SUPERCHARGED SCIENCE

Unit 15:
Chemistry Part 2

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Appropriate for Grades:
Grades 5-12 (see notes on each lesson)
Duration: 10-75 hours, depending on how many activities you do!

In this unit, you will learn how to build your own home chemistry lab safely under the direction of professionals. We'll show you how to do *real* chemistry experiments, provide chemical storage information, give guidelines on proper chemical disposal when you're finished, highlight lab tips and tricks, and warn you about things to watch out for. This is *real* chemistry for real kids.

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Key Vocabulary

Acids are sour (like a lemon), react with metals, and can burn your skin. They register between 1 and 7 on the pH scale.

An **acid-base reaction** deals with reactions that involve hydrogen (protons).

Atoms are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.

Avogadro's constant is 6.022 x 10^{23}, and since "mole" is a lot easier to write than 6.022 x 10^{23}, chemists like to use it to help keep track of the particles in a chemical reaction. It's a handy way to convert between atoms and grams, or even molecules and grams.

Balancing Chemical Reactions Learning how to figure out whether a chemical reaction will occur and what comes out the other end is found by writing a balanced chemical equation to describe a chemical reaction.

Bases are bitter (like baking soda), slippery, and can also burn your skin. They measure between 7 and 14 on the pH scale.

A **combustion reaction** gives off energy, usually in the form of heat and light.

The electrons in the outermost shell are the ones that form the **bonds** with other atoms. When one atom accepts or donates an electron to another atom, an **ionic bond** is formed. When the atoms share the electron(s), a **covalent bond** is formed. Usually an electron is more attracted to one atom than another, which forms **polar covalent** bond between atoms.

By knowing the value of the **bond energy**, we can predict if a chemical reaction will be exothermic or endothermic.
A **chemical change** rearranges the molecules and atoms to create new molecule combinations (like a campfire).
Chemists study **chemical kinetics** when they want to control the speed of a reaction as well as what gets generated from the process (the products of

the reaction). Several factors affect the speed of a chemical reaction, including catalysts, surface area, temperature, and concentration.

Chemicals form various **crystal structures** when they freeze. Water is one of the few molecules which expand when changing from a liquid to a solid.

A **decomposition** reaction breaks a complicated molecule into simpler ones

A **double displacement** (metathesis) reaction has two compounds exchanging bonds to form new compounds

The chemical reaction inside **electrochemical cells** is also a redox reaction. Batteries (also known as galvanic or voltaic cells) use a spontaneous chemical reaction inside to create energy. Non-spontaneous cells require an energy source (like a battery) in order for the chemical reaction to occur, called electrolysis.

Splitting the water molecule into parts (hydrogen and oxygen) requires power (**electrolysis**) to break the bonds.

Electronegativity is how attracted an electron is to an atom.
Thin layers of metal can be moved from one object to another using the **electroplating** technique.

Elements A substance made up of only one particular kind of atom is called a chemical element, and you can find a whole slew of these on the periodic table. The number assigned to the chemical element refers to the number of protons in the nucleus.

Endothermic reactions are reactions that absorb heat when they react (like a cold compresses).

Energy is the ability to do work. Energy can be transferred, in other words it can be changed from one form to another and from one object to another.

Exothermic reactions release energy in the form of heat, light, and sound (think fireworks).

Gases have no bonds between the molecules.

The jiggling motion in atoms is called **heat**.

Ideal Gas Law Pure substances all behave about the same when they are gases. The Ideal Gas Law relates temperature, pressure, and volume of these gases in one simple statement: PV = nRT where P = pressure, V = volume, T = temperature, n = number of moles, and R is a constant.

Different **indicators** are used for specific ranges of acids and bases. Phenolphthalein changes from clear to pink when added to a base.

Atoms that have an electrical charge are called **ions**, as they have a different number of electrons than protons.

Ionization energy (measured in electronvolts, *eV*) is the amount of energy needed to completely remove an electron from gaseous atom or ion.

Le Chatelier's Principle predicts how changes in pressure, temperature, volume, or concentration will cause a reaction to shift and compensate for these changes.

Liquids have loose, stringy bonds between molecules that hold molecules together but allow them some flexibility.

Matter is anything that has mass (anything that is affected by gravity). Most matter on our planet is made up of atoms and ions. Not all matter is made up of atoms, but all matter is made up of some kind of particle.

Changing from a solid to a liquid is called **melting**. Melting point is the temperature at which a material changes from solid to liquid. Objects absorb heat as they melt.

Moles A mole is a unit of measurement, just like inches or meters. One mole is the amount of a substance that has the same number of particles as found in 12 grams of carbon C-12, which is 6.022×10^{23} particles.

A **molecule** is the smallest unit of a compound that still has the compound's properties attached to it. Molecules are made up of two or more atoms held together by covalent bonds.

Nuclear reactions deal with changes inside the nucleus of an atom.

Neutralization Reaction (Hydrolysis) When acids and bases react with each other, they sometimes form a salt and water.

pH stands for "power of hydrogen" and is a measure of how acidic a substance is.

A **physical change** happens when the molecules stay the same, but the volume and/or shape change (like wadding up tissue).

A gas becomes a **plasma** when the molecules move about so rapidly that they knock electrons off the atoms when they collide.

Polymers are long chains of slippery molecules. Coagulation happens when you cross-linking the chains into a fishnet-looking design.

Different factors affect the **rate of reaction**, or speed of the chemical reaction, including temperature, pressure, surface area, catalysts, and more. The main idea is that the more collisions between particles, the faster the reaction will take place.

Salt doesn't necessarily mean table salt (NaCl), but rather an ionic compound formed from acid-base combinations. Salts are held together by electrical charges (that's what makes it an ionic bond), as they are formed between cations (positive ions, like Na^+) and anions (negative ions, like Cl^-).

Quarks make up the nucleus of the atom. They are subatomic particles that you can arrange in certain ways to get protons and neutrons.
Redox reactions involve an exchange of electrons between compounds. Redox stands for oxidation-reduction. **Oxidation** happens when a compound loses electrons (increases oxidation state) and **reduction** occurs when a compound gains electrons (decrease in oxidation state).

Solids have strong, stiff bonds between molecules that hold the molecules in place.

Materials change from one **state** to another depending on the temperature and these bonds. All materials have given points at which they change from state to state. As objects change state they do not change temperature. The heat that goes into something as its changing phases is used to change the “bonds” between molecules. Freezing points, melting points, boiling points and condensation points are the “speed limits” of the phases. Once the molecules reach that speed they must change state.

