

UNIT 2: PHYSICAL BEHAVIOR OF MATTER AND ENERGY

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ScienceNewsforStudents

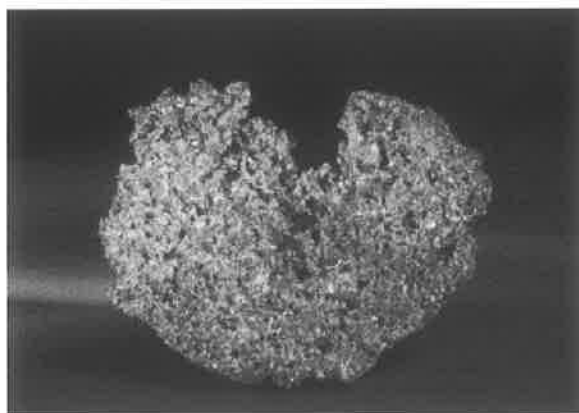
Chemistry

Gold's Glittery Rewards

Gold has properties that make it valuable not only for jewelry but also for electronics and other uses.

By Sarah Webb 12:00am, February 5, 2007

We all recognize gold, from the yellow sparkle of a chain necklace to the shiny coating on a DVD player's video and audio plugs.



This delicate, crystallized gold specimen was found in Leadville, Colorado.

© Denis Finnin/AMNH

Gold is a metal. It conducts electricity, and it can be shaped into sheets, long wires, or rings. Gold is an element—a substance made of one kind of atom. As an element, gold has its own square on the periodic table of chemical elements.

Gold also represents beauty and value, and it has done so for thousands of years. It's part of our culture and history.

Why do we value gold so much? It has a distinctive color. No other metal is a shiny yellow. It's also quite rare.

And this metal has other unique properties that help it keep its shine, as I learned on a recent trip to the new gold exhibit at the American Museum of Natural History in New York City.

Keeping its luster

The glitter of a gold nugget or flake immediately catches the eye. But gold's shine, unlike that of metals such as iron, copper, or silver, is practically permanent.

For example, copper metal has a reddish color. But copper objects turn green when they react with oxygen in the air. This coating on a copper surface, called a patina, gives the Statue of Liberty her distinctive green color.



The Statue of Liberty has a greenish color because the copper metal from which it was made combined with oxygen in the air.

Photo by I. Peterson.

In contrast, gold resists corrosion. It doesn't react with chemicals in the air or elsewhere in the environment. So it doesn't turn green as copper does, rust the way iron does, or tarnish the way silver does.

Shaping a nugget

Gold is also a soft metal that's easy to shape. People have been working with it for thousands of years.

Gold artifacts are among the oldest [human-made objects] that we know, says Jim Webster. He helped create the gold exhibit at the American Museum of Natural History and studies earth and planetary sciences at the museum.

Unlike many other metals, gold can be found on the ground in its pure form. Instead of having to go through many steps to isolate a metal from rock, early people could have used gold nuggets that were just lying around.

"Literally, now or 6,000 years ago, one could have picked up [a nugget] and just started hammering on it," says Webster. Ancient people shaped gold into jewelry, statues, coins, and other beautiful objects.



Jewelry made in the shape of animals, like these gold earrings, was popular more than 2,300 years ago in ancient Greece.

© Craig Cheseck/AMNH

The property that allows gold to be shaped easily is called malleability. Gold can be hammered into very thin sheets without breaking.

Experts can make a thin sheet measuring up to 100 square feet in area from just 1 ounce of gold, Webster says.

The museum's gold exhibit features a small room whose walls and ceilings are covered with gold—a layer just 0.18 micron thick. That's a tiny fraction of the width of a pencil point.



Sarah Webb stands in the gold room at the American Museum of

Natural History. The walls and ceiling are coated with a layer of gold only 0.18 micron thick.

Photo by Anne Sasso.

