Classification of Matter

1.1

**Matter** is anything that has mass and occupies space.

**Chemistry** is the study of the composition of matter and the changes that matter undergoes.

**Because living and nonliving things are made of matter, chemistry affects all aspects of life and most natural events.**

**Five traditional areas of study are**

* + - **organic chemistry**
    - **inorganic chemistry**
    - **biochemistry**
    - **analytical chemistry**
    - **physical chemistry**
* **Organic chemistry** is defined as the study of all chemicals containing carbon.
* **Inorganic chemistry** is the study of chemicals that, in general, do not contain carbon.
* The study of processes that take place in organisms is **biochemistry.**
* **Analytical chemistry** is the area of study that focuses on the composition of matter.
* **Physical chemistry** is the area that deals with the mechanism, the rate, and the energy transfer that occurs when matter undergoes a change.

**Pure chemistry** is the pursuit of chemical knowledge for its own sake.

**Applied chemistry** is research that is directed toward a practical goal or application.

**Pure research can lead directly to an application, but an application can exist before research is done to explain how it works.**

2

2.1

**Properties used to describe matter can be classified as extensive or intensive.**

**Extensive Properties**

* + - * The **mass** of an object is a measure of the amount of matter the object contains.
      * The **volume** of an object is a measure of the space occupied by the object.
      * An **extensive property** is a property that depends on the amount of matter in a sample.

**Intensive Properties**

An **intensive property** is a property that depends on the type of matter in a sample, not the amount of matter. The hardness of a bowling ball is an example of an intensive property.

Matter that has a uniform and definite composition is called a **substance**. These kettles are mainly copper. Copper is an example of a substance.

**Every sample of a given substance has identical intensive properties because every sample has the same composition.**

A **physical property** is a quality or condition of a substance that can be observed or measured without changing the substance’s composition.

Hardness, color, conductivity, and malleability are examples of physical properties.

**Three states of matter are solid, liquid, and gas.**

**Solids**

A **solid** is a form of matter that has a definite shape and volume.

**Liquid**

A **liquid** is a form of matter that has an indefinite shape, flows, yet has a fixed volume.

**Gases**

A **gas** is a form of matter that takes both the shape and volume of its container.

**Vapor** describes the gaseous state of a substance that is generally a liquid or solid at room temperature, as in water vapor.

**Physical Changes**

During a **physical change**, some properties of a material change, but the composition of the material does not change.

As gallium melts in a person’s hand, the shape of the sample changes, but the composition of the material does not change.

**Physical changes can be classified as reversible or irreversible.**

* + - * + All physical changes that involve a change from one state to another are reversible.
        + Cutting hair, filing nails, and cracking an egg are examples of irreversible physical changes.

**2.2  
Classifying Mixtures**

A **mixture** is a physical blend of two or more components.

A salad bar provides a range of items. Customers choose how much of each item to use in their salads. Each salad has a different composition.

**Based on the distribution of their components, mixtures can be classified as heterogeneous mixtures or as homogeneous mixtures.**

**Heterogeneous Mixtures**

A mixture in which the composition is not uniform throughout is a **heterogeneous mixture**.

**Homogeneous Mixtures**

A mixture in which the composition is uniform throughout is a **homogeneous mixture.**

Another name for a homogeneous mixture is a **solution.**

The term **phase** is used to describe any part of a sample with uniform composition and properties.

* + - * A homogenous mixture consists   
        of a single phase.
      * A heterogeneous mixture consists of two or more phases.
* When oil and vinegar are mixed they form layers, or phases. The oil phase floats on the water phase.

**Separating Mixtures**

**Differences in physical properties can be used to separate mixtures.**

**Filtration**

The process that separates a solid from the liquid in a heterogeneous mixture is called **filtration**.

A colander is used to separate pasta from the water in which it was cooked. This process is a type of filtration.

**Distillation**

During a **distillation**, a liquid is boiled to produce a vapor that is then condensed into a liquid.

2.3

**Distinguishing Elements and Compounds**

An **element** is the simplest form of matter that has a unique set of properties.

A **compound** is a substance that contains two or more elements chemically combined in a fixed proportion.

**Compounds can be broken down into simpler substances by chemical means, but elements cannot.**

**Breaking Down Compounds**

A **chemical change** is a change that produces matter with a different composition than the original matter.

