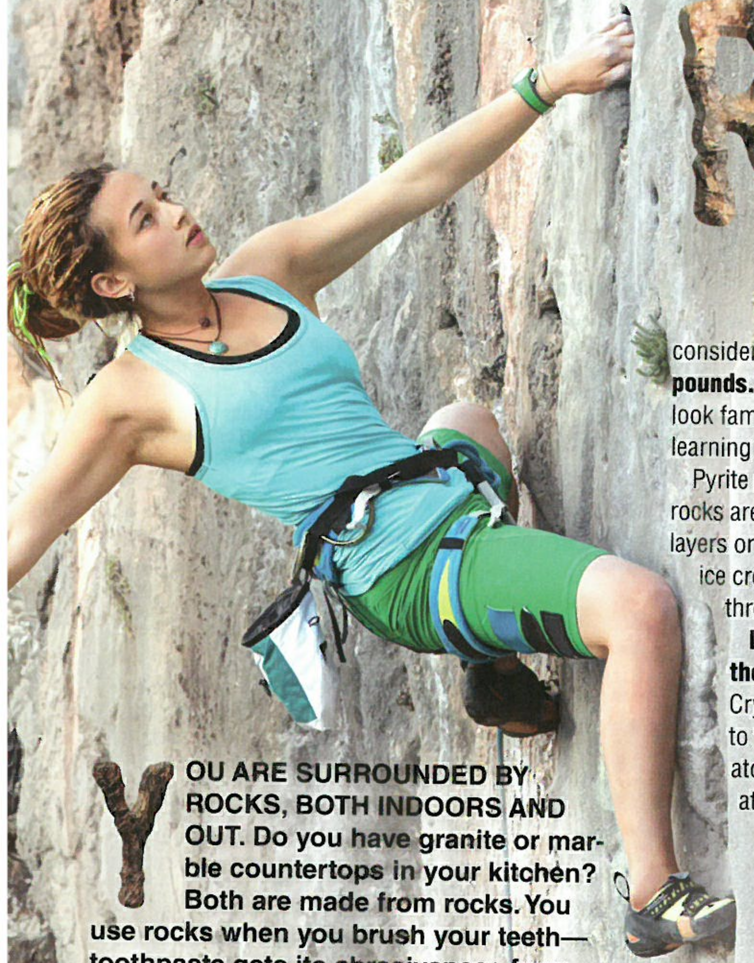
CHEMISTRY ROCKS!

By Brian Rohrig



YOU ARE SURROUNDED BY ROCKS, BOTH INDOORS AND OUT. Do you have granite or marble countertops in your kitchen? Both are made from rocks. You use rocks when you brush your teeth—toothpaste gets its abrasiveness from ground-up rocks, usually silica (from sand) or mica. If you wash your face or hands with an abrasive soap you make use of pumice, a volcanic rock. The planet we live on is essentially one giant rock, and the rocks we stumble upon are just little pieces that have broken off from the giant mother rock we call Earth. *So what are rocks and where do they come from?*

Rocks and minerals

A rock is a mineral—a naturally occurring inorganic solid with a definite chemical composition and ordered internal structure—or a mixture of several types of minerals. Pure elements that are mined, such as gold (Au) and copper (Cu) are considered minerals. But most of the **4,000 known minerals are chemical compounds.** Refer to the chart on the next page (Table 1). Do any of these formulas look familiar? They should look like the ionic formulas you have written when learning about chemical nomenclature.

Pyrite and quartz are two common rocks composed of only one mineral, but most rocks are solid mixtures of several minerals. In these rocks, the minerals can be in layers or distributed in chunks throughout the rock. The aptly named rocky road ice cream provides a good analogy—nuts and marshmallows are interspersed throughout the ice cream just like various minerals can make up a rock.

Most minerals have a crystalline structure. A crystal is a solid in which the atoms or molecules are arranged in a regular repeating pattern. Crystals take time to form. The larger the crystal, the more time it took for it to form. Glass, on the other hand, is an amorphous solid, meaning that the atoms are not orderly. When a solid forms suddenly (by cooling quickly), atoms do not have time to organize themselves into a repeating pattern.

Consider this analogy: Suppose your class entered an empty room and each person was holding a chair. Upon entering the room, what would happen if there was only one second to arrange the chairs into rows before you all had to freeze? Chances are, a haphazard arrangement of chairs would result. But if you had five minutes to arrange the chairs, your class would have plenty of time to form nice, neat rows. Likewise, the formation of atoms into a regular repeating pattern, or crystallization, takes time. Amorphous solids, however, form quickly, but without any order.

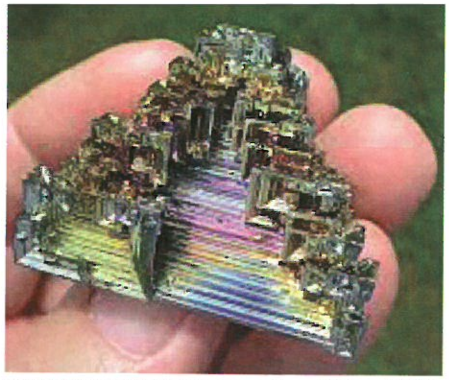
The types of bonds that exist in a crystal depend on the types of elements that it contains. Metals usually exhibit a crystalline structure, held together by metallic bonds. A metallic bond is an attraction of the nucleus of one metal atom to the electrons of another. The electrons are delocalized, as they are loosely held by their nuclei. This sea of electrons is shared equally among neighboring metal atoms. Metallic bonds can lead to intricate crystal structures. Bismuth, for example, has a fascinating structure that can be grown in the lab, as shown on the next page.

