CHAPTER 1

Chemistry: The Study of Change

As you work through your Focus Review Guide, keep this chapter's Big Ideas in mind:

AP BIG IDEAS A LOOK AHEAD

1. The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangement of atoms. These atoms retain their identity in chemical reactions.
2. Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.
3. Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
4. Rates of chemical reactions are determined by details of the molecular collisions.
5. The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
6. Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations.

Chapter Overview

Chemistry is the study of matter, with special focus on the changes that matter can undergo. The study of chemistry begins with observation of and categorization of change, and extends through classification of matter by type and/or phase. The Advanced Placement (AP) Chemistry course organizes the study of chemistry around six Big Ideas. These Big Ideas are introduced in Chapter 1. Chemistry is not just a collection of already known facts, but an evolving field of scientific inquiry. The AP science practices identify the quantitative analysis skills needed to study chemistry. Special emphasis is placed on the ability to represent change in the appropriate manner using SI units, chemical equations, and scientific notation.

1.1 Chemistry: A Science for the Twenty-First Century

Prerequisite Knowledge

Recall It

Chemistry is a very old science, yet chemistry has never lost relevance. Chemistry is referred to as 'the central science' because every other science can trace its lineage to chemistry. Chemistry remains an active discipline, with chemists continuing to advance our knowledge about how chemistry impacts our everyday lives.

Review It

On the next page, you will find a chart that has three branches of science studied in high school. Under each, place an item, event or phenomena that relates to the subject AND to chemistry in the twenty-first century. An example has been placed in each column to get you started.

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1.1 Chemistry: A Science for the Twenty-First Century *continued*

Environmental Science	Physics	Biology
-pH testing of water samples to determine acidity levels	-semiconductors for microchips in computers	-genetic studies that rely on the DNA sequence

1.2 Introducing the AP Big Ideas

Recall It

The AP Chemistry curriculum is organized around six central ideas, called the Big Ideas. Each of the Big Ideas is subdivided into important concepts called Essential Knowledge (EK). Remember that each Big Idea will be interwoven throughout the textbook, and you are likely to encounter multiple Big Ideas in any given chapter.

Review It

In your own words, summarize each of the AP Chemistry Big Ideas.

Big Idea 1	Chemical elements are the fundamental building blocks of matter, and these building blocks have certain unchanging properties.
Big Idea 2	
Big Idea 3	
Big Idea 4	
Big Idea 5	
Big Idea 6	

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1.2 Introducing the AP Big Ideas *continued*

Use It

Identify each item in the list below as a compound or an element:

water

iron

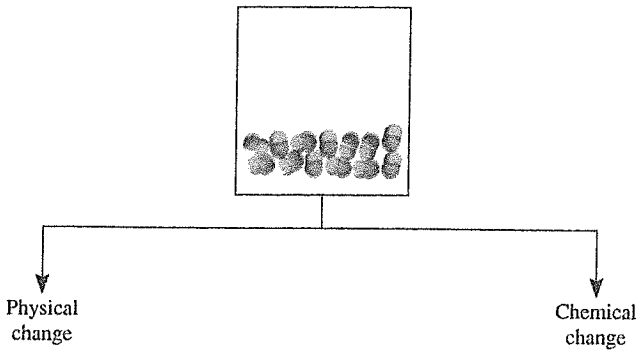
solid carbon in the form of a diamond

$CaCl_2$

gasoline

aluminum foil

Below, you will find a diagram of a compound made up of two elements, each represented using spheres of different colors. Below each, create a diagram to show each of the indicated changes:



Beside each statement, place the term solid, liquid or gas that correctly applies to the statement.

Molecules are tightly held together with little room for motion.

Molecules are close together, but can move past one another with little restriction.

Molecules are far apart and free to move in all directions.

1.3 Introducing the AP Science Practices

Recall It

Chemistry is an active and evolving scientific field. Chemists, like all scientists, possess a number of skills that allow them to propose and investigate scientific questions, make predictions, analyze data, and justify conclusions. The AP Chemistry exam will expect all AP Chemistry students to be proficient in these science practices.

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1.3 Introducing the AP Science Practices *continued*

Review It

For each of the seven science practices, identify how you might use the practice in your study of chemistry:

Science Practice	Example Use
SP 1: Using Models	A chemical modeling kit to understand the structure of molecules
SP 2: Using Math to Solve Problems	
SP 3: Engaging in Scientific Questioning	
SP 4: Collecting Data	
SP 5: Analyzing Data	
SP 6: Articulating Claims	
SP 7: Connecting the Pieces	

1.4 Review: The Scientific Method

Prerequisite Knowledge

Recall It

The scientific method, which you should be familiar with from previous science classes, is the systematic manner by which research is done. You will notice that many of the steps of the scientific method correspond to the skills identified in the AP science practices. Research (and experiments) can be broadly classified into two main classes; quantitative research, which strives to generate numerical data as the product, and qualitative research, which strives to generate observable change as the product. Research begins with a hypothesis, which upon testing can become theory, which upon further testing might become law.

