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DAN RIMNICEANU

*this certificate for the prescribed program of study for the*  
GENERAL EDUCATION CURRICULUM

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*Saylor Academy awards*

**Dan Rimniceanu**

*this certificate of achievement for*  
**CHEM101: General Chemistry I**

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# CHEM101: General Chemistry I

The ancient Egyptians first identified, studied, and applied the principles of chemistry to extract metal from ores, make alcoholic beverages, glaze pottery, turn fat into soap, and much more. What began as a quest to build better weapons and create potions capable of ensuring everlasting life became the foundation of modern science.

Take a look around you: chemistry is the science that describes everything you touch, see, and feel: from the shampoo you used this morning, to the plastic container that holds your lunch! In this course, we will study chemistry from the ground up, beginning with the basics of the atom and its behavior, then progressing to the chemical properties of matter and the chemical changes and reactions that take place all the time in our world.

## Unit 1: Matter and Measurements

Our first step in this course is to gain a basic understanding of matter and define the basic terminology used to describe matter. This unit will also provide you with a refresher on measurements, as much of this class will require you to express quantities in standard units and amounts. We will also learn about significant figures, which may be a new concept for those of you who have not yet taken a science course.

**Completing this unit should take you approximately 8 hours.**

- Upon successful completion of this unit, you will be able to:
  - define chemistry;
  - distinguish between physical and chemical properties of matter;
  - classify changes of matter as physical or chemical;
  - explain the solid, liquid, and gas states in terms of particles;
  - distinguish between a quantity, a unit, and a measurement standard;
  - name and use SI units for length, mass, time, and volume;
  - determine the number of significant figures in measurements;
  - perform mathematical operations involving significant figures; and
  - convert measurements into scientific notation.

### • 1.1: Matter

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#### ○ [Extensive and Intensive PropertiesURL](#)

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Read the "Extensive and Intensive Properties" section. Remember that extensive properties, such as volume and mass, rely on the "extent" to which matter is present. Intensive properties, such as density and viscosity, are independent of the quantity of matter and are inherent to the matter.

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#### ○ [Physical and Chemical PropertiesURL](#)

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Read the "Physical and Chemical Properties" section. Because the two properties of matter are closely related, the distinction between physical and chemical

properties can be difficult to discern. For our purposes, we will define a physical property as one that can be observed without changing the matter's composition.

○ [Solids, Liquids, and GasesURL](#)

Read the "Solids, Liquids, and Gases" section. Note the differences between these three phases of matter on both the microscopic and macroscopic levels. Solids, like wooden blocks, have definite shape and definite volume, and the particles are ordered and close together. Liquids have definite volume and indefinite shape, meaning they take on the shape of the container. Imagine the differences between iced tea in a pitcher versus in a glass. A liquid's particles are less ordered, but still relatively close together. Gases, such as the air inside balloons, have indefinite shape and indefinite volume and their particles are highly disordered.

○ [Density and Its UsesURL](#)

Read the first two sections: "So What Is Density?" and "Densities of Common Substances". Density is temperature-dependent, and the units differ for solids ( $\text{g/cm}^3$ ), liquids ( $\text{g/mL}$ ), and gases ( $\text{g/L}$ ).

○ [Virtual Lab: Identifying an Unknown MetalURL](#)

In this activity, you will use the virtual lab to identify an unknown metal by measuring its density and comparing your measurements to the densities of known metals. To see the instructions, click the name of the problem ("Metals Density Problem") on the virtual lab screen.

○ [Virtual Lab: Identifying an Unknown Liquid from its DensityURL](#)

In this activity you will use the virtual lab to design an experiment to determine the identity of mislabeled bottles using the densities of the solutions inside. To see the instructions, click the name of the problem ("Liquid Density Problem") on the virtual lab screen.

○ [Energy, Heat, and TemperatureURL](#)

Read this page. Notice the distinctions made between heat and temperature. While both deal with kinetic energy, the energy of motion, "heat" refers to thermal energy transfer, while "temperature" is a measure of the kinetic energy of a system. Potential energy, the energy of position, in chemistry usually refers to the energy stored in chemical bonds. This material will be discussed in more detail in Unit 6.

○ [Classification and Properties of MatterURL](#)

Read the "How do We Classify Matter?" section. All matter can be classified as either a pure substance or a mixture. Furthermore, for a pure substance, a

subcategory of either single-element or compound can be applied. Mixtures are further categorized as either homogeneous (single-phase) or heterogeneous (multiple phases). The distinction between homogeneous and heterogeneous mixtures presented here is dependent on phase, or physical, boundaries. This section also contains material relevant to the next section of the course.