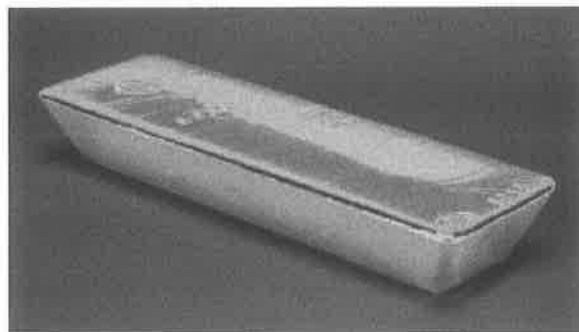
Because gold is so soft, jewelers and other users often combine it with other metals to make it stronger. The purity of gold is measured in karats, and pure gold is 24 karats. Jewelry in the United States is often 14 karats, or about 60 percent gold, combined with other metals, such as silver or copper.

Rare metal

Even though gold has many special properties, the main reason for its value is its rarity.

Researchers estimate that the total amount of gold ever mined would fit into 60 tractor trailers, Webster says. This might seem like a lot—until you compare it with iron. Iron mining and smelting companies produce six times that amount *every year*.

Because of its value, people have made coins out of gold, and banks store gold in the form of bars. Some people collect gold coins or trade gold in international markets. Its current value is more than \$600 per ounce.



Banks and gold markets can use gold bars for transactions. This bar weighs about 27 pounds and is roughly 6 inches long, 3 inches wide, and 2 inches thick. At current prices, it's worth more than a quarter of a million dollars.

© C. Chesek/AMNH, Courtesy of Johnson Matthey, Inc.

Electronic gold

Most gold that's mined today still goes into making jewelry. You also see it in Olympic medals and many other special awards, including the Oscar statuettes that honor movies.

But modern electronics and the journey into space have helped give gold an important place in the technology that we use every day.

Audio and video cables often have gold-coated plugs for two reasons. Gold conducts electricity better than all but two other metals, Webster says. And because gold doesn't corrode, the surface on the plug stays clean.

For the same reasons, computer chips also often contain gold, as do a variety of other electronic components.

We've also launched gold into space.



A thin layer of gold covered the visor on the helmet of an astronaut on the moon. The gold layer is transparent but still keeps out the sun's heat.

NASA

Gold reflects heat better than any other metal. The visor on an astronaut's helmet has an ultrathin layer of gold. The layer is thin enough to be transparent, so the astronaut can still see through it. But this thin layer reflects the sun's heat away from the astronaut.

The museum's gold exhibit includes a helmet from the Apollo 11 mission, when astronauts first landed on the moon in 1969.

Even after thousands of years, gold remains a precious metal—one that has long been prized for its glitter and is now more useful than ever.

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salting roads

THE SOLUTION FOR WINTER DRIVING

By Doris R. Kimbrough

Most of you are probably planning to be in a car at some point this winter, so be sure to wear your seatbelt, obey the speed limit, and be extra cautious in “winter driving conditions”. It is actually physics that makes being in a car on an icy road hazardous; friction is an important part of keeping a car under control. However, your state and local transportation departments make use of some pretty interesting chemistry to keep roads safer for travelers in the winter-time. In addition to plowing, one of the ways that highway workers keep roads clear of ice and snow is by spreading salt on the roads. Even though salt can cause rust and corrosion on cars, bridges, and other parts of the highway, it more than makes up for this costly damage by saving lives. Let’s take a look at how it works.

Freezing point depression

Pure water freezes at 0°C; adding salt to water depresses or lowers the freezing point below zero. When you remove heat from water (or any substance), the molecules slow down. The freezing process occurs when the molecules stop sliding and tumbling all over each other (liquid phase) and settle into fixed positions in a large network called a *crystal lattice*, which is the solid phase. The molecules are still moving, but in the solid phase that motion involves bonds stretching and compressing or the atoms wiggling a little bit. This is called vibrational motion.