Diamond is probably the best-known example of a crystal; however, this crystal contains the same non-metallic atoms—it's all carbon. Each carbon atom in diamond is bonded to four other carbon atoms with a covalent bond. A covalent bond is a chemical bond that involves the sharing of an electron pair between two atoms. Diamond is the hardest material in the world—a lot of energy is needed to separate the atoms in diamond because the covalent bonds are strong, and diamond contains many of them.

SHUTTERSTOCK

Identifying minerals

There are many ways to determine the identity of a mineral. Even though metals are typically more lustrous or shiny than non-metals, this distinction does not always hold true with minerals. Diamond, made up of the non-metal carbon, is lustrous. Other notable minerals that are lustrous are pyrite (a metal-containing mineral), quartz (a metalloid-containing mineral), and galena (a metal-containing mineral). Galena (PbS) is a shiny mineral and is a common ore from which elemental lead (Pb) is extracted.



This bismuth crystal has a coating of bismuth(III) oxide on its surface. Like the colors seen in a soap bubble, variations in the thickness of the coating cause optical interference—waves of visible light reflect off the inner surface and the coating, and overlap constructively and destructively to create a rainbow of colors.

Mineral Group	Major Minerals	Chemical Formulas
Carbonates	Calcite **Dolomite**	$CaCO_3$ $CaMg(CO_3)_2$
Silicates	Quartz Potassium Feldspar	SiO_2 $KAlSi_3O_8$
Sulfides	**Pyrite** Sphalerite	FeS_2 $(Zn,Fe)S$
Oxides	**Hematite** Magnetite	Fe_2O_3 Fe_3O_4
Sulfates	Gypsum Anhydrite	$CaSO_4 \bullet 2H_2O$ $CaSO_4$
Halides	Halite **Fluorite**	NaCl CaF_2
Native Elements	Silver Graphite/Diamond	Ag C

Table 1. Some mineral groups and examples of common minerals with their chemical formulas

Minerals often have a very specific color. Elemental sulfur is always yellow, while copper-containing compounds are usually blue or green. The color of a mineral is due to the absorption of certain wavelengths and emission of other wavelengths. Transition metals (groups 3–12) are often responsible for vivid mineral colors; even trace amounts of these elements can contribute to a dizzying array of hues. If a ruby and a sapphire were put in front of you, you could tell them apart right away. Rubies have a distinct red color, and many sapphires are blue. But on the molecular level, they are the same mineral—corundum (Al_2O_3). Rubies appear red because of chromium impurities in the crystal structure that cause light to reflect in a way that our eyes see red. Sapphires, however, appear blue because of iron and titanium impurities.

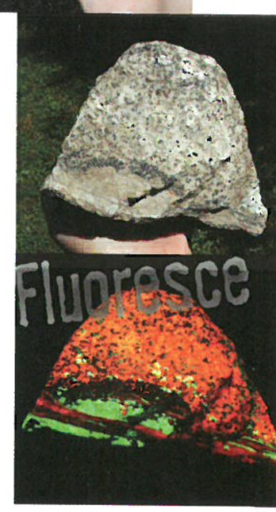
A reliable way to distinguish minerals is to determine their hardness. Minerals with strong bonds, such as diamonds, are very hard. Minerals with weaker bonds, such as talc ($Mg_3Si_4O_{10}(OH)_2$), tend to be softer. Talc is a mineral but is more commonly recognized as a powder—that's how little hardness it has.

The Mohs scale is used to classify the hardness of minerals. Your fingernail has a hardness of 2.5 on the Mohs scale. It can scratch any substance with a hardness of 2.5 or less but cannot scratch a substance with a hardness greater than 2.5. If two substances can scratch each other, they have the same hardness. **Diamond, with a hardness of 10, can scratch nearly any substance.** Talc has a hardness of 1 and won't scratch any other mineral with more hardness.

Another common way to identify minerals is the streak test, in which the mineral is rubbed across a piece of unglazed porcelain. The color of the resulting mark is often different from the color of the mineral because large particles of the mineral tend to make it appear more opaque, and thus darker, than it would in a fine-grained form. For example, hematite (Fe_2O_3), one of the most common ores of iron, typically appears black in mineral form but always leaves a reddish streak.

Streak tests are valuable for distinguishing between two minerals that have similar appearances. For example, the streak for fool's gold (iron(II) disulfide (FeS_2)) is black, while that for real gold (Au) is yellow.

Some minerals fluoresce a different color under ultraviolet light, making black light a useful tool for mineral identification. If a mineral fluoresces, it absorbs ultraviolet light and emits visible light. Some ordinary-looking minerals look stunning when viewed under black light. Fluorite (CaF_2) is so-named because of its fluorescent appearance under black light. About 15% of all minerals fluoresce when viewed under black light.



