Experiments Manual for

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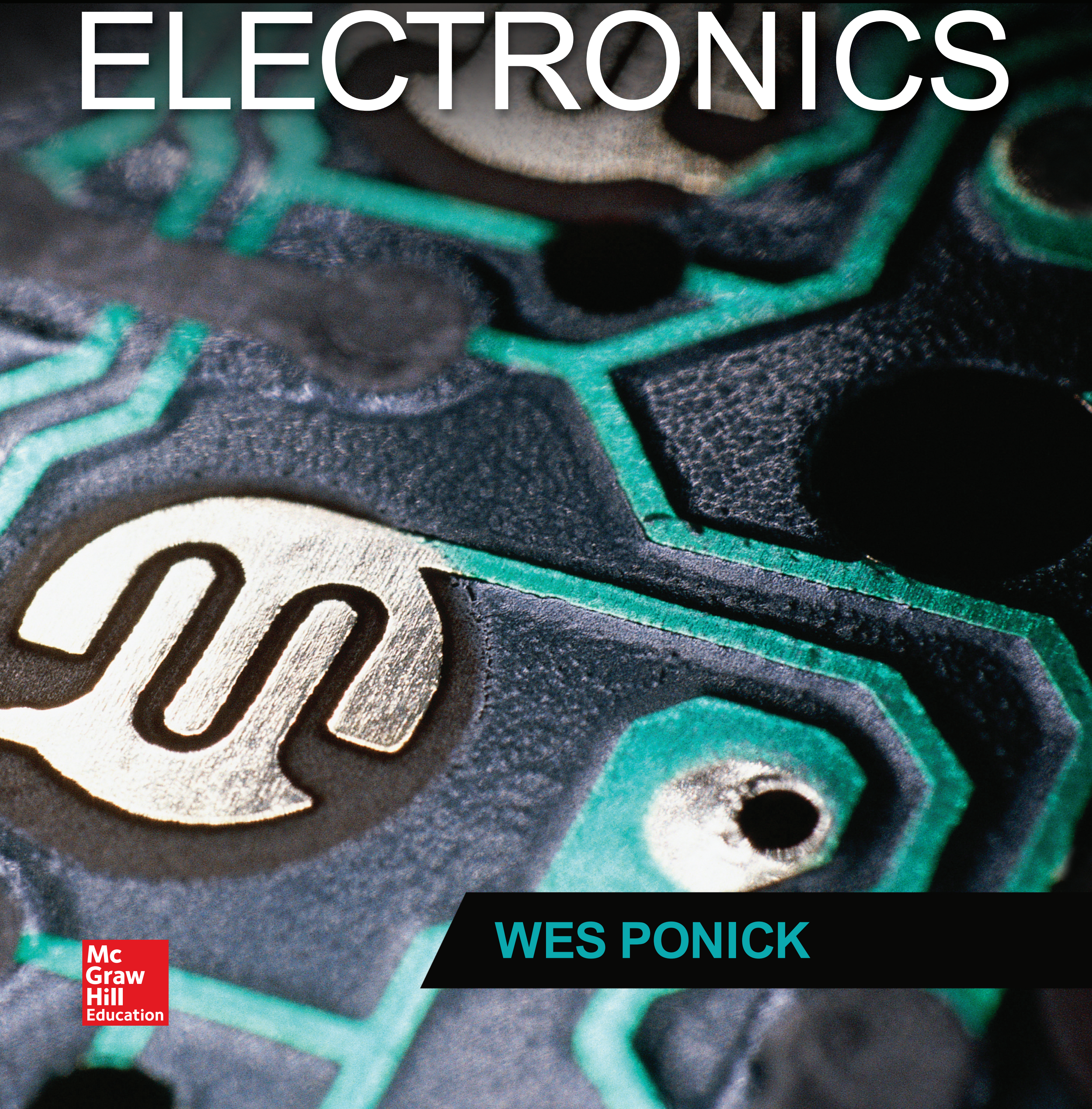
GROB'S BASIC ELECTRONICS



WES PONICK

Mc Graw Hill Education

Experiments Manual

for

Grob's Basic Electronics

Experiments Manual

for

Grob's Basic Electronics

Twelfth Edition

Wes Ponick

Technical Consultant

Mc Graw Hill Education

EXPERIMENTS MANUAL FOR GROB'S BASIC ELECTRONICS, TWELFTH EDITION

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SUPPLEMENTAL EXPERIMENTS

Preface

The *Experiments Manual for Grob's Basic Electronics* gives you step-by-step guidance with electronic components, circuits, and test equipment. The manual will help you develop the skills you need to build, measure, and troubleshoot electronic circuits of all types. It is designed for the beginning student and assumes they have no previous knowledge or experience with electronics technology.

The experiments build on the chapters in *Grob's Basic Electronics*. There are more than 70 experiments, and each one has a separate introduction describing the theory and the objectives. All the necessary components and equipment are listed. The procedures include all the necessary steps and drawings.

The experiments begin with electronics math basics, lab safety, component recognition, and details on how to use basic lab equipment. Afterward, the labs progress to simple resistive circuits and then on to reactive circuits. Circuits using diodes and transistors are also included, so you learn to work on power supplies, amplifiers, and much more. Of course, you will be using lab equipment such as digital multimeters (DMM), DC power supplies, signal generators, and oscilloscopes.

In addition to the experiments, the MultiSim circuit simulation software (available on the textbook's associated website) can also be used with this lab manual. You can use it to simulate the circuit experiments and view the results or to see what happens with circuit failure. MultiSim runs on your computer so that it does not require using real circuits or equipment. Your instructor can provide more information about MultiSim and how it applies to this set of experiments.

The experiments usually take less than 2.5 hours to complete, but some are longer than others. Every experiment begins with an introduction (theory) before detailing the step-by-step procedures that you will follow. Each experiment has exercises or questions and tables or graphs for recording your data. Finally, a blank report form is included, where you describe how the objectives were met or how the theory was verified.

The Appendix lists all the required components and equipment and has extra graphs, plots, and example reports to get you started.

In conclusion, thanks to all the students and instructors using this manual, including Ed Sikes and Dave Farina at Santa Rosa Junior College, John M. Horkey and Kevin Holmin at Blackhawk Technical College, and many others for their help. Lastly, thanks to Vincent Bradshaw (the product developer), who has assisted with this latest edition.

This *Experiments Manual* is dedicated to every student who needs a working knowledge of basic electronics.

