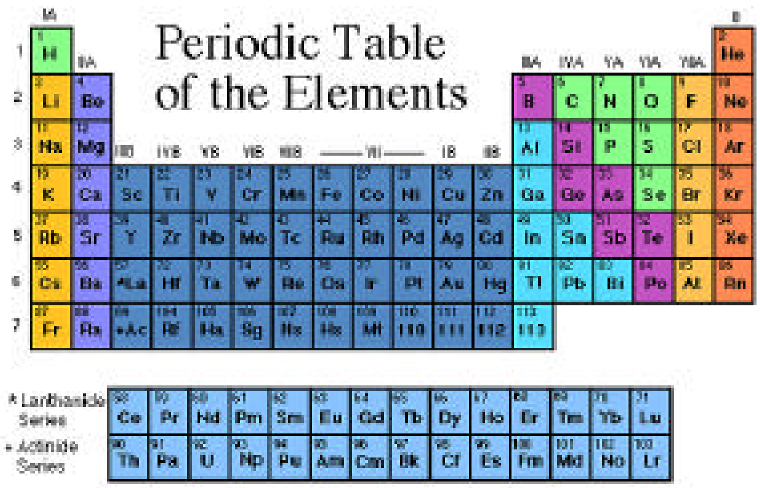
Cosmic Chemistry: An Elemental Question

The Modern Periodic Table

STUDENT TEXT



Chemists at Los Alamos National Laboratory, a Genesis partner organization, supply the nation with purified chemicals. Their Web site displays a modern periodic table of the elements.

At the Web site http://pearl1.lanl.gov/periodic/ you may click on any element and access information about its physical and chemical properties, as well as other fascinating facts.

Reading the Modern Periodic Table

Our modern day periodic table is expanded beyond Mendeleev's initial 63 elements. Most of the current periodic tables include 108 or 109 elements.

It is also important to notice how the modern periodic table is arranged. Although we have retained the format of rows and columns, which reflects a natural order, the rows of today's tables show elements in the order of Mendeleev's columns. In other words the elements of what we now call a "period" were listed vertically by Mendeleev. Chemical "groups" are now shown vertically in contrast to their horizontal format in Mendeleev's table.

Note also that Mendeleev's 1871 arrangement was related to the atomic ratios in which elements formed **oxides**, binary compounds with oxygen; whereas today's periodic tables are arranged by increasing atomic numbers, that is, the number of protons a particular element contains. Although we can imply the formulas for oxides from today's periodic table, it is not explicitly stated as it was in Mendeleev's 1871 table. The oxides ratio column was not shown in earlier Mendeleev versions. Can you think of a reason why not?

Groups

The modern periodic table of the elements contains 18 **groups**, or vertical columns. Elements in a group have similar chemical and physical properties because they have the same number of outer electrons. Elements in a group are like members of a family--each is different, but all are related by common characteristics.

Notice that each group is titled with Roman numerals and the letters A and B. Scientists in the United States and Europe now use different titles to refer to the same groups. To avoid confusion, the Roman numerals and letters designating groups will eventually be replaced by the numerals from one to eighteen.

Periods
Each of the table's horizontal rows is called a **period**. Along a period, a gradual change in chemical properties occurs from one element to another. For example, metallic properties decrease and nonmetallic properties increase as you go from left to right across a period. Changes in the properties occur because the number of protons and electrons increases from left to right across a period or row. The increase in number of electrons is important because the outer electrons determine the element's chemical properties.

The periodic table consists of seven periods. The periods vary in length. The first period is very short and contains only 2 elements, hydrogen and helium. The next two periods contain eight elements each. Periods four and five each have 18 elements. The sixth period has 32 elements. The last period is not complete yet because new **exotic** or man-made elements are still being made in laboratories.

Classification of General Properties
The general properties of elements allow them to be divided into three classifications: metals, nonmetals and metalloids. The distribution of metals is shown in your periodic table as boxes colored yellow, purple and two shades of blue. Metalloid elements are in the diagonal boxes colored pink and nonmetal elements are above the diagonal line to the right of the metalloids, in boxes colored green, gold, and red. Notice that hydrogen's box is colored green, even though it is at the top of a group of metals.

