a brief summary of the planned procedure. On the second page of data collection (p. 31, really the third page on this experiment) there are some reasonably neat tables of data; in the lower left corner of those tables, there's a comment about the large range in the bounce height and a suggested modification of the setup and procedure to reduce this range. Then there's enough room left on the page to take more data with the revised setup (illegibly labeled "2nd try"), and to record the mean and standard deviation (see Chapter 5 on experimental uncertainty) of each set of five measurements.

On the facing page (p. 30), which was originally left blank, there's a graph of the results, which she drew after taking all the data and calculating the averages. It was originally drawn in pencil, although she went back over it in ink so it would show up on the photocopy. If you look at Chapter 2 (graphing), you can see that the graph satisfies the guidelines for the "low-level" graphs you would keep in your notebook: both axes are labeled, including units, and the graph has a brief title. In this experiment, Dr. Zook expected a linear relation between the initial height and the bounce height, and she has drawn in her eyeballed "best" line and calculated its slope from the two points marked with x's. She initially left out the error bars, because this is only a low-level graph, but later put them in. If she were repeating this experiment now, she might have plotted the graph on a computer, printed it and the result of running *LinReg* (see Chapter 8 on linear regression) and stapled or taped the printout to p. 30 of her notebook.

[p. 29] 8/9/91

Colliding falling balls

Apparatus: Two superballs, one ~3/4” in diameter and the other ~2” in diameter. Each ball has a 1/4” hole through its center in which a teflon sleeve has been inserted, as shown below.

(sketch)

2 meters of nylon monofilament twine suspended from upper Unistrut in lab.

Wood box to which nylon cord is attached, w/ two 2-kg weights holding it down.

(another sketch)

The two balls have been threaded on the nylon cord.

The nylon cord is marked every 10 cm w/ a magic marker.

Procedure: Raise both balls some distance, holding the lower and larger ball. Release from rest. Measure the maximum height of the upper ball as a result of the collision between the two balls after the larger ball collides w/ the floor. Repeat several times for a given height and also for several different heights.

(Small data table)

N.B. I didn’t unstring the balls for either of these measurements.

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(Data tables)

I can’t tell if the large range in heights is the result of random error or the result of my not starting the balls at the same mark. So I’ve added a (tall) ring stand w/ two rods to mark the initial location and approx. maximum height.

The distance recorded under “initial position” is the location of the bottom of the larger ball. The center of the larger ball [must really refer to the smaller ball] is higher by the sum of the diameter of the large ball and the radius of the small ball, or

$$4.65 \text{ cm} + 1.26 \text{ cm} = 5.91 \text{ cm} \approx 6 \text{ cm}$$

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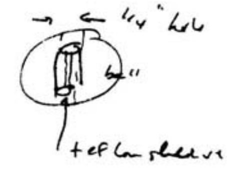
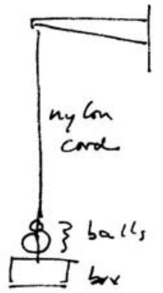
Colliding falling balls

apparatus: ~~Two~~ Two superballs, one ~3/4" in diameter + the other ~2" in diameter. Each ball has a 1/4" hole through its center in which a teflon sleeve has been inserted, as shown below.

2 meters of nylon monofilament twine suspended from upper Unistrut in lab.

Wood box to which nylon cord is attached, w/ two 2-kg weights holding it down





The two balls have been threaded on the nylon cord.