Wes Ponick

E X P E R I M E N T I

INTRODUCTION EXPERIMENT—ELECTRONICS MATH

LEARNING OBJECTIVES

At the completion of this experiment, you will be able to:

- Understand electronics math concepts
- Use power of ten, scientific, and engineering notation
- Understand precision and accuracy in electronic measurements

SUGGESTED READING

Introduction, *Basic Electronics*, Grob/Schultz, twelfth edition.

INTRODUCTION

The topics covered in this introduction may also be covered in separate math courses or in your electronics courses. They are presented here to enhance, review, or introduce you to electronics math, which you will use in the lab to predict or verify measurement results. The material here assumes you have basic math skills to add, subtract, multiply, and divide, including working with fractional values (using decimal points). In addition, the ability to do some basic algebra or geometry is recommended. You can also go online to learn about or review any math concepts that are unfamiliar. However, most math concepts you need will be explained in this lab manual. If you are skilled at mathematics, this introduction will only be a review, except for the introduction of electronic values and units of measure.

The first section begins with *power of 10* notation, which is based on our number system of tens. Next, scientific notation and then engineering notation (other variations of the power of 10 notation) will be introduced. The last section will introduce you to significant numbers, metric prefixes, and Ohm's law, which is used with calculations and measurements.

Calculators: It is expected that you will be using a scientific calculator. You should be familiar with using the add, subtract, multiply, and divide functions on your calculator as a minimum, and be sure you can clear the entries using the C (clear) or CE (clear entry) keys. These keys will be specific to your calculator; for example, some calculators use AC (all clear) or DEL (clear entry), and so on. Other functions such as using exponents (EXP on most calculators), square roots (√), and others may also be required. So be sure to read the information in your calculator's manual.

EQUIPMENT

Calculator, paper, and pencil.

PROCEDURE

Read through the four sections and be sure you understand each one before you move on. The sections have examples of calculating values of circuit voltage, current, and resistance, which are common practice in electronics. At the end of each section are exercise problems.

Exercise Problems: Do the exercise problems after each section and record the results in the tables at the end of this introduction. Also, check with your instructor for specifics about which exercises may require calculations turned in on a separate sheet of paper.

Power of Ten Notation

In most sciences, like electronics, very large or very small numbers are used in measurements and calculations. Therefore, it is necessary to have a method for displaying and using numbers in a convenient manner. For example, a small number like 0.00000254 or a large number like 512,000,000 can be more easily written using a notation we call **power of 10.** This means using the number 10 with a multiplier (the exponent) instead of using lots of zeros. This is often referred to as 10 raised to the n^{th} power. So, the small raised or superscript number on the right of the 10 is the exponent. The exponent indicates how many times you multiply the base number (10), as shown here:

Large or Positive Numbers in Powers of Ten

1	=	1 (not multiplied by 10)	or 10^0
10	=	10×1	or 10^1
100	=	10×10	or 10^2
1,000	=	$10 \times 10 \times 10$	or 10^3
10,000	=	$10 \times 10 \times 10 \times 10$	or 10^4
100,000	=	$10 \times 10 \times 10 \times 10 \times 10$	or 10^5
1,000,000	=	$10 \times 10 \times 10 \times 10 \times 10 \times 10$	or 10^6

Therefore, a number such as 16,000, which is $16 \times 10 \times 10 \times 10$, can be simply written as 16×10^3, or a larger number such as 512,000,000 can be simply written as 512×10^6. Also, when speaking about a number such as 1,000, we say 10 to the third power.

Small numbers, less than 1, can also be expressed as a power of 10 using a negative sign before the exponent. This means 10 is multiplied by the negative exponent. And don't forget that multiplying positive numbers by negative numbers results in a negative number. For example, the number -1000 in exponential form (power of 10) is 1×10^{-3}. This refers to one thousandth of something, or spoken as ten to the minus third power.

Small or Negative Numbers in Powers of Ten

-1	=	-1 (not multiplied by 10)	or 10^0
-10	=	-10×1	or 10^{-1}
-100	=	-10×10	or 10^{-2}
$-1{,}000$	=	$-10 \times 10 \times 10$	or 10^{-3}
$-10{,}000$	=	$-10 \times 10 \times 10 \times 10$	or 10^{-4}
$-100{,}000$	=	$-10 \times 10 \times 10 \times 10 \times 10$	or 10^{-5}
$-1{,}000{,}000$	=	$-10 \times 10 \times 10 \times 10 \times 10 \times 10$	or 10^{-6}

Therefore, a number like 0.016, which is $16 \times -10 \times 10 \times 10$, can be written as 16×10^{-3}. Or a smaller number such as 0.000512 can be simply written as 512×10^{-6}.

Note that the number before the multiple of 10 (such as 16 or 512 here) is known as the *coefficient* or *factor* because it is used in the multiplication. Regardless, you should now be able to express large or small numbers using exponents for power of 10 notation. Next, let's look at using a calculator with these numbers.

Using the Calculator (positive exponent): On your calculator, you should have an exponent button: **Exp**, **EXP**, or it may use a caret **^** or second function with **EE**. This button will allow you to enter a value and then enter the exponent value (power of 10 value). The calculator should also display the letter **e** or **E** afterward. If your calculator does not have this type of button or function, you should replace it with one that does. Otherwise, you will have more difficulty in this course and your work. Note that the Exp button (function) is not the same as the X^y or the 10^x button, both of which perform slightly different exponential functions. For example, the 10^x button means you enter the number of times that 10 is multiplied by itself (10). Also, you can use the C or CE button to clear mistakes.

If you are not sure about your calculator, read its manual or ask an instructor for help. A good inexpensive scientific calculator or even a mobile phone application of one can be easily obtained to ensure your success. The following steps show how to use power of 10 notation (with exponents) on a generic scientific calculator that has an Exp button. Try this:

1. Enter the number 16,000 in exponential (power of 10) notation: $\mathbf{16 \times 10^3}$. For this type of calculator, press the buttons in this order (see diagrams below): 1, 6, Exp, and then 3. You should now see the entry is 16.e + 3. The plus sign should appear automatically to indicate it is a positive number. See Figure I-1.