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1.4 Review: The Scientific Method *continued*

Review It

Label the following observations as either qualitative or quantitative

The metal bar was 15 cm long.

The temperature of the metal bar was 21°C.

The surface of the metal was shiny.

The metal bar heated quickly.

It took 17 minutes for the bar to cool from 35°C to 21°C.

Describe the difference between a *hypothesis*, a *theory*, and a *law*.

1.5 Review: Measurements

Prerequisite Knowledge

Recall It

Measurement in science is done using the revised metric system known as the SI system. Each quantity has a base unit associated with it; the meter for length, the kilogram for mass, etc. There are three different yet interconvertible temperature scales. Fahrenheit, which you are likely familiar with from the daily weather report, is used rarely in science.

Review It

A student is given a sample of one of seven metals and asked to identify it based on the density of the material. A copy of the data table collected by the student is given below.

Mass of metal: 32.06g
Initial volume of the graduated cylinder: 50.40mL
Final volume of the graduated cylinder: 54.85

What is the density of the unknown metal?

Substance	Density (g/cm^3)
Aluminum	2.70
Iron	7.9
Lead	11.3
Gold	19.3
Osmium	22.6
Chromium	7.15
Tin	7.27

The student is provided a table with the densities of seven possible metals which could comprise the unknown sample. Based on the calculated density of the unknown sample, can the student identify the metal? Justify your answer.

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1.5 Review: Measurements *continued*

A sample of osmium is found to have a volume of 15.95 cm^3. What would be the mass of this sample? Use the density of osmium from the table above.

1.6 Review: Handling Numbers

Prerequisite Knowledge

Recall It

Data handling is of extreme importance. Depending on the circumstance, a chemist may be handling very large or very small numbers. This becomes ungainly without the use of scientific notation. The number of digits that are included when data is recorded or manipulated is governed by the rules of significant figures, which involves specific rules for addition and subtraction, multiplication and division. Also important is the distinction between accuracy and precision.

Review It

A dart player throws three darts and all three dots land in the bull's eye. However, the dart player was aiming for the triple 20 with all three darts. Comment on the precision and accuracy of the player.

16 Review: Handling Numbers *continued*

Use It

The table below shows the volumetric tolerances for a variety of chemical glassware.

Tolerances for Volumetric Ware			
	Maximum Allowed Error, mL		
Volume, mL	Volumetric Flask	Volumetric Pipet	Burette
5	-	0.01	-
10	-	0.02	-
25	0.03	0.03	0.03
50	0.05	0.05	0.05
100	0.08	0.08	0.10
250	0.10	-	-
500	0.15	-	-
1000	0.30	-	-

*Data from J.S. Fritz and G. H. Schenk. *Quantitative Analytical Chemistry*, 3rd edition. Allyn & Bacon, Boston, 1974. p. 560.

If you filled a 25 mL volumetric pipet exactly to the line, what range of values would the volume exist between?

Which piece of equipment would best be used to measure exactly 25 mL of solution: a volumetric flask or a pipette? Explain your answer.

Perform the indicated calculations, reporting your final answer to the correct number of significant figures.

86.25 g + 14.3 g =

16.4 g/cm^3 × 1.35 cm^3 =

3 bars of gold × 25.3 kg per bar =

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17 Review: Dimensional Analysis

Prerequisite Knowledge

Recall It

Of the myriad techniques that scientists use to handle or manipulate data, one of the most powerful is dimensional analysis, or factor-label method. This allows the interconversion of units between SI and the English system, or within SI itself. Factor label relies heavily on conversion factors, which can be readily created from any unit of measurement.

1.7 Review: Dimensional Analysis *continued*

Review It

You plan on traveling to Europe this summer and wish to convert some of your US dollars ($) to euro (€)

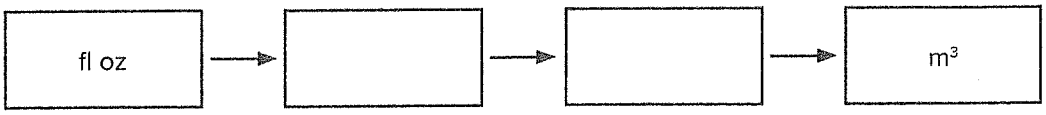
You are told that 1 US dollar is the equivalent to 0.73 euro.

How many euro would you get out of $450?

How much would you need in dollars to be able to convert have 1000€?

If 8 gold coins weigh 43.5 g, what would 31 gold coins weigh?

