Teacher Tune-up

Quick Content Refresher for Busy Professionals

What is the difference between chemicals and mixtures?

Outside of scientific contexts, people sometimes use "**chemical**" as a dirty word. When people say, "I don't want chemicals in my food," they probably mean they don't want to swallow pesticides, preservatives, artificial sweeteners, and stuff like that. But of course food is made of chemicals (like water, sugar, salt, etc.). In science, "chemical" is just a word for pure substances, in contrast to **mixtures** of two or more pure substances.

What is a chemical?

There are two basic categories of chemicals: elements and compounds.

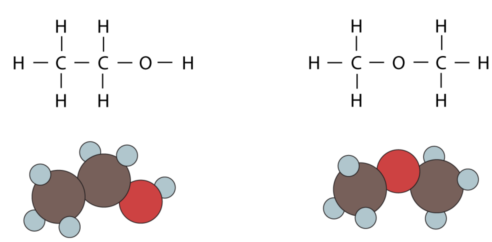
Elements are substances that can't be separated into any more basic chemical ingredients. In other words, an element is a substance made of one kind of atom, i.e., atoms with a certain number of protons. Pure elements can come in various forms, called **allotropes.** For example, oxygen can be O_2 (the oxygen we breath) and O_3 (ozone, good for blocking UV light high in the atmosphere, but bad as a pollutant near ground level). Carbon has several allotropes, including diamond, graphite, coal, and some other more exotic forms.

Compounds are substances that are made of **definite proportions** of elements in **specific structural arrangements**. Let's take the two parts of that definition one at a time.

Definite proportions of elements in compounds can be understood in terms of mass, atoms, or both. Water is always made of an 8-to-1 ratio of oxygen and hydrogen by mass. That's because water molecules are made of 1 oxygen atom and 2 hydrogen atoms, and each oxygen atom has about 16 times the mass of one hydrogen atom. You can't make water that's a little more "oxygeny" by combining 8.5 grams of oxygen and 1 gram of hydrogen. Once you've used up all that hydrogen, you'll just be left with 0.5 g of oxygen. Chemists can't fudge the recipes for compounds. The definite proportions of atoms in a compound are shown in its chemical formula, like H_2O for water.

The *specific structural arrangement* of atoms in a compound is definitive because sometimes the same definite proportions of elements can be combined in more than one way. Different compounds that share the same recipe are called **isomers** (*iso* means same, and *mer* means part, so these are compounds that have the *same parts* even though they are different). For example, ethanol and dimethyl ether both have the chemical formula C_2H_6O, but they are different compounds—with different physical and chemical properties—because they have different structures.

Two isomers, both C_2H_6O



ethanol   dimethyl ether

What kinds of mixtures are there?

Most atoms are eager to link up with other atoms and form either compounds like water and carbon dioxide, or elemental molecules like the nitrogen (N_2) and oxygen (O_2) that together make up 98 percent of Earth's atmosphere. But what about that atmosphere? What chemical is that?

It isn't, of course—air is not a chemical; it's a mixture of chemicals. More specifically, air is a **homogeneous** mixture, which means the chemicals in it are evenly mixed. Even very small macroscopic samples taken from the same roomful of air have essentially the same chemical composition.

Another word for a homogeneous mixture is a **solution**. The most abundant chemical in a solution is called the solvent, and less abundant chemicals that are dissolved in the solvent are called solutes. We typically think of solutions as liquid, but they can be gaseous or solid. Metal alloys, for example, are solutions. Bronze is a solution of tin (and sometimes other elements) dissolved in copper.

Mixtures aren't always homogeneous. Imagine a homogeneous solution of oxygen, silicon, and other elements in the hot fluid of an underground magma intrusion. Over a long stretch of time, the magma starts to cool. The different kinds of atoms respond differently to falling temperatures. Some elements are ready to link up and come out of solution sooner than others. Solid mineral grains start to form in the goo, changing the composition of the remaining solution. Different grains form at even lower temperatures, until the intrusion is one giant connected mass of granular minerals—silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), potassium oxide (K_2O), and a host of other minerals. This mixture of grains is granite, and it is an uneven, **heterogeneous** mixture because if you take a bit from here, you've got silicon dioxide, whereas if you take the bit right next to it, you've got iron oxide, or sodium oxide, or… you get the idea.

Heterogeneous mixtures can be coarser than granite, but they can also be finer. When bits of one material are finely dispersed in another (called the continuous medium), but aren't dissolved, the heterogeneous mixture is a **suspension**. Dust floating in air, silt coloring river water, and oil and vinegar shaken together in a salad dressing, are all suspensions. They tend to settle out by density if left undisturbed for a while.

Extremely fine suspensions, where the dispersed particles are less than 1 micron ($< 1 \times 10^{6}$ meter), are called **colloids**, or colloidal suspensions. They don't settle out, at least not nearly as quickly as coarser suspensions. Milk is a colloidal suspension of butterfat globules in a watery solution. Clouds are colloidal suspensions too, of liquid in gas. If air is already saturated with all the water vapor it can hold (at a given temperature and pressure), then any extra water must form microscopic droplets—i.e., a cloud. Depending on changing conditions, that colloidal suspension of water may coalesce into larger droplets and fall as precipitation—or the cloud may evaporate into thin air, leaving only clear blue sky.