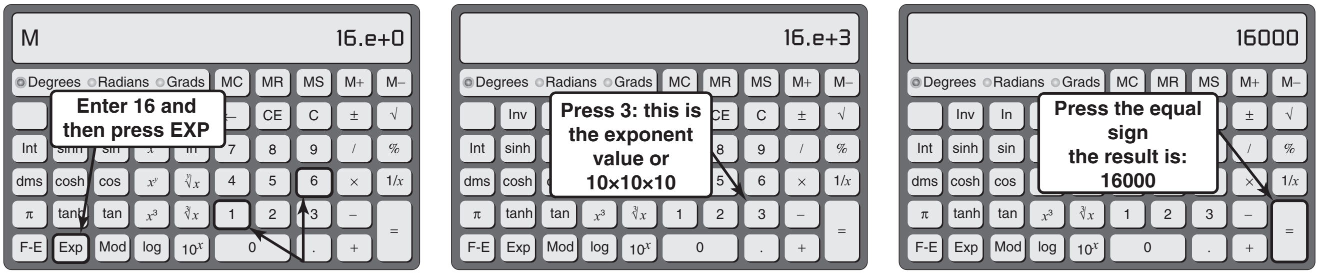

Fig. I-1

2. Now, press the equal button, and you will see the result in regular notation: 16000 (see the diagram above). By using this method, you can do all the necessary power of 10 math on your calculator using the exponent button or function. In fact, this will allow you to add, subtract, multiply, and divide exponential values easily. As you'll see, doing it by hand is much more difficult and time consuming.

Also, notice that the number you enter may automatically appear with a decimal point. This happens because scientific calculations typically use decimal points, and you will be using the decimal point often with electronic values.

3. Locate the decimal point on your calculator (usually near the zero button) and enter 16,050 in exponential form: 16.05×10^3. When you press the Exp or EXP button, the letter **e** or **E** should appear to indicate that the following number is the exponent. Your calculator should read: 16.05e+3. Always know the buttons on your calculator and how to use them.

Using the Calculator (negative exponent): On your calculator, type in the value 16×10^{-3}. This would be pressing the buttons 1, 6, EXP, and then 3 like before. However, you need to press the **Change Sign** button **(±)** to make the exponent negative. Finally, press the equal button and you will see the result in regular notation: 0.016 (see the Figure I-2 below).

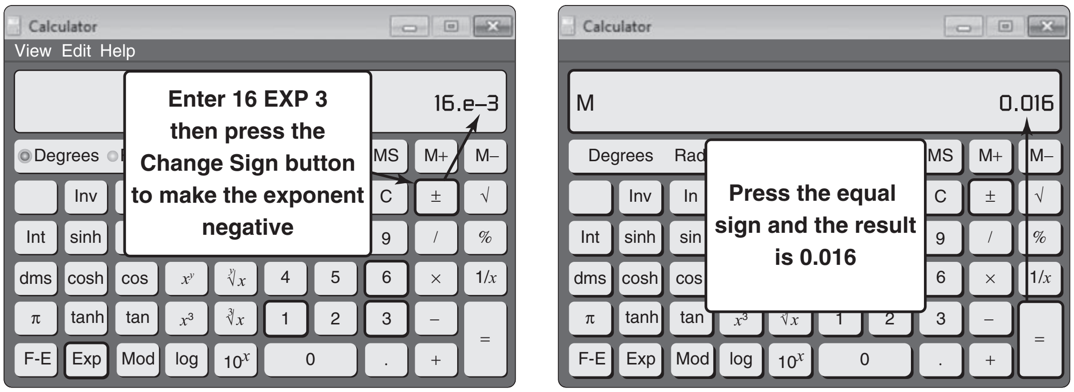

Fig. I-2

Using the F-E Key: The **F-E** button (fixed-exponential) on scientific calculators will toggle between fixed-point notation (regular numbers with a specific number of digits) and the same number in exponential form.

4. If you have an F-E key (or similar) on your calculator, enter the number 16,050 and then press the F-E key. You should see the fixed digit number become an exponential number: 1.605e + 4. Press F-E again it should toggle back to 16,050. Try it with some other numbers and then clear the calculator using C or Clear key. Remember that CE only clears the last entry.

Adding and Subtracting Power of 10 Notation: Without a calculator, adding or subtracting power of 10 values means you must convert them to the same power of 10 (same exponent). It does not matter which number you convert as long as they are the same. For example:

Add: 50.69×10^8 and 3.67×10^7
Convert one of the numbers: 3.67×10^7 becomes 0.367×10^8
Now you can add: $50.69 + 0.367 = 51.057$ and attach the common exponent 8
The result is: 51.057×10^8

Rules for Converting Exponents: When the exponent is increased, the decimal point of the numeric part must be shifted to the left. For each increase of the exponent, move the decimal point the same number of places to the left. Or, when the exponent is decreased, move the decimal point of the numeric part the same number of places to the right.

Or to subtract, you must also convert them to the same exponent:

Subtract: 9.67×10^7 from 50.69×10^8
Convert one of the numbers: 9.67×10^7 becomes 0.967×10^8
Now you can subtract: $50.69 - 0.967 = 50.323$ and attach the common exponent 8
The result is: 49.723×10^8

Of course, using a calculator means you do not need to convert different exponents—the calculator does it for you. But it's good to know how it's done by hand. You should also know the rules for adding or subtracting negative and positive numbers, such as how adding negative numbers results in a greater negative number, but subtracting negative numbers can result in either negative or positive values. These are rules of algebra and are available online or in most math books. We will not cover them here because you will use your calculator most of the time.

Multiplying Power of 10 Notation: Without your calculator, you multiply the numeric digits (coefficients) and algebraically add the exponents. For example:

Multiply: 12.19×10^{-7} by 1.97×10^9
Multiply the numeric values: $12.19 \times 1.97 = 24.0143$
Algebraically add the exponents: -7 and $9 = 2$
The result is: 24.0143×10^2

Dividing Power of 10 Notation: Without your calculator, you subtract the exponents (subtract the denominator from the numerator). Then divide the numeric digits (coefficients). For example:

Divide: $60.34 \times 10^{-4}/2.17 \times 10^3$
Subtract exponents (denominator minus the numerator): $(-4) - 3 = -7$
Divide the numeric digits: $60.34/2.17 = 27.81$ (rounded off)
The result is: 27.81×10^{-7}

Again, using a calculator means you do not have to know the rules that have been described. But it's a good idea to know how to do this math because it enhances your critical thinking and analytical skills.

I-1.1 EXERCISE PROBLEMS: Power of Ten Notation

Perform the indicated operation for the following power of 10 quantities. Record your snaswers on the Results page. Round your answers to the 10th place, and note that the Results page in Table I-1.1 has already assigned a power of 10 notation to conform your answer to.

