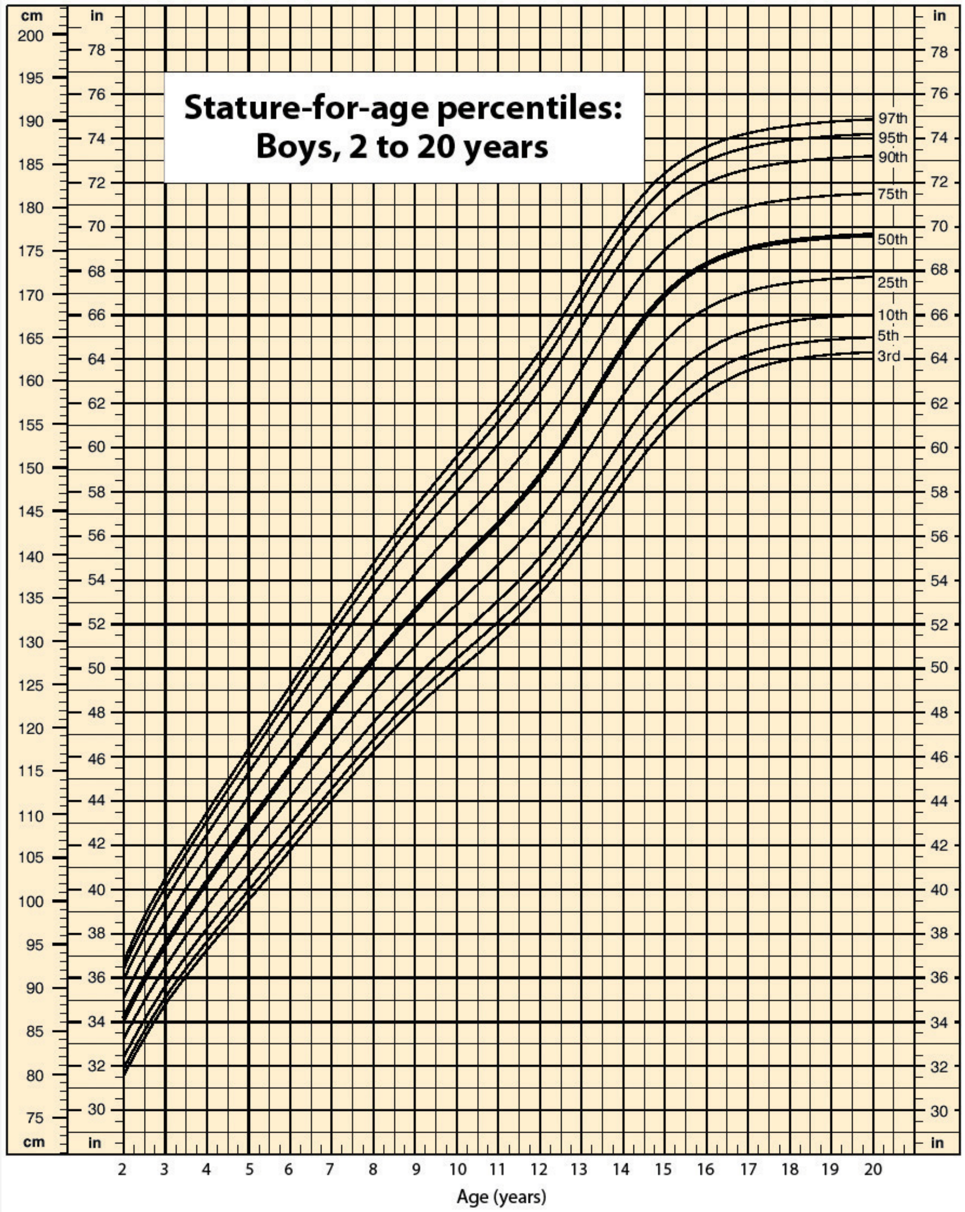
Chapter 2
Measurements

Opening Essay

Data suggest that a male child will weigh 50% of his adult weight at about 11 years of age. However, he will reach 50% of his adult height at only 2 years of age. It is obvious, then, that people eventually stop growing up but continue to grow out. Data also suggest that the average human height has been increasing over time. In industrialized countries, the average height of people increased 5.5 inches from 1810 to 1984. Most scientists attribute this simple, basic measurement of the human body to better health and nutrition.



Source: Chart courtesy of Centers for Disease Control and Prevention,http://www.cdc.gov/nchs/nhanes.htm#Set%201.