Synthesis Reaction happens when simple compounds come together to form a more complicated compound

Unit Description

In this unit, you will learn how to build your own home chemistry lab safely under the direction of professionals. We'll show you how to do *real* chemistry experiments, provide chemical storage information, give guidelines on proper chemical disposal when you're finished, highlight lab tips and tricks, and warn you about things to watch out for. This is *real* chemistry for real kids.

Why old chemistry sets are better…Today's chemistry sets are complete *wimps* when compared with the sets from 1920-1960s. Packed with radioactive uranium, pure magnesium foil (which burns at 4000 ^{o}F), details on how to blow your own glassware, and instructions on how to make your own rocket engines, these older chemistry sets inspired thousands of scientists and engineers into their current careers.

What happened to learning *real* science? Today's chemistry sets are limited to color change reactions and mixing polymers into slime. Why such a switch from their robust ancestors? Well, we've learned about toxic chlorine gas, deadly sodium cyanide, and other risky stuff, so it makes sense to pull out the really dangerous chemicals. But what about the rest?

Fear. Fear of liability, fear of irresponsibility, and overreacting to 'what if…?' are the major causes for limiting our current levels of chemistry education. As a parent, it's your job to make sure your kid understands the full potential of what they are learning, and add a dose of ethics and common sense alongside their lessons.

It's a lot easier to learn safe chemistry practices through a unit like this than to skip this unit completely and toss your child out into the real world where there are no instructions or safety boundaries put into place. This unit will build a strong foundation in essential lab skills, chemistry techniques, and safe practices.

How do I use this information? You have two options, depending on your comfort level and ultimate educational goals. You can just watch the videos and talk about what's going on with your child, or you can watch the videos and then perform the experiment with your child.

This unit includes the instructional videos for Chemistry, and is meant to be used in conjunction with the experiments in the Thames and Cosmos C1000 and/orC3000 chemistry lab kits. The manual included in the C1000 and 3000 has complete safety information and many more experiments for you to complete after you finish this unit.

We here at Supercharged Science believe that **ignorance ultimately costs you more than knowledge**, and also that **clarity is power**. You can make the best decisions after you fully understand what's possible. We bring to you the best home chemistry experiments from the best sources around.

However, if you ever aren't sure about an experiment, DON'T DO IT. Get help from a local professional (visit your local college chemistry department) who has a successful track record at doing whatever it is you want to do (someone without eyebrows may not be a good choice).

All experiments presented here at AT YOUR OWN RISK. You are fully responsible for your own safety and those around you. (No building nuclear reactors in your garage.) If, however, you act in a way that is not appropriate (say, you are only interested in making fireworks, explosives, rockets, or somehow making a problem for anyone else on the planet), you are entitled to the following: a large, nitrogen triiodide hat with your name etched inside. Given that NI_3 explodes on contact with the lightest touch of anything, we would recommend use only during thundershowers and windstorms. You are also at liberty to sample our crystal violet black tea - the caffeine will not only alert your senses to peak performance, but the passing of brilliant purple urine specimen will also get your attention. Finally, we'll provide a liberal sprinkling of dimethyl sulfoxide on all your doorknobs, which will remind you of the ocean, as you will taste oysters in your mouth as soon as your fingers touch the door handle.

To put it simply, don't eat anything in your chemistry lab, keep children and pets away from your lab, lock up your chemicals safely, learn how to store your chemicals safely, and don't create large quantities of anything explosive, corrosive, or toxic. Always wear safety equipment and do your experiments in a spot what has plenty of air for ventilation, water and a drain, and a phone.

In all seriousness, be safe, have fun, play with the kids, and if you run across anything that boggles the mind, let us know and we'll try to help you out.

Objectives

Lesson 1: Intermediate Chemistry

Split the water molecule, fire copper ions across a solution, capture oxide gases, create a magnesium battery, and more with this lesson in chemistry.

You'll also be able to identify the elements in different chemical substances with dazzling colors in flame tests.

With this lesson, you will begin to build a strong foundation in chemistry with exposure to a broad range of chemical phenomena and hands-on laboratory experience. Here's what you can expect to learn about by the end of the lesson:

Highlights:

- **Acids** react with metals and can burn your skin. They register between 1 and 7 on the pH scale.
- **Bases** are slippery and can also burn your skin. They measure between 7 and 14 on the pH scale.
- **pH** stands for "power of hydrogen" and is a measure of how acidic a substance is.
- An **acid-base reaction** deals with reactions that involve hydrogen (protons).
- **Atoms** are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.
- **Elements** A substance made up of only one particular kind of atom is called a chemical element, and you can find a whole slew of these on the periodic table. The number assigned to the chemical element refers to the number of protons in the nucleus.
- A **molecule** is the smallest unit of a compound that still has the compound's properties attached to it. Molecules are made up of two or more atoms held together by covalent bonds.
- The electrons in the outermost shell are the ones that form the **bonds** with other atoms.
- When one atom accepts or donates an electron to another atom, an **ionic bond** is formed.

- When the atoms share the electron(s), a **covalent bond** is formed.
- Usually an electron is more attracted to one atom than another, which forms **polar covalent** bond between atoms.
- **Endothermic** reactions are reactions that absorb heat when they react (like a cold compresses).
- **Exothermic** reactions release energy in the form of heat, light, and sound (think fireworks).
- Different factors affect the **rate of reaction**, or speed of the chemical reaction, including temperature, pressure, surface area, catalysts, and more. The main idea is that the more collisions between particles, the faster the reaction will take place.

Objectives

Lesson 2: Advanced Chemistry

Learn first-hand the fundamental principles of this essential science as you perform real chemistry experiments.

For example, you will experiment with fuels and combustion, make your own hydrochloric acid, separate mixtures, produce oxygen gas, and more.

In doing these experiments, you will build a strong foundation in chemistry as you are exposed to a broad range of chemical phenomena and hands-on lab experience. As you gain experience with the tools and chemicals of the modern chemistry lab, you with also learn advanced topics such as chemical equations, atomic structures and the periodic table — concepts that are critical to continued study of chemistry.

This lab is an excellent way to prepare for high-school level, and even college level, chemistry.

Here's what you can expect to pick up during your lesson on chemistry:

Highlights:

- **Atoms** are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.
- **Elements** A substance made up of only one particular kind of atom is called a chemical element, and you can find a whole slew of these on the periodic table.
- A **molecule** is the smallest unit of a compound that still has the compound's properties attached to it. Molecules are made up of two or more atoms held together by covalent bonds.
- **Avogadro's constant** (6.022×10^{23}) Chemists like to use it to help keep track of the particles in a chemical reaction.
- **Moles** A mole is a unit of measurement, just like inches or meters. One mole is the amount of a substance that has the same number of particles as found in 12 grams of carbon C-12, which is 6.022×10^{23} particles.

