Cosmic Chemistry: Understanding Elements

The Periodic Table: Atoms, Elements, and Isotopes

TEACHER TEXT

The following is teacher background information and should only be used with students after they have completed the interactive periodic table lesson.

CLASSIFICATION

Classification is an important science process skill. In the interactive simulation, students will classify elements based on their physical and chemical properties. This process is part of a larger realm, which is the unifying concept of systems order and organization. According to *The National Science Education Standards,* “The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigation can be referred to as 'systems'." The periodic table represents such a system. Systems can be organized into a way that is useful. The standards point out that the “Types of organization include the periodic table of elements and the classification of organisms. Physical systems can be described at different levels of organization-such as fundamental particles, atoms, and molecules.”

WHAT IS NEXT?

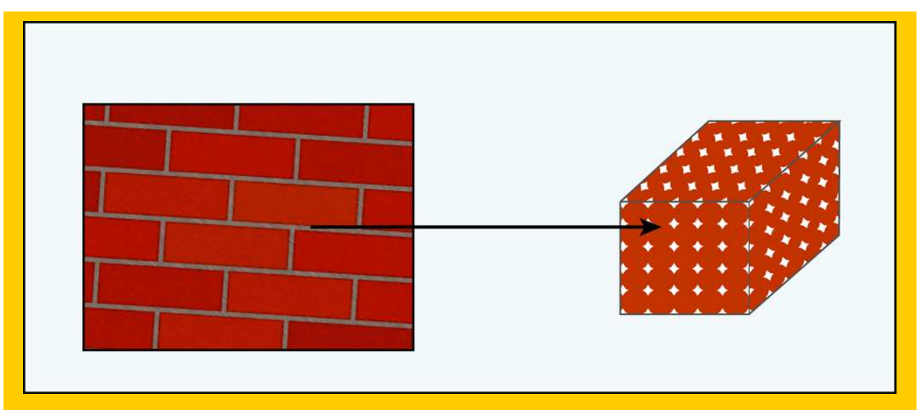
Background information for teachers follows. The four sections include:

- The Atom
- The Periodic Table
- Isotopes
- Oxygen Isotopes and the Genesis Mission

ATOMS AND ELEMENTS

An atom is the basic structure from which all matter is composed, in the same manner as a brick is the basic structure from which a wall is built. Although atoms are too small to be seen with our eyes, scientists have long had indirect evidence for the existence of atoms. We can now use the world's most powerful scanning tunneling microscopes to "see" the magnified images of atoms and to study surface reaction sites on an atom-by-atom basis.