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○ [Chemical CompositionURL](#)

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Read the "Chemical Composition" section. Keep in mind that mixtures, whether homogeneous or heterogeneous, can be separated by physical means into pure substances. Techniques of separation were discussed in the previous section. Pure substances comprise elements and compounds.

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○ [Chemical ChangeURL](#)

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Read the "Chemical Change", "Energetics of Chemical Change", and "Dynamics of Chemical Change" sections. The energetics of chemical change will be discussed more thoroughly in Unit 6. To determine if you are dealing with a physical or chemical change, ask yourself if you can reverse the process to recover the original material. For example, ice melting is a physical change because you can re-freeze the water; however, cooking a steak is a chemical change because you cannot recover the raw meat.

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● **1.2: Measurement and Notation**

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○ [Units of MeasureURL](#)

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Read the "Units of Measure" section. Remember that every measurement has a numerical value associated with a unit!

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○ [The SI \(Metric\) SystemURL](#)

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Read "The SI Base Units" and "The SI Decimal Prefixes" sections. Note that the base unit for mass (kg) is the only "base" unit with a prefix. This arises from the fact that the "gram" is so small (i.e., a nickel weighs approximately 5 grams) that "real world" objects cannot feasibly be measured in grams. Can you imagine how many grams a table would weigh? Also, with the exception of seconds, the SI system (System International) is a base-10 system, allowing easier conversion between units.

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○ [UncertaintyURL](#)

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Read the "Uncertainty Is Certain!" section. Be aware that every measured value contains some uncertainty in the last digit. For example, if you are using a ruler to measure length, it is necessary to interpolate between gradations given on the ruler. This gives the uncertain digit in the measured length. While there may not

be much deviation, what you estimate to be the last digit may not be the same as someone else's estimation.

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o [Scatter and Error in Measured ValuesURL](#)

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Read the "Scatter and Error in Measured Values" section. While error is inherent to measurement, some errors are easier to detect and/or eliminate.

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o [Accuracy and PrecisionURL](#)

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Read the "Accuracy and Precision" section. Imagine accuracy as hitting the bullseye on a dartboard every time, while precision corresponds to hitting the "triple 20" consistently. As another example, consider an analytical balance with a calibration error such that it reads 0.24 grams too high. Then, even though measuring identical mass readings of a single sample would mean excellent precision, the accuracy of the measurement would be poor.

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o [Significant Figures and Rounding OffURL](#)

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Read this webpage. The concept of significant figures, commonly referred to as "sig figs", is important when solving scientific math problems and should be carefully observed! The rules for significant figure rounding of addition and subtraction calculations are the same, but different than those for multiplication and division.

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## Unit 2: The Atom

The atom, along with its protons, neutrons, and electrons, is the basic unit of matter and serves as our starting point for the study of chemistry. Scientists have studied atoms for hundreds of years and have developed a number of different models to describe them. Chemists currently use the quantum mechanical model, which has been around for decades. The "laws" of this model continue to intrigue and spark debate among scientists. For example, one theory states it is impossible to know the exact location and velocity of an electron at the same time.

### Completing this unit should take you approximately 11 hours.

- Upon successful completion of this unit, you will be able to:
  - define the atom;
  - list the properties of protons, neutrons, and electrons;
  - define isotopes and explain how they relate to naturally occurring element mass;
  - define atomic number and atomic mass and describe how they apply to isotopes;
  - define Avogadro's number and describe the mole quantification of matter;
  - discuss the wave-particle duality of light;
  - describe the Bohr model of the hydrogen atom;
  - list the four quantum numbers and describe their significance; and

- describe the structure and organization of the periodic table.

- **2.1: Atoms and Elements**

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- [The ElementsURL](#)

Read the "Elements" section. Elements get their names from many sources. The "new" elements are purely synthetic and are usually named by the scientist who develops them. What would you name an element?

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- [AtomsURL](#)

Read the "Atoms Become Real" section. Familiarize yourself with the laws of conservation of mass, constant composition, and multiple proportion. These concepts play a key role in Dalton's atomic theory. Also look at the section on relative masses of atoms, which arose from Dalton's theory.

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- [The Nuclear AtomURL](#)

Read "The Nuclear Atom" section on subatomic particles. The section also covers isotopes and isotopic notation - the concept that a given element type can possess different numbers of neutrons. These concepts were not part of Dalton's atomic theory. Can you identify why?

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- [Elements and AtomsPage](#)

Watch these lectures to reinforce the concepts we just discussed.

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- [Atomic MassesURL](#)

Read the "Atomic Masses" section, which introduces the concept of unified atomic masses.

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- **2.2: Avogadro's Number and Moles**

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- [Avogadro's Number and the MoleURL](#)

Read this page. This material covers moles and molar masses, which will be a recurring theme in later units. Keep in mind that the "mole" is nothing more than a number. Just as a dozen always equals 12 and a gross is always 144, a mole always equals  $6.022 \times 10^{23}$ .