When table sugar is heated, it goes through a series of chemical changes. **The final products of these chemical changes are solid carbon and water vapor.**

**Properties of Compounds**

In general, the properties of compounds are quite different from those of their component elements.

When the elements sodium and chlorine combine chemically to form sodium chloride, there is a change in composition and a change in properties.

**Distinguishing Substances and Mixtures**

**If the composition of a material is fixed, the material is a substance. If the composition of a material may vary, the material is a mixture.**

**Symbols and Formulas**

**Chemists use chemical symbols to represent elements, and chemical formulas to represent compounds. Each element is represented by a one or two-letter chemical symbol.**

2.4

**Chemical Changes**

The ability of a substance to undergo a specific chemical change is called a **chemical property.**

Chemical properties can be used to identify a substance. But chemical properties can be observed only when a substance undergoes a chemical change.

**During a chemical change, the composition of matter always changes.**

Recall that during a physical change, the composition of matter never changes.

A magnet separates iron from sulfur. This is an example of a physical change.

A mixture of iron and sulfur is heated. The iron and sulfur react and form iron sulfide. This is an example of a chemical change.

* + - * A chemical change is also called a chemical reaction.
      * One or more substances change into one or more new substances during a **chemical reaction.**
      * A substance present at the start of the reaction is a **reactant.**
      * A substance produced in the reaction is a **product.**

**Recognizing Chemical Changes**

**Possible clues to chemical change include:**

* + - **a transfer of energy**
    - **a change in color**
    - **the production of a gas**
    - **the formation of a precipitate.**
* A **precipitate** is a solid that forms and settles out of a liquid mixture.

**Conservation of Mass**

**During any chemical reaction, the mass of the products is always equal to the mass of the reactants.**

The **law of conservation of mass** states that in any physical change or chemical reaction, mass is conserved.

The conservation of mass is easily observed when a change occurs in a closed container.

6.1

**Searching For an Organizing Principle**

**Chemists used the properties of elements to sort them into groups.**

Chlorine, bromine, and iodine have very similar chemical properties.

**Mendeleev’s Periodic Table**

**Mendeleev arranged the elements in his periodic table in order of increasing atomic mass.**

The periodic table can be used to predict the properties of undiscovered elements.

**The Periodic Law**

**In the modern periodic table, elements are arranged in order of increasing atomic number.**

The **periodic law:** When elements are arranged in order of increasing atomic number, there is a periodic repetition of their physical and chemical properties.

* + - * The properties of the elements within a period change as you move across a period from left to right.
      * The pattern of properties within a period repeats as you move from one period to the next.

**Metals, Nonmetals, and Metalloids**

**Three classes of elements are metals, nonmetals, and metalloids.**

Across a period, the properties of elements become less metallic and more nonmetallic.

**Metals**

**Metals** are good conductors of heat and electric current.

* + - * 80% of elements are metals.
      * Metals have a high luster, are ductile, and are malleable.

**Nonmetals**

In general, **nonmetals** are poor conductors of heat and electric current.

* + - * Most nonmetals are gases at room temperature.
      * A few nonmetals are solids, such as sulfur and phosphorus.
      * One nonmetal, bromine, is a dark-red liquid.

**Metalloids**

A **metalloid** generally has properties that are similar to those of metals and nonmetals.

The behavior of a metalloid can be controlled by changing conditions.

6.2

**Squares in the Periodic Table**

**The periodic table displays the symbols and names of the elements, along with information about the structure of their atoms.**

The background colors in the squares are used to distinguish groups of elements.

* + - * The Group 1A elements are called **alkali metals.**
      * The Group 2A elements are called **alkaline earth metals.**
      * The nonmetals of Group 7A are called **halogens.**

**Electron Configurations in Groups**

**Elements can be sorted into noble gases, representative elements, transition metals, or inner transition metals based on their electron configurations.**

**The Noble Gases**

The **noble gases** are the elements in Group 8A of the periodic table. The electron configurations for the first four noble gases in Group 8A are listed below.

**The Representative Elements**

Elements in groups 1A through 7A are often referred to as **representative elements** because they display a wide range of physical and chemical properties.

* + - * The *s* and *p* sublevels of the highest occupied energy level are not filled.
      * The group number equals the number of electrons in the highest occupied energy level.

