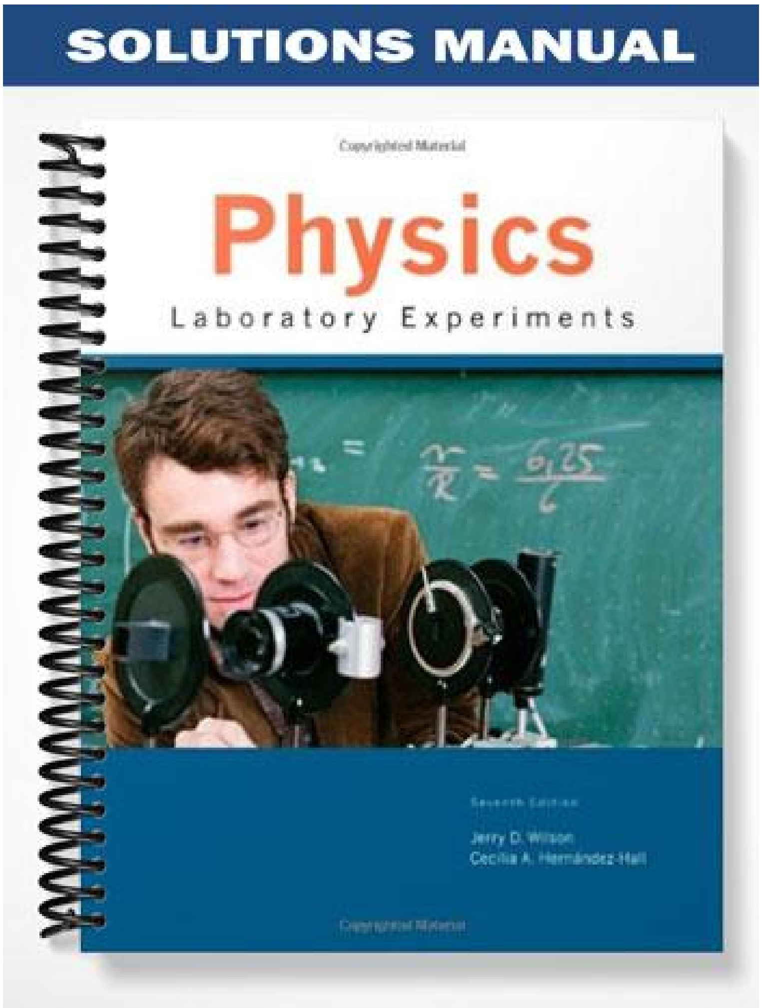
SOLUTIONS MANUAL
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Physics
Laboratory Experiments
Seventh Edition
Jerry D. Wilson
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INSTRUCTOR'S RESOURCE MANUAL

Physics Laboratory Experiments

SEVENTH EDITION

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Preface

This *Instructor's Resource Manual* is designed to support the sixth edition of *Physics Laboratory Experiments* by Jerry D. Wilson by providing various resources that most of us would have liked to have had available at one time or another.

In the laboratory, equipment varies and time is always limited. Thus the laboratory manual is written to give the instructor a choice of many different types of equipment and experiments. Experiments vary greatly in length. In some cases the length can be attributed to the fact that concepts don't come in neat 2- or 3-h packages. In other cases extra parts have been included to allow for use of alternative equipment to investigate the same concept. This makes it possible for the instructor to adjust the experiment to the available equipment or to reinforce the concept by having the students do the procedure several ways. Adjustments can also be made to the experiments to accommodate the needs of the students in the class. Some experiments are relatively short, so the instructor could assign two experiments in the same laboratory period, particularly when they use the same equipment.

With each experiment we have provided some hints and suggestions, answers to the experiment questions, and Post-Lab Quiz Questions (with answers) for those instructors who wish to test students on the principles of the experiment. Another excellent source of essay questions for a Post-Lab Quiz can be found at the end of the Introduction and Objectives section of each lab in the laboratory manual.