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- [The Mole and Avogadro's NumberPage](#)

Watch this lecture to reinforce the concepts of the mole and Avogadro's number.

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- **2.3: Atomic Theories**

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- [Quanta: A New View of the WorldURL](#)

Read this page, which explains how classical physics was modified, leading to the development of quantum theory. The term quantum refers to the observation that energy is a system that can only exist in discrete, or distinct, levels.

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○ [Light, Particles, and WavesURL](#)

Read this page, which describes why light can be classified as both a wave and a particle.

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○ [The Bohr AtomURL](#)

Read this page. The Bohr model of the atom introduces orbitals and explains the observation of atomic line spectra. Orbitals are regions of space where electrons orbiting the nucleus of an atom can reside. Atomic line spectra is electromagnetic radiation, or light energy, associated with electron redistribution among pairs of orbitals.

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○ [The Quantum AtomURL](#)

Read this page, which describes the quantum model of the atom. This model differs slightly from the Bohr model in how it explains electron behavior. Do not get them confused! Many of the fundamental concepts of modern physics grew out of these models, so much of the material may be reminiscent of a physics course.

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○ [OrbitalsPage](#)

Watch this lecture to reinforce your understanding of models of the atom.

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• **2.4: The Periodic Table of the Elements**

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○ [Orbitals and Electron ConfigurationPage](#)

Watch these videos to learn more about the periodic table and how electron orbitals are modeled.

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○ [Atomic Electron ConfigurationsURL](#)

Read this page, which covers electron configurations and the arrangement of the periodic table. An electronic configuration is a listing of the occupancy of an atom's electrons amongst its orbitals. The periodic table was purposefully designed to reflect the chemical nature of each element. Metals, for example, are on the left-hand side, while noble gases are on the right. Halogens are always to the immediate left of the noble gases. By the end of this section, you should be able to identify these and other groups on a periodic table. Remember that a group is a vertical column, while a period is a horizontal row.

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○ [Periodic Properties of the ElementsURL](#)

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Read this page, which reinforces what you just learned about the arrangement of the periodic table. It also discusses the general trends exhibited, including atomic size, ionization energy, electron affinity, and electronegativity.

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o [The Periodic TablePage](#)

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Groups on the periodic table are important because elements within a particular group, in general, have similar chemical properties and reactivity. Ionization refers to the process of removing an electron from an atom. Ionization energy pertains to the energy supplied to facilitate this process. Watch these three lectures to reinforce the concepts covered in the reading assignment.

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### Unit 3: Bonding

Bonds are connections between atoms. A solid grasp of valence shell electron pair repulsion (VSEPR) theory will help you understand how elements that differ by one or two atomic numbers behave.

According to VSEPR theory, the number of electrons an element has corresponds with its chemical properties. For example, sodium differs from neon and potassium by one atomic number, but it resembles potassium, not neon. Sodium and potassium both have one valence electron, which explains their similar properties, while neon is a stable element with eight valence electrons. We use VSEPR to predict the three-dimensional structure, or geometry, of molecules.

**Completing this unit should take you approximately 10 hours.**

- Upon successful completion of this unit, you will be able to:
  - define chemical bonds;
  - explain why most atoms form chemical bonds;
  - describe ionic, covalent, and metallic bonding;
  - describe and give examples of Van der Waals forces as part of intermolecular forces;
  - explain VSEPR theory;
  - predict the shape of molecules or polyatomic ions using VSEPR theory;
  - explain how the shapes of molecules are accounted for by hybridization theory;
  - explain what determines molecular polarity; and
  - draw resonance structures.

#### • 3.1: Chemical Bonds

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o [Introduction to Chemical BondingURL](#)

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Read this page. Pay close attention to how bond length and bond energies are related.

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o [Models of Chemical BondingURL](#)

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Read this page. Keep in mind that these are only models used to depict bonding and may not explain the behavior of every bond.

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○ [The Shared-Electron Covalent BondURL](#)

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Read this page. A covalent bond in a molecule, the most commonly occurring type, happens when each atom undergoing bonding contributes one electron to a shared electron pair. This page also introduces resonance structures. Resonance occurs when more than one correct Lewis structure can be drawn.

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○ [Polar CovalenceURL](#)

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Read this page, which utilizes the concept of electronegativity. Do you remember the trend? Keep in mind that these bonding categories are models and are used to approximate behavior.

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○ [Ionic, Covalent, and Metallic Bonds, and Covalent Networks, Metallic, and Ionic CrystalsPage](#)

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Watch these lectures to reinforce the concepts covered in the reading assignment. An ionic bond occurs when one atom contributes two electrons to an electron pair and another atom contributes none. Metallic bonding occurs when many electrons occupy a large region of space and their atoms are cationic sites to balance overall charge.