1. $4.24 \times 10^2 \quad \times \quad 6.87 \times 10^3$

2. $3.21 \times 10^7 \quad \times \quad 8.66 \times 10^9$

3. $5.35 \times 10^4 \quad \times \quad 4.33 \times 10^3$

4. $72.8 \times 10^1 \quad \times \quad 8.62 \times 10^2$

5. $6.45 \times 10^5 \quad \times \quad 0.12 \times 10^7$

6. $18.4 \times 10^6 \quad \times \quad 7.34 \times 10^6$

7. $34.5 \times 10^9 \quad \times \quad 15.1 \times 10^8$

8. $7.24 \times 10^2 \quad \times \quad 6.37 \times 10^1$

9. $35.8 \times 10^5 \quad \times \quad 23.7 \times 10^5$

10. $3.84 \times 10^7 \quad \times \quad 1.21 \times 10^7$

11. $42.2 \times 10^1 \times 0.02 \times 10^3$

12. $7.65 \times 10^8 \times 0.27 \times 10^9$

13. $1.00 \times 10^2 \times 2.00 \times 10^5$

14. $3.46 \times 10^{-2} \times 7.25 \times 10^4$

15. $18.3 \times 10^4 \times 20.1 \times 10^{-5}$

16. $2.67 \times 10^{-7} \times 16.8 \times 10^{-2}$

17. $5.55 \times 10^1 \times 3.46 \times 10^2$

18. $3.14 \times 10^{-3} \times 1.22 \times 10^{-3}$

19. $\dfrac{4.84 \times 10^2}{2.22 \times 10^4}$

20. $\dfrac{8.00 \times 10^3}{2.00 \times 10^3}$

21. $\dfrac{7.50 \times 10^{-4}}{0.50 \times 10^3}$

22. $\dfrac{6.40 \times 10^{-5}}{2.00 \times 10^{-4}}$

23. $\dfrac{12.6 \times 10^2}{3.00 \times 10^{-3}}$

24. $\dfrac{8.88 \times 10^3}{1.00 \times 10^{-4}}$

Scientific Notation

Another form of *power of 10 notation* used in electronics is scientific notation. Like power of 10 notation, it uses exponents. The difference is that scientific notation usually has only one number followed by a decimal point and then the other numbers and exponent. For example, 17,645 is written in scientific notation as 1.7645×10^4 or 1.7645e4. So, if you understand power of 10 notation, then scientific notation is an even simpler version of it. As you can see here, all these power of ten numbers (all the same value) can be written as a single value in scientific notation:

$$\left.\begin{array}{l} 17{,}645 \times 10^0 \\ 1764.5 \times 10^1 \\ 176.45 \times 10^2 \\ 17.645 \times 10^3 \\ 1.7.645 \times 10^4 \\ 0.17645 \times 10^5 \\ 0.017645 \times 10^6 \end{array}\right\} = 1.7645 \times 10^4$$

Note: Scientific notation does not always require an exponent. For example, 3.14 is correct scientific notation. You do not need to add the 10^0 because it is understood. Also, the single number to the left of the decimal will always be between 1 and 10 or −10 and −1.

Converting to Scientific Notation: Move the decimal point of the number being converted to the right of the first non-zero digit. Then count the number of places you moved it. This will become the exponent. If you move the decimal point to the left, the exponent will be positive (+). If you move the decimal point to the right, the exponent will be negative (−). Here are some examples:

$2970 = 2.97 \times 10^3$	Decimal point moved left 3 places so the exponent is +3
$0.0016 = 1.60 \times 10^{-3}$	Decimal point moved right 3 places so the exponent is −3
$52.9 = 5.29 \times 10^1$	Decimal point moved left one place so the exponent is +1

Note again that you can also use **e** instead of ×10, for example: 2.97e3. You can check these with your calculator (enter them and use the F-E button). Remember that you need the **change sign button** for entering negative values (as change 3 to −3).

Converting from Scientific Notation: If the number has a positive exponent, move the decimal point to the right the same number of places as the exponent. If the number has a negative exponent, then move the decimal point to the left the same number of places. You may also need to add zeros. Here are some examples:

$4.02 \times 10^3 = 4020$	Decimal point moved right 4 places
$3.11 \times 10^{-3} = 0.00311$	Decimal point moved left 3 places
$0.61 \times 10^6 = 610{,}000$	Decimal point moved right 6 places

You can check these with your calculator (enter them and use the F-E button). Again, scientific notation has one number to the left of the decimal point, and this makes it easy to list a lot of numbers when taking measurements.

Adding and Subtracting Scientific Notation: Without a calculator, adding or subtracting numbers in scientific notation uses the same rules as power of 10 notation: the exponents must be the same number. The difference is that the result will be in scientific notation: one number to the left of the decimal point. Here are some examples:

Add: 4.61×10^5 and 7.31×10^7
Convert one of the numbers: 4.61×10^5 becomes 0.0461×10^7
Now you can add: $0.0461 + 7.31 = 7.3561$ and attach the common exponent 7
The result is: 7.3561×10^7 or 7.3561 e^7

Also,

Subtract: 6.42×10^{-3} from 8.70×10^{-2}
Convert one of the numbers: 6.42×10^{-3} becomes 0.642×10^{-2}
Now you can subtract: $8.70 - 6.42 = 8.058$ and attach the common exponent -2
The result is: 8.058×10^{-2} or 8.058 e^{-2}

Multiplying Scientific Notation: Without your calculator, you multiply the numeric digits (coefficients) and algebraically add the exponents. This is the same as multiplying power of 10 notation except that the final result must be in scientific notation. For example:

Multiply: 2.19×10^{-7} by 1.97×10^9
Multiply the numeric values: $2.19 \times 1.97 = 4.3143$
Algebraically add the exponents: $(-7) + 9 = 2$
The result is: 4.3143×10^2

Dividing Scientific Notation: Without your calculator, you subtract the exponents (subtract the denominator from the numerator) and then divide the numeric digits (coefficients). This is the same as multiplying power of 10 notation except that the final result must be in scientific notation. For example:

Divide: $6.34 \times 10^{-4}/2.17 \times 10^3$
Subtract exponents (denominator minus numerator): $(-4) - 3 = -7$
Divide the numeric digits: $6.34/2.17 = 2.92$ (rounded off)
The result is: 2.92×10^{-7}

Note on rounding-off numbers: Most of the time, if the value is less than 5, you can ignore it. If the value is greater than 5, increase the preceding number by 1. This will be described later in more detail.

