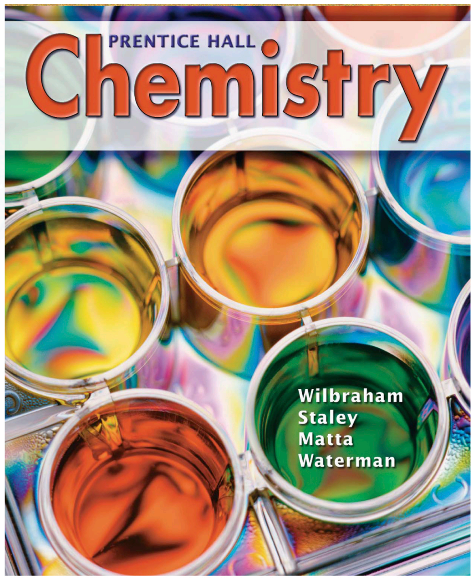


Slide
1 of 48

3.1 Measurements and Their Uncertainty

Connecting to Your World

On January 4, 2004, the Mars Exploration Rover *Spirit* landed on Mars. Each day of its mission, *Spirit* recorded measurements for analysis. In the chemistry laboratory, you must strive for accuracy and precision in your measurements.

Slide
2 of 48

Using and Expressing Measurements

How do measurements relate to science?

A **measurement** is a quantity that has both a number and a unit.

Measurements are fundamental to the experimental sciences. For that reason, it is important to be able to make measurements and to decide whether a measurement is correct.

In **scientific notation**, a given number is written as the product of two numbers: a coefficient and 10 raised to a power.

The number of stars in a galaxy is an example of an estimate that should be expressed in scientific notation.

$200{,}000{,}000{,}000. = 2 \times 10^{11}$

Decimal moves 11 places to the left. Exponent is 11

Accuracy, Precision, and Error

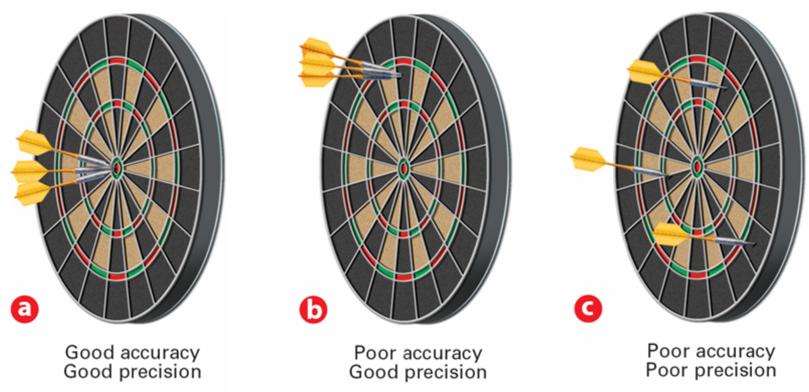
How do you evaluate accuracy and precision?

Accuracy and Precision

- **Accuracy** is a measure of how close a measurement comes to the actual or true value of whatever is measured.
- **Precision** is a measure of how close a series of measurements are to one another.

To evaluate the accuracy of a measurement, the measured value must be compared to the correct value. To evaluate the precision of a measurement, you must compare the values of two or more repeated measurements.

3.1 Measurements and Their Uncertainty > Accuracy, Precision, and Error



Slide 9 of 48

3.1 Measurements and Their Uncertainty > Accuracy, Precision, and Error

Determining Error

- The **accepted value** is the correct value based on reliable references.
- The **experimental value** is the value measured in the lab.
- The difference between the experimental value and the accepted value is called the **error**.

$$\text{Error} = \text{experimental value} - \text{accepted value}$$

Slide 10 of 48

The **percent error** is the absolute value of the error divided by the accepted value, multiplied by 100%.

$$\text{Percent error} = \frac{|\text{error}|}{\text{accepted value}} \times 100\%$$

$$\text{Percent error} = \frac{|99.1°\text{C} - 100.0°\text{C}|}{100.0°\text{C}} \times 100\%$$

$$= \frac{0.9\cancel{°\text{C}}}{100.0\cancel{°\text{C}}} \times 100\%$$

$$= 0.009 \times 100\%$$

$$= 0.9\%$$

Just because a measuring device works, you cannot assume it is accurate. The scale below has not been properly zeroed, so the reading obtained for the person's weight is inaccurate.

Significant Figures in Measurements

Why must measurements be reported to the correct number of significant figures?

Suppose you estimate a weight that is between 2.4 lb and 2.5 lb to be 2.46 lb. The first two digits (2 and 4) are known. The last digit (6) is an estimate and involves some uncertainty. All three digits convey useful information, however, and are called significant figures.

The **significant figures** in a measurement include all of the digits that are known, plus a last digit that is estimated.

Measurements must always be reported to the correct number of significant figures because calculated answers often depend on the number of significant figures in the values used in the calculation.