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○ [Interactions Between Molecular UnitsURL](#)

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Read this page, which takes a look beyond the solid-liquid-gaseous states of matter to explore why these states exist. This tutorial also explains important molecular interactions other than bonding.

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○ [Van Der Waals ForcesPage](#)

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Watch this lecture to reinforce your understanding of Van der Waals forces.

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○ [Water and Hydrogen BondingURL](#)

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Read this page, which describes the significance of hydrogen bonding, one of the most important intermolecular forces. Without hydrogen bonding, DNA wouldn't exist as a double helix!

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● **3.2: Molecular Structure**

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○ [Molecular GeometryURL](#)

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Read this page. Can you explain why carbon dioxide is a linear molecule, while water is bent? Lone pairs of electrons from the Lewis structures become very important here.

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- [The Hybrid Orbital Model, Part 1URL](#)

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Read this page, which introduces hybrid orbital theory and explains why atomic orbitals do not explain bonding. Molecules examined here contain single bonds and lone pairs.

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- [The Hybrid Orbital Model, Part 2URL](#)

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Read this page, which is a continuation of hybrid orbital theory, examining multiple bonds, resonance, and *d* orbitals.

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#### **Unit 4: Chemical Formulas and Equations**

Chemists need to write out formulas and equations to solve chemistry problems. In this unit, we begin to name and write compounds and learn how to write out and balance chemical equations.

Equations enable us to describe chemistry topics in mathematical terms and predict the outcomes of reactions. For example, what volume of steam created if we turn one kilogram of ice into pure steam, at 200° Celsius and sea-level air pressure? We can calculate the precise answer when we write the reaction out in the form of an equation!

**Completing this unit should take you approximately 6 hours.**

- Upon successful completion of this unit, you will be able to:
  - list the rules for assigning most common electronic charge states (oxidation numbers) of compounds or elements;
  - give oxidation numbers for each element in the formula of a compound;
  - explain the significance of a chemical formula;
  - determine the formula of an ionic compound when given the name;
  - name an ionic compound when given a formula;
  - name binary molecular compounds using prefixes; and
  - balance a chemical equation.

- **4.1: Chemical Formulas**

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- [Empirical and Molecular FormulasPage](#)

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Watch these videos for an introduction to molecular formulas.

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- [Chemical Formulas and Their ArithmeticURL](#)

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Read this page, which explains what information chemical formulas reveal and how to derive chemical equations from experimental data. This is one of the most math-intensive units in general chemistry, but it is not as tricky as it may seem at first. Follow the method.

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- [Introduction to Chemical NomenclatureURL](#)
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Read this page. "Nomenclature" is a fancy word for the process of naming compounds. The more you practice systematically naming compounds, the easier it will become. Here, primarily inorganic substance nomenclature is covered. While organic nomenclature is introduced here, it will be covered in more detail in organic chemistry.

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## • 4.2: Stoichiometry and Limiting Reagents

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### ○ [Stoichiometry and Limiting ReagentsPage](#)

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Watch these videos, which introduce stoichiometry. Stoichiometric coefficients are numbers of chemical compounds necessary to mass balance a chemical reaction.

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### ○ [Chemical Equations and CalculationsURL](#)

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Read this page, which explains what information is given in a balanced chemical equation. Although balancing may seem easy, it can become quite difficult when there are multiple reactants and/or products. As a general rule, begin balancing the chemical equation with a unique atom, or one that is only found in one reactant and one product. Balance hydrogen and oxygen last; they usually present the biggest challenge. You must learn to properly balance equations, as you will need this skill in every chemistry course you take.

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### ○ [Virtual Lab: Limiting Reagents 1URL](#)

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In this virtual lab, you will use limiting reagents to solve problems. To see the instructions, click the name of the problem ("Limiting Reagents Problems 1") on the virtual lab screen.

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### ○ [Virtual Lab: Limiting Reagents 2URL](#)

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In this virtual lab, you will use limiting reagents to determine the concentration of an unknown solution. To see the instructions, click the name of the problem ("Limiting Reagent Problem 2") on the virtual lab screen.

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## **Unit 5: States of Matter**

In this unit, we look at how matter behaves. We will begin with gases because we can describe their behaviors and properties in straightforward equations. We will also study the phase diagram, which predicts the state (solid, liquid or gas) of any group of molecules at any given temperature or pressure.

### **Completing this unit should take you approximately 15 hours.**

- Upon successful completion of this unit, you will be able to:
  - use kinetic-molecular theory to explain the relationships between gas volume, temperature, number of moles, and pressure;
  - perform dimensional analysis conversions for gas law calculations;
  - state the ideal gas law;

- describe the motion of particles in liquids and the properties of liquids;
- discuss the process by which liquids can change into a solid or a gas;
- define the characteristics of bonding in ionic compounds;
- interpret phase diagrams; and
- describe and explain the processes of boiling, evaporation, freezing, melting, and sublimation.