The comments and hints come from personal experiences and input from various physics instructors. In particular, we would like to thank Professor I. L. Fischer of Bergen Community College, Paramus, New Jersey, and Professor Marles L. McCurdy of Tarrant County Junior College, Hurst, Texas.

At the back of this manual are references for laboratory safety manuals and a list of scientific equipment suppliers. Graph copy masters are included so that you may inexpensively supply students with common graph paper if you wish.

It is hoped that you will find this resource manual helpful. If you think of other items that might prove useful in laboratory instruction, your suggestions and comments are welcomed.

Fred B. Otto
Jerry D. Wilson

E X P E R I M E N T   1

Experimental Uncertainty (Error) and Data Analysis

COMMENTS AND HINTS

This experiment is considered to be an important initial operation for students. It is inexpensive, and the principles learned will be applied in error and data analyses in following experiments.

(a) Because the sets of data taken in many of the following experiments have only several values, they do not lend themselves to detailed statistical analysis. For this reason, the section in this experiment on standard deviation is labeled as optional. As the instructor, it is your option to include or omit this section. It is considered to be instructive for most students to be at least introduced to statistical analysis. Of course, your decision must be guided by the time for the laboratory and student speed and skills as well as by the nature of your course (i.e., this section should probably not be omitted for students of physics and engineering).

(b) Of particular importance is the section on Graphical Representation of Data. It has been the experience of the author that students generally submit poor graphical representations of data (i.e., they turn in lousy graphs). This is in the form of graphs with unlabeled axes and omission of units, straight lines connecting data points (Figure 1.6, Graph A) instead of smooth curves, etc. It is strongly recommended that major emphasis be placed on proper graphing procedures. It is highly important that persons in science fields know how to graphically represent data properly and how to interpret those graphs to acquire useful information.

A concept introduced here and used in various experiments is the reduction of nonlinear functions to linear functions of the form $y = mx + b$ so that they may be plotted on Cartesian coordinates and the slope and intercept values determined. This should be stressed. (An optional method of plotting exponential functions with semilog and log-log graph paper is discussed in Appendix D of the lab manual.)

(c) Optional equipment in this experiment consists of students' hand calculators (for ease of calculations) and French curves. The latter may be shown as a demonstration or used by the students in drawing curves if you have a sufficient quantity available.

(d) Although students should be encouraged to use calculators, the instructor should remain aware that most students feel that if their calculator displays 7 or 8 digits, then this is what should always be reported. This is often done without any regard for the significant figures of the numbers used to make the calculation involved. The section on significant figures should be emphasized with regard to instrument limitations, etc. This concept is followed up on Experiment 2.

The answers to the questions comprise the laboratory report for this experiment.

ANSWERS TO EXERCISES

1. (a) Student answers will depend on the size of the object they are given to measure.

(b) Student answers will depend on data

2. (a)

0.524	5.28×10^3
15.1	6.00×10^{-2}
1440	8.25×10
0.0254	1.00×10^{-4}
83,900	2.70×10^9

(b) $11.2 \times 3.4 \times 4.10 = 15\underline{6.128} = 1.6 \times 10^2 \text{ cm}^3$

(c) 3.15 (no units)

3. (a) Fractional error 0.0027

Percent error 0.27%

(b) Percent difference 2.4%

Percent error E_1 1.6%

Percent error E_2 0.82%

Percent error of mean 0.41%

(c) In the table, the determination of average deviation and standard deviation presents a problem. Since the subtraction usually produces only one significant figure, the results are good to only one figure. Since the significant-figure rule of thumb breaks down at one figure, I tell my students that they should always keep at least two. Also, rounding should not be done until the final result.

DATA TABLE 4
Purpose: To practice analyzing data.