When a solution of salt in water is cooled to a low enough temperature, the water molecules begin to stick together in an organized way to form solid crystals. The crystal framework tends not to include the salt ions because the ions would disturb this

organization. So when you cool a solution enough, the ice crystals that start to form are made of pure frozen water. You can actually purify salty water like this, by freezing a portion of the solution and washing the salty water off of the ice crystals and then thawing the ice to produce pure water. Eventually, if you cooled it enough, the whole solution will freeze, but it does not have a sharply defined freezing temperature. Getting the water molecules organized into a crystal from a solution requires that you remove more energy (actually free energy) than if you are freezing pure water, so the water in a solution typically does not start freezing until it reaches a lower temperature than the normal freezing point. This is true of all solutions, not just those made with water.

The difference in temperature between where the pure solvent (water in our case) freezes and where the solution starts to freeze is called the *freezing point depression*. How low



you go depends upon what the solvent is and how concentrated the solution is. The more concentrated the solution, the lower the freezing point. This is why if you freeze a solution completely, you have to keep lowering the temperature. As the pure water freezes away from the solution, the concentration of the solution remaining increases. How does your Department of Transportation use this chemistry to keep roadways clear of snow and ice in the wintertime?

Salting roads

Highway workers use salt in two ways: 1) to melt ice that is already on the roadway and 2) to prevent ice from forming on the roadway. The second one is a little easier to understand, so we will start there. Let's say a snowstorm is forecast for your town. Municipal workers get out and spread salt on the roads. As the storm hits, snow starts to fall, but the road surface is warmer than the air, so the first flakes melt. As they melt, the salt dissolves in the liquid water. Now you have a solution of salty water, which has a lower freezing point than pure snow, so that even though the additional snow might cool the road enough to "stick" to the road surface, the temperature will not get cold enough to freeze the solution the way it could freeze pure water. In the end, the real snow removal is done by the plows, but salt plays a crucial role in preventing snow and ice from bonding to the pavement.

"Hold it!" you say. Suppose the tempera-

ture does get cold enough to freeze the solution. Or suppose that enough snow falls so that the salt water solution gets too dilute to work, what happens then? In both of those cases, snow could build up on the road. This

tals, water molecules do not have the same stable arrangement they have on the interior; they are more mobile and more reactive. So the surface ice reacts with the surface of the salt crystals, allowing a small amount of salty



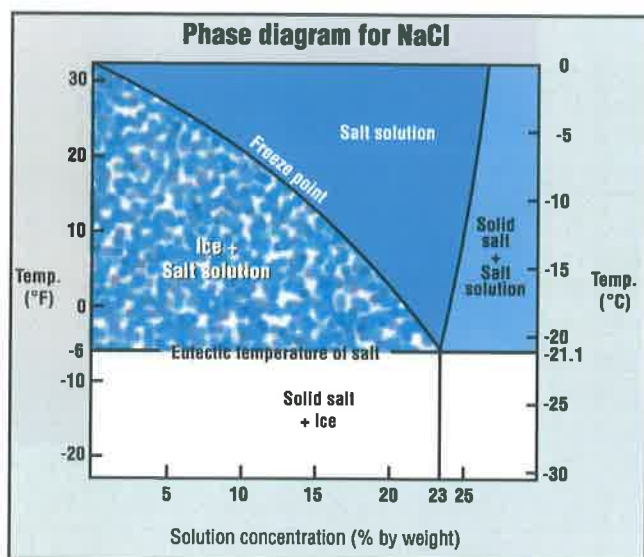
Sodium chloride and calcium chloride.

is why your highway workers are out there round-the-clock, plowing and spreading more salt as long as the storm is in the area. Communities with really cold temperatures, like parts of Canada and Alaska, where it can get to -20°C (below zero on the Fahrenheit scale), don't even bother with salting the roads, because it doesn't help. They typically plow off as much as they can and use gravel or sand to add traction.