3.1 Measurements and Their Uncertainty > Significant Figures in Measurements

Rules for determining whether a digit in a measured value is significant:

1. Every nonzero digit in a reported measurement is assumed to be significant. The measurements 24.7 meters, 0.743 meter, and 714 meters each express a measure of length to three significant figures.
2. Zeros appearing between nonzero digits are significant. The measurements 7003 meters, 40.79 meters, and 1.503 meters each have four significant figures.
3. Leftmost zeros appearing in front of nonzero digits are not significant. They act as placeholders. The measurements 0.0071 meter, 0.42 meter, and 0.000 099 meter each have only two significant figures. The zeros to the left are not significant. By writing the measurements in scientific notation, you can eliminate such placeholding zeros: in this case, 7.1×10^{-3} meter, 4.2×10^{-1} meter, and 9.9×10^{-5} meter.
4. Zeros at the end of a number and to the right of a decimal point are always significant. The measurements 43.00 meters, 1.010 meters, and 9.000 meters each have four significant figures.

Slide 17 of 48

3.1 Measurements and Their Uncertainty > Significant Figures in Measurements

Insert Illustration of a sheet of paper listing the six rule... measu... illustra... be a separa...

Rules for determining whether a digit in a measured value is significant:

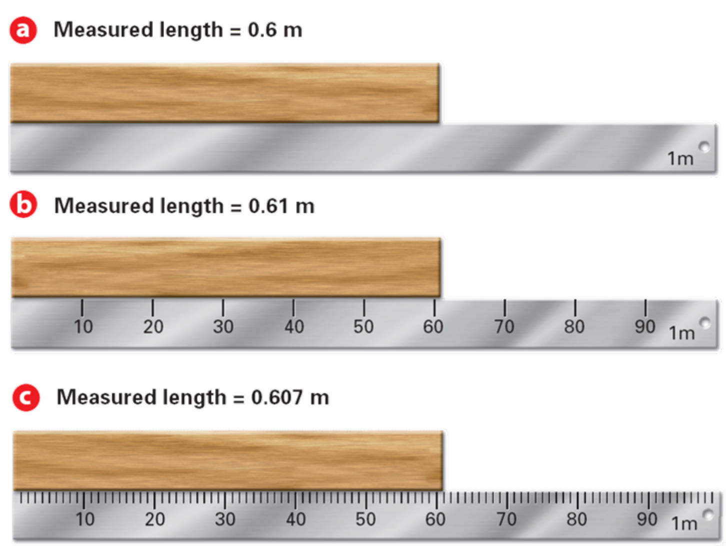
5. Zeros at the rightmost end of a measurement that lie to the left of an understood decimal point are not significant if they serve as placeholders to show the magnitude of the number. The zeros in the measurements 300 meters, 7000 meters, and 27,210 meters are not significant. The numbers of significant figures in these values are one, one, and four, respectively. If such zeros were known measured values, however, then they would be significant. For example, if all of the zeros in the measurement 300 meters were significant, writing the value in scientific notation as 3.00×10^2 meters makes it clear that these zeros are significant.
6. There are two situations in which numbers have an unlimited number of significant figures. The first involves counting. If you count 23 people in your classroom, then there are exactly 23 people, and this value has an unlimited number of significant figures. The second situation involves exactly defined quantities such as those found within a system of measurement. When, for example, you write 60 min = 1 hr, or 100 cm = 1 m, each of these numbers has an unlimited number of significant figures. As you shall soon see, exact quantities do not affect the process of rounding an answer to the correct number of significant figures.

Slide 18 of 48

ChemASAP
click to start

Animation 2

See how the precision of a calculated result depends on the sensitivity of the measuring instruments.



CONCEPTUAL PROBLEM 3.1

Counting Significant Figures in Measurements

How many significant figures are in each measurement?

a. 123 m

b. 40,506 mm

c. 9.8000×10^4 m

d. 22 meter sticks

e. 0.070 80 m

f. 98,000 m

CONCEPTUAL PROBLEM 3.1

1 Analyze *Identify the relevant concepts.*

The location of each zero in the measurement and the location of the decimal point determine which of the rules apply for determining significant figures.

CONCEPTUAL PROBLEM 3.1

2 Solve ***Apply the concepts to this problem.***

All nonzero digits are significant (rule 1). Use rules 2 through 6 to determine if the zeros are significant.

a. three (rule 1) **b.** five (rule 2)
c. five (rule 4) **d.** unlimited (rule 6)
e. four (rules 2, 3, 4) **f.** two (rule 5)

Practice Problems for Conceptual Problem 3.1

2. How many significant figures are in each measurement?

a. 143 grams **b.** 0.074 meter
c. 8.750×10^{-2} gram **d.** 1.072 meter

ChemASAP click to start

Problem Solving 3.2 Solve Problem 2 with the help of an interactive guided tutorial.

Significant Figures in Calculations

How does the precision of a calculated answer compare to the precision of the measurements used to obtain it?