Time t (s)	Distance (m)					$\bar{y}$	$\bar{d}$	t^2 (s^2)
	y_1	y_2	y_3	y_4	y_5			
0	0	0	0	0	0	0	0	0
0.50	1.0	1.4	1.1	1.4	1.5	1.28	0.18	0.25
0.75	2.6	3.2	2.8	2.5	3.1	2.84	0.25	0.56
1.00	4.8	4.4	5.1	4.7	4.8	4.76	0.17	1.00
1.25	8.2	7.9	7.5	8.1	7.4	7.82	0.30	1.56

(d) Student graph.

(e) Slope should be very close to 5.0, making $g = 10$.

(f) Percent error based on student result in (e) above.

(g) $k = (31.3 \text{ N})/(0.400 \text{ m}) = 78.25 \approx 78.3 \text{ N/m}$

(h) The slope of the graph should measure about 39.1 s^2/kg.

$$\text{Slope} = T^2/m = 4\pi^2/k$$

$$\text{Therefore, } k = 4\pi^2/\text{slope} = 4\pi^2/39.1 = 1.01 \text{ N/m}.$$

ANSWERS TO EXPERIMENT QUESTIONS

1. Ruler #1 has a least count of 1 cm, making 1/10 cm the best that can be estimated by eye. The black bar clearly extends to a point over half way between 3 and 4 cm. I would accept answers of 1.6 or 1.7 cm from students. Ruler #2 has a least count of 0.5 cm. The bar extends about 3/10th of the least count division beyond 3.5 cm, which works out to be 3.65 cm, but there is a big uncertainty in that last digit, so much so that most would say that it should not be written or it should be reported as 3.65 ± 0.03 cm. Ruler #3 has a least count of 1 mm, the scale can be read as 3.65 cm. Now the last digit is significant since we can say the result is 3.65 ± 0.01 cm.
2. Probably not. The last measurement was read to more decimal places.
3. The points would be widely spaced, but the cluster would be centered at the center of the target. An extreme example would be a series of evenly spaced points around the edge of the target.
4. Percent error is an indication of accuracy, but the scatter or precision of the data is not indicated. Percent difference is an indication of precision since it shows the ability of two methods to give the same answer.
5. The measurement of a physical constant usually involves several individual measurements and a calculation. The uncertainty in the form of a plus or minus for each measurement would be determined considering the nature of the instrument used to make the measurement. A range of possible values for the physical constant is then found by repeating the calculation with the extreme values of each of the measurements.

POST-LAB QUIZ QUESTIONS

Completion

1. Errors associated with the calibration and zeroing of measurement instruments or techniques are called <u>systematic errors</u>.
2. Errors resulting from unknown and unpredictable variables in experimental situations are called <u>random errors</u>.
3. In general, the accuracy of an experimental value depends on <u>systematic errors</u> and the precision on <u>random errors</u>.
4. If there is no decimal point in a number, the <u>rightmost nonzero</u> digit is the least significant figure.
5. To avoid problems with zeros in significant figures, <u>powers of 10 or scientific notation</u> may be used.
6. The number of significant figures in the result of a multiplication or division is equal to the number of significant figures in the data with the <u>least number of significant figures</u>.
7. In general when a calculation involves several operations, rounding should be done <u>only at the end</u>.
8. To express percent error, an <u>accepted</u> value must be known.
9. The average value of a set of measurements is sometimes called the <u>mean</u> value.
10. In the equation of a straight line, $y = ax + b$, the a is the <u>slope</u> of the line and b is the <u>*Y* intercept</u>.

11. The slope of a straight line on a graph is the ratio $\underline{\Delta y/\Delta x}$.
12. For a straight line on a graph ($y = ax + b$), the X intercept ($y = 0$) is given by $\underline{-b/a}$.