Of course, you will be using your calculator most of the time; therefore, you do not have to remember the rules for performing these calculations. But is it a good idea to know how to do this math with confidence because it enhances your critical thinking and analytical skills. These qualities are valuable in any science, especially electronics.

I-1.2 EXERCISE PROBLEMS: Scientific Notation

Convert the following numbers to scientific notation. Record your answers on the Results page in Table I-1.2.

1. 34

2. 139

3. 1,296

4. 12.65

5. 0.067

Convert the following numbers to regular notation. Record your answers on the Results page.

6. 2.04×10^6

7. 3.45×10^{-8}

8. 7.24×10^2

9. 3.779×10^{-7}

10. 3.66×10^6

Perform the indicated operation for the following power of 10 quanitities. All results should be in scientific notation. Record your answers on the Results page.

11. $4.28 \times 10^{1} + 1.02 \times 10^{1}$

12. $7.45 \times 10^{8} + 1.17 \times 10^{9}$

13. $3.00 \times 10^{2} + 2.00 \times 10^{3}$

14. $5.46 \times 10^{-2} + 7.25 \times 10^{-4}$

15. $1.93 \times 10^{1} + 2.91 \times 10^{-1}$

16. $3.65 \times 10^{7} - 1.68 \times 10^{6}$

17. $5.33 \times 10^{3} - 3.46 \times 10^{2}$

18. $4.24 \times 10^{-3} - 1.22 \times 10^{-3}$

19. $2.90 \times 10^{-3} - 1.90 \times 10^{-4}$

20. $5.73 \times 10^{2} - 3.67 \times 10^{-1}$

21. $(3.91 \times 10^{2})\ (4.67 \times 10^{5})$

22. $(2.19 \times 10^{3})\ (7.63 \times 10^{-4})$

23. $(4.45 \times 10^{-5})\ (3.83 \times 10^{-6})$

24. $(6.34 \times 10^{7})\ (2.56 \times 10^{-3})$

25. $(5.55 \times 10^{4})\ (2.78 \times 10^{4})$

26. $(9.00 \times 10^{2})\ /\ (3.00 \times 10^{1})$

27. $(2.56 \times 10^{-2})\ /\ (5.44 \times 10^{5})$

28. $(7.71 \times 10^{4})\ /\ (1.00 \times 10^{-4})$

29. $(9.31 \times 10^{-3})\ /\ (2.99 \times 10^{-3})$

30. $(1.10 \times 10^{2})\ /\ (3.35 \times 10^{6})$

Engineering Notation and Metric Prefixes

Engineering notation and the use of metric prefixes is what you will usually use to describe values in an electronic circuit. Engineering notation is simply a variation of scientific notation. The difference is that engineering notation only uses **multiples of three** for the exponent: 10^{3}, 10^{6}, 10^{-3}, 10^{-6}, and so on. Therefore, it's convenient to use metric prefixes (symbols or text) to represent the exponent in engineering notation which is a multiple of three (e.g., 10^{3} is kilo, 10^{-6} is micro). In electronics, you will commonly hear technicians and engineers refer to kilo ohms, micro amps, and so on.

Another way to describe engineering notation or metric prefixes is that they represent a power of 10 in a grouping of three (1,000, 100,000, 0.001, 0.000001, etc.). For example, 5 milliamps means: 5×10^{-3} amps, or 1 kilo ohm means 1, 000 ohms. When talking about milliamps, it's understood that it means thousandths (10^{-3}) of an amp.

Shown here are metric prefix names, metric symbols, and their power of 10 values in groupings of three. Some of these are rarely used, but those near the middle are used all the time. You may also see these referred to as SI units (International System of Units).

Metric Prefixes, Symbols, Power of 10 Value

Metric Name	Metric Symbol	Power of 10 Value
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
None (Base Unit)	None	10^{0}
milli	m	10^{-3}
micro	μ	10^{-6}

(continued)

Metric Name	Metric Symbol	Power of 10 Value
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	A	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

Common Units of Measure in Electronics: A, V, Ω, W: As you become familiar with electronics terminology, you will usually see the following units of measure with engineering notation used to specify their values. For example, 10 kΩ means 10,000 ohms, where ohm (Greek symbol Ω) is the unit of measure for resistance to electrical current. Or, 20 μV where volts (Latin letter V) is the unit of measure for voltage, which is the potential difference between two electrical points. You do not have to know these units at this time; however, they will be used in the examples that follow for engineering notation. Here is a table of some common electronic units of measure and their symbols.

Electronic Units and Symbols

Unit Name	Unit Symbol	Quantity
Ampere (amp)	A	Electric current (I)
Volt	V	Voltage (V, E) Electromotive force (E) Potential differene (Δφ)
Ohm	Ω	Resistance (R)
Watt	W	Electric power (P)

Here are some examples of electronic units of measure, such as amps., volts, ohms, and watts. These examples show engineering notation and their equivalent values using metric prefixes. Notice how the metric prefixes are used after the units of measure:

μ (micro) is 1^{-6}	Therefore, 0.0000165 A	$= 16.5 \times 10^{-6}$ A	= 16.5 μA
k (kilo) is 10^3	Therefore, 27,000 V	$= 27 \times 10^3$ V	= 27 kV
M (mega) is 10^6	Therefore, 1,200,000 Ω	$= 1.2 \times 10^6$	= 1.2 MΩ
m (milli) is 10^{-3}	Therefore, 0.039 W	$= 39 \times 10^{-3}$ W	= 39 mW

Converting to Engineering Notation: To convert a non-exponential number to engineering notation, you move the decimal point to a power of 10 notation where the exponent is a multiple of 3 (such as −3, 6, 12, etc.).

Note: Use the same general rules as scientific notation for moving the decimal point right or left and assigning the value of the exponent. However, use a multiple of three.