How does it work if the road already has snow or ice on it? You may have seen how spreading salt on an icy sidewalk will cause the snow or ice to melt. The very beginning of the melting process begins where solid ice contacts solid salt. At the surface of ice crys-



Water freezes at lower temperatures when it is saltier. But solubility of salt in water decreases with decreasing temperature. So at some point, a solution is too cold to hold the salt that keeps it from freezing. The *eutectic* temperature is the lowest temperature at which a mixture of two or more substances can stay liquefied. For a NaCl and water mixture, the eutectic temperature is -21.1°C . For road ice, -10°C is the practical limit for salt.



This phase diagram illustrates the impact of NaCl concentration and temperature on the phase of an aqueous NaCl solution.

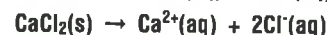
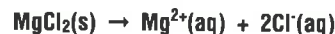
solution to form. This first step is relatively slow, but then the growing solution continues to dissolve more salt and melt more ice. Passing vehicles warm the slush through friction, which speeds the dissolution of the ice and may crush the salt and ice together, which will increase the surface areas of the particles in contact with each other. Some communities use "prewetted" salt (usually rock salt with a CaCl₂ solution sprayed on it) to speed the process.

Road salt history, fun facts, and current technology

Putting salt on the roads to lessen the buildup of snow and ice began in the 1930s, and by the 1960s, it was used by most communities where snow and ice are a problem. Concerns about the effect of the use of sodium chloride (common table salt) on the environment have prompted some state and local road crews to explore the use of more environmentally friendly salts, such as magnesium chloride and calcium chloride. These two salts have the advantage of being more effective at lowering the freezing point and there is some interesting chemistry behind this benefit.

As you probably know, sodium chloride has the formula NaCl. When it dissolves in water, it dissociates into its ions: Na⁺ and Cl⁻, producing two ions in solution for every NaCl for-

mula unit. Magnesium chloride (MgCl₂) and calcium chloride (CaCl₂) dissociate to three ions each because the metal has a 2⁺ charge and there are two chlorides per metal ion:



It is the number of dissolved particles that determine the extent of the lowering of the freezing point of a solution. So although NaCl produces two ions, MgCl₂ and CaCl₂ each produce three, making them more effective. Other variations include mixtures of the magnesium and calcium chlorides, as well as magnesium and calcium acetates, Mg(C₂H₃O₂)₂ and Ca(C₂H₃O₂)₂.

	Practical Melt Temp.	Eutectic Temp.
CaCl ₂	-32°C	-56°C
MgCl ₂	-15°C	-33°C

The technology of salting roads has become fairly sophisticated. Often, these salts are dissolved in water or some other solvent so that they can be sprayed onto the road surface. Having the deicing substance in a solution (i.e., fluid) form makes it possible to pump through hoses, which allows for a more targeted application. In addition, various anticorrosive substances are added to protect highways and cars from the damage the salts can cause over time. Some 15 million tons of deicing salt is used each year in the United States and about 4–5 million tons in Canada.

You may have seen signs that warn about bridges freezing before road surfaces. This is because bridges are more exposed and not insulated by the ground from underneath like the rest of the highway. Some high-tech highway bridges have been constructed with deicing sprayers built right into the pavement, complete with sensors that detect when conditions are right (e.g., cold temperatures, high wind speeds, high humidity) for ice to form. The sensors detect the possible formation of ice, and the deicing sprayers go to work to keep the roadway from freezing.

Highway engineers have been working with other interesting variations. One deicing material that is currently on the market mixes magnesium chloride with sugar cane or sugar beet molasses. The sticky molasses keeps the magnesium chloride from getting blown or washed off the road surface. There are also substances that are added directly to the top layer of concrete or asphalt when the road is built or repaved that help prevent ice from forming. Highway workers can then get away with using less salt than before, which is cheaper, easier on the environment, and helpful in preventing corrosion. Scientists and engineers continue to develop new ways to keep winter highways safe while minimizing expense and environmental harm. Just another way that chemistry is keeping you out of harm's way. ▲



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Science Diction: The Origins of the Bunsen Burner

Every high school chemist has no doubt fiddled with a Bunsen burner--but where did the apparatus get its name? Science historian Howard Markel talks about the German chemist Robert Bunsen, and why his experiments necessitated the invention of the gas burner still in use today.