In atoms of the Group 1A elements below, there is only one electron in the highest occupied energy level.

In atoms of the Group 4A elements below, there are four electrons in the highest occupied energy level.

**Transition Elements**

There are two types of transition elements—transition metals and inner transition metals. They are classified based on their electron configurations.

In atoms of a **transition metal**, the highest occupied *s* sublevel and a nearby *d* sublevel contain electrons.

In atoms of an **inner transition metal**, the highest occupied *s* sublevel and a nearby *f* sublevel generally contain electrons.

Underlying Structure of Matter

4.1

**Early Models of the Atom**

* + - * An **atom** is the smallest particle of an element that retains its identity in a chemical reaction.
      * Philosophers and scientists have proposed many ideas on the structure of atoms.

**Democritus’s Atomic Philosophy**

**Democritus believed that atoms were indivisible and indestructible.**

Democritus’s ideas were limited because they didn’t explain chemical behavior and they lacked experimental support.

**Dalton’s Atomic Theory**

**By using experimental methods, Dalton transformed Democritus’s ideas on atoms into a scientific theory.**

The result was **Dalton’s atomic theory. All elements are composed of tiny indivisible particles called atoms.**

**Atoms of the same element are identical. The atoms of any one element are different from those of any other element.**

**Atoms of different elements can physically mix together or can chemically combine in simple whole-number ratios to form compounds.**

**Chemical reactions occur when atoms are separated, joined, or rearranged. Atoms of one element are never changed into atoms of another element in a chemical reaction.**

**Sizing up the Atom**

**Despite their small size, individual atoms are observable with instruments such as scanning tunneling microscopes.**

**4.2**

**Subatomic Particles**

**Three kinds of subatomic particles are electrons, protons, and neutrons.**

**Electrons**

In 1897, the English physicist J. J. Thomson (1856–1940) discovered the electron. **Electrons** are negatively charged subatomic particles.

Thomson performed experiments that involved passing electric current through gases at low pressure.   
  
The result was a glowing beam, or **cathode ray**, that traveled from the cathode to the anode. A cathode ray is deflected by a magnet. Thomson concluded that a cathode ray is a stream of electrons. Electrons are parts of the atoms of all elements.

**Protons and Neutrons**

In 1886, Eugen Goldstein (1850–1930) observed a cathode-ray tube and found rays traveling in the direction opposite to that of the cathode rays. He concluded that they were composed of positive particles.

Such positively charged subatomic particles are called **protons**.

In 1932, the English physicist James Chadwick (1891–1974) confirmed the existence of yet another subatomic particle: the neutron.

**Neutrons** are subatomic particles with no charge but with a mass nearly equal to that of a proton.

**The Atomic Nucleus**

J.J. Thompson and others supposed the atom was filled with positively charged material and the electrons were evenly distributed throughout.

This model of the atom turned out to be short-lived, however, due to the work of Ernest Rutherford (1871–1937).

**Rutherford’s Gold-Foil Experiment**

In 1911, Rutherford and his coworkers at the University of Manchester, England, directed a narrow beam of alpha particles at a very thin sheet of gold foil.

**The Rutherford Atomic Model**

Rutherford concluded that the atom is mostly empty space. All the positive charge and almost all of the mass are concentrated in a small region called the nucleus.

The **nucleus** is the tiny central core of an atom and is composed of protons and neutrons.

**In the nuclear atom, the protons and neutrons are located in the nucleus.   
The electrons are distributed around the nucleus and occupy almost all the volume of the atom.**

4.3

**Atomic Number**

**Elements are different because they contain different numbers of protons.**

The **atomic number** of an element is the number of protons in the nucleus of an atom of that element.

**Mass Number**

The total number of protons and neutrons in an atom is called the **mass number.**

**The number of neutrons in an atom is the difference between the mass number and atomic number.**

**Isotopes**

**Isotopes** are atoms that have the same number of protons but different numbers of neutrons.

**Because isotopes of an element have different numbers of neutrons, they also have different mass numbers.**

Despite these differences, isotopes are chemically alike because they have identical numbers of protons and electrons.

**Atomic Mass**

It is useful to to compare the relative masses of atoms to a standard reference isotope. Carbon-12 is the standard reference isotope. Cabon-12 has a mass of exactly 12 atomic mass units.