Here are some examples of converting a regular notation number to engineering notation and also the metric prefix used instead of the exponent. Notice that you can have more than one correct answer with multiples of three:

0.00005 A:	Move the decimal right 3 places	$= 0.05 \times 10^{-3}$	= 0.05 m (milli)
	Move the decimal right 6 places	$= 50 \times 10^{-6}$	= 50 μ (micro)
3,200,000 Ω:	Move the decimal left 3 places	$= 3200 \times 10^3$	= 3,200 k (kilo)
	Move the decimal left 6 places	$= 3.2 \times 10^6$	= 3.2 M (mega)

Adding and Subtracting Engineering Notation or Metric Prefixes: Without a calculator, adding or subtracting numbers in engineering notation uses similar rules as scientific notation. That is, you convert the numbers to the same exponential form, except the exponents should be in common multiples of three. If they have the same metric prefix (m, M, k, etc.), it is even easier to add or subtract. Here are some examples, including metric prefixes instead of the exponent:

Add:	$0.003 + 0.0204$	$= 0.0234$	
Or,	$3 \times 10^{-3} + 20.4 \times 10^{-3}$	$= 29.4 \times 10^{-3}$	using engineering notation
Or,	9 m + 20.4 m	= 29.4 m (milli)	where m or milli is the metric prefix
Subtract:	$2600 - 1000$	$= 1600$	
Or,	$2.6 \times 10^{3} - 1 \times 10^{3}$	$= 1.6 \times 10^{3}$	using engineering notation
Or,	2.6 k − 1k	= 1.6 k (kilo)	where k or kilo is the metric prefix

Note: If your calculator has an ENG button, pressing it can convert the displayed number to engineering notation, but not all scientific calculators have this button. If your calculator has this button, then you can use it.

I-1.3 EXERCISE PROBLEMS: Engineering Notation

For each of the following problems, perform the indicated operation and record your answers on the Results page in Table I-1.3.

Place the following numbers in engineering notation.

1. 7.94×10^{2}

2. 2.21×10^{7}

3. 5.35×10^{4}

4. 72.8×10^{1}

Replace the power of 10 notation with the appropriate metric prefix.

5. 6.55×10^{6}

6. 98.1×10^{-3}

7. 32.7×10^{3}

8. 9.24×10^{-9}

Add the following numbers, and place the answer in engineering notation.

9. $56.8 \times 10^{-3} \quad + \quad 33.7 \times 10^{-6}$

10. $384 \times 10^{3} \quad + \quad 121 \times 10^{3}$

11. $42.2 \times 10^{-6} \quad + \quad 1.02 \times 10^{-3}$

12. $7.65 \times 10^{-12} \quad + \quad 274 \times 10^{-9}$

Subtract the following numbers, and place the answer in engineering notation.

13. $1.00 \times 10^{3} \quad - \quad 0.10 \times 10^{3}$

14. $3.46 \times 10^{-6} \quad - \quad 2.25 \times 10^{-3}$

15. $18.3 \times 10^{9} \quad - \quad 16.1 \times 10^{12}$

16. $2.67 \times 10^{-3} \quad - \quad 1.68 \times 10^{0}$

Multiply the following numbers, and place the answer in engineering notation.

17. $(7.50 \times 10^{-3}) \times (3.46 \times 10^{3})$

18. $(3.44 \times 10^{-3}) \times (1.22 \times 10^{-3})$

19. $(6.84 \times 10^{9}) \times (2.12 \times 10^{9})$

20. $(8.00 \times 10^{-3}) \times (2.00 \times 10^{-3})$

Divide the following numbers, and place the answer in engineering notation.

21. $(7.50 \times 10^{-3})/(0.50 \times 10^{3})$

22. $(6.00 \times 10^{-3})/(2.00 \times 10^{-6})$

23. $(12.6 \times 10^{3})/(3.00 \times 10^{-3})$

24. $(8.88 \times 10^{3})/(1.00 \times 10^{-6})$

Multiplying Engineering Notation or Metric Prefixes: Use the same rules as those used for scientific notation. Without your calculator, you first multiply the numeric digits (coefficients) and then algebraically add the exponents. Afterward, you can convert the result to engineering notation if the exponent is not a multiple of three. For example:

Multiply: 14.5×10^{-3} A by 2.07×10^{6}
Multiply the numeric values: $14.5 \times 2.07 = 30.15$

Algebraically add the exponents: -3 and $6 = 3$
The result is: 30.15×10^3 using engineering notation
Using the metric prefix: 30.15 m (milli as in mA)

Dividing Engineering Notation or Metric Prefixes: Without your calculator, you subtract the exponents (subtract the denominator from the numerator), then divide the numeric digits (coefficients). This is the same as multiplying power of 10 notation except that the final result must be in scientific notation. For example:

Divide: $6.34 \times 10^2 / 2.18 \times 10^{-4}$.
Subtract exponents (denominator minus numerator): $2 - (-4) = 6$.
Divide the numeric digits: $6.34/2.18 = 2.91$ (rounded off).
The result is: 2.91×10^6.
Using engineering notation: 416×10^3
Using the metric prefix: 416 k (as in kΩ)

Significant Figures, Accuracy, and Precision

When doing electronics math on your calculator, you use exact or finite numbers (not infinite). Finite numbers are like the number of people in a room or the number of pages in a book: exact or finite values. But when measurements are taken with meters and instruments, the values you obtain are not finite and may not match your calculations exactly. Remember that no measuring instrument is perfect, even if it has a digital display. But first, it's important to introduce you to types of calculations you will need to use with your measurements—and that begins with a quick description of Ohm's law for calculating values in an electronics circuit.

Ohm's Law: Ohm's law describes the relationships between current, voltage, and resistance in an electronic circuit. As a technician, you will be measuring and calculating these values using Ohm's law. Ohm's law is based on the work of German physicist George Ohm in 1827 and states: $I = V/R$, where I is the current in amperes, V is the voltage in volts, and R is the resistance in ohms. Therefore, to find the current I in a circuit, you divide the voltage V by the resistance R. The result will be in ohms using the Ω symbol.

Notice that current is written as I in the formula ($I = V/R$) because I refers to the Intensity of current (this is an old scientific term). Resistance (R) is how the circuit resists or opposes the flow of current and is always in ohms (Ω). And, V is easy to recognize as voltage (in volts). Finally, another early scientist, James Watt from Scotland, determined that electronic consumed power can also be determined by Ohm's law using V, I, and R (more about this later).

As you continue, you will see these units of current, voltage, and resistance used in the problems that follow. And Ohm's law will be one of your most used formulas.

Measurement Accuracy and Precision

The accuracy and precision of a measurement are always provided in the manufacturer's specification sheet. Here is a simplified example: a digital multimeter (DMM) specifies that voltage measurements are accurate ±5 % when in a range between 1 and 5 volts. This means that a measurement of 3 volts can be +0.15 V or between 2.85 and 3.15 volts. This is also known as the uncertainty of the measurement. But, if you take the measurement 100 times exactly the same way and it always reads the same number, such as 2.95, then it's precise but not necessarily accurate. It's like a scale where when you weigh something three times the same way within a few minutes, and each time you get a slightly different reading.