Fill in the sequence of unit conversions needed to change from fl oz to m^3.



Given that there are 0.033814 fl oz in 1 mL, use your sequence from the question above to convert 828 fl oz to m^3.

Explain how you arrived at the number of significant figures in this answer.

1.8 Review: Problem Solving – Information, Assumptions, and Simplifications

Prerequisite Knowledge

Recall It

It is often useful to estimate the solution to a problem rather than solve it discretely. One must be careful to address any uncertainty or assumption that is made in the solution of a problem, and to consider its impact on the ultimate solution.

1.8 Review: Problem Solving – Information, Assumptions, and Simplifications *continued*

Review It

A pile of gravel is in the approximate shape of an inverted cone, with a diameter of 18 m and a height of 34 m. The gravel has a density of 1255 kg/m^3.

The formula for the volume of a cone $V = \frac{1}{3}\pi r^2 h$, what assumptions can you make in your calculation for the volume of the pile of gravel?

Use this approximation to find the volume of the gravel pile.

Using your answer to the above question and the density of the gravel, determine the approximate mass of the gravel pile.

What assumptions were made in this calculation?

AP CHAPTER SUMMARY

Summarize It

These questions were posed in the Chemistry chapter opener (page 2). Answer them using the knowledge you've gained from this chapter.

1. What are the six AP Big Ideas?

2. What are the seven AP Science Practices?

3. How is the study of chemistry relevant to your life?

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CHAPTER 2

Atoms, Molecules, and Ions

As you work through your Focus Review Guide, keep this chapter's Big Ideas in mind:

AP BIG IDEAS A LOOK AHEAD

- Atomic theory, which has been built over time by many scientists, describes the structure of the atom.
- The fundamental structure of the atom defines how atoms come together to form higher order structures.

Chapter Overview

The study of modern chemistry is said to have begun with Dalton's atomic theory, which itself was based on the theories of Democritus and others; Dalton's theory suggested that all matter was composed of small particles called *atoms*. These atoms combine in predictable ratios to form compounds, have defined structures, and can be described by their atomic number and/or their mass number. The representation of chemical compounds relies heavily on shorthand notation by way of chemical formulas, which can take on several varieties. Chemical compounds can be further subdivided into ionic and covalent compounds, which are defined by the mode by which the elements bind together. Chemical compounds are given systematic names that can be predicted from the proper chemical formula, and vice versa.

2.1 The Atomic Theory

Recall It

Although many chemists contributed to the ultimate description of the atom, it was John Dalton who is credited with the first cogent proposal of a set of hypotheses that governed the atom's behavior. Dalton's atomic theory is based on four fundamental hypotheses:

1. All elements are composed of atoms, which are very small particles.
2. All atoms of a given element are identical, and the atoms of different elements are themselves different.
3. Atoms combine in predictable ratios.
4. Atoms cannot be created or destroyed in reactions, only rearranged in some manner.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.D.1: As is the case with all scientific models, any model of the atom is subject to refinement and change in response to new experimental results. In that sense, an atomic model is not regarded as an exact description of the atom, but rather a theoretical construct that fits a set of experimental data.

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2.1 The Atomic Theory *continued*

Review It

Nitrogen dioxide gas (NO_2) can react with itself to form a single different compound. Which of the following is the most likely formula for this new compound? Justify your choice.

a. NO
b. N_2O
c. N_2O_4
d. NO_4

Use It

The Greek philosopher Democritus named the small particles that he thought all things were made of 'atomos,' which means 'indivisible' or 'uncuttable.' Would he still choose that name if he were alive today and knew what you know? Why or why not?

2.2 The Structure of the Atom

Recall It

The atom itself is composed of three fundamental subatomic particles; the proton, neutron, and electron. The electron is the fundamental unit of negative charge and is located in the periphery of the atom. The proton is the fundamental unit of positive charge and is located in the nucleus of the atom along with the neutron, which has no charge. All of these particles have known masses.

Essential Knowledge covered

1.B.1: The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's law is qualitatively useful for understanding the structure of the atom.
1.D.1: As is the case with all scientific models, any model of the atom is subject to refinement and change in response to new experimental results. In that sense, an atomic model is not regarded as an exact description of the atom, but rather a theoretical construct that fits a set of experimental data.