- **Balancing Chemical Reactions** Learning how to figure out whether a chemical reaction will occur and what comes out the other end is found by writing a balanced chemical equation to describe a chemical reaction.
- **Acids** are sour (like a lemon), react with metals, and can burn your skin. They register between 1 and 7 on the pH scale.
- **Bases** are bitter (like baking soda), slippery, and can also burn your skin. They measure between 7 and 14 on the pH scale.
- An **acid-base reaction** deals with reactions that involve hydrogen (protons).
- **pH** stands for "power of hydrogen" and is a measure of how acidic a substance is.
- The electrons in the outermost shell are the ones that form the **bonds** with other atoms.
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- By knowing the value of the **bond energy**, we can predict if a chemical reaction will be exothermic or endothermic.
- **Ionization energy** (measured in electronvolts, *eV*) is the amount of energy needed to completely remove an electron from gaseous atom or ion.
- A **combustion reaction** gives off energy, usually in the form of heat and light.
- A **decomposition** reaction breaks a complicated molecule into simpler ones
- A **double displacement** (metathesis) reaction has two compounds exchanging bonds to form new compounds
- **Redox reactions** involve an exchange of electrons between compounds. Redox stands for oxidation-reduction.
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- **Nuclear reactions** deal with changes inside the nucleus of an atom.
- **Neutralization Reaction (Hydrolysis)** When acids and bases react with each other, they sometimes form a salt and water.
- **Synthesis Reaction** happens when simple compounds come together to form a more complicated compound
- The chemical reaction inside **electrochemical cells** is also a redox reaction. Splitting the water molecule into parts (hydrogen and oxygen) requires power (**electrolysis**) to break the bonds.
- **Electronegativity** is how attracted an electron is to an atom.
- **Ideal Gas Law** relates temperature, pressure, and volume of these gases in one simple statement: $PV = nRT$
- **Le Chatelier's Principle** predicts how changes in pressure, temperature, volume, or concentration will cause a reaction to shift and compensate for these changes.
- Different factors affect the **rate of reaction**, or speed of the chemical reaction, including temperature, pressure, surface area, catalysts, and more. The main idea is that the more collisions between particles, the faster the reaction will take place.

Textbook Reading

What *is* chemistry? Chemistry is the study of matter, the properties of that matter (like temperature, density, etc.), and how it interacts with other matter and energy.

Note: This is also the definition for physics, by the way! But in physics, the focus is more on the nucleus itself and the smaller bits inside, whereas chemistry focuses on the properties of the atom and how it interacts with other things.

Why study chemistry, anyway? Well, if you think about it, everything you touch, smell, see, or observe in some way is a chemical. Baking bread, starting a car engine, eating dinner, growing a plant… it's all chemistry. Lots of folks use chemistry in their jobs every day, including doctors, fire fighters, engineers, biologists, dentists, veterinarians, artists, plumbers, hair designers, pilots, astronomers, rocket scientists, and more!

You'll find chemists at your local pharmacy measuring out the right amount of medications for a patient, or in a research lab testing new kinds of rocket fuel. You can find chemists almost everywhere, from boiler rooms that heat large buildings to manufacturing plans that make yogurt.

Even though it may seem that these chemists do different jobs, for the most part they all have these things in common: they know how to ask questions, test their ideas (hypothesis) with experiments, and have become very good at observing results.

The Scientific Method

Do I need to do the scientific method in order to do chemistry? No. The scientific method is only one of several different methods that scientists use for getting answers to their questions.

However, the scientific method is the most-used method in these two areas: Science Fair Projects and by scientists in research labs. Most everyday scientists use a wide variety of methods, from *Iteration* to *Divide-and-Conquer* to a simplified version of the scientific method called the *Lab Report*.

The Scientific Method is the one you want to use when you're entering a Science Fair or need to keep very careful track of your experiment. Because this method is so cumbersome and requires a lot of documentation and tedious record-keeping (most of which is above and beyond what most scientists need), it's not generally used in the scientific field (excluding research labs). Here are the main steps to doing the *Scientific Method:*

Step 1: *Make observations.* This is where you think up your great idea that you want to test. For example, you might be wondering how to make a larger loaf of bread quickly, without adding a ton of ingredients. Or if chewing gum during test-taking yields higher test scores. Any great idea that doesn't have an answer you can look up in a book is one worth testing. (*What's the life cycle of a frog?* is not a great question to ask, because it's already been done and it's easy to find the answer.)

Step 2: *Formulate a Hypothesis* This is where you take a guess at what your outcome will be. When you formulate a hypothesis, make it a one-line statement that clearly says what you think will happen. *"Doubling the yeast will get a loaf twice the size."*

Step 3: *Design the Experiment* Since there are several ways to test your hypothesis, you'll want to design an experiment that specifically tests one variable at a time. Keep it simple and clear to get the best results. Don't change the amount of yeast and salt… just the yeast. If you change more than one variable, you can't be exactly sure which change gave you the result.

Step 4: *Test the Hypothesis* This is the fun part! Set up your experiment and run through it a few times before recording any data. This way, you work out any bugs in your experiment and get good quality numbers when you do your experiment.

Step 5: *Accept/Refine Hypothesis* Before you wrap things up, take a quick look at your numbers. Does your data fit your hypothesis? Did you get an answer to your question? If not, then go back and reform your hypothesis or redesign your experiment. Keep working at this until you get an answer.

Step 6: *Results/Conclusion* Can you write up what you found in one sentence? That's the main idea here. Make it simple, clear, and concise. Your results are a cleaned-up version of your data (in the form of a graph, chart, or table) and your conclusion states your hypothesis and results in one line. *"Doubling the yeast gave a loaf two-thirds the original size."*

Simplifying the Scientific Method: Whew! That's a lot of work for one question! This method is great when you need to keep very accurate track of all the details, but it's usually too cumbersome for everyday use by most scientists (yes, even for NASA engineers!) Especially when the question is more of a troubleshooting question, like the following situation:

Most scientists follow the three-step process of *Observe, Think, and Modify.* For example, if you've wired up a circuit that doesn't seem to be working, you don't need to haul out the Scientific Method to solve the issue.

The first thing you do is notice what's not working: the light bulb isn't illuminating, for example. Now think about what things affect this result: Is the battery fresh? Are the wires making a metal-to-metal connection? Is the light bulb blown? Now test each one – get a new battery and see if that fixes the problem. No? Well, check all your wires and see if there's an open circuit somewhere… you get the idea.

This method of troubleshooting is based on an iterative technique that most engineers and scientists use every day.

Now you have a good idea of what chemists do and how they do it… but what is chemistry exactly? Let's dive right in and learn about the strange world of atoms, ions, and how they interact to form chemical reactions.