METALS

As you can see, the vast majority of the known elements are metals. Many metals are easily recognized by non-chemists. Common examples are copper, lead, silver and gold. In general, metals have a luster, are quite dense, and are good conductors of heat and electricity. They tend to be soft, **malleable** and **ductile** (meaning that they are easily shaped and can be drawn into fine wires without breaking).

All of these properties are directly related to the fact that solid metals are crystals formed from positive ions surrounded by mobile electrons. This mobility allows electrons to absorb and reflect light in many wavelengths, giving the metals their typical luster. It also permits electrons to absorb thermal and electrical energy from the environment or neighboring electrons and transfer this energy to other electrons; in this way, heat and electricity can be conducted throughout the metal. These mobile electrons hold the positive metallic ions so tightly that even when the metal sample is only a few layers thick, as in gold foil, the sample stays intact. So, the density, malleability, and ductility of metals are also due to electron mobility.

The difference in the coloring on the periodic table indicates that the most metallic elements are those on the left side of the table. The Group I Alkali Metals and the Group II Alkaline Earths have more metallic characteristics than elements farther right whose square are colored blue, especially those that border on the metalloid elements. Generally speaking, the most metallic metals are in the bottom left corner. As you move toward the upper right on the periodic table, elements become less metallic in property.

Alkali Metals

The alkali (IA) metals show a closer relationship in their properties than do any other family of elements in the periodic table. Alkali metals are so chemically reactive that they are never found in the element form in nature. All these metals react spontaneously with gases in the air, so they must be kept immersed in oil in the storeroom. They are so soft that they can be cut with an ordinary table knife, revealing a very "buttery", silvery metal surface that immediately turns dull as it reacts with water vapor and oxygen in the air. The chemical reactivity of alkali metals increases as the atomic number increases.

Their reactions with halogens, elements in Group VIIA, are especially spectacular because some of them emit both light and heat energy. They react with other nonmetals, albeit more slowly, forming compounds that are very stable. They also react with acids, forming hydrogen gas and salts; with water they form hydrogen gas and metallic hydroxides, which are sometimes called bases. They react with hydrogen to form metallic hydrides, which form strong bases in water. In all these reactions, the metals form ionic compounds, in which each metal atom loses one electron to form a positively-charged ion or **cation**.

All compounds of alkali metals are soluble in water. These compounds are widely distributed. Large mineral deposits of relatively pure compounds of sodium and potassium are found in many parts of the world. Sodium and potassium chlorides are among the most abundant compounds in sea water. Potassium compounds are found in all plants and sodium and potassium compounds are essential to animal life—including human life. Lithium (Li) is the alkali metal of most interest to Genesis scientists.

Alkaline Earth Metals

The alkaline earth (IIA) metals also exhibit the typical metal characteristics of high density, metallic luster and electrical and thermal conductivity. Rocks and minerals containing silica, magnesium, and calcium compounds are widely distributed. These chemicals are also abundant as compounds in sea water. Their chlorides are abundant in sea water. Radium, the largest of the alkaline earths, is a radioactive element that occurs naturally only in very small quantities. Chlorophyll, the green coloring in plants, is a magnesium-containing compound. Calcium is a major component of animal bones, teeth and nerve cells.

Alkaline earth elements form compounds by losing, or in the case of beryllium, sharing two electrons per atom. These atoms hold their electrons more tightly than alkali metals. They are, therefore, smaller than and not so chemically reactive as the neighboring alkali metals. They do not require special storage because the surface of these metals reacts with air, forming a tightly adhering layer that protects the metal and prevents additional reactions. None of them is found naturally as a free element.