In 1983, an Air Canada airplane had to make an emergency landing because it unexpectedly ran out of fuel; ground personnel had filled the fuel tanks with a certain number of pounds of fuel, not kilograms of fuel. In 1999, the Mars Climate Orbiter spacecraft was lost attempting to orbit Mars because the thrusters were programmed in terms of English units, even though the engineers built the spacecraft using metric units.

In 1993, a nurse mistakenly administered 23 units of morphine to a patient rather than the "2–3" units prescribed. (The patient ultimately survived.) These incidents occurred because people weren't paying attention to quantities.

Chemistry, like all sciences, is quantitative. It deals with *quantities*, things that have amounts and units. Dealing with quantities is very important in chemistry, as is relating quantities to each other. In this chapter, we will discuss how we deal with numbers and units, including how they are combined and manipulated.

2.1 Expressing Numbers

LEARNING OBJECTIVE

1. Learn to express numbers properly.

Quantities have two parts: the number and the unit. The number tells "how many." It is important to be able to express numbers properly so that the quantities can be communicated properly.

Standard notation is the straightforward expression of a number. Numbers such as 17, 101.5, and 0.00446 are expressed in standard notation. For relatively small numbers, standard notation is fine. However, for very large numbers, such as 306,000,000, or for very small numbers, such as 0.000000419, standard notation can be cumbersome because of the number of zeros needed to place nonzero numbers in the proper position.

Scientific notation is an expression of a number using powers of 10. Powers of 10 are used to express numbers that have many zeros:

10^0	= 1
10^1	= 10
10^2	= 100 = 10 × 10
10^3	= 1,000 = 10 × 10 × 10
10^4	= 10,000 = 10 × 10 × 10 × 10

and so forth. The raised number to the right of the 10 indicating the number of factors of 10 in the original number is the **exponent**. (Scientific notation is sometimes called *exponential notation*.) The exponent's value is equal to the number of zeros in the number expressed in standard notation.

Small numbers can also be expressed in scientific notation but with negative exponents:

10^{-1}	= 0.1 = 1/10
10^{-2}	= 0.01 = 1/100
10^{-3}	= 0.001 = 1/1,000
10^{-4}	= 0.0001 = 1/10,000

and so forth. Again, the value of the exponent is equal to the number of zeros in the denominator of the associated fraction. A negative exponent implies a decimal number less than one.

A number is expressed in scientific notation by writing the first nonzero digit, then a decimal point, and then the rest of the digits. The part of a number in scientific notation that is multiplied by a power of 10 is called the **coefficient**. Then determine the power of 10 needed to make that number into the original number and multiply the written number by the proper power of 10. For example, to write 79,345 in scientific notation,

$$79{,}345 = 7.9345 \times 10{,}000 = 7.9345 \times 10^4$$

Thus, the number in scientific notation is 7.9345×10^4. For small numbers, the same process is used, but the exponent for the power of 10 is negative:

$$0.000411 = 4.11 \times 1/10{,}000 = 4.11 \times 10^{-4}$$

Typically, the extra zero digits at the end or the beginning of a number are not included. (See Figure 2.1 "Using Scientific Notation".)

Figure 2.1 *Using Scientific Notation*

The earth is about 93,000,000 miles from the sun. In scientific notation, this is 9.3×10^7 miles.

EXAMPLE 1

Express these numbers in scientific notation.

1. 306,000
2. 0.00884
3. 2,760,000
4. 0.000000559

Solution

1. The number 306,000 is 3.06 times 100,000, or 3.06 times 10^5. In scientific notation, the number is 3.06×10^5.
2. The number 0.00884 is 8.84 times 1/1,000, which is 8.84 times 10^{-3}. In scientific notation, the number is 8.84×10^{-3}.
3. The number 2,760,000 is 2.76 times 1,000,000, which is the same as 2.76 times 10^6. In scientific notation, the number is written as 2.76×10^6. Note that we omit the zeros at the end of the original number.

4. The number 0.000000559 is 5.59 times 1/10,000,000, which is 5.59 times 10^{-7}. In scientific notation, the number is written as 5.59×10^{-7}.

Test Yourself

Express these numbers in scientific notation.

1. 23,070
2. 0.0009706

Answers

1. 2.307×10^{4}
2. 9.706×10^{-4}

Another way to determine the power of 10 in scientific notation is to count the number of places you need to move the decimal point to get a numerical value between 1 and 10. The number of places equals the power of 10. This number is positive if you move the decimal point to the right and negative if you move the decimal point to the left:

56
↖

Many quantities in chemistry are expressed in scientific notation. When performing calculations, you may have to enter a number in scientific notation into a calculator. Be sure you know how to correctly enter a number in scientific notation into your calculator. Different models of calculators require different actions for properly entering scientific notation. If in doubt, consult your instructor immediately.