Chemistry Basics

Matter Everything is either matter or energy. And in chemistry, we deal with both and how they interact with each other. For example, you add one chemical to another chemical, and *wham-o!* a completely new substance is formed that has totally different properties from what you started with.

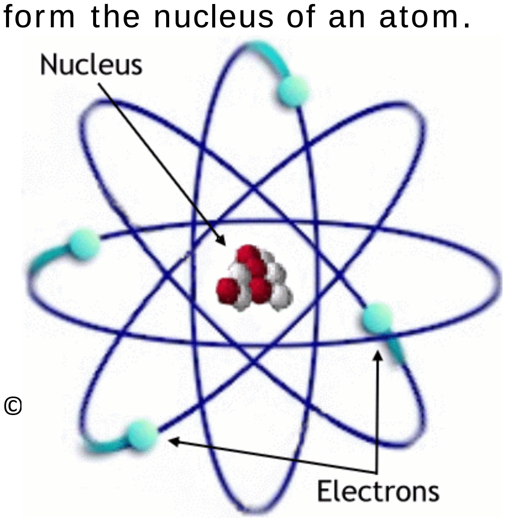
That's the cool part of chemistry. And I promise, you're going to learn and do a *lot* with this course. We need to not only whip up mixtures, but understand what's going on inside your mixture and why it's happening. And to do that, we have to talk about what stuff is made of. Remember what *matter* is?

Matter is anything that has mass (anything that is affected by gravity). Most matter on our planet is made up of atoms and ions. Not all matter is made up of atoms, but all matter is made up of some kind of particle.

Most of the ordinary matter you and I have experience with is made up of quarks and electrons, but most of the matter in the universe is actually dark matter (and we're still working on defining what exactly dark matter *is*).

This chemistry unit deals with regular, ordinary matter – the kind that tables, penguins, trees, and books are made of… which is atoms.

Atoms All atoms are not created equal – they contain different amounts of protons, neutrons, and electrons inside. Protons and neutrons are made up of fundamental particles (meaning that they can't be split apart any further) called quarks. These quark groups form together to create protons and neutrons, which cluster the center of the atom and form the nucleus of an atom.



Although atoms are mostly empty space, at the outer edge of the 'empty space' lies an electron cloud. If an atom were blown up to be the size of the earth, the nucleus would be the size of a basketball at the Earth's core with the electron cloud on the outer surface. Electrons have very low mass and carry a negative charge. Most atoms carry enough protons to cancel out the negative charge of the electrons, giving the atom a net charge of zero (which is great, otherwise it would be like a very bad static-cling day… all day, every day).

Elements A substance made up of only one particular kind of atom is called a chemical element, and you can find a whole slew of these on the periodic table. The number assigned to the chemical element refers to the number of protons in the nucleus. The properties of elements (how they interact with other matter and energy) depend on how they are structured at the atomic level.

The most abundant element in the universe is hydrogen, which makes up about ¾ of all ordinary matter. Helium makes up most of the rest of the matter, with oxygen coming in third.

The most abundant element on our planet (meaning in the Earth's crust) is oxygen (about 46% of the earth's crust mass), followed by silicon (28%). There are small amounts of aluminum (8%), iron (5%), potassium (2%), and magnesium (2%).

You and I are mostly made up of six elements: oxygen (65%), carbon (18%), hydrogen (10%), nitrogen (3%), calcium (1%) and phosphorous (1%). Less than 1.5% of the human body is made up of other stuff (sulfur, sodium, copper, iron, lead, arsenic…)

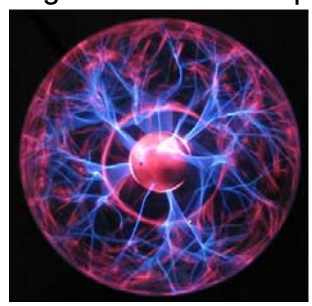
There are two elements that are a liquid at room temperature (25^{o}C): bromine (Br), a reddish-brown liquid that turns both toxic and corrosive when in vapor form; and mercury (Hg), a toxic silvery metal liquid used in old-fashioned thermometers.

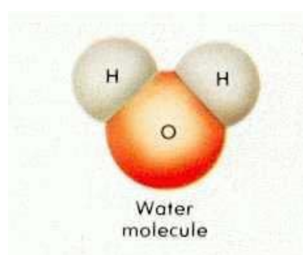
States of Matter Ordinary matter exists in one of four states: solid, liquid, gas, and plasma. Which state an atom (or molecule or ion) is in depends on how much energy it has and how much freedom the particles have to move around.

Substances can move between states by losing or gaining heat energy. For example, you can melt an ice cube (solid) in the sun (adding energy) into a liquid and eventually into water vapor.

In a solid, the bonds locking the substance together are strong, however in a liquid the bonds are weaker. In a gas, the molecules are bound together very weakly and can move about easily (and even bump into each other).

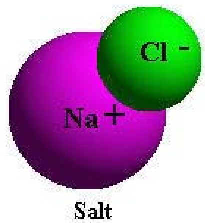
A gas becomes a plasma when the molecules move about so rapidly that they knock electrons off the atoms when they collide. Plasmas are made up of electrons and ions moving about with high amounts of energy. You've seen plasma in neon signs, lightening, fluorescent lights, plasma globes, and stars.





Atoms can be linked up together to form molecules. For example, a covalent bond between two atoms share an electron (there's a covalent bond between the oxygen and each hydrogen in a water molecule – both atoms share the electrons).

Ions and molecules can be chemically linked together using the electrostatic force to form crystals. For example, table salt combines the negatively charged chlorine atom (Cl^-) and the positively charged sodium atom (Na^+) together to form NaCl.



Types of Chemical Bonds A molecule is the smallest unit of a compound that still has the compound's properties attached to it. Molecules are made up of two or more atoms held together by covalent bonds.

Ionic compounds aren't really real molecules. When ionic compounds are solids, they are really a structure of charged particles.

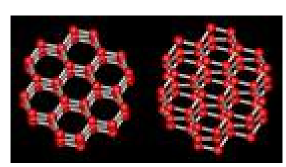
In the space where electrons from different atoms interact with each other, chemical bonds form. The electrons in the outermost shell are the ones that form the bonds with other atoms.

Since electrons are all negatively charged, they repel each other. However they are attracted to the protons in the nucleus within atoms. How they choose to stick together and interact is what chemical bonds is all about.

There are two main types of bonds that form between atoms: ionic bonds and covalent bonds. When one atom accepts or donates an electron to another atom, an ionic bond is formed, like in table salt (NaCl). When the atoms share the electron(s), a covalent bond is formed. Electrons aren't perfect, though, and usually an electron is more attracted to one atom than another, which forms a polar covalent bond between atoms (like in water, H_2O).