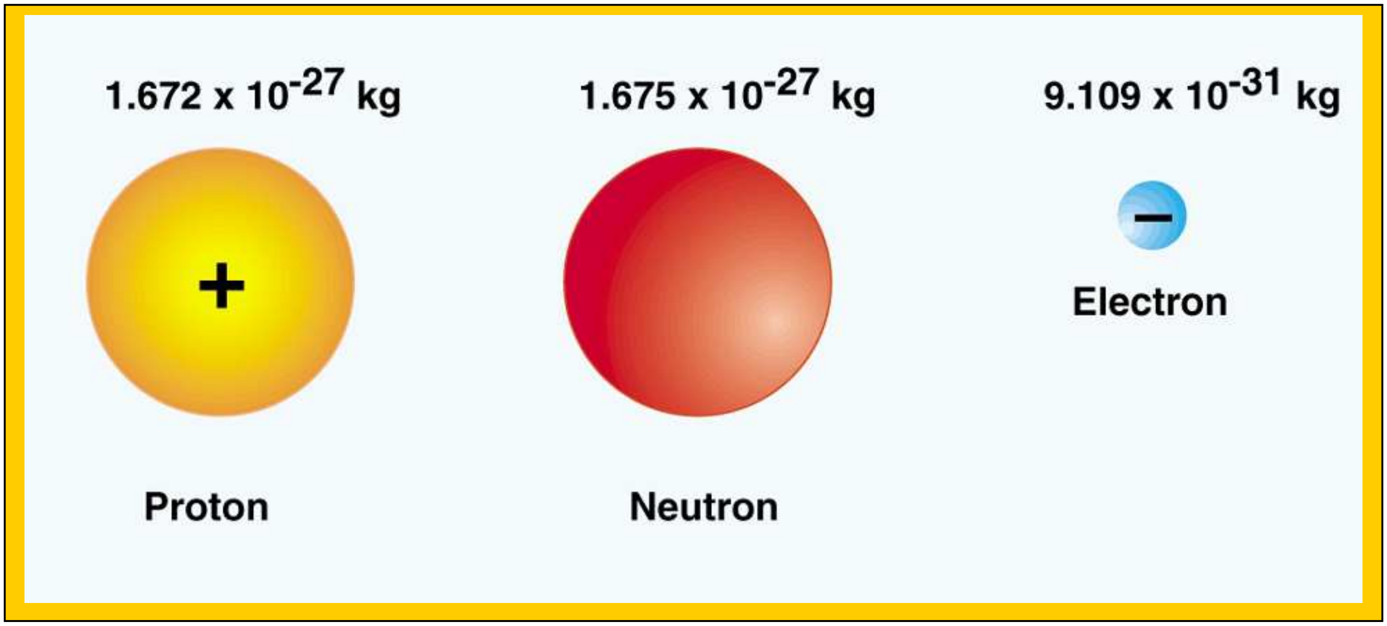
Figure 1



Just as a brick is basic to the structure of a wall, an atom is basic to the structure of matter.

Atoms are made of small particles called protons, neutrons, and electrons. Each of these particles is described in terms of measurable properties, including mass and charge. Mass is the amount of matter that an object contains. The proton and neutron have roughly the same mass and have approximately one thousand times the mass of the electron. The proton and electron have equal, but opposite, electrical charges. A neutron does not have an electrical charge.

Figure 2



Model of Proton, Neutron and Electron

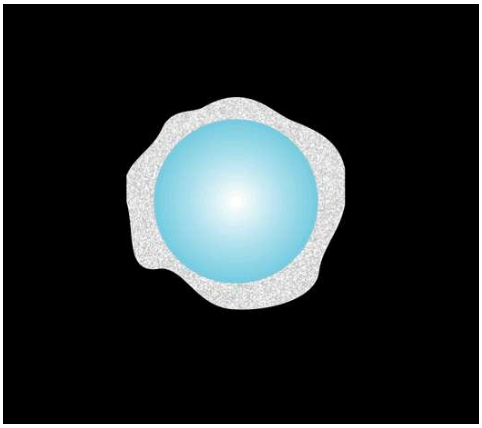
Figure 3

Comparison of Masses

If the proton and neutron were enlarged, and each had the approximate mass of a panda, the electron, enlarged to the same scale, would have less mass than an owl.

In an atom, the protons and neutrons clump together in the center and are called the nucleus. Because the protons are positively charged, the nucleus has a positive electric charge. The electrons of the atom move rapidly around the nucleus. If we attempt to detect an electron in an atom, we might find evidence of it located almost anywhere around the nucleus. However, if we repeat this experiment many times, it will be found that the electron is much more likely to be located in certain regions of space surrounding the nucleus than in other regions of space. We might think that the electron is rapidly moving around the nucleus and our experiment "catches" the electron as an instantaneous "snapshot" of it in motion. The probability of finding the electron in any region of space can then be described by a cloud that rapidly thins out as one goes farther from the nucleus. The density of the cloud at any point is the probability of finding the electron at that point.

Figure 4



Electron Probability Cloud Around a Nucleus

Most of an atom is empty space. The nucleus of the atom contains almost all of the mass of the atom. A greatly enlarged atom might look like a marble (the nucleus) inside an empty football stadium (the electron probability cloud).

The attractive electric force between the positively-charged protons in the nucleus and the negatively-charged electrons around the nucleus holds the atom together. Atoms containing the same number of protons and electrons have no net charge. Atoms that have extra electrons or are missing electrons have a net electrical charge and are called ions. Ions can interact with other ions due to the electrical attraction between opposite charges.