## • 5.1: Gases and Gas Laws

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- [Observable Properties of GasesURL](#)

Read this page. Understanding how pressure, temperature, and volume of a gas differ from those of forces that exist within solids and liquids will be fundamental for understanding the upcoming subunits of this course.

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- [Ideal Gas LawsPage](#)

Watch these lectures, which introduce ideal gases.

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- [The Basic Gas LawsURL](#)

Read this page. Ideal gas laws are laws that apply to gases that behave "ideally", which is when molecules take up no volume and have no attractive forces between one another. In the real world, however, no gas behaves ideally. However, gases are closest to being ideal when they are high-temperature and low-pressure.

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- [Partial PressurePage](#)

Watch this lecture, which discusses partial pressure. A key concept here is that a mixture has a total pressure that is the sum of its component, or partial, pressures.

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- [Moles, Mixtures, and DensitiesURL](#)

Read this page, which covers molar properties of gases and partial pressures. After reading this section, you should understand what happens to scuba divers who suffer from nitrogen narcosis, or "the bends".

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- [Introduction to Kinetic-Molecular TheoryURL](#)

Read this page. Kinetic molecular theory (KMT) explains the properties of gas molecules and their motion. KMT helps explain how radio waves are transmitted and why the sky is blue.

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## • 5.2: Phase Changes

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- [Liquids and Their InterfacesURL](#)

Read this page, which takes a more in-depth look at the properties of liquids, which were introduced previously. Have you ever wondered why all soap bubbles are round? The concepts discussed here will explain.

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○ [Liquid Phase PropertiesPage](#)

Watch these videos, which explain how to calculate the amount of energy associated with both temperature changes and phase changes of a particular substance.

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○ [Introduction to CrystalsURL](#)

Read this page, and focus on the section about the unit cell. Some terms related to symmetry and spectroscopy are introduced here but not covered in detail. More advanced chemistry courses would go into these concepts further.

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○ [Ionic and Ion-Derived SolidsURL](#)

Read this page, which covers the class of solids that form from ions and the energetics of these compounds.

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○ [Cubic Crystal Lattices and Close-PackingURL](#)

Read this page, which builds on the concept of the unit cell and describes the packing structures of simple cubic lattices.

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○ [Changes of StateURL](#)

Read this page, which describes the dynamic equilibrium between phases and introduces phase diagrams. There are six different processes by which phases can change from one to another. Some will be familiar to you, such as evaporation or freezing; others might be less familiar, like sublimation and deposition.

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○ [Phase DiagramsPage](#)

Watch these videos to reinforce your understanding of phase diagrams. Although we deal with the three primary states of matter (gases, solids, and liquids) every day, we are often not familiar with their microscopic interactions.

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## **Unit 6: Thermochemistry and Thermodynamics**

In this unit, we study thermochemistry, which deals with the temperature- and heat-related aspects of chemistry, and thermodynamics, which focuses on the overall energies associated with chemical reactions. Thermodynamics will lead us to the Gibbs free energy equation, which tells us whether a chemical reaction is spontaneous (or will occur without external help).

**Completing this unit should take you approximately 10 hours.**

- Upon successful completion of this unit, you will be able to:

- define temperature;
- define heat and state its units;
- define and perform enthalpy change, enthalpy of reaction, enthalpy of combustion, and enthalpy of formation calculations;
- define entropy;
- describe the driving force of a chemical reaction and relate it to Gibbs free energy;
- define Hess' law and state its functions; and
- use Hess' law to solve thermodynamic problems.

- **6.1: Energy**

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- [Energy, Heat, and WorkURL](#)

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Read this page. Pay close attention to how the system and surroundings are defined; this will determine the direction of energy flow in thermodynamic systems.

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- [Molecules as Energy Carriers and ConvertersURL](#)

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Read this page. Make sure you can follow the concept map at the bottom of the page, which relates potential and kinetic chemical energy to the enthalpy of a system.

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- [Enthalpy and Heat of FormationPage](#)

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Watch these videos. The enthalpy of a system is the energy contained in its chemical bonds plus any pressure-volume work the system can do.

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- [Virtual Lab: Camping Problem 1URL](#)

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In this virtual lab, you will measure the enthalpy of a reaction. To see the instructions, click the name of the problem ("Camping 1") on the virtual lab screen.

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- [Virtual Lab: Camping Problem 2URL](#)

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In this virtual lab, you will determine change in the enthalpy of a reaction as the concentration of reactants are varied. To see the instructions, click the name of the problem ("Camping 2") on the virtual lab screen.