While it may seem a bit random right now, with a little bit of study, you'll find you can soon understand how molecules are formed and the shapes they choose once you figure out the types of bonds that can form. Let's take an example:

Why does ice float? In the water molecule (H_2O) is held together by polar covalent bonds. Water molecules are also attracted to each other by weak (hydrogen) bonds between the atoms. As water cools below 4°C, the hydrogen bonds forms a hexagonal crystal lattice (known as 'ice'). The solid form of water is a larger structure than the liquid form, as the crystal structure has a hole in the center. In other words, ice takes up about 9% more space than liquid water, so a liter of ice weighs less than a liter water. By peeking into the molecules closely, you can explain why ice is one of the very



few solids that is lighter than its liquid form.

Chemistry is about Measuring

So many chemistry courses skip this vital step, and it's essential if you want to master chemistry lab skills. You must learn how to measure if you're going to make any headway in doing chemistry.

Moles A mole is a unit of measurement, just like inches or meters. Since chemical reactions take place on such a small scale, the unit of the mole was invented to help keep track of the particles interacting with each other.

One mole is the amount of a substance that has the same number of particles as found in 12 grams of carbon C-12. How many particles, you ask? 602,214,150,000,000,000,000,000 particles to be precise. Or in shorter notation: 6.022×10^{23} particles.

This special number is called Avogadro's constant, and since "mole" is a lot easier to write than 6.022×10^{23}, chemists like to use it to help keep track of the particles in a chemical reaction. It's a handy way to convert between atoms and grams, or even molecules and grams. Here's how:

Let's figure out how many moles are in 500 grams of CO_2. First, we peek at the periodic table and find out the atomic mass of carbon is 12, and the atomic mass for oxygen is 16. Here's how you find the mass of CO_2:

$C + 2\,(O) \rightarrow 12 + 2(16) = 44$

So one mole of CO_2 weighs 44 grams. This now becomes our conversion factor of (1 mole)/(44 grams) and we use it like this:

Number of moles of CO_2 = 500g x (1 mole/44grams) = 11.4 moles

So there are 11.4 moles of CO_2 in 500 grams.

We can also work backward, finding the mass from knowing the number of moles. If we have 4 moles of H_2SO_4, how many grams is that?

First, look up H, S, and O in the periodic table to find their atomic masses:

H = 1, S = 32, O = 16. So the atomic mass of H_2SO_4 is:

$H_2SO_4 \rightarrow 2H + S + 4O \rightarrow 2(1) + 32 + 4(16) = 98$

So one mole of H_2SO_4 weighs 98 grams. Now use this conversion to find the mass for 4 moles:

Grams of H_2SO_4 = 4 moles x (98 grams/1mole) = 392 grams

So there are 392 grams of H_2SO_4 in 4 moles.

How to Measure Chemicals If you're going to do a chemistry experiment, you're going to use chemicals. How much of each one you use is going to change the results you get, so it's important to find a way to accurately measure out the same amount of chemical each time. Always use a container to hold your chemicals – never place them directly on the scale itself.

Most chemist use an accurate balance to weigh out solids and liquids. For example, if you need 0.1 mole of $HCl_{(l)}$, you could calculate the volume of concentrated HCl that contains 0.1 mole of acid and then use a graduated cylinder (37% 12M).

Here's another way to do it: you already know that the gram-molecular mass is 36.5 grams/mole (from the periodic table), so you can quickly figure out that you need 3.65 grams for 0.1 mole by doing this calculation:

(3.65 grams) / (0.37grams/gram of solution) = 9.85 grams of the acid solution. So place a container on the scale, hit tare, and fill it with your solution until the scale reads 9.85 grams.

Chemical Reactions

Learning how to figure out whether a chemical reaction will occur and what comes out the other end is what we're going to focus on with this unit. One way chemists figure this out is by writing a balanced chemical equation to describe a chemical reaction (more on this later). Once you learn how to balance the atoms and charges in a chemical reaction, you can figure out the energy of the reaction as well.

Physical and Chemical Changes A chemical reaction happens when a chemical change (something that produces a new substance, like burning wood into ash, rusting a nail, decomposing a dead tree… all these take the starting materials (reactants) and create~~s~~ new substances (products). On the flip side, a physical change happens when a sheet of paper gets wadded up, a banana is cut in half, etc.

Chemical reactions usually mean the movement of electrons or protons, leading to linking up or breaking chemical bonds. There are many different kinds of chemical reactions:

Combustion: A combustion reaction gives off energy, usually in the form of heat and light. The reaction itself includes oxygen combining with another compound to form water, carbon dioxide, and other products. A campfire is an example of wood and oxygen combining to create ash, smoke, and other gases. Here's the reaction for the burning of methane (CH_4) which gives carbon dioxide (CO_2) and water (H_2O):

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Synthesis: This reaction happens when simple compounds come together to form a more complicated compound (A + B → AB). The iron (Fe) in a nail combines with oxygen (O_2) to form rust, also called iron oxide (Fe_2O_3).

$2Fe + O_2 \rightarrow Fe_2O_3$

Oxidation-Reduction (Redox Reaction): Redox reactions involve electrons zipping around between compounds. Anytime you have an oxidation, you also have a reduction process, hence the term *redox*.

Oxidation happens when a compound loses electrons (increases oxidation state) and reduction occurs when a compound gains electrons (decrease in oxidation state). In this reaction, the magnesium is oxidized and the carbon dioxide is reduced:

$2Mg + CO_2 \rightarrow 2\ MgO + C$

You do not need oxygen to have a redox reaction. In fact, you can have combustion without oxygen when you combine iron (Fe) and sulfur (S) to get iron sulfide ($Fe^{2+}S^{2+}$):

$Fe + S \rightarrow Fe^{2+}S^{2+}$

Note that oxygen is not involved to create iron sulfide. (This experiment can even be done in a container without oxygen.)

The chemical reaction inside electrochemical cells is also a redox reaction. Batteries (also known as galvanic or voltaic cells) use a spontaneous chemical reaction inside to create energy. The acid inside the battery reacts with the metal electrodes (the plus and minus ends of the battery) to provide electricity (energy).

Non-spontaneous cells require an energy source (like a battery) in order for the chemical reaction to occur. When you break apart the water molecule into hydrogen and oxygen (electrolysis), it requires energy.

Back in 1800, William Nicholson and Johann Ritter were the first ones to split water into hydrogen and oxygen using electrolysis. (Soon afterwards, Ritter went on to figure out electroplating.) They added energy in the form of an electric current into a cup of water and captured the bubbles forming into two separate cups, one for hydrogen and other for oxygen.