The chemical reactivity of these elements increases with size. Calcium, strontium, and barium react with water forming hydrogen and alkaline compounds. Magnesium reacts with steam to produce magnesium oxide. Common oxides of alkaline earth metals include lime (CaO) and magnesia (MgO), which react with water to produce strongly alkaline solutions. The alkali metals also react readily with many other types of chemicals, including acids, sulfur, phosphorus, the halogens (Group VIIA), and, with the exception of beryllium, hydrogen.

Alkaline earth halides are quite soluble in water. The water solubility of their hydroxides increases, but the solubility of their carbonates and sulfates decrease with increasing atomic number. The presence of calcium and magnesium ions in water make it "hard" because they form insoluble salts with soap. Solid calcium carbonate deposits form on container surfaces when water evaporates. Magnesium (Mg), calcium (Ca), barium (Ba), and beryllium (Be) are all of interest to Genesis researchers.

Transition Metals

The transition (or heavy) metals have most of the usual properties of metals. Their densities, which are greater than the Group IA and IIA metals, increase and then decrease across a period. The transition metals are also called heavy metals because their atoms are relatively small and their large numbers of protons and neutrons give them relatively large masses.

There is a great variance in the chemical reactivity of transition metals. All the transition elements react with halogens and most react with sulfur and oxygen. The elements from scandium through copper form compounds that are soluble in water. The heavier elements of Group VIIB are sometimes called the *platinum metals*, which, in addition to gold, are very nonreactive.

One of the main uses for transition metals is the formation of **alloys—**mixtures of metals—to produce tools and construction materials for specific uses. For example, structural steel alloys, which are used in automobiles and building construction, can contain as much as 95% iron. There are also carbon and at least six different high-alloy steels, some which contain manganese, chromium, nickel, tungsten, molybdenum and cobalt: all transition metals.

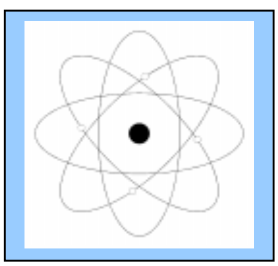
Copper, silver and gold are sometimes known as **coinage metals** because they can be found naturally in the free state and because they tarnish slowly. Since prehistoric times, they have been used in coins, utensils, weapons, and jewelry.

Although many transition metals have very high melting and boiling points, mercury (Hg) has such a low melting point that it is a liquid at room temperature.

All the transition metals are electrical conductors, with copper, silver and gold being among the best; they vary from very good to only fairly good thermal conductors.

Some of the transition metals exhibit colored luster and some of them are more brittle than the Group IA and IIA metals. Whereas the compounds of the Group IA and IIA metals are white, many of the transition metal compounds are brightly colored. Many heavy metal compounds, such as those of mercury, cadmium, zinc, chromium and copper, are poisonous.

When transition metal ions are present in even small percentages in crystalline silicates or alumina, the minerals become gems. Rubies are gems in which small numbers of chromium ions are substituted for aluminum ions in aluminum oxide. Chromium substitution for a small number of aluminum ions in another clear crystal, beryllium aluminum silicate, forms the green gem known as emerald. Alexandrine may appear red or green due to chromium ion substitution in its crystal. Iron ions can produce red garnets, purple amethysts, and blue aquamarines. Iron and titanium ions cause yellow-green peridot, and blue turquoise gems are colored by copper ions. Titanium and chromium are two transition metals about which Genesis scientists expect to learn a great deal.



Rare Earth Metals

The rare earth metals consist of the lanthanide series and the actinide series. Because they are difficult to find, they are termed rare earths. They often appear to be an add-on to the rest of the periodic table, but actually, they should be shown in the center of the table. The table should be split after 137 barium, and the Lanthanide series inserted. The Actinide series should be inserted after 88 radium.

(Lanthanides)
The fourteen lanthanide elements follow lanthanum (La) in the periodic table. They generally occur together in a phosphate mineral such as monazite. They are so similar in chemical and physical properties that they are especially difficult to separate from each other. Promethium (Pm) is unstable, and is not found in nature.