An **atomic mass unit (amu)** is defined as one twelfth of the mass of a carbon-12 atom.

The **atomic mass** of an element is a weighted average mass of the atoms in a naturally occurring sample of the element.

A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

**To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.**

For example, carbon has two stable isotopes:

* + - * Carbon-12, which has a natural abundance of 98.89%, and
      * Carbon-13, which has a natural abundance of 1.11%.

**The Periodic Table—A Preview**

A **periodic table** is an arrangement of elements in which the elements are separated into groups based on a set of repeating properties.

**A periodic table allows you to easily compare the properties of one element (or a group of elements) to another element (or group of elements).**

Each horizontal row of the periodic table is called a **period**.

Within a given period, the properties of the elements vary as you move across it from element to element.

Each vertical column of the periodic table is called a **group**, or family.

Elements within a group have similar chemical and physical properties.

5.1

**The Development of Atomic Models**

**Rutherford’s atomic model could not explain the chemical properties of elements.**

Rutherford’s atomic model could not explain why objects change color when heated.

**The Bohr Model**

**Bohr proposed that an electron is found only in specific circular paths, or orbits, around the nucleus.**

Each possible electron orbit in Bohr’s model has a fixed energy.

* + - * The fixed energies an electron can have are called **energy levels.**
      * A **quantum** of energy is the amount of energy required to move an electron from one energy level to another energy level.
* Like the rungs of the strange ladder, the energy levels in an atom are not equally spaced.
* The higher the energy level occupied by an electron, the less energy it takes to move from that energy level to the next higher energy level.

**The Quantum Mechanical Model**

**The quantum mechanical model determines the allowed energies an electron can have and how likely it is to find the electron in various locations around the nucleus.**

Austrian physicist Erwin Schrödinger (1887–1961) used new theoretical calculations and results to devise and solve a mathematical equation describing the behavior of the electron in a hydrogen atom.

The modern description of the electrons in atoms, the **quantum mechanical model**, comes from the mathematical solutions to the Schrödinger equation.

The propeller blade has the same probability of being anywhere in the blurry region, but you cannot tell its location at any instant. The electron cloud of an atom can be compared to a spinning airplane propeller.

In the quantum mechanical model, the probability of finding an electron within a certain volume of space surrounding the nucleus can be represented as a fuzzy cloud. The cloud is more dense where the probability of finding the electron is high.

**Atomic Orbitals**

An **atomic orbital** is often thought of as a region of space in which there is a high probability of finding an electron.

**Each energy sublevel corresponds to an orbital of a different shape, which describes where the electron is likely to be found.**

Different atomic orbitals are denoted by letters. The *s* orbitals are spherical, and *p* orbitals are dumbbell-shaped.

Four of the five *d* orbitals have the same shape but different orientations in space.

The numbers and kinds of atomic orbitals depend on the energy sublevel.

5.2

**Electron Configurations**

The ways in which electrons are arranged in various orbitals around the nuclei of atoms are called **electron configurations.**

**Three rules—the aufbau principle, the Pauli exclusion principle, and Hund’s rule—tell you how to find the electron configurations of atoms.**

**Aufbau Principle**

According to the **aufbau principle**, electrons occupy the orbitals of lowest energy first. In the aufbau diagram below, each box represents an atomic orbital.

**Pauli Exclusion Principle**

According to the **Pauli exclusion principle**, an atomic orbital may describe at most two electrons. To occupy the same orbital, two electrons must have opposite spins; that is, the electron spins must be paired.

**Hund’s Rule**

**Hund’s rule** states that electrons occupy orbitals of the same energy in a way that makes the number of electrons with the same spin direction as large as possible.

**Orbital Filling Diagram**

**Exceptional Electron Configurations**

**Why do actual electron configurations for some elements differ from those assigned using the aufbau principle?**

**Some actual electron configurations differ from those assigned using the aufbau principle because half-filled sublevels are not as stable as filled sublevels, but they are more stable than other configurations.**

Exceptions to the aufbau principle are due to subtle electron-electron interactions in orbitals with very similar energies.

Copper has an electron configuration that is an exception to the aufbau principle.

6.3

**Trends in Atomic Size**

The **atomic radius** is one half of the distance between the nuclei of two atoms of the same element when the atoms are joined.