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- [Thermochemistry and CalorimetryURL](#)

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Read this page. Calorimetry is used to measure the change in enthalpy of reactions in a laboratory setting. Since enthalpy is a state function, Hess' law is applied to calculate the change in enthalpy from literature values.

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- [Hess' Law and Reaction Enthalpy ChangePage](#)

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Watch these videos to reinforce your understanding of Hess' Law.

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○ [Heats of Reaction and Hess' LawURL](#)

This virtual lab will demonstrate Hess' Law using three reactions: the solubility of NaOH in water, the solubility of NaOH in HCl, and the reaction of a solution of HCl and a solution of NaOH. To see the instructions, click the name of the problem ("Heats of Reaction") on the virtual lab screen.

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○ [Some Applications of Enthalpy and the First LawURL](#)

Read this page. Using bond energy to calculate the enthalpy of reaction is not particularly accurate because energies are affected by each molecule's unique surroundings, such as intermolecular forces. For this reason, energies are only an average across many different reactions.

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• **6.2: Thermodynamics**

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○ [The First Law of ThermodynamicsURL](#)

Read this page. The first law of thermodynamics is sometimes referred to as the law of conservation of energy. It states that energy can be neither created nor destroyed, but it may change form. For example, imagine a campfire: the energy is stored in chemical bonds in the wood and is released as light and heat.

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○ [The First Law of Thermodynamics and Internal EnergyPage](#)

Watch this lecture, which covers exothermic and endothermic reactions.

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○ [The Availability of EnergyURL](#)

Read this page. The second law of thermodynamics deals with heat transfer and explains why a perpetual motion machine can never exist.

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○ [What is Entropy?URL](#)

Read this page, which gives a detailed description of entropy and how it relates to the system and surroundings. The third law of thermodynamics deals with a theoretical absolute zero state, which is a physical impossibility.

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○ [Gibbs Free EnergyURL](#)

Read this page. The Gibbs free energy equation predicts whether a reaction will happen spontaneously or not. Gibbs free energy applies to reactions of every magnitude, from water freezing to industrial chemical processes. It is important to note that while a reaction may be predicted to be spontaneous, its reaction rate may be very slow.

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○ [Gibbs Free Energy and SpontaneityPage](#)

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Watch these videos. If the computed change in Gibbs free energy is negative for a chemical reaction, then the reaction is spontaneous.

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### **Unit 7: Acid-Base and Oxidation-Reduction Reactions**

Now let's look at two types of chemical reactions: acid-base and oxidation-reduction. We will review the properties of acids and bases and introduce two acid-base definitions: Arrhenius and Brønsted-Lowry. We will also examine pH calculations, and learn how to use the pH scale to identify acidic and alkaline solutions. Next, we discuss oxidation and reduction, learn how to write and balance equations for oxidation-reduction reactions, and introduce some common oxidizing and reducing agents.

**Completing this unit should take you approximately 12 hours.**

- Upon successful completion of this unit, you will be able to:
  - use the Arrhenius and Brønsted-Lowry definitions to identify acids and bases;
  - write and balance equations for neutralization reactions;
  - explain the process of self-ionization of water molecules;
  - conduct pH calculations and use pH scale to classify solutions as acidic, basic, or neutral;
  - explain the process of titration;
  - explain relationship between conjugated acids and bases;
  - compare and contrast processes of oxidation and reduction;
  - write and balance equations for oxidation-reduction reactions; and
  - identify common oxidizing agents, common reducing agents, and substances that can act both as oxidizing and reducing agents.

#### **7.1: Acids and Bases**

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○ [What are Acids and Bases?URL](#)

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Read this page, which introduces the concepts of acids, bases, salts, and neutralization reactions. The Arrhenius theory views acids and bases as substances that produce hydrogen ions or hydroxide ions on dissociation.

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○ [Arrhenius' Definition of Acids and BasesPage](#)

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Watch this video, which explains Arrhenius' definition of acids and bases. Arrhenius acids increase the concentration of hydrogen ions in aqueous solutions, while Arrhenius bases increase the concentration of hydroxide ions.

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○ [Virtual Lab: Strong Acids and BasesURL](#)

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In this virtual lab, you will solve problems related to strong acids and bases. To see the instructions, click the name of the problem ("Strong Acid Textbook Problems") on the virtual lab screen.

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○ [Virtual Lab: Weak Acids and BasesURL](#)

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In this virtual lab, you will solve problems related to weak acids and bases. To see the instructions, click the name of the problem ("Weak Acid Textbook Problems") on the virtual lab screen.