Review It

Complete the following table with respect to the fundamental subatomic particles:

Particle	Mass (g)	Charge (C)	Unit of Charge
Proton			
Electron			
Neutron			

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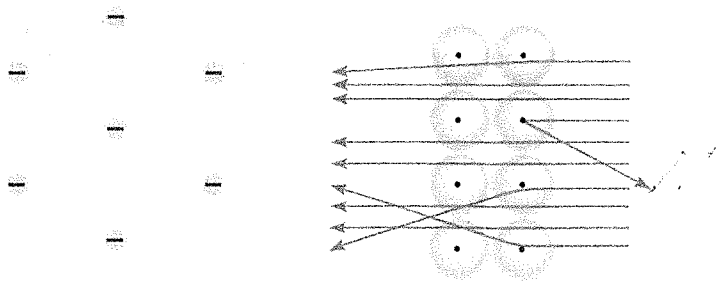

Label the regions of positive and negative charge in both Thomson's 'Plum Pudding' model and Rutherford's Gold Foil Experiment. Now, imagine that both Rutherford and Thomson exist in 2017 and that Rutherford wants to inform Thomson of his discovery using social media. In 140 characters or less, what would Rutherford say?

Use It

Why do scientists refer to Atomic Theory and not Atomic Law?

2.3 Atomic Number, Mass Number, and Isotopes

Recall It

An atom is described by its atomic number, which defines the number of protons and electrons in an uncharged atom. The atomic number can be used in conjunction with the mass number to determine how many neutrons are present. Any two atoms which have the same atomic number but different mass numbers are related as isotopes.

Essential Knowledge covered

1.D.1: As is the case with all scientific models, any model of the atom is subject to refinement and change in response to new experimental results. In that sense, an atomic model is not regarded as an exact description of the atom, but rather a theoretical construct that fits a set of experimental data.

1.D.2: An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.

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2.3 Atomic Number, Mass Number, and Isotopes *continued*

Review It

On the periodic table, the atomic symbol (either one or two letters) is typically shown with one or two numbers beside it. Define what each number means and how they are calculated.

Most elements have more than one isotope, which is an atom that has the same atomic number but a different mass number. How many protons and neutrons are in the following isotope of He (helium four)?

$^{4}_{2}He$

Use It

Why do all atoms of the same element have the same atomic number but not necessarily the same mass number?

2.4 The Periodic Table

Recall It

The periodic table contains, in a lightly encoded sense, a wealth of information about the elements. In it, the elements are grouped according to the similarity of their physical and chemical properties.

Essential Knowledge covered

1.C.1: Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.

Review It

Several groups have characteristic names. Give an example of two elements in each group/family:

Alkali Metals:

Alkaline Earth Metals:

Halogens:

Noble Gases:

Using the periodic table in the front of your textbook, determine what category of elements comprises the majority of the periodic table.

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2.4 The Periodic Table *continued*

How do metals differ from nonmetals?

Use It

You are building a device that uses, in its construction, a significant amount of magnesium (Mg). You notice that your supply of Mg has run out, but you have aluminum as well as beryllium available. Explain which element would most likely be the best element to use as a substitute, given that you do not want to change the device's physical properties?

2.5 Molecules and Ions

Recall It

Most of the elements exist in nature in a combined form with other elements. The manner by which these compounds form is determined by how the elements come together. Molecules are discrete collections of atoms that unite in a predictable fashion, while ions are atoms or groups of atoms that have characteristic levels of positive or negative charge.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.B.1: The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's law is qualitatively useful for understanding the structure of the atom.

Review It

Referring to the periodic table in the front of your textbook, how many hydroxide ions would need to combine with a single cation of the given element to form a neutral compound? List the number necessary for each of the common monatomic ion possible for each element, or "no reaction" if the listed ion would not combine with a hydroxide ion.

Fe:

Na:

Mn:

Sn:

N:

Ag:

F:

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2.5 Molecules and Ions *continued*

In the previous example, what is common between all the ions that will form neutral compounds with a hydroxide ion?

A subscripted number immediately following an atomic symbol indicates the number of that species present in a molecule. Identify the lowest whole–number ratio of hydrogen atoms to oxygen atoms in the following compounds:

H_3PO_4:

H_2O:

H_2O_2:

Use It

Turn to the periodic table in the front of your textbook. It appears that only elements coded in green tend to form cations, whereas elements in blue tend to form anions. What general trend about ionic bonds can you conclude from this?

Using the periodic table in the front of your textbook, identify the trends relating to the preferred cationic or anionic charge and group number. The principle group numbers are followed by the letter A.

2.6 Chemical Formulas

Recall It

Chemical formulas are the shorthand representations used to express the composition of molecules or ions using atomic symbols. They exist in several varieties: molecular formulas, which show the exact number of atoms of each element that are present in the smallest unit of a substance, empirical formulas, which indicate which elements are present in a substance and what the smallest whole-number ratio of their atoms is, but not the exact number of each atom, and ionic formulas, which more closely resemble empirical formulas due to the makeup of an ionic compound.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
2.C.2: Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.