The terms are usually defined this way:

- **Accuracy** is how close a measurement is to the true value.
- **Precision** is the consistency of the measured value in the same circumstances.
- **Significant figures** are a number of digits used to describe accuracy or precision.

When you use a meter or instrument, such as a DMM, it may be accurate but not precise. This means it may display a measured value slightly different each time. For example, three voltage measurements made exactly the same way might be displayed as 1.43 V, then 1.45 V, then 1.47 V; the displayed value varied by 0.02 V each time. Therefore, the accuracy appears to be ±0.02 V (not very accurate by some standards). However, it may be precise if it displays exactly the same number of digits to the right of the decimal point each time: 1.43 V, 1.47 V, and 1.45 V all use exactly two digits after the decimal. Therefore, the measurement is precise to two digits each time (never uses 3 or 4, etc.). So the measurement may be precise but not accurate.

Or it may do just the opposite, showing you the same value each time you measure the voltage but with a different number of digits to the right of the decimal point. For example, 1.45 V, then 1.4499 V, and then 1.4500001 V are all similar. But, the precision varies because the number of digits to the right of the decimal is not repeatable—therefore it's not precise. In summary, all these values are close, but instruments do have differences in their accuracy or precision or both. Therefore, we need to know which values are significant and which are not.

Significant Figures or Digits: A standard way to describe accuracy or precision is to use significant figures (digits). Here are the rules for significant figures (digits):

Rule 1: All non-zero digits are significant. For example:
215 has three significant digits.
18.2 has three significant digits.
5.6 × 103 has two significant digits. (Note: disregard the exponential. There is no exponential in the problem.)

Rule 2: All zeros between significant digits are significant. For example:
1405 has four significant digits.
20,005 has five significant digits.
10.06 has four significant digits.

Rule 3: All zeros to the right of a decimal point are significant. For example:
94.0 has three significant digits.
34.00 contains four significant digits.
10.0 × 10-3 contains three significant digits.

***Note*:** Some instruments may display zeros to the right of a decimal point as placeholders. This may affect the number of significant digits in a measurement.

Rule 4: Zeros to the right of a whole number are NOT significant. For example:
600 has one significant digit.
12,000 has two significant digits.
150 has two significant digits.

Rule 5: Zeros to the left of a number less than one are NOT significant. For example:
0.2 has one significant digit.
0.056 has two significant digits.
0.44×10^{-3} has two significant digits.

Significant Digits and Measured Values: For measurements with a DMM, you can use the least significant digit to describe the precision. The least significant digit is the smallest displayed significant digit. Here are some examples:

Example 1: When a DMM is used as a voltmeter, it displays a measured 12,000 volts. The least significant digit is 2, which appears in the 1000's place. Therefore, the precision is to the nearest 1000 volts. The DDM may be capable of measuring 12,005 volts accurately, but the displayed value is to the nearest 1000 volts in this case.

Example 2: When a DMM is in the ohmmeter setting (Ω), it displays a measured 625 ohms of resistance. The least significant digit is 5, which appears in the 1's place. Therefore, the precision is to the nearest ohm or Ω. Or, if 625.1 were displayed, the precision would be to the nearest tenth of an ohm.

Example 3: When a DMM is in the A or uA setting, it displays a measured value of 0.007896 amps. The least significant digit is 6, which is in the one-millionth place. Therefore, the precision is to the nearest microamp (μA) or 10-6 amps.

Rounding: In calculations or measurements, rounding is used to simplify values. Also, for a DMM, displayed numbers are often rounded to avoid showing insignificant figures or to make it easier to read—and don't forget that many basic measurements are OK if they are not exact. For example, if you calculate a value of current using Ohm's law (I = V/R) and the answer is 16.501 μA (microamps), your DMM might display only 16.5 in the μA setting. That is OK, especially because it's a very small number.

General rules for rounding: If the last digit is less than 5, you can eliminate it and use the remaining digits. For example, 163.92 can be rounded to 163.9, or the number 0.0447 can be rounded to 0.045.

Adding, Subtracting, Multiplying, and Dividing Significant Digits: When doing any of these, your final answer should have no more significant figures than the value with the least number of significant digits. In other words, the answer can never be more precise or accurate than the least accurate or precise number measured. Here are some examples:

Adding voltages: 10.1 V + 123.41 V + 56.01 V = 189.52 V
The least precise measured value is 10.1 V.
Therefore, the rounded answer = 189.5 V.

Multiplying resistance and current: ($I \times R = V$, derived from Ohm's law: $I = V/R$)
$1.4\ A \times 15.68\ \Omega = 21.952\ V$
The least precise measure value is 1.4 A (2 significant digits).
Therefore, the answer is 21.9 V or rounded to 22 V (2 significant digits).

Because these are measured values, a final answer may depend upon some established protocol or lab practice. In the last example, 22 V is more precise (using significant digits), but it may be more accurate to use 21.9 V, especially if you are using that value in another calculation with a very small or large number (such as 21.9/20 uA). Check with your instructor for any established protocol on what number of significant digits should be used in the lab experiments.

I-1.4 EXERCISE PROBLEMS: Significant Figures, Accuracy, Precision

For each of the following problems, perform the indicated operation and record your answers on the Results page in Table I-1.4.

How many significant figures are contained in the following measured quanitities?

1. 8.001

2. 721

3. 0.632

How many significant figures are contained in the following measured quanitities?

4. 14.11

5. 738.6

6. 0.0012

What is the accuracy of each of the following measured quantities?

7. 12.63

8. 7684

9. 0.6117

Add the following measured quantities, and reduce the answer accordingly usually 2 or 3 significant digits.

10. 16.3 + 17.14

11. 10,031 + 6763

12. 101 + 12

Subtract the following measured quantities, and reduce the answer accordingly.

13. 15.6 + 3.33

14. 1002 − 863

15. 12.000 + 11,110

Add the following measured quantities, and reduce the answer accordingly.

16. 6.23 × 1.23

17. 6.1 × 21.21

18. 34 + 12.1

Divide the following measured quantities, and reduce the answer accordingly.

19. 73/6.1

20. 108/12.4

21. 17.3/10.03

Round each of the following measured quantities to three significant figures.