Multiple Choice

1. The type of error that is associated with the calibration and zeroing of measurement instruments or techniques is (a) personal error, *(b) systematic error, (c) random error, (d) mathematical error.
2. The type of error that is minimized by making a large number of measurements and taking the mean value is (a) personal error, (b) systematic error, *(c) random error, (d) mathematical error.
3. The type of error on which the precision of a measurement generally depends is (a) personal error, (b) systematic error, *(c) random error, (d) incorrect significant figures in calculations.
4. When several numbers are multiplied or divided, the proper number of significant figures in the answer is equal to the (a) significant figures of the number with the most, *(b) significant figures of the number with the least, (c) sum of the significant figures found in the data, (d) average number of significant figures found in the data.
5. When a calculation involves several steps, the result should be rounded (a) after each step, (b) whenever the number of digits becomes large, *(c) only at the end, (d) never.
6. The correctness of an experimental measurement is expressed in terms of (a) significant figures, *(b) accuracy, (c) precision, (d) personal error.
7. The comparison of two equally reliable experimental measurements is often expressed in terms of *(a) percent difference, (b) percent error, (c) average or mean value, (d) significant figures.
8. The average or mean value of an experimental set of data gives the best value when the measurements involve only (a) personal error, (b) percent difference, (c) significant figures, *(d) random error.
9. The Y axis of a Cartesian graph is called the (a) mean, (b) abscissa, *(c) ordinate, (d) slope.
10. The plotting of two variables such as T versus θ generally means that the θ values are plotted on the *(a) X axis, (b) ordinate axis, (c) slope, (d) Y axis.
11. Error bars on a graph give an indication of (a) units, (b) abscissa values, (c) accuracy, *(d) precision.
12. The slope of a straight-line graph is given by the (a) X intercept, (b) Y intercept, *(c) ratio of a particular ordinate difference and the corresponding abscissa difference, (d) ratio of the maximum X-axis scale to the Y-axis scale.

Essay

1. Distinguish and explain the difference between straight-line graphs with positive slopes and those with negative slopes.
2. What would cause a skew or shift of the maximum of a normal or Gaussian distribution of experimental values?

EXPERIMENT 2

Measurement Instruments (Mass, Volume, and Density)

COMMENTS AND HINTS

To introduce students to experimental measurements, length and mass measurements are made in this experiment and the densities of various materials are computed. The concept of instrument scale least count is included, which further reinforces significant figures (or digits) in measurements — in particular, the estimated or doubtful figure. Density computations give practice using significant figures in calculations. Students are also introduced to the vernier caliper and micrometer, which are usually unfamiliar measurement instruments. Student difficulties in this experiment generally arise from the following:

(a) Reading a vernier scale. Should you wish to emphasize the convenience of the metric system, try having them use the upper English vernier scale, but most wisely after the students have learned the use of the lower metric scale.

(b) The double rotation of the micrometer thimble for a 0.01-mm spindle movement. The idea of a double “50-cent” rotation to give “one dollar” as described in the experiment has been found to be helpful.

(c) Unless you are very specific in your pre-lab discussion, you will often find that many students use the displacement method to find the volumes of all objects instead of just using it to find the volume of the irregularly shaped object as instructed in Procedure 10.

(d) Many students’ idea of completing an investigation is to flip to the data table and try to fill in the blanks without regard to procedure. This is a very good place for you to emphasize the importance of following procedure for this and for subsequent experiments.

ANSWERS TO EXPERIMENT QUESTIONS

1. The biggest source of error is probably the least count and the zero reading, particularly on the single sheet measurements. The inconsistent compression of air spaces between pages is another source of error.

2. The most important factors will depend on the equipment used. In general, the smaller measurements like the diameter of the wire and the thickness of the sheet will give the largest percent error. It also should be noted that the densities given in Tables are for pure materials. The samples tested in the lab are probably alloys designed to give better mechanical properties.

3. Air bubbles will add to the measured volume. It is a systematic error since it always adds. This error will give an experimental density that is too low.

4. Use a sinker weight attached to the floating object by means of a string to immerse the object. Note the cylinder reading with only the sinker immersed; then note the cylinder reading with both the sinker and object immersed (see Experiment 22).