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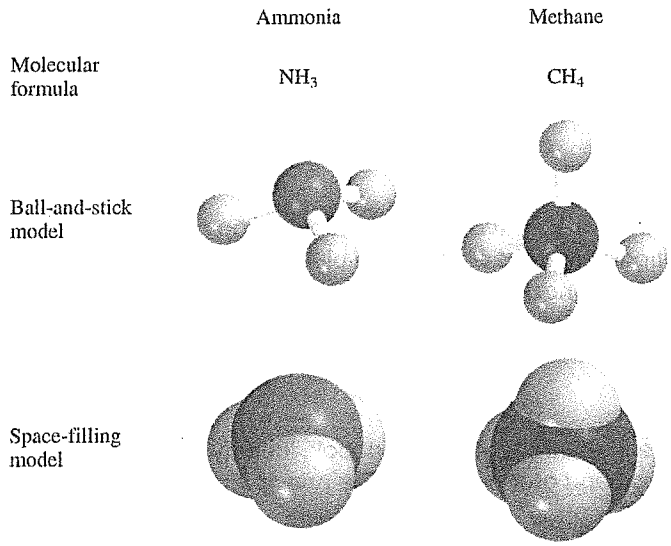
Review It

How do the empirical formulas for water (H_2O) and hydrogen peroxide (H_2O_2) compare? How do they differ?



Label all the atoms in both ball-and-stick and space filling models above according to the formula given in the molecular formula.

Ionic compounds are, by nature, electrically neutral. What are the formulas for potassium oxide and calcium oxide:

Use It

Draw the ball-and-stick models for ethane, $H_3C—CH_3$. What is ethane's empirical formula?

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2.7 Naming Compounds

Prerequisite Knowledge

Recall It

There exist systematic processes for the naming of all compounds in chemistry, whether they are ionic, molecular, organic, binary, ternary, acids, bases, etc. The focus of nomenclature, the subject of naming, must be the ability to determine the class of compounds to which a target compound belongs. Once the compound's classification is determined, one must simply follow the nomenclature rules that exist for that particular class.

Review It

Complete the table, using appropriate rules for the nomenclature of ionic compounds:

Cation	Anion	Formula	Name
			magnesium bicarbonate
		$SrCl_2$	
Fe^{3+}	NO_2^-		
		$SnBr_4$	

Write formulas for the following names. In the last box, indicate the type of compound present.

Name	Formula	Compound Type
Copper(I) cyanide		
Perbromic acid		
Hydrogen sulfide		
Tin(II) fluoride		
Boron trichloride		
Tetraphosphorus decasulfide		

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2.8 Introduction to Organic Compounds

Prerequisite Knowledge

Recall It

Organic chemistry is the study of chemical compounds that contain carbon; carbon is unique in its ability to form compounds which consist of carbon atoms bound to one another in a nearly limitless series. The variability of organic compounds is astounding.

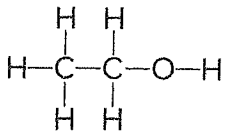
2.8 Introduction to Organic Compounds *continued*

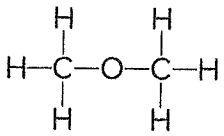
Review It

Organic chemistry assigns names based on the number of carbon atoms present. Complete the chart indicating the names of the alkanes that contain 1–10 carbon atoms.

# Carbons	Name	# Carbons	Name
1	methane	6	
2		7	
3		8	
4		9	
5		10	

Isomers are compound that have the same molecular formulas but different structural formulas. Are the compounds shown below identical or isomers? Explain your answer.





AP CHAPTER SUMMARY

Summarize It

These questions were posed in the Chemistry chapter opener (page 41). Answer them using the knowledge you've gained from this chapter.

1. How does an atom differ from a molecule?

2. What developments have changed our understanding of atoms and molecules since Dalton's proposed atomic theory?

3. What particles comprise an atom?

4. How do elements differ at the atomic level? Are all atoms of a given element identical?

5. What is the basic structure of the periodic table?

6. Can atoms form ions? How do ionic compounds maintain electrical neutrality?

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CHAPTER 3

Mass Relationships in Chemical Reactions

As you work through your Focus Review Guide, keep this chapter's Big Ideas in mind:

AP BIG IDEAS A LOOK AHEAD

An understanding of atomic mass, molar mass and percent composition is important for performing calculations involving chemical reactions.

Determining the amounts of products that can form when given amounts of reactants are used allows for the calculation of reaction yields.

Chapter Overview

While a single atom cannot be weighed, chemists have many methods to interact with matter on a quantitative basis. The atomic mass is the average mass of all naturally occurring isotopes for a particular element, and the sum of the atomic masses of the elements in a molecule yields the molecular mass. These masses can be used to calculate the number of particles present via Avogadro's Number. Chemists quantify the number of atoms present in a sample using the mole. The mole permits the balancing of chemical equations which, in turn, allows for the determination of percent composition as well as more in depth discussions of stoichiometry.

