

Chapter 3

Scientific Measurement

3.1 Using and Expressing Measurements

3.2 Units of Measurement

3.3 Solving Conversion Problems

How can you convert U.S. dollars to euros?

Because each country's currency compares differently with the U.S. dollar, knowing how to convert currency units correctly is essential. Conversion problems are readily solved by a problem-solving approach called dimensional analysis.



Conversion Factors



What happens when a measurement is multiplied by a conversion factor?

3.3 Solving Conversion Problems > Conversion Factors

- If you think about any number of everyday situations, you will realize that a quantity can usually be expressed in several different ways.
- For example:
 - 1 dollar = 4 quarters = 10 dimes = 20 nickels = 100 pennies
- These are all expressions, or measurements, of the same amount of money.

3.3 Solving Conversion Problems > Conversion Factors

- The same thing is true of scientific quantities.
- For example:
 - 1 meter = 10 decimeters = 100 centimeters = 1000 millimeters
- These are different ways to express the same length.

3.3 Solving Conversion Problems > Conversion Factors


- Whenever two measurements are equivalent, a ratio of the two measurements will equal 1, or unity.
- For example, you can divide both sides of the equation $1 \text{ m} = 100 \text{ cm}$ by 1 m or by 100 cm .

$$\frac{1 \text{ m}}{1 \text{ m}} = \frac{100 \text{ cm}}{1 \text{ m}} = 1 \quad \text{or} \quad \frac{1 \text{ m}}{100 \text{ cm}} = \frac{100 \text{ cm}}{100 \text{ cm}} = 1$$

3.3 Solving Conversion Problems > Conversion Factors

- The ratios 100 cm/1 m and 1 m/100 cm are examples of conversion factors.
- A **conversion factor** is a ratio of equivalent measurements.


$$\frac{1 \text{ m}}{1 \text{ m}} = \frac{100 \text{ cm}}{1 \text{ m}} = 1 \quad \text{or} \quad \frac{1 \text{ m}}{100 \text{ cm}} = \frac{100 \text{ cm}}{100 \text{ cm}} = 1$$

conversion factors

3.3 Solving Conversion Problems > Conversion Factors

- The measurement in the numerator (on the top) is equivalent to the measurement in the denominator (on the bottom).
- The conversion factors shown below are read “one hundred centimeters per meter” and “one meter per hundred centimeters.”

$$\frac{1 \text{ m}}{1 \text{ m}} = \frac{100 \text{ cm}}{1 \text{ m}} = 1 \quad \text{or} \quad \frac{1 \text{ m}}{100 \text{ cm}} = \frac{100 \text{ cm}}{100 \text{ cm}} = 1$$

conversion factors

3.3 Solving Conversion Problems > Conversion Factors



Smaller number \rightarrow 1 **m** \leftarrow Larger unit

Larger number \rightarrow **100** **cm** \leftarrow Smaller unit

- The figure above illustrates another way to look at the relationships in a conversion factor.
- The smaller number is part of the measurement with the larger unit.
- The larger number is part of the measurement with the smaller unit.

3.3 Solving Conversion Problems > Conversion Factors

- Conversion factors are useful in solving problems in which a given measurement must be expressed in some other unit of measure.

3.3 Solving Conversion Problems > Conversion Factors



When a measurement is multiplied by a conversion factor, the numerical value is generally changed, but the actual size of the quantity measured remains the same.

- For example, even though the numbers in the measurements 1 g and 10 dg (decigrams) differ, both measurements represent the same mass.

3.3 Solving Conversion Problems > Conversion Factors

- In addition, conversion factors within a system of measurement are defined quantities or exact quantities.
- Therefore, they have an unlimited number of significant figures and do not affect the rounding of a calculated answer.

3.3 Solving Conversion Problems > Conversion Factors

- Here are some additional examples of pairs of conversion factors written from equivalent measurements.
- The relationship between grams and kilograms is $1000 \text{ g} = 1 \text{ kg}$.
- The conversion factors are

$$\frac{1000 \text{ g}}{1 \text{ kg}} \quad \text{and} \quad \frac{1 \text{ kg}}{1000 \text{ g}}$$

3.3 Solving Conversion Problems > Conversion Factors

- The figure at right shows a scale that can be used to measure mass in grams or kilograms.
- If you read the scale in terms of grams, you can convert the mass to kilograms by multiplying by the conversion factor $1 \text{ kg}/1000 \text{ g}$.