But how did they know which bubbles were which? You can tell the difference between the two by the way they ignite (don't' worry – you're only making a tiny bit of each one, so this experiment is completely safe to do with a grown up).

It takes energy to split a water molecule. (On the flip side, when you combine oxygen and hydrogen together, it makes water and a puff of energy. That's what a fuel cell does.) Back to splitting the water molecule - as the electricity zips through your wires, the water molecule breaks apart into smaller pieces: hydrogen ions (positively charged hydrogen) and oxygen ions (negatively charged oxygen). Remember that a battery has a plus and a minus charge to it, and that positive and negative attract each other.

So, the positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire. Same thing happens on the positive battery wire. After a bit of time, the ions form a larger gas bubble. If you stick a cup over each wire, you can capture the bubbles and when you're ready, ignite each to verify which is which.

Both types of these electrochemical cells (voltaic and electrolysis) use electrodes: a cathode and an anode. Oxidation happens on the positive anode and reduction on the negative cathode.

You already know that electrical current created by batteries only flows when you connect the battery up to a circuit. The chemical reaction starts only when the electrodes are connected. You can change the chemical reaction rate by changing the temperature of the battery, which is why when you use a battery fresh from the freezer, it doesn't work as well as a room temperature battery. (Try that sometime!)

If the chemical reaction only works when the battery is connected to something, then why do some people still store them in the freezer? It turns out that batteries not connected in a circuit will slowly leak and discharge. You can test this out for yourself using rechargeable batteries – you'll find that you can nearly double their charge length by placing them in the freezer.

With redox reactions, there are special rules about how to account for the mass and charge transfers going on in the chemical reaction. And figuring out which compounds are reduced and which are oxidized are also part of the game. Oxidation numbers are used to help keep track of everything, and you'll find information on how to do this in your high school level textbook download.

Decomposition: This type of reaction breaks a complicated molecule into simpler ones (AB → A + B). When you leave a bottle of hydrogen peroxide on the counter, it decomposes into water (H_2O) and oxygen (O_2).

$2H_2O \rightarrow O_2 + 2H_2$

Displacement: There are several different types of displacement reactions, including single, double, and acid-base.

An example of a single **substitution reaction** (A + BC → AC + B) occurs when zinc combines with hydrochloric acid. The zinc replaces the hydrogen: $Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$

A **double displacement** (metathesis) reaction has two compounds exchanging bonds to form new compounds (AB + CD --> AD + CB). Antacids like calcium hydroxide (CaOH) combine with stomach acid (HCl) to form calcium chloride salt ($CaCl_2$) and water (H_2O).

$CaOH + HCl \rightarrow CaCl_2 + H_2O$

An **acid-base reaction** deals with reactions that involve hydrogen (protons). This is a type of double displacement reaction that occurs, oddly enough, between an acid and a base. The reaction between hydrobromic acid (HBr) and sodium hydroxide (NaOH) is an example of an acid-base reaction:
$HBr + NaOH \dashrightarrow NaBr + H_2O$

Neutralization Reaction (Hydrolysis) When acids and bases react with each other, they sometimes form a salt and water.

Now I want to be clear about this: 'Salt' doesn't mean table salt (NaCl), but rather an ionic compound formed from acid-base combinations. Salts are held together by electrical charges (that's what makes it an ionic bond), as they are formed between cations (positive ions, like Na^+) and anions (negative ions, like Cl^-).

The salt can either stay in the solution as ions, or 'fall out' of the solution like a snow globe (called precipitate). When the acids and bases combine to form salt and water, it's called a neutralization reaction.

Salts can be any color of the rainbow, from the deep orange of potassium dichromate to the vivid purple of potassium permanganate to the inky black of manganese dioxide. Did you know that MSG (monosodium glutamate) is a salt? Most salts are not consumable, as in the lead poisoning you'd get if you ingested lead diacetate.

The combination of a strong acid (HCl) and a strong base (NaOH) neutralize each other (pH = 7) and the ions that are left over do not react with the water:

$HCl + NaOH \rightarrow H_2O + NaCl$

If you combine a strong acid and a weak base, it will also produce a salt but not the water. For example, combining hydrochloric acid (HCl) with ammonia (NH_3):

$HCl + NH_3 \rightarrow NH_4Cl$

$HCl_{(aq)} + NH_{3(aq)} \leftrightarrow NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$

$NH_4^-{}_{(aq)} + H_2O \leftrightarrow NH_{3\,(aq)} + H_3O^+{}_{(aq)}$

The combination of a strong base and weak acid tends to form the water without the salt, as the salt goes back into forming an acid product:

$HClO + NaOH \rightarrow NaClO + H_2O$

When mixing together a weak base and a weak acid, the pH is going to depend on the pH of each before you mixed them together (reactants):

$HClO + NH_3 \text{ <--> } NH_4ClO$

When the reverse occurs (salt and water combine to form acids and bases), you have a hydrolysis reaction.

Aqueous Reactions

There are three types of chemical reactions that occur in water: precipitation, acid-base, and redox (oxidation-reduction) reactions. When a substance is mixed with water (water is the solvent, the substance is the solute), it's called an aqueous solution. For example, salt water is an aqueous solution, and water is the solvent and salt is the solute.

Precipitate reactions are like watching a snow globe, but the snow appears out of nowhere. For example, you can combine two liquid solution, silver nitrate ($AgNO_3$) and salt (NaCl) to get a solid white precipitate, silver chloride (AgCl).

When silver nitrate is dissolved in water, it decomposes into silver ions (Ag^+) and nitrate ions (NO_3^-). The silver ions (Ag^+) combine with the chlorine ions (Cl^-) to form the silver chloride, which looks like white snow in your test tube.

$Ag^+{}_{(aq)} + Cl^-{}_{(aq)} \rightarrow AgCl_{(s)}$

If you were to use potassium bromide (KBr) instead of salt, you'd find a yellowish snowstorm of silver bromide (AgBr).

Acid-Base reactions donate H^+ (protons) and OH^- ions, as in the reaction of mixing hydrochloric acid and sodium hydroxide together to form salt and water:

$HCl + NaOH \rightarrow H_2O + NaCl$

When the hydrochloric acid (HCl) is in solution, it completely dissociates into ions, as does the sodium hydroxide (NaOH):

$HCl \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

$NaOH \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

Which leaves the ions to come together to form water and salt:

$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O$ (water)

$Cl^-_{(aq)} + Na^+_{(aq)} \rightarrow NaCl$ (salt)

*Note: It's **never** okay to eat or drink anything you use in your chemistry lab, no matter how safe you think it is!*

In a redox reaction, electrons zip between the two reactants like in this example of hydrochloric acid (HCl) and zinc (Zn):

$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^-$ (the zinc is oxidized)

The H^+ ions of the HCl gain electrons and are reduced to H atoms, which combine to form H_2 molecules:

$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$

The main equation for the reaction:

$Zn_{(s)} + 2H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$

When balancing redox reaction equations, just keep two important things in mind. First, your equation includes only the things that form products. Second, the total charge is the same on both sides of the equation. (If there are three plus signs on one side, then there should be three plus signs on the other.)