An **unstable isotope** of an element decays or disintegrates spontaneously, emitting various types of radiation. Another name for an unstable isotope is a **radioisotope**. In some instances, the decay process is slow, with the unstable atom lasting days or months. In others, the process is rapid, lasting tiny fractions of a second. In addition to radiation, the unstable element changes its nucleus to become one or more other lighter elements. Approximately 5,000 natural and artificial or manmade radioisotopes have been identified.

(Actinides)
The fourteen actinides follow actinium (Ac) in the periodic table. They are all unstable, and most do not occur in nature. Less is known about these elements than about any other family, since some of them have only been produced in tiny quantities. Uranium (U) is the most well-known naturally occurring member of this group of elements. Mendelevium (Md), element number 101, is named for Dmitri Mendeleev, the Russian chemist who first arranged the elements in a table in order of increasing atomic mass.

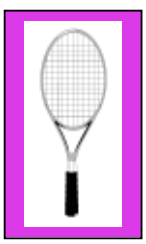
Examining radioactive nuclei in solar wind is one of the measurement objectives of the Genesis mission.

Other Metals

Other metals include heavier elements of Groups IIIA, IVA, and VA. They form a staircase inside the periodic table. The metals in Group IIIA are aluminum (Al), gallium (Ga), indium (In), and thallium (Tl). The metals in Group IVA are tin (Sn) and lead (Pb), and the only metal in Group VA is bismuth (Bi). As atomic number decreases within each group, their metallic character gets weaker. For instance, boron (B), above aluminum in Group IIIA, is a metalloid rather than a metal. Aluminum, tin, and lead are readily recognized as metals by non-chemists.

Aluminum (Al) is the only true metal in Group IIIA. Aluminum ores are found in great abundance in the Earth's crust, but the metal's manufacture by an electrochemical process from bauxite ore requires ten times the energy needed to produce steel. Because aluminum is light, strong, very malleable and resists corrosion, it is an especially good industrial and construction metal.

The principal use of tin (Sn) is as a corrosion-resistant coating for iron, although it is widely used in alloys, such as bronze and solder. Lead (Pb) is the principal constituent of lead storage batteries, but it is also used to form solder. Its use in paints has been discontinued because of its toxic effect on the human body. Bismuth (Bi) is hard and brittle; it is used in alloys with low melting points that are used for electrical safety appliances.



METALLOIDS

The metalloids include boron (B), silicon (Si) and germanium (Ge), arsenic (As) and antimony (Sb), tellurium (Te) and polonium, (Po). Note that they are arranged in stair steps between the metals and nonmetals.

Metalloids have some of the properties of metals and nonmetals—and each metalloid has its own unique mixture. A few are shiny like metals, but do not really have a metallic luster. Some metalloids have very high melting and boiling points; others do not. Others conduct electricity, but their electrons are mobile in only certain directions, so they are called semi-conductors. This makes them useful in designing transistors and other solid state electronic components. Genesis scientists are interested in boron because the collection wafer material is pure silicon.

NONMETALS

The nonmetallic elements are in the upper right portion of the periodic table. At room temperature and pressure, many of them exist as gases, but one is a liquid. Others are either the hardest or the softest of solids. The nonmetals have few chemical properties in common. They range from fluorine, the most active nonmetal, to the most nonreactive of the elements, the noble gases. Millions of compounds formed from carbon, hydrogen, oxygen, sulfur and nitrogen are known as **organic chemicals**.

Oxides of sulfur and nitrogen have been identified as atmospheric pollutants. Nonmetallic compounds also include salts as well as many acids and bases. Many of these salts are found in soil or dissolved in ocean water. Any ions formed by nonmetals are negatively charged.

Almost eighty percent of our atmosphere is made up of nitrogen gas and most of the rest is oxygen, which is necessary for human respiration and metabolism. There are negligible amounts of noble gases in our atmosphere.
Many of the nonmetals are colored, including yellow sulfur, red and yellow phosphorus, yellow-green fluorine, pale yellow chlorine, red-brown bromine, and violet-black iodine. Others, like oxygen, nitrogen, and the noble gases are colorless. Only sulfur is found as a free element in nature.

