

The Physics Handbook

(The Physics “bible”)

**A Handbook of Tables, Skills, and
Calculator Technologies for the
Physical Sciences**



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Chapter One: Exponents, Scientific Notation, and the Calculator

Scientists, engineers, and technicians work with quantitative data that range from the infinitesimal quantum measurements to the large astronomical measures used in the cosmos. In order to represent and facilitate manipulating these measurements, a special system, called scientific notation, has been utilized. In this system, numbers are expressed as the product of a number between 1 and 10 inclusive of 1, and a power of ten. This notation makes comparing, calculating, and representing a wide range of measurements quite easy. For example, the speed of light in mi/sec is 186,200; written in scientific notation it is 1.862×10^5 mi/sec.

Numbers in Scientific Notation

The method often used to write numbers in scientific notation is to write the significant digits (discussed later) as a number between 1 and 10 by placing by the decimal after the first non zero digit. Then multiply that number by the power of ten needed to make the new number equivalent to the original. For example, 186,200 is written as 1.862×10 raised to the fifth power because the number 1.862 must be multiplied by 10,000 or 10^5 to make it equivalent to the original number. Thus, $186,200 = 1.862 \times 10^5$.

The method works well for very small measurements, too. Again, the rule of thumb is to place the decimal after the first non zero digit and multiply the result by a power of ten equivalent to the number needed to make the new number equal to the original. Remember that a negative exponent is a reciprocal. Thus, 10^{-2} means $1/10^2$ or one hundredth ($1/100$). Therefore, a negative exponent indicates that one moves the decimal in the opposite direction to create the original number. For example $0.0000000000667 = 6.67 \times 10^{-11}$.

If the number is already between 1 and 10, then write the number and multiply by 10 raised to the zero power. Recall that any number raised to the zero power (except 0) is one. Therefore, multiplying any number by 10^0 is equivalent to multiplying by one, the multiplicative identity. For example, $3.275 = 3.275 \times 10^0$ in scientific notation.

Example 1: Write 15, 700 in scientific notation.

Place the decimal after the first non zero digit, the 1, and multiply by ten raised to the power which the decimal was moved, namely 4 places.

$$5,700 = 1.57 \times 10^4$$

Example 2: Write 0.00283 in scientific notation.

Place the decimal after the first non zero digit, the 2, and multiply the result by ten raised to the power which the decimal was moved, namely four places.

$$0.00283 = 2.83 \times 10^{-3}$$

In general, all measurements or discrete numbers can be written in scientific notation as follows:

$$n \times 10^q$$

where $1 \leq n < 10$ and q is the number of places which the decimal is moved to change the original number into n . The exponent q is positive if the original number is larger than 10, negative if the number is smaller than 1, and zero if the number is between 1 and 10.

To change numbers already in scientific notation to regular base ten notation, the process is reversed. Write all the significant digits of the factor n and then move the decimal the number of places equal to the power of ten in the standard scientific notation. If the exponent of ten is positive, move the decimal to the right making a number larger than 1. If the exponent is negative, move the decimal to the left creating a number smaller than 1. If the exponent of the ten factor is zero, then simply write the initial factor without any changes.

Examples:

$$\begin{aligned} 3.00 \times 10^8 \text{ m/sec} &= 300,000,000 \text{ m/sec} \text{ \{Move decimal 8 places to the right\}} \\ 5.76 \times 10^{-3} \text{ cm} &= 0.00576 \text{ cm} \text{ \{Move the decimal 3 places left counting the 5\}} \\ 9.875 \times 10^0 \text{ yards} &= 9.875 \text{ yards} \text{ \{10^0 is one; just write the first factor\}} \\ 1.49 \times 10^{11} \text{ m} &= 149,000,000,000 \text{ m} \text{ \{Move decimal 11 places to the right\}} \\ 2 \times 10^{-5} \text{ mm} &= 0.00002 \text{ mm} \text{ \{Move decimal 5 places left counting the 2\}} \end{aligned}$$

Scientific Notation and the Calculator (TI 83 and TI 83 plus)

Quite often the graphing calculator will represent an answer in scientific notation whether the number were input in regular or scientific notation. Therefore, it is essential to understand how to read output answers and how to input numbers into the calculator in scientific notation properly. Generally, scientific notation is shorter and easier to write than the regular base ten notation.