3.1 Atomic Mass

Recall It

Initially, discussions of mass involve the amu, or the atomic mass unit, which is defined as 1/12th of the mass of one Carbon-12 atom. Due to the propensity of atoms to form more than one stable isotope, however, it is more common to use the average atomic mass, which factors in the mass and percent abundance of each isotope (i.e. a weighted average). This is the number that is reflected on the periodic table.

Essential Knowledge covered

1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

Review It

A scientist found an element with three naturally occurring isotopes, shown in the chart below. The most abundant is an atom with an equal number of protons and neutrons.

Isotope	Mass (amu)	Abundance (%)
A	22.00	82.4
B	23.01	15.2
C	25.02	2.4

Use this information in the table above to determine the average atomic mass for the element.

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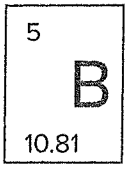
3.1 Atomic Mass *continued*

Why is the average atomic mass closer to the atomic mass of isotope A than it is to isotope B or isotope C?

Use It

The element box below is that of boron. It has two naturally occurring isotopes: boron-10 and boron-11.



Fill in the table for each isotope of boron:

Isotope	Number of protons	Number of neutrons
Boron-10		
Boron-11		

Boron-10 has an abundance of 19.9%. Verify the value of the average atomic mass.

Explain any difference between your calculated value and the value in the element box.

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3.2 Avogadro's Number and the Molar Mass of an Element

Recall It

The mole is one of the most fundamental concepts to master in the study of chemistry. The mole is simply a counting number, like pair or dozen, and reflects the presence of exactly 6.022×10^{23} (called Avogadro's Number) things. Indeed, the mole is the linchpin that allows conversion of the mass of an element to the number of atoms present of that element via the molar mass, which is the mass of one mole of that element. Care should be taken to accurately produce the correct conversion factors when attempting this type of conversion via factor-label method.

3.2 Avogadro's Number and the Molar Mass of an Element *continued*

Essential Knowledge covered

1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

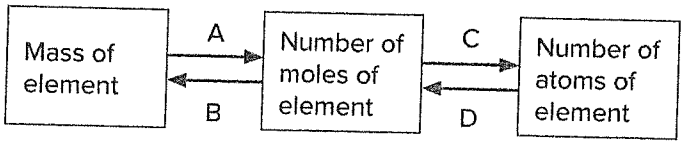
Review It

Fill in the blanks below. Do not use a calculator on this problem.

12.0 g of carbon-12 is 1 mol, so 36.0 g of the material would be _____ mol and 1.20 g would be _____ mol.

Find the periodic table in the front of your textbook. How many moles of atoms are in a 2.50 g sample of magnesium?

Use It



In the flow chart above, there are four arrows labeled A, B, C, and D. Each of these arrows represents a mathematical operation that must be done to move from value to value. What mathematical operation is needed for each numbered step?

A:

B:

C:

D:

3.2 Avogadro's Number and the Molar Mass of an Element *continued*

Use the flow chart on the previous page to determine the number of atoms in a 334.21 g sample of iron if the molar mass of iron is 55.845 g/mol.

3.3 Molecular Mass

Recall It

It is quite straightforward to move from calculations involving only one element to calculations involving a number of elements, such as in a compound. Chemists use molecular mass to describe the sum of the atomic masses in the molecule and formula mass to describe the sum of the atomic masses in one formula unit of an ionic compound.

Essential Knowledge covered

1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

Review It

Determine the number of each type of atom in one molecule of diphosphorus pentoxide.

For each compound, determine the formula masses (in amu):

Acetylsalicylic acid, $C_9H_8O_4$, the key ingredient in many pain relievers

Aluminum chloride, $AlCl_3$, added to many antiperspirants

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3.3 Molecular Mass *continued*

Use It

You are given a sample of 255.30 g of propane (C_3H_8) and are asked to determine the number of moles this sample contains, assuming the molar mass of hydrogen is 1.0079 g/mol and the molar mass of carbon is 12.01 g/mol.

Determine the number of moles in the 255.30 g sample.

3.4 The Mass Spectrometer

Recall It

A mass spectrometer is an instrument that allows for the precise experimental measurement of atomic and/or molecular masses.

Essential Knowledge covered

1.D.2: An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.

Review It

An element exists with three naturally occurring isotopes:

Isotope	Mass (amu)	Abundance (%)
A	82.00	78.2
B	85.05	17.8
C	87.10	4.0

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3.4 The Mass Spectrometer *continued*

Sketch a mass spectrum for this element.

Use It

Explain how you arrived at your mass spectrum above.