3.3 Solving Conversion Problems > Conversion Factors

- The relationship between nanometers and meters is given by the equation $10^9 \text{ nm} = 1 \text{ m}$.
- The possible conversion factors are

$$\frac{10^9 \text{ nm}}{1 \text{ m}} \quad \text{and} \quad \frac{1 \text{ m}}{10^9 \text{ nm}}$$

3.3 Solving Conversion Problems > Conversion Factors

- Common volumetric units used in chemistry include the liter and the microliter.
- The relationship $1 \text{ L} = 10^6 \mu\text{L}$ yields the following conversion factors:

$$\frac{1 \text{ L}}{10^6 \mu\text{L}} \quad \text{and} \quad \frac{10^6 \mu\text{L}}{1 \text{ L}}$$

3.3 Solving Conversion Problems >



What is the relationship between the two components of a conversion factor?



What is the relationship between the two components of a conversion factor?

The two components of a conversion factor are equivalent measurements with different units. They are two ways of expressing the same quantity.

Dimensional Analysis



What kinds of problems can you solve using dimensional analysis?

3.3 Solving Conversion Problems > Dimensional Analysis

- Many problems in chemistry are conveniently solved using dimensional analysis, rather than algebra.
- **Dimensional analysis** is a way to analyze and solve problems using the units, or dimensions, of the measurements.
- Sample Problem 3.9 explains dimensional analysis by using it to solve an everyday situation.

Using Dimensional Analysis

How many seconds are in a workday that lasts exactly eight hours?

1 Analyze List the knowns and the unknown.

To convert time in hours to time in seconds, you'll need two conversion factors. First you must convert hours to minutes: $\text{h} \rightarrow \text{min}$. Then you must convert minutes to seconds: $\text{min} \rightarrow \text{s}$. Identify the proper conversion factors based on the relationships $1 \text{ h} = 60 \text{ min}$ and $1 \text{ min} = 60 \text{ s}$.

KNOWNs

time worked = 8 h

1 hour = 60 min

1 minute = 60 s

UNKNOWN

seconds worked = ? s

2 Calculate Solve for the unknown.

The first conversion factor is based on 1 h = 60 min. The unit hours must be in the denominator so that the known unit will cancel.

$$\frac{60 \text{ min}}{1 \text{ h}}$$

2 Calculate Solve for the unknown.

The second conversion factor is based on 1 min = 60 s. The unit minutes must be in the denominator so that the desired units (seconds) will be in your answer.

$$\frac{60 \text{ s}}{1 \text{ min}}$$

3.3 Solving Conversion Problems >

Sample Problem 3.9

2 Calculate Solve for the unknown.

Multiply the time worked by the conversion factors.

Before you do the actual arithmetic, it's a good idea to make sure that the units cancel and that the numerator and denominator of each conversion factor are equal to each other.

$$8 \cancel{\text{h}} \times \frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \times \frac{60 \text{ s}}{1 \cancel{\text{min}}} = 28,000 \text{ s} = 2.8800 \times 10^4 \text{ s}$$

3 Evaluate Does the result make sense?

The answer has the desired unit (s). Since the second is a small unit of time, you should expect a large number of seconds in 8 hours. The answer is exact since the given measurement and each of the conversion factors is exact.

3.3 Solving Conversion Problems > Dimensional Analysis

- As you read Sample Problem 3.10, you might see how the same problem could be solved algebraically but is more easily solved using dimensional analysis.
- Try to be flexible in your approach to problem solving, as no single method is best for solving every type of problem.

Using Dimensional Analysis

The directions for an experiment ask each student to measure 1.84 g of copper (Cu) wire. The only copper wire available is a spool with a mass of 50.0 g. How many students can do the experiment before the copper runs out?

1 Analyze List the knowns and the unknown.

From the known mass of copper, use the appropriate conversion factor to calculate the number of students who can do the experiment. The desired conversion is mass of copper \rightarrow number of students.

KNOWNs

mass of copper available = 50.0 g Cu

Each student needs 1.84 grams of copper.

UNKNOWN

number of students = ?

2 Calculate Solve for the unknown.

The experiment calls for 1.84 grams of copper per student. Based on this relationship, you can write two conversion factors.

$$\frac{1.84 \text{ g Cu}}{1 \text{ student}} \quad \text{and} \quad \frac{1 \text{ student}}{1.84 \text{ g Cu}}$$

2 Calculate Solve for the unknown.

Because the desired unit for the answer is students, use the second conversion factor. Multiply the mass of copper by the conversion factor.

$$50.0 \text{ g Cu} \times \frac{1 \text{ student}}{1.84 \text{ g Cu}} = 27.174 \text{ students} = 27 \text{ students}$$

Note that because students cannot be fractional, the answer is rounded down to a whole number.