Input Notation for Calculator

Entering a number in scientific notation is very easy, although not necessarily obvious. It is NOT necessary to enter the first factor and then multiply by 10 raised to the appropriate power. This can lead to an erroneous result. Instead, enter the first factor which is between 1 and 10 (inclusive of 1), and press $\langle 2^{\text{nd}} \rangle$ then $\langle \text{EE} \rangle$ and enter the exact exponent. Remember, if the exponent is negative, use the $\langle - \rangle$ (opposite) key rather than the subtraction key. The calculator will display the first factor followed by E and then the exponent. This is normal.

Example 1: 2.50×10^4 is entered as 2.50 $\langle 2^{\text{nd}} \rangle \langle \text{EE} \rangle 4$ and is displayed as 2.50E4.

Example 2: 6.67×10^{-11} is entered as 6.67 $\langle 2^{\text{nd}} \rangle \langle \text{EE} \rangle -11$ and is displayed as 6.67E-11.

Example 3: 5280 is entered 5.28 $\langle 2^{\text{nd}} \rangle \langle \text{EE} \rangle 3$ and is displayed 5.28E3.

NOTE: The calculator will allow you to enter the number in either regular notation or scientific notation. Therefore, enter the number in the simplest or shortest way.

Output Notation for the Calculator

Reading a number expressed in scientific notation by the calculator is a cinch. The first factor shown is the first factor of the standard scientific notation and is followed by E and the exponent of the tens factor. Thus,

$$2.3 \text{ E}8 = 2.3 \times 10^8 \text{ and } 4.78 \text{ E}-6 = 4.78 \times 10^{-6}.$$

EXERCISES: Exponents, Scientific Notation, and the Calculator

Express in scientific notation. Practice writing the scientific notation numbers in the calculator.

1.) 1,930

6.) 0.0713

2.) 262,000

7.) 0.00007631

3.) 63,420

8.) 0.476

4.) 93,500,000

9.) 0.0000000965

5.) 307

10.) 0.00743

Express in regular base ten notation.

11.) 3.05×10^5

16.) 1.60×10^{-19}

12.) 9.914×10^8

17.) 3.047 E7

13.) 2.02×10^{-4}

18.) 1.308 E-9

14.) 2.02×10^4

19.) 2.275 E-4

15.) 9.109×10^{-31}

20.) 6.0075 E6

Chapter 2: Significant Digits

In physics as well as in other sciences, there are two types of quantitative (numerical) data which might be collected and analyzed. One type of data is discrete; this data is found by counting objects using whole numbers, and thus have an infinite number of significant digits. However, the second type of quantitative data is found by measuring objects using instruments and recording the observations with real numbers. Since any measure is an estimate from a continuous scale, then the result must be an estimate and can only be represented by a finite number of digits as dictated by the measuring instrument itself. These digits, when read to a given accuracy, are called the significant digits and are very important to any measurements in physics, engineering, or any science field. Most instruments are neither constructed nor calibrated to permit measurement of a quantity with exactness. There is always some uncertainty associated with measuring.

When reading a ruler or a balance, an estimate of the length or the mass is made from the instrument. *All of the certain digits in a measured quantity plus the first estimated, or doubtful, digit are recorded as the significant figures.* Of course, most digital instruments do not permit one to estimate beyond the digits displayed; therefore, these displayed digits on a digital measuring device represent the significant digits with no estimate necessary.