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○ [Aqueous Solutions, pH, and TitrationURL](#)

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Read this page, which introduces the pH scale and explains how titration is done. We can titrate an acid with a base or a base with an acid. The substance whose concentration we are determining is called the analyte. The substance we are adding in measured amounts is called the titrant.

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○ [More on pH, Titration, Acids, and BasesPage](#)

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Watch these videos. The first explains pH and the pH scale and explains how to conduct pH calculations. The pH scale ranges from 0 to 14. A solution with a pH of 7 is neutral. If the pH is less than 7, the solution is acidic. If the pH is greater than 7, the solution is basic. Since the pH scale is logarithmic, each whole pH value below 7 is ten times more acidic than the next higher value.

The second covers common strong acids and strong bases and presents examples of pH calculations. Do not forget that strong acids and strong bases nearly completely dissociate in ions in aqueous solutions.

The third explains how titration is conducted and presents an example of titrating strong acid with a strong base. It covers indicators, endpoint, equivalence point, and calculating the unknown concentration. Note that the endpoint of titration is defined as the moment when enough titrant has been added to the titrand to facilitate a color change. The equivalence point is defined as the moment when the amount of titrant added is enough to completely neutralize the analyte solution.

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○ [Virtual Lab: Acid-Base TitrationURL](#)

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In this virtual lab, you will standardize an unknown NaOH solution four significant figures via titration with 25.00 mL of a standard solution of KHP. To see the instructions, click the name of the problem ("Standardization of NaOH") on the virtual lab screen.

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○ [Proton Donors and AcceptorsURL](#)

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Read this page, which presents auto-ionization of water molecules, explains Brønsted-Lowry definition of acids and bases, and introduces the formation of

conjugate acid-base pairs. Note that Brønsted-Lowry theory expands categories by defining acids as proton donors and bases as proton acceptors.

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- [Brønsted-Lowry, Autoionization, and Conjugate Acids and BasesPage](#)

Watch these videos. The first explains the Brønsted-Lowry definition of acids and bases. The second explains how auto-ionization of water molecules happens. Water is an amphoteric compound: it can act as either an acid or a base. Hydrogen ions do not exist in water on their own but immediately get grabbed by water molecules to form hydronium ions. The third explains the relationship between conjugate acids and bases. A conjugate pair is always one acid and one base.

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- [Acid-Base ReactionsURL](#)

Read this page, which covers different kinds of neutralization reactions. Make sure you can sketch proton-energy diagrams for a strong acid, a weak acid or base, and a strong base.

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- [Acid-Base Properties of SaltsPage](#)

Watch this video, which covers different kinds of neutralization reactions. We use the term "neutralization" to define these reactions because the acid and base properties of hydrogen and hydroxide ions are destroyed or neutralized. Hydrogen and hydroxide ions combine to form water molecules.

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- **7.2: Oxidation-Reduction Reactions**

- [Redox ReactionsURL](#)

Read this page, which presents oxidation-reduction reactions and explains how oxidation-reduction reaction can be written in the form of half-reactions. Note that oxidation is the loss of electrons, while reduction is the gain of electrons. A species that donates electrons in a redox reaction is called a reducing agent, or reductant. A species that accepts electrons in a redox reaction is called an oxidizing agent, or oxidant.

- [Oxidation Numbers and Redox ReactionsURL](#)

Read this page, which explains how oxidation states are determined and how they change due to electron transfer in the oxidation-reduction reactions. Make sure you understand the rules. You might also want to memorize the list of elements that almost always have the same oxidation states in their compounds, as well as the exceptions to those rules.

- [Balancing Redox EquationsURL](#)

Read this page, which explains how to balance equations of oxidation-reduction reactions. Different steps should be used depending on whether the solution is acidic or basic.

- [Oxidation, Reduction, and Redox ReactionsPage](#)

Watch these videos. The first introduces oxidation states, oxidation, and reduction. It also provides some tips for remembering oxidation and reduction. The second explains how to write the half-reactions in a combustion reaction. Combustion is a reaction between hydrocarbon and oxygen that produces carbon dioxide and water. Focus on what is being oxidized and what is being reduced during combustion.

- [Common Oxidizing AgentsURL](#)

Read this page, which introduces common oxidizing agents. All of them share one property: the ability to accept electrons readily.

- [Common Reducing AgentsURL](#)

Read this page, which introduces common reducing agents. All of them share one property: the ability to donate electrons readily.

- [Substances that are Both Oxidizing and Reducing AgentsURL](#)

Read this page, which introduces substances that can act both as oxidizing and reducing agents. One of these substances (water) is essential for your life. Another substance (hydrogen peroxide) is also commonly found in household products.

- [Oxidizing and Reducing AgentsPage](#)

Watch this video, which explains how to identify the oxidizing and reducing agents in an oxidation-reduction reaction. The substance being oxidized is a reducing agent; the substance being reduced is an oxidizing agent.