3.5 Percent Composition of Compounds

Recall It

The percent composition (by mass) of a compound can be readily calculated, given both the molar mass of the element and the molar mass of the compound of interest. Additionally, since the calculation rests on having the proper ratio of elements, one must be able to accurately produce the correct chemical formula for the compound.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.A.2: Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.
1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

Review It

Fill in the blanks for the flow chart that can be used to find the empirical formula when given percent composition by mass for each element in a compound.

mass percent			empirical formula

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Identify what must be done mathematically to move between steps in the flow chart on p. 25:

Determine the percent composition for each element in the compound for sodium carbonate, Na_2CO_3.

A molecule is made up of 50.05% sulfur and 49.95% oxygen. Use the flow chart on p. 25 to determine the empirical formula of the compound.

Use It

Two large deposits of aluminum were found in two areas where a mining company was looking to open a new aluminum mine. Site A has aluminum in the form of Al_2O_3 while at Site B, the aluminum is on the form of $KAl(SO_4)_2$.

What considerations would the mining company use to make a decision as to where to open a mining operation?

Determine the percent of aluminum in each compound.

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3.5 Percent Composition of Compounds *continued*

Calculate the number of grams of aluminum that would be present in 100 kg of each material.

Determine what ratio of mass deposits would be needed for both sites to be considered as sites to open a mining operation.

3.6 Experimental Determination of Empirical Formulas

Recall It

Chemists have the ability to experimentally measure the empirical, and by extension molecular, formula using appropriate instrumentation. The empirical formula, that which contains the subscripts in the smallest whole number ratio, can be converted to the molecular formula as long as molar mass is also known.

Essential Knowledge covered

1.A.2: Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.
1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

Review It

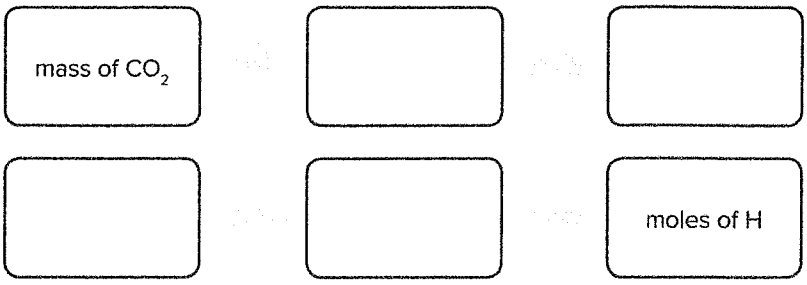
Identify which are possible molecular formulae for the empirical formula CH_2.

C_2H_4 C_2H_6 C_5H_{10} C_3H_8 C_6H_6 CH_4 C_3H_6

Use It

A compound containing only carbon and hydrogen was burned in an apparatus that can be used to detect the amount of carbon dioxide and water produced in the process. When 15.00 g of the material is burned, 50.78 g of carbon dioxide and 10.39 g of water are produced. The molar mass of this compound is found to be approximately 26 g.

Create flow charts to illustrate the process needed to find the molecular formula:



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3.6 Experimental Determination of Empirical Formulas *continued*

Use this flow chart to find the molecular formula for the compound.

3.7 Chemical Reactions and Chemical Equations

Recall It

The true power of chemistry lies in the ability to convert one material into another by chemical reaction; these are traditionally represented by balanced chemical equations. By convention, reactants are listed on the left and products on the right of an arrow. It is required by the Law of Conservation of Mass that the number of each type of element in the products must be the same as in the reactants, so the overall reaction must be balanced. There are a number of methods by which equations can be balanced.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.E.1: Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
1.E.2: Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
3.A.1: A chemical change may be represented by a molecular, ionic, or net ionic equation.
3.C.1: Production of heat or light, formation of a gas, and formation of a precipitate and/or a color change are possible evidences that a chemical change has occurred.

Review It

Balance the combustion reaction of propane, C_3H_8. In this reaction, propane combines with oxygen gas to produce carbon dioxide and water.

$$___C_3H_8 + ___O_2 \rightarrow ___CO_2 + ___H_2O$$

Fill in the chart for a balance sheet of atoms for the reaction above:

Element	Number on reactant side	Number on product side
Carbon		
Hydrogen		
Oxygen		

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Another student balanced the reaction as

$3\ C_3H_8 + 15\ O_2 \rightarrow 9\ CO_2 + 12\ H_2O$

What would you say to this student about their answer? Be specific and correct any issues that need correcting in what they did.