The measure of any measurement should contain an estimated or doubtful digit. These doubtful digits should be estimated to at least 0.5 parts of the smallest calibration of the instrument. However, it could be as accurate as 0.2 or 0.1 parts of the smallest calibration actual indicated on the measuring instrument. For example, a thermometer may be calibrated to the nearest degree, but can be easily estimated to the nearest 0.5 degrees. A meter stick has millimeters as the smallest division, but the length can be estimated to 0.2 or 0.1 parts of a millimeter. The doubtful figure read from an analog instrument should be included as a part of the significant digits.

Determining the Number of Significant Digits

As a rule of thumb, all digits that make up a number, except zeros that serve only as place holders for the decimal point, are considered significant figures. In scientific notation, the numerical coefficient should contain only the significant figures and the power of ten that serves to indicate the magnitude of the number. The following is an explanation of how to identify significant digits:

- | | |
|-----------|--|
| 758cm | There are three significant digits because none are zero. |
| 805cm | There are three significant digits because the zero is between digits other than zero. |
| 805.0cm | There are four significant digits because the measurement was made to the nearest tenth of a cm. |
| 0.805cm | There are three significant digits here. The initial zero is included for numbers between -1 and $+1$ to make them look uniform. |
| 0.80500cm | There are five significant digits with the zeros after the 5 indicating that the measurements was to the nearest one-hundredth thousandth. |

In general, any zeros on the end of a measurement to the right of the decimal are significant.

- 0.000805cm There are only three significant digits here. The initial zero and the next three zeros locate the decimal place.
- 8.05×10^5 cm There are three significant digits here because the first coefficient of a number in significant notation always contains the significant digits.
- 256.82cm There are five significant digits as no numerals are used to locate the decimal point.
- 2.500cm There are four significant digits shown here because the last zeros are measured and are not used to locate a decimal point.
- 20,500cm There are three significant digits here because the zeros are used to locate the decimal placement.
- 20,500.cm There are five significant digits here because the decimal was written and indicates the answer is exact to the decimal place.
- 20,000.00cm There are seven significant digits shown here because the last two zeros were measured, and the first three zeros are between other significant digits.

Exercises: Significant Digits 1

Identify the number of significant digits in each of the following exercises. Assume that each represents a measured quantity.

1.) 87,423

2.) 0.03007

3.) 3.405

4.) 20.082

5.) 0.00063

6.) 0.000007

7.) 4.000019

8.) 5,280

9.) 7.80

10.) 600.000

11.) 50,013

12.) 42.030

13.) 7.01×10^6

14.) 5.00×10^3

15.) 9.070×10^{-4}

Numbers with Unlimited Significant Digits

Numbers that do not represent measured quantities have an unlimited number of significant figures. This includes a numerical count, discrete data, or an exact definition. An example of a discrete, or counted, quantity is the 25 students in this room. The 25 is exact and has unlimited significant figures. Also the 2 in the equation for diameter and radius of a circle; $d = 2r$ has unlimited significant figures.

Rounding Off Rule

In carrying out mathematical operations with significant digits, it sometimes becomes necessary to drop digits that might give an erroneous impression of accuracy or may have no meaning. In these cases, the following rule should be followed:

Rounding Rule

When a superfluous digit is less than 5, the preceding figure is retained without change. When a digit to be dropped is greater than 5, the final figure retained is increased by 1. When the last digit to be dropped is exactly 5, round off so that the last digit retained is even.

<i>Examples:</i>	Original Number	Rounded Off Equivalent (nearest hundredths)
	23.763	23.76
	23.768	23.77
	23.764	23.76
	23.735	23.74
	23.76500	23.76
	23.76503	23.77

Significant Digits in Addition and Subtraction

The rule of significant figures when adding or subtracting is much more complicated than with other operations. In order to add or subtract the numbers which is generally done on a calculator, arrange the numbers in a vertical column with the decimals in a collinear vertical pattern. The sum or difference should be rounded such that no digit is to the right of a doubtful/ estimated, figure in the result.