The Bunsen burner is the iconic symbol of high school chemistry and, for millions of inquiring scientists, "such stuff as dreams are made on." Yet while we all may be familiar with this blazing apparatus, relatively few know exactly who Bunsen was.

Robert Wilhelm Eberhard Bunsen (1811-1899) was born in Göttingen, which was then part of the Kingdom of Westphalia. His father, Christian, a professor of modern philology and chief librarian at Germany's famed University of Göttingen, encouraged his son to constantly study, question, and verify. Fascinated by all things physical, geological, mathematical, and chemical, Robert Bunsen took his doctorate in physics from the University of Göttingen in 1830.

Before joining the faculty at Göttingen in 1833, Bunsen was awarded a prestigious, three-year travel grant across Germany, France and Austria where he observed the laboratories of such prominent scientists as Gay-Lussac and Liebig, mineral mines, geological sites, and the great crucibles of modern chemistry during the Industrial Revolution: the burgeoning factories that smelted, painted, processed, and mass produced virtually every modern convenience under the sun. In 1852, after teaching stints at Göttingen, Kassel, Marburg and Breslau, Bunsen was called to a professorship at the prestigious Heidelberg University.

Chemists have been arguing for years over who deserves credit for creating the gas burner. Even though it had been used in Bunsen's laboratory since 1855, Bunsen and an English chemist named Henry E. Roscoe (1833-1915) formally announced the burner now called Bunsen in an 1857 article on photochemistry. To be sure, prototypical versions of laboratory burners date back to at least the 1820s, when gas lighting was introduced to the larger cities of Europe. But the problem with many of these earlier gadgets, including a "gauze burner" Roscoe brought with him from England, was that the flame produced was diffuse and insufficiently hot; such flames also flickered and emitted changing colors caused by contaminants on these burners' metal protective screens.

The experiments Bunsen and Roscoe were pursuing at this time, in collaboration with another brilliant scientist named Gustav Kirchhoff (1824-1887), centered on the establishment of spectral standards for the identification of terrestrial and celestial matter. It all began one day in the lab when the trio were heating a sample of pure magnesium. The brilliant light emitted stunned and impressed Bunsen and his colleagues. Indeed, this observation led to the determination that different elements and compounds gave off specific, measurable wavelengths when viewed through a prism, or what is now known as spectrum analysis.

But in order to reliably reproduce these photochemical fingerprints, Bunsen required a colorless, soot-free flame of predictable and constant size. Working with an intrepid instrument maker named Peter Desaga, a long, narrow tube was fashioned with an adjustable valve that governed specific mixtures of natural gas and air. Upon achieving the precise length and width of the tube,

it became possible to prevent the flame from traveling down the device, thus obviating the need for a wire safety screen. The Bunsen burner had an added value in that it produced a much hotter and more concentrated flame, which was applicable to a wide host of chemical inquiries.

As with many major inventions, a few would-be inventors made claims of priority on the gas burner but these were successfully challenged and fought down by Peter Desaga. Interestingly, Professor Bunsen never retained a patent nor did he take any profits from the now ubiquitous apparatus.

By the close of the 1860s, the Bunsen burner had replaced the standard issue charcoal furnaces that long dominated and polluted 19th century chemical laboratories. It has been improved and tinkered with many times since but has never been replaced. Robert Bunsen was a beloved teacher and brilliant chemist. He discovered the elements cesium and rubidium, helped develop the field of spectroscopy, and even found an antidote for arsenic poisoning in a series of experiments that cost him vision in one eye. But his scientific immortality rests firmly upon his (and Desaga's) elegant flaming device.

Produced by Christopher Intagliata, Senior Producer