**Group and Periodic Trends in Atomic Size**

**In general, atomic size increases from top to bottom within a group and decreases from left to right across a period.**

**Ions**

**Positive and negative ions form when electrons are transferred between atoms.**

Some compounds are composed of particles called ions.

* + - * An **ion** is an atom or group of atoms that has a positive or negative charge.
      * A **cation** is an ion with a positive charge.
      * An **anion** is an ion with a negative charge.

**Trends in Ionization Energy**

The energy required to remove an electron from an atom is called **ionization energy**.

* + - * The energy required to remove the first electron from an atom is called the first ionization energy.
      * The energy required to remove an electron from an ion with a 1+ charge is called the second ionization energy.

**Group and Periodic Trends in Ionization Energy**

* **First ionization energy tends to decrease from top to bottom within a group and increase from left to right across a period.**

**Trends in Ionic Size**

During reactions between metals and nonmetals, metal atoms tend to lose electrons, and nonmetal atoms tend to gain electrons. The transfer has a predictable effect on the size of the ions that form.

**Cations are always smaller than the atoms from which they form. Anions are always larger than the atoms from which they form.**

**Trends in Electronegativity**

**Electronegativity** is the ability of an atom of an element to attract electrons when the atom is in a compound.

**In general, electronegativity values decrease from top to bottom within a group. For representative elements, the values tend to increase from left to right across a period.**

**Summary of Trends**

**The trends that exist among these properties can be explained by variations in atomic structure.**

7.1

**Valence Electrons**

**Valence electrons** are the electrons in the highest occupied energy level of an element’s atoms.

The number of valence electrons largely determines the chemical properties of an element.

**To find the number of valence electrons in an atom of a representative element, simply look at its group number.**

**Electron dot structures** are diagrams that show valence electrons as dots.

**The Octet Rule**

Noble gases, such as neon and argon, are unreactive in chemical reactions. In 1916, chemist Gilbert Lewis used this fact to explain why atoms form certain kinds of ions and molecules.

He called his explanation the **octet rule:** In forming compounds, atoms tend to achieve the electron configuration of a noble gas.

**Atoms of metals tend to lose their valence electrons, leaving a complete octet in the next-lowest energy level. Atoms of some non-metals tend to gain electrons or to share electrons with another nonmetal to achieve a complete octet.**

**Formation of Cations**

**An atom’s loss of valence electrons produces a cation, or a positively charged ion.**

The most common cations are those produced by the loss of valence electrons from metal atoms.

You can represent the electron loss, or ionization, of the sodium atom by drawing the complete electron configuration of the atom and of the ion formed.

The electron configuration of the sodium ion is the same as that of a neon atom.

Using electron dot structures, you can show the ionization more simply.

Cations of Group 1A elements always have a charge of 1+. Cations of group 2A elements always have a charge of 2+.

**Formation of Anions**

**The gain of negatively charged electrons by a neutral atom produces an anion.**

* + - * + An anion is an atom or a group of atoms with a negative charge.
        + The name of an anion typically ends in -*ide*.

A gain of one electron gives chlorine an octet and converts a chlorine atom into a chloride ion. It has the same electron configuration as the noble gas argon.

The ions that are produced when atoms of chlorine and other halogens gain electrons are called **halide ions**.

* + - * All halogen atoms have seven valence electrons.
      * All halogen atoms need to gain only one electron to achieve the electron configuration of a noble gas.

Chemistry10.1

The Mole: A Measurement of Matter

You could measure the amount of sand in a sand sculpture by counting each grain of sand, but it would be much easier to weigh the sand. You’ll discover how chemists measure the amount of a substance using a unit called a mole, which relates the number of particles to the mass.

Measuring Matter

What are three methods for measuring the amount of something?

You often measure the amount of something by one of three different methods—by count, by mass, and by volume.

What Is a Mole?

How is Avogadro’s number related to a mole of any substance?

A mole of any substance contains Avogadro’s number of representative particles, or 6.02  1023 representative particles.

The term representative particle refers to the species present in a substance: usually atoms, molecules, or formula units.

Converting Number of Particles to Moles

One mole (mol) of a substance is 6.02  1023 representative particles of that substance and is the SI unit for measuring the amount of a substance.

The number of representative particles in a mole, 6.02  1023, is called Avogadro’s number.