Example: Add

12.357	Note that the second addend is only measured to the nearest tenth while the other addends were measured more accurately. Thus, the sum must contain no digit to the right of the tenth place.
3.1	
23.760	
<u>6.15</u>	
45.367	is rounded to 45.4 which is the best answer.

Example: Subtract

49.732	
<u>6.96</u>	
42.772	is rounded to 42.77 which is the best answer

As can be readily seen, addition of numbers can create a sum with a larger number of significant figures than any of the addends.

Example: Add

$$\begin{array}{r} 95.1 \\ 75.8 \\ 46.1 \\ \hline 3.03 \\ \hline \end{array}$$

The sum should be written to the nearest tenth. Here the sum is rounded to four significant digits.

220.03 is rounded to 220.0 which is the best answer.

During the operation of subtraction, if the numbers subtracted are close together, then significant digits will be lost. The difference will have fewer digits than the measurements subtracted.

Example: Subtract

$$\begin{array}{r} 48.762 \\ 48.729 \\ \hline \end{array}$$

These two numbers are nearly equal. Since each was measured to the nearest hundredth, then the difference is given to the nearest hundredth.

0.035 is the answer with only two significant figures

Rule for Addition and Subtraction of Significant Figures

When adding or subtracting measured numbers, arrange the numbers in columnar form. The result is to retain no column that is to the right of a column containing a doubtful, or estimated, figure in any of the input numbers. In other words, only keep decimal places equal to those of the input number with the fewest decimal places.

Significant Digits in Multiplication and Division

The rule for multiplication or division is much simpler than for addition and subtraction. The product or quotient should have the same number of significant figures as the least number of significant figures for the input factors.

Example:

$$\frac{2.34 \times 4.7 \times 14.776}{3.1415} = 51.72893459 \text{ (Via Calculator)}$$

The best answer is 52 which has two digits dictated by the input factor 4.7 which has only two significant figures. The other factors in this operation have 3 or 5 significant digits.

Rule for Multiplication and Division of Significant Figures

In multiplication and division, the result should have no more significant figures than the input factor having the least number of significant figures.

Exception: There is an exception to this rule which may be utilized. When the first figure of the least significant number is much greater than the first figure of the product or quotient, one is justified in retaining one more significant digit than the rule states.

Example: $1.08 \times 9.7 = 10.476$ (Via Calculator)

Strictly speaking, the answer should be 10. However, inspection of the above result demonstrates that the first doubtful figure is not the zero in 10.5, but the 5. Therefore, one is justified in recording the product as 10.5.

Significant Figures for Roots and Powers

The rule for raising a number to a power or exponentiation is quite similar to the multiplication rule. The result of raising a number to a power should have the same number of digits as the base which is used. The root of a number should have the same number of significant figures as the radicand, or the number which one is finding the root of.

Example:

$$(3.407)^3 = 39.54726014 \text{ (via calculator)}$$

Since 3.407 has four digits, the result should have 4 significant digits or 39.54

Example:

$$(1.2507)^{1/2} = 1.118346994 \text{ (via calculator)}$$

Since 1.2507 has five digits, the result should have 5 significant digits or 1.1183

Rule for Roots and Powers of Significant Figures

The root or the power of a number should have as many significant figures as the original number itself.

Exercises: Significant Digits 2

Solve the following problems, expressing the answer to the proper number of significant figures.

The following numbers are given for the exercises:

A) 1.72cm B) 0.15cm C) 627.1cm D) 0.007cm E) 704.050cm

1. Find the sum of all numbers, A) through E)
2. Find the sum of A), C), and E)
3. Find the difference between C) and A)
4. Find the difference between E) and B)
5. Find the product of A) and E)
6. Find the sum of A) and B) and multiply by the sum of C) and E)
7. Find the product of C) and D)
8. Find the product of A), C), and E) divided by B)
9. Divide C) by B)
10. Divide E) by D)
11. Find the cube root of E)
12. Raise (B) to the third power