Use It

Balance each chemical reaction given here, and show the balance sheet for the number of each type of atom once each reaction has been balanced.

a. $Fe + Cl_2 \rightarrow FeCl_3$

Element	Number on reactant side	Number on product side
Iron		
Chlorine		

b. $Na + H_2O \rightarrow NaOH + H_2$

Element	Number on reactant side	Number on product side
Sodium		
Hydrogen		
Oxygen		

c. $C_6H_6 + O_2 \rightarrow CO_2 + H_2O$

Element	Number on reactant side	Number on product side
Carbon		
Hydrogen		
Oxygen		

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3.3 Amounts of Reactants and Products

Recall It

One of the most critical questions surrounding the practice of chemical experimentation is "how much product will this reaction produce?" The answer lies in the field of stoichiometry, which is the quantitative study of reactants and products in chemical reactions. Typically, stoichiometric calculations are done using moles; indeed, the mole method allows for the interpretation of the coefficients in a balanced equation as simply the number of moles of each component that are present in the reaction.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
1.E.1: Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
1.E.2: Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
3.A.1: A chemical change may be represented by a molecular, ionic, or net ionic equation.
3.A.2: Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.

Review It

Balance the reaction $P(s) + O_2(g) \rightarrow P_2O_5(s)$

Once balanced, draw a representation of the balanced chemical reaction using solid spheres for the P atoms and open spheres for the O atoms.

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3.8 Amounts of Reactants and Products *continued*

Use It

Water decomposes into hydrogen gas and oxygen gas when electricity passes through the solution. If 24.50 g of water is fully decomposed, what mass of oxygen will be collected?

3.9 Limiting Reagents

Recall It

Seldom are reactants in a reaction present in the exact stoichiometric ratio that is required. As a result, one reactant is often used up before the others, at which point the reaction stops. The reactant that is completely consumed first is referred to as the limiting reagent, as it limits how much product can form. The other reactant(s) is/are referred to as being present in excess, and will be present in their unreacted form in some quantity once the reaction has stopped.

Essential Knowledge covered

1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
1.E.1: Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
1.E.2: Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
3.A.1: A chemical change may be represented by a molecular, ionic, or net ionic equation.
3.A.2: Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.

Review It

In the process of assembling tricycles for small children, a worker has 16 frames and 60 tires with which to assemble frame and tire components.

Write a balanced equation for this process.

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In the situation on the previous page, which would be considered the limiting reagent and which would be the excess reagent?

In the reaction of $Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$,

a. What is the exact stoichiometric ratio of iron to oxygen in the reaction (be sure to balance the reaction before answering)?

b. If 2 moles of iron and 2 moles of oxygen gas were to be used, which would be the limiting reagent? Explain your answer.

Use It

Determine the mass of hydrogen gas that will form when 22.53 g of solid nickel reacts with 65.16 g of lactic acid in the reaction:

$Ni(s) + HC_2H_5O_3(aq) \rightarrow Ni(C_2H_5O_3)_2(aq) + H_2(g)$

Show all work and be sure to balance the chemical reaction before you begin the calculation. Note that the molar mass of lactic acid is 90.08 g/mol, and the molar mass for nickel is 58.69 g/mol.

3.10 Reaction Yield

Recall It

Rarely do chemical reactions follow the theoretical balanced equation exactly. For this reason chemists speak of theoretical yields and actual yields, and these are united in percent yield.

Essential Knowledge covered

1.A.1: Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.
1.A.3: The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
1.E.1: Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
1.E.2: Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
3.A.1: A chemical change may be represented by a molecular, ionic, or net ionic equation.
3.A.2: Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.

Review It

Silicon carbide, SiC(s) can be manufactured by reacting silicon dioxide with solid carbon at high temperatures. The second product in this reaction is carbon dioxide gas. The reaction can be written as

$SiO_2(s) + 3\ C(s) \rightarrow SiC(s) + 2\ CO_2(g)$

If 20.00 g of silicon dioxide is reacted with 14.02 g of carbon, 12.05 g of silicon carbide forms.

Determine which reactant is the limiting reagent in this process.

How many moles of silicon carbide will form in this process?

What is the theoretical yield in this situation?

Determine the reaction yield.

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3.10 Reaction Yield *continued*

Use It

A classmate said that they read an article stating that the percent yield of a new chemical reaction is more than 100%. What would you say to this classmate in response to this claim?

AP CHAPTER SUMMARY

Summarize It

These questions were posed in the Chemistry chapter opener (page 79). Answer them using the knowledge you've gained from this chapter.

1. How do we determine atomic mass? What is a mole? How do we determine molar mass?

2. How does mass spectroscopy demonstrate the existence of isotopes?

3. What is the percent elemental composition of a substance? How do we experimentally determine composition?

4. What is conservation of mass?

5. How do we correctly represent a chemical change?

6. How do we write a properly balanced chemical reaction?

7. What evidence is used to indicate a chemical change has taken place?

8. How do we determine the amount of product formed in a chemical reaction or the amount of reactant required? How do we determine the limiting reagent? How do we determine percent yield?