3 Evaluate Does the result make sense?

The unit of the answer (students) is the one desired. You can make an approximate calculation using the following conversion factor.

$$\frac{1 \text{ student}}{2 \text{ g Cu}}$$

Multiplying the above conversion factor by 50 g Cu gives the approximate answer of 25 students, which is close to the calculated answer.

If the exchange rate between U.S. dollars and euros is 0.7 euro to every dollar, what is the conversion factor that allows you to convert from U.S. dollars to euros?

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The conversion factor to convert from U.S. dollars to euros would be

$$\frac{0.7 \text{ euro}}{1 \text{ U.S. dollar}}$$

3.3 Solving Conversion Problems > Dimensional Analysis

Simple Unit Conversions

- In chemistry, as in everyday life, you often need to express a measurement in a unit different from the one given or measured initially.



Dimensional analysis is a powerful tool for solving conversion problems in which a measurement with one unit is changed to an equivalent measurement with another unit.

Converting Between Metric Units

Express 750 dg in grams. (Refer to Table 3.2 if you need to refresh your memory of metric prefixes.)



1 **Analyze** List the knowns and the unknown.

The desired conversion is decigrams \rightarrow grams.
Multiply the given mass by the proper conversion factor.

KNOWNs

mass = 750 dg

1 g = 10 dg

UNKNOWN

mass = ? g

2 Calculate Solve for the unknown.

Use the relationship $1 \text{ g} = 10 \text{ dg}$ to write the correct conversion factor.

$$\frac{1 \text{ g}}{10 \text{ dg}}$$

Note that the known unit (dg) is in the denominator and the unknown unit (g) is in the numerator.

2 Calculate Solve for the unknown.

Multiply the known mass by the conversion factor.

$$750 \cancel{\text{ dg}} \times \frac{1 \text{ g}}{10 \cancel{\text{ dg}}} = 75 \text{ g}$$

3 Evaluate Does the result make sense?

Because the unit gram represents a larger mass than the unit decigram, it makes sense that the number of grams is less than the given number of decigrams. The answer has the correct unit (dg) and the correct number of significant figures.

Using Density as a Conversion Factor

What is the volume of a pure silver coin that has a mass of 14 g? The density of silver (Ag) is 10.5 g/cm^3 .

Density can be used to write two conversion factors. To figure out which one you need, consider the units of your given quantity and the units needed in your answer.



1 **Analyze** List the knowns and the unknown.

You need to convert the mass of the coin into a corresponding volume. The density gives you the following relationship between volume and mass: $1 \text{ cm}^3 \text{ Ag} = 10.5 \text{ g Ag}$. Multiply the given mass by the proper conversion factor to yield an answer in cm^3 .

KNOWN

mass = 14 g

density of silver = 10.5 g/cm^3

UNKNOWN

volume of a coin = ? cm^3

2 Calculate Solve for the unknown.

Use the relationship $1 \text{ cm}^3 \text{ Ag} = 10.5 \text{ g Ag}$ to write the correct conversion factor.

$$\frac{1 \text{ cm}^3 \text{ Ag}}{10.5 \text{ g Ag}}$$

Notice that the known unit (g) is in the denominator and the unknown unit (cm^3) is in the numerator.

2 Calculate Solve for the unknown.

Multiply the mass of the coin by the conversion factor.

$$14 \text{ g Ag} \times \frac{1 \text{ cm}^3 \text{ Ag}}{10.5 \text{ g Ag}} = 1.3 \text{ cm}^3 \text{ Ag}$$

3 Evaluate Does the result make sense?

Because a mass of 10.5 g of silver has a volume of 1 cm³, it makes sense that 14.0 g of silver should have a volume slightly larger than 1 cm³. The answer has two significant figures because the given mass has two significant figures.

Multistep Problems

- Many complex tasks in your life are best handled by breaking them down into smaller, manageable parts.
- Similarly, many complex word problems are more easily solved by breaking the solution down into steps.
- When converting between units, it is often necessary to use more than one conversion factor.

Converting Between Metric Units

The diameter of a sewing needle is 0.073 cm.
What is the diameter in micrometers?