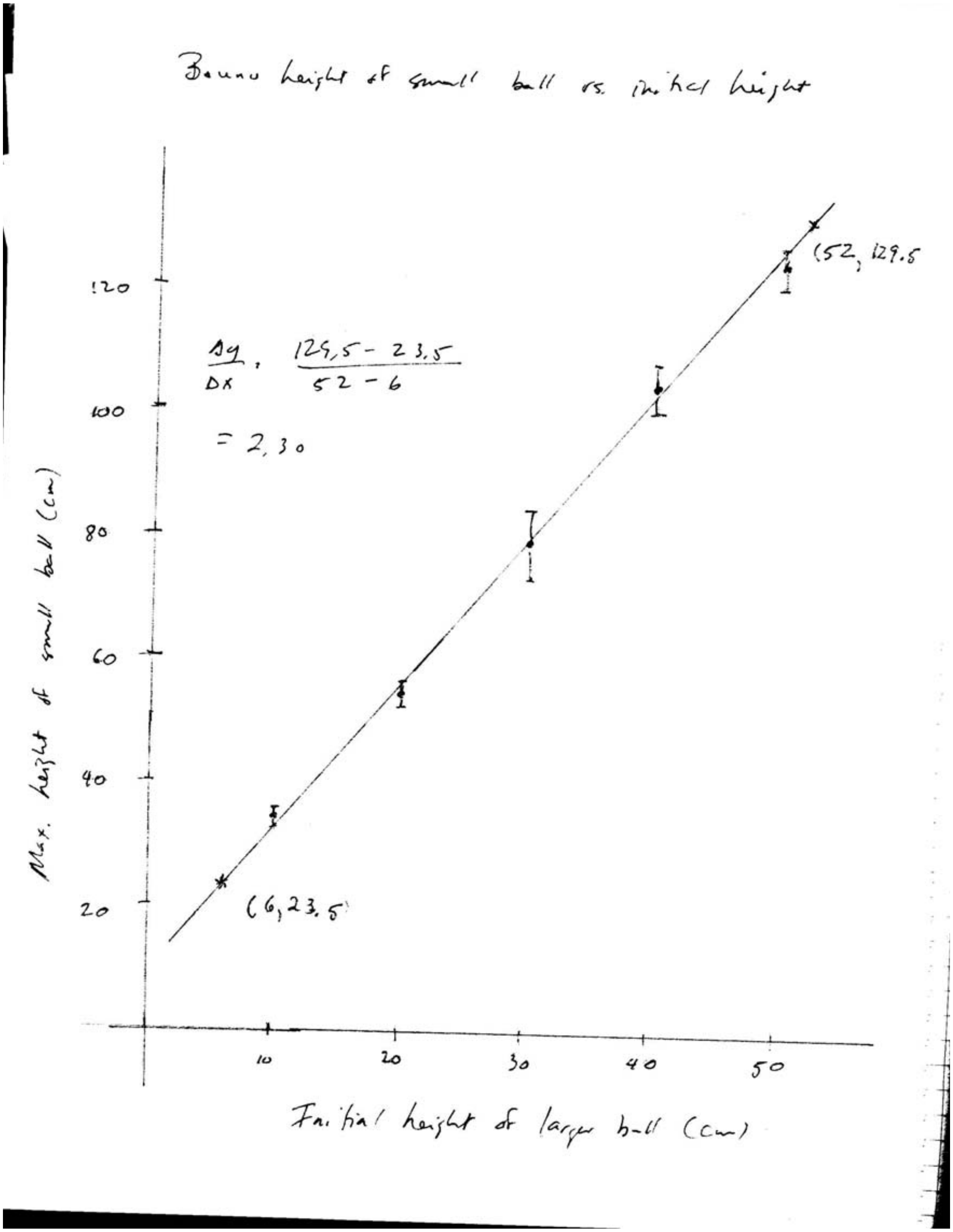
The nylon cord is marked every 10 cm w/ a magic marker.

Procedure: Raise both balls some distances, holding the lower + larger ball. Release from rest. Measure the maximum height of the upper ball as a result of the collision between the two balls after the larger ball collides w/ the floor. Repeat several times for a given height and also for several different heights

Ball masses	Balance + weight	B, w/ ball	ball alone
Large ball	12.9 g	78.0 g	65.1
Small		21.5 g	8.6

Ball diameters – measured along ~~axis~~ hole 4.65 cm
2.52 cm

N.B. I didn't center the balls for either of these measurements.


Bounce height of small ball vs. initial height
(52, 129.5
120
Δy / Δx = (129.5 − 23.5) / (52 − 6)
100
= 2.30
80
60
40
20
(6, 23.5)
Max. height of small ball (cm)
10
20
30
40
50
Initial height of larger ball (cm)

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Initial position (at bottom of lower ball)

	Height of smaller ball (approx ctr)	2nd try	Mean	σ
10 cm	30 cm	32	34.6	2.1
	35	37		
	32	33		
	33	36		
	35	35		
20 cm	52 cm	53	54.4	3.2
	60	53		
	58	54		
	51	52		
	53	60		
30 cm	68	83	79.2	6.1
	60	82		
	62	85		
	60	70		
	63	76		
40 cm	70	110	104.4	3.8
	90	105		
	71	100		
		102		
		105		
50 cm		122	124.2	3.3
		123		
		123		
		123		
		130		

I can't tell if the large range in heights is the result of random error, or the result of my not starting the balls at the same mark. So I added a stand (tall) ring stand w/ two rods to mark the initial location + approx. maximum ~~bou~~ height.

~~The~~ The distance recorded under "initial position" is the location of the bottom of the larger ball. The center of the larger ball is ~~[illegible]~~ higher by the sum of the diameter of the large ball and the radius of the small ball ≈ 4.65 cm + 1.26 cm ≈ 5.91 cm ≈ 6 cm

EXERCISES

Exercise 1.1

What are the two main reasons for only writing on one side of a set of facing pages in a lab notebook?

Exercise 1.2

Dr. Zook followed the suggested format reasonably closely but not perfectly. What are some differences between her notebook and the suggested format? In particular, what two sections are missing?