The Mass of a Mole of an Element

How is the atomic mass of an element related to the molar mass of an element?

The atomic mass of an element expressed in grams is the mass of a mole of the element.

The mass of a mole of an element is its molar mass.

Find out how Avogadro’s number is based on the relationship between the amu and the gram.

The Mass of a Mole of a Compound

How is the mass of a mole of a compound calculated?

To calculate the molar mass of a compound, find the number of grams of each element in one mole of the compound. Then add the masses of the elements in the compound.

Chemistry 11.1

Describing Chemical Reactions

On May 6, 1937, the huge airship Hindenburg erupted into a fireball. Within a short time, 210,000 cubic meters of hydrogen had burned and the airship was destroyed. The chemical reaction that occurred is “hydrogen combines with oxygen to produce water.” You will learn to represent this chemical reaction by a chemical equation.

Writing Chemical Equations

Word Equations

To write a word equation, write the names of the reactants to the left of the arrow separated by plus signs; write the names of the products to the right of the arrow, also separated by plus signs.

Reactant + Reactant  Product + Product

Writing Chemical Equations

Methane + Oxygen  Carbon dioxide + Water

iron + oxygen  iron(III) oxide

Hydrogen Peroxide  Water and Oxygen

Chemical Equations

A chemical equation is a representation of a chemical reaction; the formulas of the reactants (on the left) are connected by an arrow with the formulas of the products (on the right).

How do you write a skeleton equation?

Write the formulas of the reactants to the left of the yields sign (arrow) and the formulas of the products to the right.

A skeleton equation is a chemical equation that does not indicate the relative amounts of the reactants and products.

Here is the equation for rusting:

Fe + O2  Fe2O3

A catalyst is a substance that speeds up the reaction but is not used up in the reaction.

Balancing Chemical Equations

What are the steps in writing a balanced chemical equation?

To write a balanced chemical equation, first write the skeleton equation. Then use coefficients to balance the equation so that it obeys the law of conservation of mass.

This is a balanced equation for making a bicycle. The numbers are called coefficients—small whole numbers that are placed in front of the formulas in an equation in order to balance it.

A chemical reaction is also described by a balanced equation in which each side of the equation has the same number of atoms of each element and mass is conserved.

Chemistry 12.1

The Arithmetic of Equations

More than 3000 cocoons are needed to produce enough silk to make just one elegant Japanese kimono. Like silk manufacturers, chemists must know how much reactant they need to make a certain amount of product. Determining the quantities of reactants and products in a reaction requires a balanced chemical equation.

Using Everyday Equations

How is a balanced equation like a recipe?

A balanced chemical equation provides the same kind of quantitative information that a recipe does.

An equation can represent the manufacturing of a single tricycle.

Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.

The calculation of quantities in chemical reactions is a subject of chemistry called stoichiometry.

Interpreting Chemical Equations

In terms of what quantities can you interpret a balanced chemical equation?

A balanced chemical equation can be interpreted in terms of different quantities, including numbers of atoms, molecules, or moles; mass; and volume.

Mass Conservation in Chemical Reactions

What quantities are conserved in every chemical reaction?

Mass and atoms are conserved in every chemical reaction.

Chemistry 3.2

The International System of Units

In the signs shown here, the distances are listed as numbers with no units attached. Without the units, it is impossible to communicate the measurement to others. When you make a measurement, you must assign the correct units to the numerical value.

Which five SI base units do chemists commonly use?

All measurements depend on units that serve as reference standards. The standards of measurement used in science are those of the metric system.

The International System of Units (abbreviated SI, after the French name, Le Système International d’Unités) is a revised version of the metric system.

The five SI base units commonly used by chemists are the meter, the kilogram, the kelvin, the second, and the mole.

Units and Quantities

What metric units are commonly used to measure length, volume, mass, temperature and energy?

Units of Length

In SI, the basic unit of length, or linear measure, is the meter (m). For very large or and very small lengths, it may be more convenient to use a unit of length that has a prefix. Common metric units of length include the centimeter, meter, and kilometer.

Units of Volume

The SI unit of volume is the amount of space occupied by a cube that is 1 m along each edge. This volume is the cubic meter (m)3. A more convenient unit of volume for everyday use is the liter, a non-SI unit. A liter (L) is the volume of a cube that is 10 centimeters (10 cm) along each edge (10 cm  10 cm  10 cm = 1000 cm3 = 1 L).