This rock contains calcite ($CaCO_3$) and willemite (Zn_2SiO_4). Under a black (ultraviolet) light, the minerals fluoresce red-orange and green, respectively.

The three types of rocks are: 1) igneous, 2) sedimentary, and 3) metamorphic; and each type is formed by a different chemical process.

Igneous rocks come from volcanoes and are formed when liquid rocks cool and solidify. Think of a volcano as a giant pressure cooker that is so hot it melts rock. If this liquid rock stays below the ground, it is called magma, and if it oozes above the ground it is called lava. When lava cools, it freezes and turns back into a solid. It may seem odd to refer to a rock as a frozen substance, but freezing is the process of changing from a liquid to a solid, which is exactly what lava does at room temperature.

A common type of igneous rock is pumice. When molten rock is deep within a volcano it is under immense pressure, keeping many gases, such as water (H_2O) and carbon dioxide (CO_2), dissolved within. When this rock is violently ejected into the atmosphere, the pressure suddenly drops, causing a rapid release of these gases, much like when bubbles form when you open a can of soda. Because the rock simultaneously cools, these bubbles freeze in the rock. The little holes formed due to these escaping gases create a porous structure, making pumice one of the few rocks that float.

Not all types of igneous rock form suddenly. Granite is one type of igneous rock that forms underground as magma cools slowly. If molten rock cools below ground, it happens slowly, which allows time for minerals to crystallize.

Sedimentary rocks form a thin layer over the surface of the earth, so they are the most commonly encountered rocks. Sedimentary rocks are formed when existing rocks are worn down by erosion or other mechanical processes. The sediment then settles and seals to form a new type of rock. They bind together through physical processes, such as pressure under layers of the earth or water, or chemical processes, in which the varying components react with one another. Sandstone, coal, and limestone are common sedimentary rocks.

Metamorphic rocks form because of chemical changes that occur in rocks at high temperatures and pressures deep underground. These rocks start out as igneous or sedimentary and then undergo a metamorphosis, or change. Limestone, a sedimentary rock, can be converted into marble, a metamorphic rock, if it is subjected to enough heat and pressure. Both are mainly composed of $CaCO_3$, but marble has a much harder and stronger structure. Slate, a metamorphic rock, begins as shale, a sedimentary rock. Slate is much sturdier and is commonly used as a building material (for floors or roofs) because of its durability but also because of its attractive appearance.

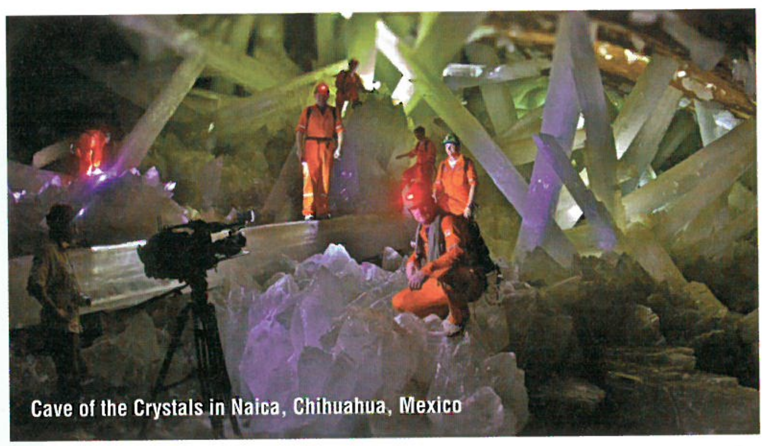
Career Paths

If you are interested in rocks and minerals, many diverse career opportunities potentially await you. **The extraction of rocks and minerals from the earth is a multibillion-dollar industry.** Engineers at mining companies locate new sources of underground mineral deposits. Once the ore is out of the ground, gemologists cut minerals into stones and polish them for jewelry. Geologists have the job of predicting earthquakes and exploring volcanoes. Each of these occupations requires an intimate knowledge of chemistry, which provides the foundation for understanding the nature of rocks and minerals. CM

How Crystals Form

SOME OF THE LARGEST CRYSTALS EVER FOUND were recently uncovered in an underwater cave in Mexico. A mining company drained the water from an area it was exploring, revealing breathtaking crystals of selenite ($CaSO_4 \cdot 2H_2O$). The largest crystals found in the cave were 12 meters long and weighed 55 tons!

These crystals did not form overnight, but rather formed slowly over thousands of years. Despite their massive size, these crystals are quite fragile—they deteriorate in air and can be scratched with a fingernail. For a stunning view of these crystals, visit the YouTube video, titled "World's biggest crystal cave" (https://www.youtube.com/watch?v=aGg2dXUSYoQ).



Cave of the Crystals in Naica, Chihuahua, Mexico

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Brian Rohrig is a science writer who lives in Columbus, Ohio. His most recent *ChemMatters* article, "Espresso, Café Latte, Cappuccino… A Complex Brew," appeared in the April/May 2017 issue.