In general, a calculated answer cannot be more precise than the least precise measurement from which it was calculated.

The calculated value must be rounded to make it consistent with the measurements from which it was calculated.

Rounding

To round a number, you must first decide how many significant figures your answer should have. The answer depends on the given measurements and on the mathematical process used to arrive at the answer.

SAMPLE PROBLEM 3.1

Rounding Measurements

Round off each measurement to the number of significant figures shown in parentheses. Write the answers in scientific notation.

a. 314.721 meters (four)

b. 0.001 775 meter (two)

c. 8792 meters (two)

SAMPLE PROBLEM 3.1

Analyze ***Identify the relevant concepts.***

Round off each measurement to the number of significant figures indicated. Then apply the rules for expressing numbers in scientific notation.

SAMPLE PROBLEM 3.1

Solve ***Apply the concepts to this problem.***

Count from the left and apply the rule to the digit immediately to the right of the digit to which you are rounding. The arrow points to the digit immediately following the last significant digit.

a. 314.721 meters
↑
2 is less than 5, so you do not round up.
314.7 meters = 3.147×10^2 meters

b. 0.001 775 meter
↑
7 is greater than 5, so round up.
0.0018 meter = 1.8×10^{-3} meter

c. 8792 meters
↑
9 is greater than 5, so round up
8800 meters = 8.8×10^3 meters

SAMPLE PROBLEM 3.1

Evaluate ***Do the results make sense?***

The rules for rounding and for writing numbers in scientific notation have been correctly applied.

Practice Problems for Sample Problem 3.1

3. Round each measurement to three significant figures. Write your answers in scientific notation.

a. 87.073 meters
b. 4.3621×10^8 meters
c. 0.01552 meter
d. 9009 meters
e. 1.7777×10^{-3} meter
f. 629.55 meters

Addition and Subtraction

The answer to an addition or subtraction calculation should be rounded to the same number of decimal places (not digits) as the measurement with the least number of decimal places.

SAMPLE PROBLEM 3.2

Significant Figures in Addition

Calculate the sum of the three measurements. Give the answer to the correct number of significant figures.

12.52 meters + 349.0 meters + 8.24 meters

SAMPLE PROBLEM 3.2

Analyze ***Identify the relevant concepts.***
Calculate the sum and then analyze each measurement to determine the number of decimal places required in the answer.

SAMPLE PROBLEM 3.2

Solve ***Apply the concepts to this problem.***
Align the decimal points and add the numbers. Round the answer to match the measurement with the least number of decimal places.

$$\begin{array}{rl} 12.52 & \text{meters} \\ 349.0 & \text{meters} \\ +\quad 8.24 & \text{meters} \\ \hline 369.76 & \text{meters} \end{array}$$

The second measurement (349.0 meters) has the least number of digits (one) to the right of the decimal point. Thus the answer must be rounded to one digit after the decimal point. The answer is rounded to 369.8 meters, or 3.698×10^2 meters.

SAMPLE PROBLEM 3.2

Evaluate ***Does the result make sense?***
The mathematical operation has been correctly carried out and the resulting answer is reported to the correct number of decimal places.

Practice Problems for Sample Problem 3.2

6. Find the total mass of three diamonds that have masses of 14.2 grams, 8.73 grams, and 0.912 gram.

Multiplication and Division

- In calculations involving multiplication and division, you need to round the answer to the same number of significant figures as the measurement with the least number of significant figures.
- The position of the decimal point has nothing to do with the rounding process when multiplying and dividing measurements.

SAMPLE PROBLEM 3.3

Significant Figures in Multiplication and Division

Perform the following operations. Give the answers to the correct number of significant figures.

a. 7.55 meters × 0.34 meter

b. 2.10 meters × 0.70 meter

c. 2.4526 meters ÷ 8.4

SAMPLE PROBLEM 3.3

Analyze ***Identify the relevant concepts.***
Perform the required math operation and then analyze each of the original numbers to determine the correct number of significant figures required in the answer.

SAMPLE PROBLEM 3.3

Solve ***Apply the concepts to this problem.***
Round the answers to match the measurement with the least number of significant figures.

a. 7.55 meters $\times$ 0.34 meter = 2.567 (meter)^2 = 2.6 meters^2
(0.34 meter has two significant figures)

b. 2.10 meters $\times$ 0.70 meter = 1.47 (meter)^2 = 1.5 meters^2
(0.70 meter has two significant figures)

c. 2.4526 meters $\div$ 8.4 = 0.291 976 meter = 0.29 meter
(8.4 has two significant figures)

SAMPLE PROBLEM 3.3

Evaluate ***Do the results make sense?***

The mathematical operations have been performed correctly, and the resulting answers are reported to the correct number of places.

Practice Problems for Sample Problem 3.3

8. Calculate the volume of a warehouse that has inside dimensions of 22.4 meters by 11.3 meters by 5.2 meters. (Volume = $l \times w \times h$)