Essentials of Chemistry 1:

Elements, Compounds & Reactions

Chemistry studies the interactions of all kinds of substances. We can use properties of substances to categorize them, and this can help us to understand their interactions.

When two substances combine to form a new substance, the process that was responsible is called a **reaction**. Some reactions break down substances into ones that have a simpler chemical structure. Some substances cannot be broken down further by any reaction whatsoever. They are as simple as possible. These substances are the **elements**. The elements are collected on the periodic table. If we take two or more different elements we may be able to react them to create a new substance. If the substance is pure, meaning it has the same properties throughout, then that substance is a **compound**. Water is an example of a compound. Any part of a sample of pure water will have the same chemical properties as any other sample of pure water, but if you run an electrical current through water, you can break it down into two simpler gases: hydrogen and oxygen, so water is not an element. If there are parts of a sample that have different chemical properties, then the substance is called a **mixture**. Orange juice is an example of a mixture. It's mostly water, but there are things in the water that are vitamins, other things that make it yellow, and other things that give it a sweeter taste than lemon juice. We can't see these chemicals individually, but it's possible to separate them and prove that they are there. The water, vitamins, colour and sugars in orange juice are all separate compounds that help to form a mixture.

On a chemical level, the difference between an element, a compound and a mixture comes down to the structure of the smallest possible particles that you can have of a substance. The smallest complete particle is an **atom**. (Atom comes from the Greek for "not cut", suggesting that it can't be divided without changing it.) Atoms come in different types that correspond to the elements — there are hydrogen atoms and oxygen atoms, and so on. There's no such thing as a water atom, since water is not an element. When atoms combine and bond, their chemical properties change. A set of bonded atoms is called a **molecule**. The smallest possible particle of a compound is a molecule; there is no smallest particle for a mixture since it is composed of a mix of different molecules. It's possible, too, for an element to form a molecule and still be an element. In nature, oxygen comes in molecules made from two oxygen atoms bonded together.

We can describe the composition of a molecule by listing the atoms used to make it. Oxygen gas is two oxygen atoms. Water is made from two hydrogen atoms and one oxygen atom. These numbers cannot change. (For example, two hydrogen atoms and *two* oxygen atoms will make hydrogen peroxide instead of water. *Three* oxygen atoms in the same molecule is ozone.) We use symbols to represent atoms, with a different symbol for each element, and $_{\text{subscripts}}$ to indicate how many atoms of that type are used. This means oxygen gas is O_2, water is H_2O, hydrogen peroxide is H_2O_2 and ozone is O_3. These are called chemical **formulas**.

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We can use chemical formulas to write down what happens during a chemical reaction. A common kind of reaction is a combustion reaction, where a substance combines with oxygen rapidly in the presence of heat to form carbon dioxide (CO_2) and water. Natural gas is mostly made up of a chemical called methane (CH_4). We can write an equation in words describing the combustion of methane. Instead of an equal sign, we use an arrow, meaning that the reaction goes in one direction:

methane + oxygen → carbon dioxide + water

The chemicals on the left, the “before” side of the reaction, are called **reactants**, or sometimes **reagents**. The chemicals on the right or “after” side are called **products**. The reactants react to produce products.

Just like the composition of a molecule, the molecules that are involved in a reaction do so in specific quantities. The atoms that are present before a reaction must also be present afterwards. Even though we think of combustion—burning—as a destructive process, nothing is actually destroyed at the molecular level. The atoms just move around to form new structures. We use a balanced reaction equation to show what happens to all the atoms, and to see how much of each substance reacts at the same time. This same reaction in symbols would look like this:

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

This isn’t finished. If we count the oxygen atoms on each side of the equation, we see 2 on the left side, but 3 on the right side (2 in carbon dioxide and one in water). In a properly written equation, no atoms should “come in from nowhere” or disappear. We need to say where the third oxygen atom came from.

We cannot fix this by changing the O_2 to O_3. That’s a different chemical. When we light a gas stove, we don’t bring in ozone to make it happen! We need to describe what does happen in the reaction in real life. We do this by adding coefficients in front of the chemical formulas to show that more than one of that kind of molecule participates in the reaction. The balanced equation looks like this:

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

It takes two oxygen gas molecules to react with one methane molecule. This produces one carbon dioxide molecule and two water molecules. There’s 1 carbon atom, 4 hydrogen atoms and 4 oxygen atoms on each side. Everything is accounted for. (You can find more detail about how to balance equations in the Chemical Formulas worksheet.)

We can use this information to know about real-world quantities reacting. Methane and oxygen are gases. If you had both of them in the same open area and you burned 1 L of methane, then you would know that you also burned 2 L of oxygen from the air at the same time, even if you didn’t measure it, because that’s how much it takes to complete the reaction. This process of figuring out how much reactant and product goes together in the same reaction is called **stoichiometry**. Stoichiometry is useful in industrialized chemical production, and laboratory analysis.