5. Given $r = 20$ cm, $t = 0.50$ mm = 0.050 cm, and $\rho_{Al} = 2.7\ g/cm^3$ (Appendix Table Al);

$$V = At = (\pi r^2)t = \pi(20)^2(0.050) = 63\ cm^3$$
$$m = \rho V = (2.7)(63) = 170\ g = 1.7 \times 10^2\ g$$

6. Determine the density of the crown using the water displacement method of finding its volume and compare it with the density of gold.

   Note: Students understanding the experiment seem to have little difficulty with Archimedes' problem in Question 6.

POST-LAB QUIZ QUESTIONS

Completion

1. If an instrument scale has a least count of 1 cm, it can be read to the nearest 0.1 cm or 1 mm.
2. A vernier scale is useful in reading the fractional part of the least count.
3. A negative zero correction is added to measurement readings.
4. When two rotations are required to move a micrometer thimble through 1.0 mm, the pitch of the micrometer screw is 0.5 mm.
5. The instrument most convenient for measuring the inner diameter of a ring would be the vernier caliper.
6. The ratchet mechanism on a micrometer permits the jaw to be tightened on objects with the same force.
7. Density provides a measure of the relative compactness of matter in substance.
8. The units of density are kg/m^3 or g/cm^3.
9. If two objects of different volume have the same mass, the larger object has a smaller density.
10. In terms of density and volume, the mass of an object is given by $m = \rho V$ (density times volume).

Multiple Choice

1. The instrument in the experiment with the smallest least count was the (a) meter stick, (b) vernier caliper, *(c) micrometer, (d) all were the same.
2. The diameter of a round pencil or pen is most conveniently measured with a (a) meter stick, *(b) vernier caliper, (c) balance, (d) graduated cylinder.
3. Before making a measurement, it is always important to check the instrument's (a) mass, (b) least count, (c) length, *(d) zero correction.
4. The function of a vernier scale is to (a) increase the least count, *(b) assist in accurately reading the fractional part of a scale division, (c) allow inner diameters to be easily read, (d) avoid positive zero corrections.
5. The main scale of a micrometer is on the (a) anvil, (b) spindle, *(c) sleeve, (d) thimble.
6. If a micrometer screw had a pitch of 1.0 mm and there were 50 divisions on the thimble, then a thimble division corresponds to (a) 0.01 mm, *(b) 0.02 mm, (c) 0.05 mm, (d) 0.10 mm.

7. A piece of dust or foreign matter on the flat jaw surface of the anvil of a micrometer could give rise to a (a) more accurate reading, *(b) positive zero correction, (c) negative zero correction, (d) random error.

8. If object *A* had twice the mass and one-half the volume of object *B*, then the density of *A* would be *(a) four times that of *B*, (b) twice that of *B*, (c) the same as that of *B*, (d) one-half that of *B*.

9. A graduated cylinder has a linear *length* scale on its side calibrated in volume units because (a) it is a vernier scale, (b) length and volume are the same, *(c) the cross-sectional area of the cylinder is assumed to be uniform, (d) it allows for different liquid densities.

10. An average density is obtained when (a) an object is irregularly shaped, (b) significant figures are not used in calculations, (c) personal error is involved, *(d) the object substance is not pure or homogeneous.

Essay

1. Explain how the number of significant figures in a measurement value depends on the least count of the measuring instrument.

2. Discuss the use of a balance on the moon. Would it accurately determine mass?

3. Could a meter stick be equipped with a vernier scale? If so, design one. (Illustrate with a sketch.)

4. Explain how the linear scale on a graduate cylinder is calibrated in volume units. How would scales vary with different-sized cylinders?

EXPERIMENT 3

The Scientific Method: The Simple Pendulum

COMMENTS AND HINTS

The simple pendulum is a standard introductory physics lab experiment. In this presentation, effort is made to couple the experimental procedure with the scientific method approach to investigations. Also, the idea of a "black box" system is introduced to emphasize the concept of system parameters in experimental investigation.

A "free" lab variation of this experiment is to simply ask students to physically describe a pendulum system without being given any theoretical background. This is a challenging approach, but it fails to incorporate the scientific method in checking theoretical predictions against experimental results.