22. 763.62

23. 64.762

24. 1.27721

SUMMARY AND REVIEW—BE FAMILIAR WITH THESE TERMS

- Coefficient and exponent (math terms)
- Power of 10 notation (×10)
- Scientific notation (one digit left of the decimal)
- Engineering notation (exponent in multiples of three)
- Metric prefixes (symbols for multiples of three: m, k, etc.)
- Units of measure in a circuit: amps, volts, ohms, watts (A, V, Ω, W)
- Ohm's law: V=I/R (where I is used for current and R used for resistance)
- Accuracy of a meter or instrument (manufacturer specifications)
- Precision of a measurement
- Significant figures (digits) and the least significant figure (digit)

Know how to use these buttons or functions on your scientific calculator:

- Exponent function (Exp, EE, etc.)
- Change sign (±) function
- FE or fixed-point change to exponential
- Eng (engineering notation) button if available

Important Note: Do not be discouraged by the math or the terminology if it is new to you. The math and the terminology will become easier to use in time if you work at it.

NAME ____________________ DATE ____________

RESULTS TABLES FOR INTRODUCTION TO ELECTRONICS MATH

TABLE I-1.1 Power of 10 Notation

1. ______ $\times 10^{3}$	**9.** ______ $\times 10^{3}$	**17.** ______ $\times 10^{3}$
2. ______ $\times 10^{9}$	**10.** ______ $\times 10^{3}$	**18.** ______ $\times 10^{-6}$
3. ______ $\times 10^{3}$	**11.** ______ $\times 10^{0}$	**19.** ______ $\times 10^{-2}$
4. ______ $\times 10^{3}$	**12.** ______ $\times 10^{6}$	**20.** ______ $\times 10^{0}$
5. ______ $\times 10^{6}$	**13.** ______ $\times 10^{7}$	**21.** ______ $\times 10^{-7}$
6. ______ $\times 10^{9}$	**14.** ______ $\times 10^{2}$	**22.** ______ $\times 10^{-1}$
7. ______ $\times 10^{9}$	**15.** ______ $\times 10^{-1}$	**23.** ______ $\times 10^{5}$
8. ______ $\times 10^{0}$	**16.** ______ $\times 10^{-9}$	**24.** ______ $\times 10^{7}$

TABLE I-1.2 Scientific Notation

1. ______	**11.** ______	**21.** ______
2. ______	**12.** ______	**22.** ______
3. ______	**13.** ______	**23.** ______
4. ______	**14.** ______	**24.** ______
5. ______	**15.** ______	**25.** ______
6. ______	**16.** ______	**26.** ______
7. ______	**17.** ______	**27.** ______
8. ______	**18.** ______	**28.** ______
9. ______	**19.** ______	**29.** ______
10. ______	**20.** ______	**30.** ______

TABLE I-1.3 Engineering Notation

1. ______	9. ______	17. ______
2. ______	10. ______	18. ______
3. ______	11. ______	19. ______
4. ______	12. ______	20. ______
5. ______	13. ______	21. ______
6. ______	14. ______	22. ______
7. ______	15. ______	23. ______
8. ______	16. ______	24. ______

TABLE I-1.4 Significant Figures, Accuracy, Precision

1. ______	9. ______	17. ______
2. ______	10. ______	18. ______
3. ______	11. ______	19. ______
4. ______	12. ______	20. ______
5. ______	13. ______	21. ______
6. ______	14. ______	22. ______
7. ______	15. ______	23. ______
8. ______	16. ______	24. ______

CHAPTER

1

EXPERIMENT 1-1

LAB SAFETY, EQUIPMENT, AND COMPONENTS (Resistor Color Code)

LEARNING OBJECTIVES

At the completion of this experiment, you will be able to:

- Understand the basic safety concepts used in a lab.
- Be familiar with lab equipment and components.
- Understand the resistor color code.

SUGGESTED READING

Chapters 1 and 2, *Basic Electronics,* Grob/Schultz, twelfth edition

INTRODUCTION

An electronics lab combines a classroom with a technician's workbench. Most classroom labs have similar equipment. You should become familiar with the equipment in your classroom lab, including safety equipment, safety policies, and practices.

SAFETY

Safety always comes first—in a lab class and at work. In fact, most large companies train their technicians in safety measures, including good ergonomic practices. You should not only know how to use the equipment safely but also how to sit at a lab station without stressing your arms, wrists, or eyes when working. Most of the time, this is a matter of common sense—avoid any stressful position for a prolonged time.

But most safety issues in an electronics lab come from the possibility of getting an electric shock. It is your responsibility to avoid this hazard by following these basic rules:

1. Do not plug in or turn on the power to any equipment without knowing how to use the equipment. This means asking for help when you do not know how to use something safely. Do not be afraid to ask for help.
2. Always check power cords. They should not be frayed, loose, or damaged in any way. In general, always inspect your equipment before using it.
3. Never wear loose jewelry or rings when working on equipment. Most jewelry is made of metal and may conduct hazardous current accidentally.
4. Do not keep beverages, open liquids, or food near electronic equipment.
5. Do not touch any circuit or components unless you know that it is safe to do so. For example, touching some components (especially some integrated circuits) can damage them. Other components (large capacitors) can discharge a dangerous current through your body if you touch them—even if they are not connected to a circuit.
6. Never use a soldering iron without proper training.
7. Never disturb another person who is using equipment.
8. Always wear safety glasses or any other required safety equipment.

Your lab class may have a safety test, signs, or some other information that you should read or respond to as required. Although most electronics courses are not known to cause injury, it is still a good idea to be cautious and prepared. Be sure you know where first aid is available and what to do in an emergency.

EQUIPMENT

Every electronics lab, and every school, has different types of equipment. However, there are some basic meters that are common to all electronics labs. In one form or another, your school will have these meters. They may appear to be different only because they are made by different manufacturers. Typical equipment is shown in Grob/Schultz, *Basic Electronics,* twelfth edition.

Simple Meters (Single Purpose)

Ohmmeter: Used to measure resistance (in ohms). Remember that resistance is the opposition to current flow in a circuit. Resistors usually have color stripes on them to identify their values. One way to be sure your resistor is the correct value is to measure it with an ohmmeter.

Ammeter: Used to measure current (in amperes). Remember that current is an electric charge in motion. Ammeters usually measure the current in milliamperes (0.001 A) because most electronics lab courses do not require large amounts of current.