Rates of Reaction

Chemists want to control not only what comes out of a chemical reaction, but how fast the reaction occurs. For example, scientists are working to slow down the depletion rate of the ozone in the upper level of our atmosphere, so we stay protected from harmful UV rays.

The rate of the chemical reaction of a nail rusting is slow compared to how fast baking soda reacts with vinegar. Different factors affect the speed of the reaction, but the main idea is that the more collisions between particles, the faster the reaction will take place.

Increasing the temperature will usually increase the rate of reaction, as the higher the temperature of the reactants, the more kinetic energy is in the system. A general rule is that the rate of reaction will double for every 10^oC increase in temperature. (Note that if you heat your reactants above a certain point, you can actually *decrease* the rate of reaction because the properties of the substance has ben altered.)

A higher concentration of the reactants increases the reaction rates because the number of collisions increase.

Fine powders react more quickly than large chunks because there's more area exposed to react when a substance is in powder form, so surface area plays a role in the reaction rates as well.

To speed up a reaction without altering the chemistry of the reaction involves adding a *catalyst*. A catalyst changes the rate of reaction but doesn't get involved in the overall chemical changes.

For example, leaving a bottle of hydrogen peroxide outside in the sunlight will cause the hydrogen peroxide to decompose. However, this process takes a long time, and if you don't want to wait, you can simply toss in a lump of charcoal to speed things along.

The carbon is a catalyst in the reaction, and the overall effect is that instead of taking two months to generate a balloon full of oxygen, it now only takes five minutes. The amount of charcoal you have at the end of the reaction is exactly the same as before it started.

A catalyst can also slow down a reaction. A catalytic promoter increases the activity, and a catalytic poison (also known as a negative catalyst, or inhibitor) decreases the activity of a reaction.

Catalysts offer a different way for the reactants to become products, and sometimes this means the catalyst reacts during the chemical reaction to form intermediates. Since the catalyst is completely regenerated before the reaction is finished, it's considered 'not used' in the overall reaction.

Le Chatelier's Principle

This predicts how changes in pressure, temperature, volume, or concentration will cause a reaction to shift and compensate for these changes. For example, if the temperature of an exothermic reaction is increased, the equilibrium position shifts to use up the heat by creating more reactants.

In the reaction of colorless solution of silver (Ag) with colorless solution of chlorine (Cl) gives a white solution of AgCl:

$Ag^{+} + Cl^{-} \rightleftharpoons AgCl + \text{energy}$

Increasing the temperature shifts the equilibrium to the left, consuming some of the energy and products to produce more reactants. There will be less white AgCl in the reaction vessel. Reducing the temperature shifts the equilibrium position to the right, producing more heat and more white AgCl.

Bond Energy

By knowing the value of the bond energy, we can predict if a chemical reaction will be exothermic or endothermic. If the bonds in the products are stronger than the bonds in the reactants, then the products are more stable and the reaction will give off heat (exothermic).

Exothermic Reactions Many chemical reactions release energy as heat, light, or sound (or all three). Some release heat gradually (for example, a disposable hand-warmer), while others are more explosive (like burning magnesium). The energy comes from breaking the bonds within the chemical reaction. The combination of sodium and chlorine to form table salt and energy:

$Na + ½ Cl_2 = NaCl + energy$

Endothermic Reactions Other chemical reactions need to absorb energy in order to react. Often you'll notice a temperature drop when the reaction takes place (a disposable ice pack, for example). The energy goes to forming new chemical bonds between molecules within the reaction. For example, splitting apart the water molecule (H_2O) into hydrogen and oxygen gases requires adding energy into the system (usually in the form of electricity).

$H_2O + energy \rightarrow H_2 + O_2$

Electronegativity is how attracted an electron is to an atom. The higher the electronegativity of an atom, the greater its attraction for the bonding electrons. Elements with high ionization energy have high electronegatives because of the strong pull by the nucleus on the electrons.

Ionization energy (measured in electronvolts, *eV*) is the amount of energy needed to completely remove an electron from gaseous atom or ion. If the electron is tightly bound, the ionization energy levels are higher and it's harder to remove.

The first ionization energy is the amount of energy needed to remove one electron from the atom, and the second ionization energy is the energy to remove a second electron (and is always a higher value). It's harder and harder to remove subsequent electrons because the electrons are closer to the nucleus, which also is more positively charged.

Acids and Bases

When dissolved in water, an acid has more hydrogen ions than regular water and a pH lower than 7.0.

Generally, acids are sour in taste, change litmus paper from blue to red, react with metals to produce a metal salt and hydrogen, react with bases to produce a salt and water, and conduct electricity. Strong acids often produce a stinging feeling on mucus membranes (don't ever taste an acid, or any chemical for that matter!).

Lots of fruits contain citric acid and ascorbic acids, and the distilled white vinegar in your kitchen is a weak form of acetic acid. You'll find carbonic acids in sodas, lactic acid in buttermilk and malic acid in apples.

Acids are proton donors (they produce H^+ ions). Strong acids and bases all have one thing in common: they break apart (completely dissociate) into ions when placed in water. This means that once you dunk the acid molecule in water, it splits apart and does not exist as a whole molecule in water. Strong acids form H^+ and an anion, such as sulfuric acid:

$H_2SO_4 \rightarrow H^+ + HSO_4$

There are six strong acids: hydrochloric acid (HCl), nitric acid (HNO_3) used in fireworks and explosives, sulfuric acid (H_2SO_4) which is the acid in your car battery, hydrobromic acid (HBr), hydroiodic acid (HI), and perchloric acid ($HClO_4$). The record-holder for the world's strongest acid are the carborane superacids (over a million times stronger than concentrated sulfuric acid).

Carborane acids are not highly corrosive even though are super-strong. Here's the difference between acid strength and corrosiveness: the carborane acid is quick to donate protons, making it a super-strong acid. However, it not as reactive (negatively charged) as hydrofluoric (HF) acid, which is so corrosive that it will dissolve glass, many metals, and most plastics.

What makes the HF so corrosive is the highly reactive Fl^- ion. Even though HF is super-corrosive, it's not a strong acid because it does not completely dissociate (break apart into H^+ and Fl^-) in water. Do you see the difference?