Some of the nonmetals are molecular, such as the diatomic halogens, nitrogen, and oxygen; phosphorus forms molecules of four atoms and sulfur is found in rings of eight atoms. The noble gases exist as monoatomic gases. On the other hand, any sample of carbon, whether it be the graphite in your pencil lead or a diamond, is one large molecule of carbon atoms.

If metal atoms are closely packed like stacked building materials, leading to high densities, then the low density of nonmetals is like the same building materials widely distributed with open spaces between them in the constructed building. Electrons in the crystalline structures of nonmetallic solids are tightly held in chemical bonds; so, nonmetals are notably good electrical and thermal insulators.

Halogens

The halogens are the gases in Group VIIA of the periodic table. Their name indicates that they are *salt-formers*. This is appropriate since they react easily with other elements, especially the alkali and alkaline earth elements in the left columns of the periodic table. They are all considered highly reactive elements.

Chlorine (Cl) is one of the halogens. It is a highly poisonous yellow and green-colored gas. It combines easily with an explosive alkali metal called sodium (Na) to form a compound called sodium chloride. The compound's chemical formula is NaCl, and it goes by the common name of table salt.

Actually the term **salt** is used in a more general sense to mean any compound of a halogen with an alkali metal or alkaline earth metal. These can combine in many different arrangements. Some types of salts include magnesium bromide ($MgBr_2$) and potassium iodide (KI).

Except for the noble gases, the chemical reactivity of nonmetals decreases as the size of the family member increases. Fluorine is the most **electronegative** of the elements, which means that it has the most attraction for a pair of electrons being shared. It is so reactive that metal flakes, glass, and even water will react brightly in it, so it requires special handling and great care in its use and storage.

Melting points and boiling points increase as the size of the atom in the family increases. Note the physical states of the halogens. Fluorine and chlorine are gases, bromine is a liquid, and iodine is a solid at room temperatures. Astatine is a radioactive member of the halogen family and radon has some radioactive isotopes that are dangerous to human health.

Fluorine (F), the lightest halogen, is also the most reactive element on Earth. It is also the most electronegative, having the ability to *steal* electrons from other elements easily. Fluorine is so reactive that metal flakes, glass, and even water will burn brightly in it. This dangerously reactive element requires special handling and great care in its use and storage.

Noble Gases

The noble gases were unknown in Mendeleev's time. The lightest and most stable of these gases, helium, was discovered from its bright yellow solar spectral line in 1868. The existence of helium on Earth was not discovered until 1895. The noble gases are Group 0 in the periodic table.

These elements are termed noble because they do not interact with other elements to form compounds. Another way to say this is that they are inert. Their atoms do not even interact with each other, so they exist as mono atomic gases.

Examining noble gas elements and isotopic ratios in solar wind is a major science objective of the Genesis mission. The foil collectors returned from the moon on Apollo missions provided precise solar wind helium (He) and neon (Ne) isotope ratios not previously known. One surprise was a $^{20}Ne/^{22}Ne$ ratio that was 38% higher than that of samples of Earth’s atmosphere. The results of the Genesis mission may help scientists better understand the solar system’s diversity of noble gas distribution.

Hydrogen

Chemists are not in agreement about the placement of hydrogen on the periodic table. In the periodic table in this module, hydrogen is shown as a nonmetal, but placed above Group 1A metals, because it also exhibits some chemical properties similar to those metals. It exists in the free state as diatomic molecules and it reacts with active metals in much the same manner as the halogens. But it also found bonded to other nonmetals in organic compounds.

Hydrogen is the most abundant element in the universe. It is estimated that ninety percent of the atoms in the universe are hydrogen atoms. The Sun and other stars appear to be composed largely of hydrogen, as do the gases found in interstellar space.

Hydrogen is a component of more compounds than any other element and makes up 11% of the mass of water, its most abundant compound. It is found in only negligible quantities uncombined on the Earth, even though it is the ninth most abundant element in the Earth's crust.