One common student error is to count "one" as the timer starts. This results in a count that is one more than the number of swings timed. Students also often count each time the pendulum swings through the mid-position and thus make two counts per period.

ANSWERS TO EXPERIMENT QUESTIONS

1. (a) The errors due to the least count of the timer and human reaction time are reduced.

   (b) Because the errors are the same long times as for short times, when many periods are timed, the error is divided by the number of periods counted. The larger the number of periods timed the smaller the error in the period, but there are limits, the time available and the fact that people tend to loose count after 50 or 100 counts.

2. $$T = T_1\left(1+\frac{1}{4}\sin^2\frac{\theta}{2}+\frac{9}{64}\sin^4\frac{\theta}{2}+\ldots\right)$$

   For $\theta = 5°$,

   $T = T_1(1.0004762)$

   For $\theta = 20°$,

   $T = T_1(1.00767)$

   For $\theta = 60°$,

   $T = T_1(1.07129)$

   Note: The point is that for 5° no change would be detected without 5 significant figures, whereas for 60° the change is noticeable with only 3 significant figures.

3. Air resistance is a systematic error. It would tend to make the period longer.

4. $T = 2\pi\sqrt{L/g}$ For $g = 9.80\ \mathrm{m/s^2}$, & $L = 1.00\ m$, $T = 2.0070899$ There is an inherent problem with using this to establish the meter. g is not constant, it is different in different places and changes with time.

5. With $g = 1/6$ that of Earth, the period would increase by $\sqrt{6}$ to 4.9 s.

POST-LAB QUIZ QUESTIONS

Completion

1. Testing theoretical predictions against experimental results is the principle of the scientific method.
2. The length of a pendulum is measured from the point of suspension to the center (of mass) of the bob.
3. The theoretical expression $T = 2\pi\sqrt{\frac{L}{g}}$ is a first-order approximation.
4. The theoretical expression $T = 2\pi\sqrt{\frac{L}{g}}\left(1+\frac{1}{4}\sin^2\frac{\theta}{2}+\frac{9}{64}\sin^4\frac{\theta}{2}+\ldots\right)$ is a third-order approximation.
5. The "black box" relationship connects the input and output parameters of a system.
6. In a "black box" representation, the measured quantities are called output parameters.
7. The period of a simple pendulum is dependent on the pendulum length and angle (of oscillation).
8. The period of a simple pendulum is independent of the mass of the bob.
9. In a Cartesian plot of L versus T of the first-order approximation for a simple pendulum, the curve is a parabola.
10. If L versus T^2 is plotted on a Cartesian graph for the first-order approximation for a simple pendulum, the graph is a straight line with $g/4\pi^2$ as its slope.

Multiple Choice

1. Testing theoretical predictions against experimental results is called (a) first-order approximation, (b) second-order approximation, (c) trial and error, *(d) scientific method.

2. The length of a simple pendulum is determined by the (a) angle of oscillation, (b) mass of the bob, *(c) location of the center (of mass) of the bob, (d) friction of the support.

3. When the length and mass of the bob of a simple pendulum are increased, for small-angle oscillations, *(a) the pendulum swings more slowly, (b) the first-order approximation is no longer valid, (c) the general theoretical period no longer depends on θ, (d) the scientific method is no longer applicable.

4. In a "black box" representation, the output parameters (a) are independent variables, (b) are independent of all the independent variables, *(c) describe the behavior of the system, (d) are absent in a simple pendulum system.

5. When the angle of oscillation of a simple pendulum exceeds the first-order approximation limit, as the angle increases, the period (a) depends on the mass of the bob, (b) is unaffected, (c) is less than the first-order approximation, *(d) increases slightly.

Essay

1. Describe how a simple pendulum might be used to experimentally determine g (the acceleration due to gravity).

2. Discuss the "black box" representation and effects with T, m, and θ as input parameters.