Common metric units of volume include the liter, milliliter, cubic centimeter, and microliter.

The volume of 20 drops of liquid from a medicine dropper is approximately 1 mL.

A sugar cube has a volume of 1 cm3. 1 mL is the same as 1 cm3.

A gallon of milk has about twice the volume of a 2-L bottle of soda.

Units of Mass

The mass of an object is measured in comparison to a standard mass of 1 kilogram (kg), which is the basic SI unit of mass. A gram (g) is 1/1000 of a kilogram; the mass of 1 cm3 of water at 4°C is 1 g. Common metric units of mass include kilogram, gram, milligram, and microgram.

Units of Temperature

Temperature is a measure of how hot or cold an object is. Thermometers are used to measure temperature. Scientists commonly use two equivalent units of temperature, the degree Celsius and the kelvin.

On the Celsius scale, the freezing point of water is 0°C and the boiling point is 100°C.

On the Kelvin scale, the freezing point of water is 273.15 kelvins (K), and the boiling point is 373.15 K.

The zero point on the Kelvin scale, 0 K, or absolute zero, is equal to 273.15 °C.

Because one degree on the Celsius scale is equivalent to one kelvin on the Kelvin scale, converting from one temperature to another is easy. You simply add or subtract 273, as shown in the following equations.

Units of Energy

Energy is the capacity to do work or to produce heat. The joule and the calorie are common units of energy. The joule (J) is the SI unit of energy. One calorie (cal) is the quantity of heat that raises the temperature of 1 g of pure water by 1°C.

Chemistry 10.2

Mole–Mass and Mole–Volume Relationships

How can you guess the number of jelly beans in a jar? You estimate the size of a jelly bean and then estimate the dimensions of the container to obtain its volume. In a similar way, chemists use the relationships between the mole and quantities such as mass, volume, and number of particles to solve chemistry problems.

Mole–Mass Relationship

How do you convert the mass of a substance to the number of moles of the substance?

Use the molar mass of an element or compound to convert between the mass of a substance and the moles of a substance.

The Mole–Volume Relationship

What is the volume of a gas at STP? Avogadro’s hypothesis states that equal volumes of gases at the same temperature and pressure contain equal numbers of particles.

The volume of a gas varies with temperature and pressure. Because of these variations, the volume of a gas is usually measured at a standard temperature and pressure.

Standard temperature and pressure (STP) means a temperature of 0°C and a pressure of 101.3 kPa, or 1 atmosphere (atm).

At STP, 1 mol or, 6.02  1023 representative particles, of any gas occupies a volume of 22.4 L.

The quantity 22.4 L is called the molar volume of a gas.

Chemistry 10.3

Percent Composition and Chemical Formulas

It helps to know the percents of the components in a shirt because they affect how warm it is, whether it will need to be ironed, and how it should be cleaned. You will learn how the percents of the elements in a compound are important in chemistry.

The Percent Composition of a Compound

How do you calculate the percent by mass of an element in a compound?

The percent by mass of an element in a compound is the number of grams of the element divided by the mass in grams of the compound, multiplied by 100%.

Percent Composition from Mass Data

The relative amounts of the elements in a compound are expressed as the percent composition or the percent by mass of each element in the compound.

Percent Composition as a Conversion Factor

You can use percent composition to calculate the number of grams of any element in a specific mass of a compound.

The Percent Composition of a Compound

Propane (C3H8) is 81.8% carbon and 18% hydrogen. You can calculate the mass of carbon and the mass of hydrogen in an 82.0 g sample of C3H8.

Empirical Formulas

What does the empirical formula of a compound show? The empirical formula gives the lowest whole-number ratio of the atoms of the elements in a compound.

The empirical formula of a compound shows the smallest whole-number ratio of the atoms in the compound.

Ethyne (C2H2) is a gas used in welder’s torches. Styrene (C8H8) is used in making polystyrene.

These two compounds of carbon have the same empirical formula (CH) but different molecular formulas.

Molecular Formulas

How does the molecular formula of a compound compare with the empirical formula? The molecular formula of a compound is either the same as its experimentally determined empirical formula, or it is a simple whole-number multiple of its empirical formula.