Hydrogen is the principal energy source in the Sun's high temperature nuclear fusion reaction. This major nuclear reaction, which occurs at temperatures in excess of 40,000,000°C, is thought to involve the combination of the nuclei of a deuterium atom and a tritium atom to form a helium nucleus and a neutron.

In examining the modern periodic table, one notices the chemical elements arranged in groups and periods. They are classified by their general physical and chemical properties into their groups: metals, metalloids, and nonmetals, which can be further subdivided. These classifications help chemical researchers understand known elements and predict the properties of new manmade elements.

Some Elemental Mysteries to be Solved by Genesis Scientists

The scientific purpose of the Genesis mission is to collect information about the isotopic abundances of certain elements in the solar wind. This information will be used to help scientists explain the transition between star and planet. Given the accepted theory that the planets formed from the same materials as the Sun, isotopic abundance information also helps to explain why the planets came to be so diverse. The solar wind is the only plausible source of precise solar isotopic composition information, and the Genesis mission will bring back samples containing this information.

The most important element to Genesis scientists is oxygen, since widespread variations in isotopic abundances among planetary materials are already established. No one really knows why these variations exist. Theories about processes that occurred in the original solar nebula make specific predictions about the relationships between the isotopic composition of solar matter and that of different planets. One interesting possibility is that the planets formed from interstellar dust that had not mixed thoroughly with interstellar gas. Had the gas and dust not mixed well four and a half million years ago, the solar oxygen composition could be quite different from that on Earth.

The second highest priority element for Genesis research is nitrogen. A major planetary mystery, nitrogen shows a large variation from terrestrial values for isotopic abundances in other planetary samples. Many solar chemists believe the nitrogen composition of the Sun must have changed over time in order to account for these differences. This theory leads to a very specific prediction of the solar nitrogen isotope composition. Solar physicists do not have a theory to explain how this could happen. If the chemists are correct, the physicists will have to discover the mechanism responsible for the changes.

Carbon is another kind of mystery. Unlike the other nonmetals mentioned here, carbon does <u>not</u> show large variations in isotopic composition among planetary materials. Given what we know about oxygen and nitrogen, the results found by Genesis researchers for carbon may be challenging to explain.

The noble gases are very interesting to geochemists precisely because they have no chemistry. They are little affected by chemical processes, and therefore are a unique source of information. Apollo mission experiments with foil collectors show the isotopic composition of neon in the solar wind to be very different from that of the Earth's atmosphere. The accepted explanation is that early in the history of our planet, much of the Earth's atmosphere escaped into space, thus altering its composition. The ultraviolet radiation of the Sun may have changed the isotopic composition of the Earth's early atmosphere. The quantitative models for this isotopic alteration make specific predictions of the isotopic composition of other noble gases (argon, krypton, and xenon) in the solar wind. These values will be established accurately for the first time by Genesis scientists.

Single crystal silicon wafers will be used to collect many of the targeted solar wind samples. The silicon wafers in the Genesis sample return capsule provide an ultraclean collector material to measure the relative amounts of various elements. The highest grades of semiconductor silicon crystals are the cleanest things known. Therefore the abundances of most elements in the periodic table can be measured accurately from samples collected in silicon wafers that are free of contaminants.

One interesting application of the cleanliness of silicon is to compare the Genesis-discovered information about the solar composition with that of certain kinds of meteorites that appear to be very similar in composition to the Sun. Scientists are looking for a pattern in which the compositions of the solar wind and the meteorites agree for elements lighter than iron, but not for heavier elements. They expect a depletion of heavier elements in the solar wind. This would be explained if the heavier elements "settled out" at the bottom of the surface mixing zone of the Sun.

Genesis scientists are looking for information about elements from many families of the periodic table. They are interested in information about the abundances of these elements and their isotopes in solar wind, to examine various theories of cosmic chemistry. Results of the analysis of the returned solar wind samples are expected to begin to appear in scientific journals within a few years after recovery and archiving are completed.