Weak acids only partly dissociate in water, such as acetic acid (CH_3COOH).

On the other hand, bases taste bitter (again, don't even think about putting these in your mouth!), feel slippery (don't touch bases with your bare hands!), don't change the color of litmus paper, but can turn red litmus back to blue, conduct electricity when in a solution, and react with acids to form salts and water. Soaps and detergents are usually bases, along with house cleaning products like ammonia.

Bases are also electron pair donors (they produce OH^- ions). Strong bases also completely dissociate into the OH^- (hydroxide ion) and a cation. LiOH (lithium hydroxide), NaOH (sodium hydroxide), KOH (potassium hydroxide),

RbOH (rubidium hydroxide), CsOH (cesium hydroxide), $Ca(OH)_2$ (calcium hydroxide), $Sr(OH)_2$ (strontium hydroxide), and $Ba(OH)_2$ (barium hydroxide). Weak bases only partly dissociate in water, such as ammonia (NH_3)

pH stands for "power of hydrogen" and is a measure of how acidic a substance is. We can make homemade indicators to test how acidic (or basic) something is by squeezing out a special kind of juice (dye) called anthocyanin.

Certain flowers have anthocyanin in their petals, which can change color depending on how acidic the soil is (hibiscus, hydrangeas, and marigolds for example). The more acidic a substance, the more red the indicator will become.

Balancing Equations

A chemical reaction can be described on paper by writing a chemical equation that shows what you started with and how it ended up. There's a lot inside once of these equations, such as the molecules at the start of the reaction, what they formed, the states of each molecule (solid, liquid, or gas), the amount of each, and the energy flow. When the equation is balanced, then the math works out. Chemical equations can be written in terms of grams or moles.

There are three basic steps to balancing an equation:

1. *Write an unbalanced equation.* Put the stuff you start with on the left side (reactants) and the stuff created on the right side (products). Separate them by an arrow to show the direction of the reaction (left to right), or with an arrow facing both directions if you have a reaction at

equilibrium (meaning that it self-adjusts to go either way).

$SnO_2 + H_2 \rightarrow Sn + H_2O$

You can already tell it's not balanced because the number of oxygen atoms on both sides isn't the same. So we have an unbalanced equation.

2. *Balance the equation.* Count the number of atoms of each element on each side of the arrow. It's easiest to start with an element that appears in only one of the reactants and products. Use a pencil, because it might take you a few tries to get the numbers right. Write the numbers as coefficients in front of each molecule.

   I would start with tin (Sn), since it appears only once on each side. Notice that there is only one Sn atom on each side, so Sn is balanced. However, the oxygen (O) has two on the left, but only one on the right. Here's what I came up with in the end:

   $SnO_2 + 2H_2 \rightarrow Sn + 2H_2O$

3. *Indicate the states of matter in the reactants and products.* Use (g) for gaseous, (s) for solids, (l) for liquids), (aq) for compounds in water. Sometimes you'll need a bit of help from an experiment to find out which states each are in before you complete this last step:

   $SnO_{2\,(s)} + H_{2\,(g)} \rightarrow Sn_{(s)} + H_2O_{(g)}$

We'll be practicing balancing equations a lot during our chemistry experiments together, so you'll be sure to get comfortable with these ideas.

Properties of Gases

Pure substances all behave about the same when they are gases. For example, at 0^oC and 1 atmosphere of pressure, one mole of gas occupies 22.4 liters of volume. This nifty trick relies on the fact that gases completely fill their containers, and the atoms of the gas are usually about 10 diameters apart. (This doesn't work with solids and liquids, however.) The Ideal Gas Law relates temperature, pressure, and volume of these gases in one simple statement:

$PV = nRT$ where P = pressure, V = volume, T = temperature, n = number of moles, and R is a constant. What I really want you to notice is how Pressure, volume, and temperature are related: when the pressure goes up, the temperature also goes up. When you squish a volume of air into a tighter space, the temperature also goes up. Does this make sense?

Nuclear Reactions

Chemical reactions usually deal with only electron or atom exchanges. Nuclear reactions deal with changes inside the nucleus of an atom.

In the 20th century, scientistss figured out that the core of an atom can break apart or join together with others. If you split an atom (called fission), you get smaller parts and a whole lot of energy. When this happens in nature, it's called radioactivity. Unstable atoms spontaneously break apart and release particles and energy.

Fusion is taking place inside the sun. The fusion process smacks particles together, which results in a big release of energy. The core of the sun is about one million degrees Celsius, while the surface temperature is a mere 15,000 degrees Celsius. The fusion process in the sun takes two naked protons (also known as a hydrogen nuclei) and smacks them together in a special sequence that results in the formation of helium. This complicated reaction is called the proton-proton chain, and occurs in all stars burning hydrogen in their core.

When people think of nuclear power, they often think of disaster-type scenes. Actually, power plants are very similar to coal-burning power plants. They both heat water into steam, which turn generators. The main difference between them is the way they heat the water. Some plants burn fossil fuels (like coal and oil), and nuclear plants use the energy from fission (splitting atoms apart) to heat water.

Remember when we talked when an atom spontaneously undergoes fission, it's called radioactivity? Uranium-235 is the perfect example of this kind of atom. U-235 decays naturally by splitting off an alpha particle or two neutrons and two protons bound together.

However, U-235 is one of the few materials that can undergo fission both naturally and artificially, so it's a great choice for nuclear power plants. If a naked neutron zipping along by itself suddenly runs into the nucleus of a U-235 atom, the neutron gets absorbed by the core, which cases the atom to be unstable and split immediately.

Nuclear weapons allow the explosive energy in the atom to essentially run rampant, while nuclear power plants harness the atomic energy to heat water.

One of the dreams of early chemists was to figure out how to transform lead into gold. Lead has 82 protons in its core whereas gold contains only 79. So conceivably all you'd need to do is remove three protons and presto! So how do you do that?

Since protons can't be stripped off with a chemical reaction, you need to smack it *hard* with something to knock off just the right amount. Lead, however, if a very stable element, so it's going to require a lot of energy to remove three protons. How about a linear accelerator?

In a linear accelerator, a charged particle moves through a series of tubes that are charged by electrical and/or magnetic fields. The accelerated particle smacks the target, knocking free protons or neutrons and making a new element (or isotope).

Glenn Seaborg, 1951 Nobel Laureate in Chemistry, actually succeeded in transmuting a tiny quantity of lead into gold in 1980.

And in 1972, Soviet physicists near Lake Baikal in Siberia in a nuclear research lab accidentally turned lead into gold during their tests – they were using lead as a shield in a reactor and later found it had changed to gold.

