Cosmic Chemistry: Understanding Elements

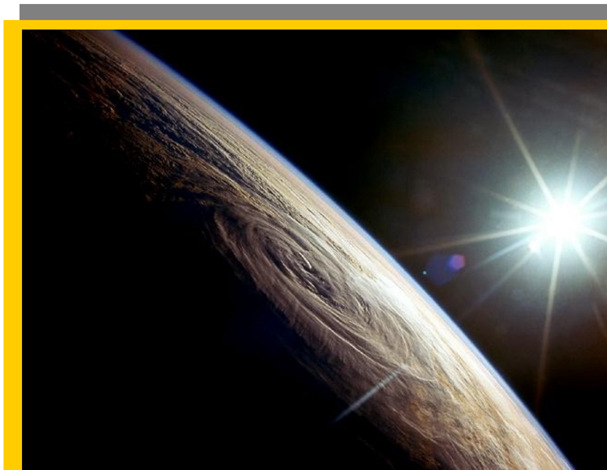
Elemental Mysteries for Genesis Scientists

STUDENT TEXT

PURPOSE

Some science goals of NASA are to understand the formation, development, and present state of the solar system. To do this, the Genesis spacecraft will travel outside the Earth's magnetosphere and collect solar wind samples that will help scientists go "back in time" to see the building blocks of the early solar system first-hand. The Genesis mission will also test the basic assumption that the solar material and the material used to form the planets are the same. The biggest difference between the planets is their chemical composition. Diversity in the planets then is defined as the chemical difference between each planet and the sun. Yet little is known about isotopic abundances in the sun.

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. With current information, there is no difference between the solar and terrestrial isotope abundances for C, O, and Mg. But the uncertainty level of this information is too high. The Apollo missions provided the first precise solar wind data for He and Ne isotopes.



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SOLAR NEBULA

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Solar Nebula: How well did gas and dust mix?

Stars form from interstellar gas and dust in molecular clouds. Interstellar gas is made up mostly of hydrogen gas and is much more common than interstellar dust. There is one dust grain for every one trillion-gas particles. These molecular clouds are regions in space where there might be 10,000 hydrogen molecules in one cubic centimeter of space. How well mixed are the gas and dust particles in the solar nebula? Is the solar photosphere and the solar nebula made of the same material? Scientists believe the sun and planets formed from a common mixed reservoir. If the scientists are wrong, there will be differences in the solar wind isotopic compositions compared with planetary materials.

OXYGEN

The most important element to Genesis scientists is oxygen. Scientists do not currently have precise oxygen isotope information about the sun. It is possible that there are widespread differences in isotopic ratios of oxygen on the Earth, moon and Mars versus asteroid materials. No one really knows why these variations might 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 billion years ago, the solar oxygen composition could be quite different from that on Earth. Therefore, solar oxygen isotope abundance will help scientists better understand the origin of our solar system.

NITROGEN

The second highest priority element for Genesis research is nitrogen. As a major planetary mystery, scientists think that nitrogen has a variation in nitrogen isotope ratios with age in lunar surface samples. There are three possible explanations as to why this exists. First, there may have been a systematic change in the isotopic composition of nitrogen in the solar wind over time. Second, there may be other nitrogen sources on the lunar surface beside that of the sun. Third, there might have been more high energy solar particles with low nitrogen isotope ratios in older lunar samples. Each of these explanations would predict different nitrogen isotope abundances from the Genesis results. This would mean one of these observations would have to be more fully explained.

CARBON

Carbon seems to show small variations among bulk planetary materials. However, carbon suffers from the fact that it has only two stable isotopes. Without a third stable isotope, it is impossible to tell the cause of these small variations. Interestingly, interstellar grains of carbon found in some meteorites have very large variations relative to everything else in the solar system. These reflect the diverse conditions in the stellar atmospheres where these grains were formed.

NOBLE GASES

The noble gases are very interesting to geochemists because they are extremely unreactive. They are little affected by chemical processes, and therefore are a unique source of information. Apollo mission experiments using 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. When this happened different components of the atmosphere escaped at various rates thus altering its overall composition. The ultraviolet (UV) radiation of the sun may have changed the isotopic composition of the Earth's early atmosphere. Ultraviolet radiation can lead to loss of gases from the upper atmosphere. UV radiation dissociates molecules and some of the resulting atomic species will escape into space, with the lighter isotopes escaping faster than the heavier ones. Models indicate that nearly all of the neon was lost, some of the argon was lost, and slight amounts of krypton and xenon were lost (helium is constantly being lost presently from the earth). The quantitative models for this isotopic alteration of neon make specific predictions of the isotopic composition of other noble gases (argon, krypton, and xenon) in the solar wind. Genesis scientists will establish these values accurately for the first time.

COLLECTORS

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.

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Solar Collector Wafers made of mostly silicon will be exposed to solar wind for two years.

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.

Meteorite Samples: Solar isotope abundance for non-volatile elements are currently based on analyses of carbonaceous chondrite meteorites. How accurate is this comparison?

CHEMISTS vs. PHYSICISTS

Many solar chemists believe the isotopic composition of the sun must have changed over time in order to account for the possible differences between isotope abundance ratios between the sun and the planets. 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. What if the chemists are wrong?

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 recover and archiving are completed. Researchers will study the isotopic data obtained from this mission for many years. Scientists will use the information on solar wind to better explain the genesis of our solar system.

References:

Arnett, B., The Nine Planets [On-line].
Available: http://seds.lpl.arizona.edu/nineplanets/nineplanets/nineplanets.html#toc

Beatty, J. K., Petersen, C. C. & Chaikin, A. (1998). The New Solar System (4th ed.). Cambridge University Press.

Lindstrom, M., & Allen, J. (1997). Building Blocks of Planets. In Exploring Meteorite Mysteries [On-line].
Available: http://www-curator.jsc.nasa.gov/sn/outreach/Activities/ExpMetMys/ExpmetMys.htm

Sonett, C.P., Coleman, P.J., Wilcox, J.M. (1972). Solar Wind National Aeronautics and Space Administration. Washington, D.C.

Yu, Ka Chun (1999). Interstellar Clouds, Genesis Fact Sheet. [On-line].
Available: http://www.genesismission.org/educate/kitchen/resource/factsheets/Interstellarclouds.pdf