1 Analyze List the knowns and the unknown.

The desired conversion is centimeters \rightarrow micrometers. The problem can be solved in a two-step conversion. First change centimeters to meters; then change meters to micrometers: centimeters \rightarrow meters \rightarrow micrometers.

KNOWNs

$$\text{length} = 0.073 \text{ cm} = 7.3 \times 10^{-2} \text{ cm}$$

$$10^2 \text{ cm} = 1 \text{ m}$$

$$1 \text{ m} = 10^6 \mu\text{m}$$

UNKNOWN

$$\text{length} = ? \mu\text{m}$$

2 Calculate Solve for the unknown.

Use the relationship $10^2 \text{ cm} = 1 \text{ m}$ to write the first conversion factor.

$$\frac{1 \text{ m}}{10^2 \text{ cm}}$$

Each conversion factor is written so that the unit in the denominator cancels the unit in the numerator of the previous factor.

2 Calculate Solve for the unknown.

Use the relationship $1 \text{ m} = 10^6 \mu\text{m}$ to write the second conversion factor.

$$\frac{10^6 \mu\text{m}}{1 \text{ m}}$$

2 Calculate Solve for the unknown.

Multiply the known length by the conversion factors.

$$7.3 \times 10^{-2} \text{ cm} \times \frac{1 \text{ m}}{10^2 \text{ cm}} \times \frac{10^6 \text{ } \mu\text{m}}{1 \text{ m}} = 7.3 \times 10^2 \text{ } \mu\text{m}$$

3 Evaluate Does the result make sense?

Because a micrometer is a much smaller unit than a centimeter, the answer should be numerically larger than the given measurement. The units have canceled correctly, and the answer has the correct number of significant figures.

Converting Ratios of Units

The density of manganese (Mn), a metal, is 7.21 g/cm^3 . What is the density of manganese expressed in units of kg/m^3 ?

1 Analyze List the knowns and the unknown.

The desired conversion is $\text{g/cm}^3 \rightarrow \text{kg/m}^3$. The mass unit in the numerator must be changed from grams to kilograms: $\text{g} \rightarrow \text{kg}$. In the denominator, the volume unit must be changed from cubic centimeters to cubic meters: $\text{cm}^3 \rightarrow \text{m}^3$. Note that the relationship $10^6 \text{ cm}^3 = 1 \text{ m}^3$ was derived by cubing the relationship $10^2 \text{ cm} = 1 \text{ m}$. That is, $(10^2 \text{ cm})^3 = (1\text{m})^3$, or $10^6 \text{ cm}^3 = 1 \text{ m}^3$.

KNOWNs

density of Mn = 7.21 g/cm^3

$$10^3 \text{ g} = 1 \text{ kg}$$

$$10^6 \text{ cm}^3 = 1 \text{ m}^3$$

UNKNOWN

density of Mn = ? kg/m^3

2 Calculate Solve for the unknown.

Multiply the known density by the correct conversion factors.

$$\frac{7.21 \cancel{\text{g}}}{1 \cancel{\text{cm}^3}} \times \frac{1 \text{ kg}}{10^3 \cancel{\text{g}}} \times \frac{10^6 \cancel{\text{cm}^3}}{1 \text{ m}^3} = 7.21 \times 10^3 \text{ kg/m}^3$$

3 Evaluate Does the result make sense?

Because the physical size of the volume unit m^3 is so much larger than cm^3 (10^6 times), the calculated value of the density should be larger than the given value even though the mass unit is also larger (10^3 times). The units cancel, the conversion factors are correct, and the answer has the correct ratio of units.

3.3 Solving Conversion Problems >



What kind of problems can you solve using dimensional analysis?



What kind of problems can you solve using dimensional analysis?

Problems that require the conversion of a measurement from one unit to another can be solved using dimensional analysis.

3.3 Solving Conversion Problems > Key Concepts



When a measurement is multiplied by a conversion factor, the numerical value is generally changed, but the actual size of the quantity measured remains the same.



Dimensional analysis is a powerful tool for solving conversion problems in which a measurement with one unit is changed to an equivalent measurement with another unit.

3.3 Solving Conversion Problems > Glossary Terms

- **conversion factor**: a ratio of equivalent measurements used to convert a quantity from one unit to another
- **dimensional analysis**: a technique of problem-solving that uses the units that are part of a measurement to help solve the problem

3.3 Solving Conversion Problems >

BIG IDEA

Dimensional analysis is a problem-solving method that involves analyzing the units of the given measurement and the unknown to plan a solution.

3.3 Solving Conversion Problems >

END OF 3.3