KEY TAKEAWAYS

- Standard notation expresses a number normally.

- Scientific notation expresses a number as a coefficient times a power of 10.
- The power of 10 is positive for numbers greater than 1 and negative for numbers between 0 and 1.

EXERCISES

1. Express these numbers in scientific notation.

   a. 56.9
   b. 563,100
   c. 0.0804
   d. 0.00000667

2. Express these numbers in scientific notation.

   a. −890,000
   b. 602,000,000,000
   c. 0.0000004099
   d. 0.000000000000011

3. Express these numbers in scientific notation.

   a. 0.00656
   b. 65,600
   c. 4,567,000
   d. 0.000005507

4. Express these numbers in scientific notation.

a. 65

b. −321.09

c. 0.000077099

d. 0.000000000218

5. Express these numbers in standard notation.

 a. 1.381×10^{5}

 b. 5.22×10^{-7}

 c. 9.998×10^{4}

6. Express these numbers in standard notation.

 a. 7.11×10^{-2}

 b. 9.18×10^{2}

 c. 3.09×10^{-10}

7. Express these numbers in standard notation.

 a. 8.09×10^{0}

 b. 3.088×10^{-5}

 c. -4.239×10^{2}

8. Express these numbers in standard notation.

 a. 2.87×10^{-8}

 b. 1.78×10^{11}

 c. 1.381×10^{-23}

9. These numbers are not written in proper scientific notation. Rewrite them so that they are in proper scientific notation.

   a. 72.44×10^{3}
   b. $9,943 \times 10^{-5}$
   c. $588,399 \times 10^{2}$

10. These numbers are not written in proper scientific notation. Rewrite them so that they are in proper scientific notation.

   a. 0.000077×10^{-7}
   b. 0.000111×10^{8}
   c. $602,000 \times 10^{18}$

11. These numbers are not written in proper scientific notation. Rewrite them so that they are in proper scientific notation.

   a. 345.1×10^{2}
   b. 0.234×10^{-3}
   c. $1,800 \times 10^{-2}$

12. These numbers are not written in proper scientific notation. Rewrite them so that they are in proper scientific notation.

   a. $8,099 \times 10^{-8}$
   b. 34.5×10^{0}
   c. 0.000332×10^{4}

13. Write these numbers in scientific notation by counting the number of places the decimal point is moved.

    a. 123,456.78
    b. 98,490
    c. 0.000000445

14. Write these numbers in scientific notation by counting the number of places the decimal point is moved.

    a. 0.000552
    b. 1,987
    c. 0.00000000887

15. Use your calculator to evaluate these expressions. Express the final answer in proper scientific notation.

    a. $456 \times (7.4 \times 10^8) = ?$
    b. $(3.02 \times 10^5) \div (9.04 \times 10^{15}) = ?$
    c. $0.0044 \times 0.000833 = ?$

16. Use your calculator to evaluate these expressions. Express the final answer in proper scientific notation.

    a. $98{,}000 \times 23{,}000 = ?$
    b. $98{,}000 \div 23{,}000 = ?$
    c. $(4.6 \times 10^{-5}) \times (2.09 \times 10^3) = ?$

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17. Use your calculator to evaluate these expressions. Express the final answer in proper scientific notation.

    a. 45 × 132 ÷ 882 = ?

    b. [(6.37 × 10^4) × (8.44 × 10^{-4})] ÷ (3.2209 × 10^{15}) = ?

18. Use your calculator to evaluate these expressions. Express the final answer in proper scientific notation.

    a. (9.09 × 10^8) ÷ [(6.33 × 10^9) × (4.066 × 10^{-7})] = ?

    b. 9,345 × 34.866 ÷ 0.00665 = ?

ANSWERS

1. a. 5.69 × 10^1
   b. 5.631 × 10^5
   c. 8.04 × 10^{-2}
   d. 6.67 × 10^{-6}

3. a. 6.56 × 10^{-3}
   b. 6.56 × 10^4
   c. 4.567 × 10^6
   d. 5.507 × 10^{-6}

5. a. 138,100
   b. 0.000000522
   c. 99,980

7. a. 8.09

b. 0.00003088

c. −423.9

9. a. 7.244×10^4

   b. 9.943×10^{-2}

   c. 5.88399×10^7

11. a. 3.451×10^4

    b. 2.34×10^{-4}

    c. 1.8×10^1

13. a. 1.2345678×10^5

    b. 9.849×10^4

    c. 4.45×10^{-7}

15. a. 3.3744×10^{11}

    b. 3.3407×10^{-11}

    c. 3.665×10^{-6}

17. a. 6.7346×10^0

    b. 1.6691×10^{-14}