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Chemical Calculations

The effectiveness of car’s air bags is based on the rapid conversion of a small mass of sodium azide into a large volume of gas. The entire reaction occurs in less than a second. You will learn how to use a balanced chemical equation to calculate the amount of product formed in a chemical reaction.

Writing and Using Mole Ratios

How are mole ratios used in chemical calculations? In chemical calculations, mole ratios are used to convert between moles of reactant and moles of product, between moles of reactants, or between moles of products.

Mole-Mole Calculations

A mole ratio is a conversion factor derived from the coefficients of a balanced chemical equation interpreted in terms of moles. To determine the number of moles in a sample of a compound, first measure the mass of the sample. Then use the molar mass to calculate the number of moles in that mass.

Mass-Mass Calculations

Other Stoichiometric Calculations

What is the general procedure for solving a stoichiometric problem?

In a typical stoichiometric problem, the given quantity is first converted to moles. Then the mole ratio from the balanced equation is used to calculate the number of moles of the wanted substance. Finally, the moles are converted to any other unit of measurement related to the unit mole, as the problem requires.

Chemistry 12.3

Limiting Reagent and Percent Yield

If a carpenter had two tabletops and seven table legs, he could only build one four-legged table. The number of table legs is the limiting factor in the construction of four-legged tables. Similarly, in chemistry, the amount of product made in a chemical reaction may be limited by the amount of one or more of the reactants.

Limiting and Excess Reagents

How is the amount of product in a reaction affected by an insufficient quantity of any of the reactants?

In a chemical reaction, an insufficient quantity of any of the reactants will limit the amount of product that forms. The limiting reagent is the reagent that determines the amount of product that can be formed by a reaction.

In the reaction of nitrogen and hydrogen, hydrogen is the limiting reagent. Nitrogen is the reagent that is not completely used up in the reaction. The reagent that is not used up is called the excess reagent.

Percent Yield

What does the percent yield of a reaction measure? The percent yield is a measure of the efficiency of a reaction carried out in the laboratory. A batting average is actually a percent yield.

The theoretical yield is the maximum amount of product that could be formed from given amounts of reactants. In contrast, the amount of product that actually forms when the reaction is carried out in the laboratory is called the actual yield.

The percent yield is the ratio of the actual yield to the theoretical yield expressed as a percent.

Chemistry 16.2

Concentrations of Solutions

Water must be tested continually to ensure that the concentrations of contaminants do not exceed established limits. These contaminants include metals, pesticides, bacteria, and even the by-products of water treatment. You will learn how solution concentrations are calculated.

Molarity

How do you calculate the molarity of a solution? The concentration of a solution is a measure of the amount of solute that is dissolved in a given quantity of solvent. A dilute solution is one that contains a small amount of solute. A concentrated solution contains a large amount of solute.

Molarity (M) is the number of moles of solute dissolved in one liter of solution.

To calculate the molarity of a solution, divide the moles of solute by the volume of the solution.

To make a 0.5-molar (0.5M) solution, first add 0.5 mol of solute to a 1-L volumetric flask half filled with distilled water.

Swirl the flask carefully to dissolve the solute.

Fill the flask with water exactly to the 1-L mark.

Making Dilutions

What effect does dilution have on the total moles of solute in a solution? Diluting a solution reduces the number of moles of solute per unit volume, but the total number of moles of solute in solution does not change.

The total number of moles of solute remains unchanged upon dilution, so you can write this equation.

M1 and V1 are the molarity and volume of the initial solution, and M2 and V2 are the molarity and volume of the diluted solution.

Making a Dilute Solution

To prepare 100 ml of 0.40M MgSO4 from a stock solution of 2.0M MgSO4, a student first measures 20 mL of the stock solution with a 20-mL pipet.

She then transfers the 20 mL to a 100-mL volumetric flask.

Finally she carefully adds water to the mark to make 100 mL of solution.

Percent Solutions

What are two ways to express the percent concentration of a solution? The concentration of a solution in percent can be expressed in two ways: as the ratio of the volume of the solute to the volume of the solution or as the ratio of the mass of the solute to the mass of the solution.

Concentration in Percent (Volume/Volume)

Isopropyl alcohol (2-propanol) is sold as a 91% solution. This solution consist of 91 mL of isopropyl alcohol mixed with enough water to make 100 mL of solution.

Concentration in Percent (Mass/Mass)