- [Virtual Lab: Oxidation-Reduction ReactionsURL](#)

In this virtual lab, you will design an experiment to determine which metals are the strongest and weakest reducing agents. To see the instructions, click the name of the problem ("Redox") on the virtual lab screen.

## **Unit 8: Nuclear Chemistry**

Finally, let's examine the processes of nuclear decay, nuclear fusion, and nuclear fission. We will discuss different types of nuclear decay, learn how to write equations that describe nuclear reactions, review the concept of half-life in the context of radioactive decay, and learn how city planners use nuclear fission to generate electric energy.

**Completing this unit should take you approximately 4 hours.**

- Upon successful completion of this unit, you will be able to:
  - distinguish different types of nuclear decay;
  - balance nuclear equations;
  - explain the process of radioactive dating;
  - describe the processes of nuclear fission and fusion; and
  - explain how radioactive decay is used as a source of energy.

## • 8.1: Types of Nuclear Decay

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- [Radioactive DecayURL](#)

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Read this page, which introduces the concept of radioactivity and radioactive decay. This chapter also reintroduces the concept of isotopes, which are different types of atoms (nuclides) of the same chemical element. Each has a different atomic mass (mass number) but the same atomic number.

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- [Alpha DecayURL](#)

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Read this page, which introduces alpha decay and provides an example of an alpha-decay equation. The two main characteristics of alpha-decay are 1) the sum of the mass numbers on the left and right of the equation are the same, and 2) the sum of the atomic number on the left and right are the same.

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- [Beta DecayURL](#)

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Read this page, which introduces beta decay and provides an example of a beta-decay equation. There is no change in the mass number in beta decay, but the atomic number increases by one.

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- [Radioactive Decay SeriesURL](#)

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Read this page, which introduces the concept of radioactive decay series. You do not need to memorize this particular chain; just note how the transition from one isotope to another occurs through alpha or beta decay.

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- [Nuclear DecayPage](#)

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Watch these videos, which present four different types of nuclear decay. In addition to alpha and beta decay, gamma and positron emission can occur. The positron is a particularly interesting particle. It is an example of anti-matter, as it is an anti-electron. In the case of positron decay, there is no change in mass number, but the atomic number decreases by one. The second video explains how to write nuclear equations for alpha, beta, and gamma decay.

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## • 8.2: The Half-Life of Radioactive Isotopes

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- [Half-LifeURL](#)

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Read this page, which introduces the concept of a half-life for a radioactive isotope. The half-life is the time it takes half of the atoms in a current sample to decay. The sample size doesn't matter: whether you have one gram or one ton of isotope, half of the sample will decay during the first half-life. The sample will continue to shrink by half during each successive half-life.

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- [Carbon DatingURL](#)

Read this page, which explains how carbon dating is used to determine the age of an object. Since the half-life for C-14 is approximately 5700 years, carbon dating is useful only for fossils up to about 50,000 years old. For older fossils, isotopes with longer half-lives are used.

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- [Half-Life and Carbon DatingPage](#)

Watch this video, which explains half-life in the context of radioactive decay.

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- **8.3: Nuclear Fusion, Nuclear Fission, and Energy Production**

- [Transmutation of the ElementsURL](#)

Read this page, which discusses the processes of transmutation. Transmutation is the conversion of one element to another. Transmutation of stable isotopes can be achieved by bombarding the nucleus with neutrons. Historically, transmutation has been used to synthesize new elements.

- [The Mass DefectURL](#)

Read this page, which introduces the concept of mass defect. Mass defect is the difference in the observed atomic mass of an atom and the sum of the masses of the protons, neutrons, and electrons that make up the atom. It also explains why 1 gram of uranium-235 undergoing decay can provide enough energy to light a typical light bulb for approximately 28,000 years!

- [Nuclear FissionURL](#)

Read this page, which presents the process of nuclear fission. The critical mass is the smallest amount of fissile material needed for a sustained nuclear chain reaction.

- [Nuclear EnergyURL](#)

Read this page, which explains how nuclear decay is used to produce electricity and presents real and imagined dangers of atomic energy. A coal power plant releases 100 times as much radiation as a nuclear power plant of the same wattage. The major concern with nuclear plants is high-level radioactive waste that should be safely stored for more than 10,000 years.

- [Nuclear FusionURL](#)

Read this page, which presents the process of nuclear fusion. This is the process that powers stars, including our sun. Scientists have been attempting to develop controlled fusion; if this goal can be achieved, it will provide the world with almost limitless clean energy.

- [How Does a Nuclear Reactor Work?URL](#)

Read this page, which explains how a nuclear reactor works. It also covers the different parts of the nuclear reactor (the core, coolant, turbine, containment, and cooling towers) and their functions.