Figure 5

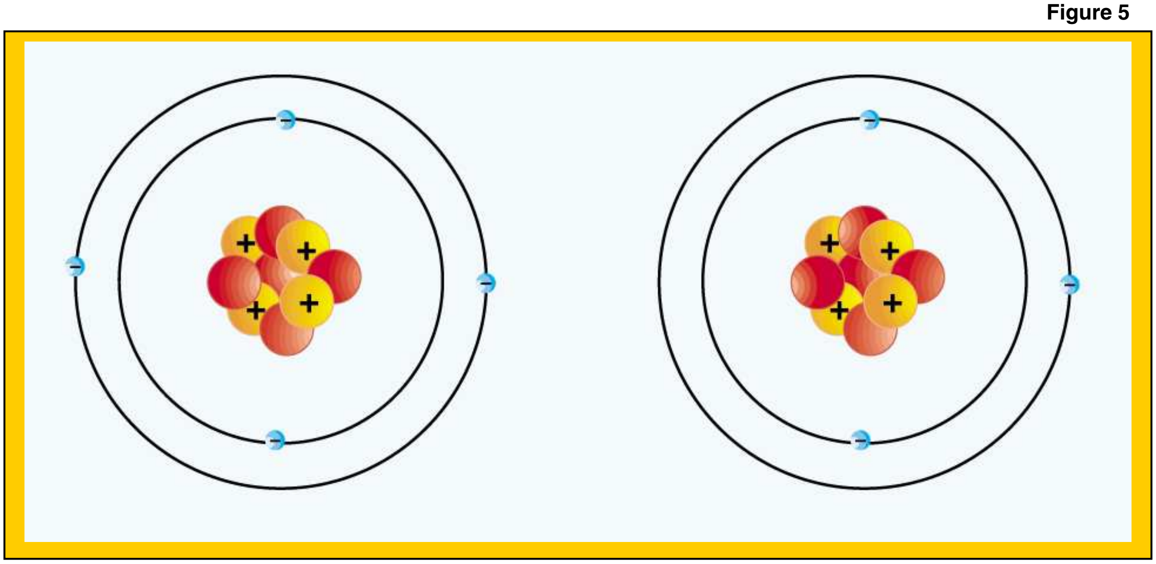
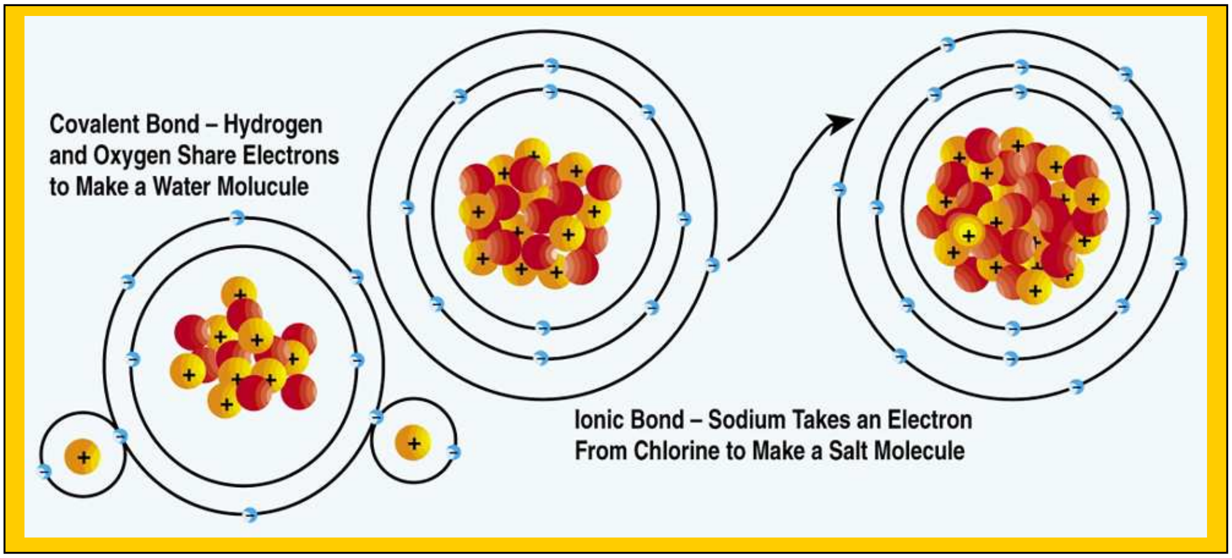


Diagram Comparing a Beryllium Atom and a Positively-Charged Beryllium Ion

Atoms interact with other atoms by sharing or transferring electrons that are farthest from the nucleus. These electrons are sometimes called valence electrons. These outer electrons determine the chemical properties of the element, such as how readily it interacts with other elements and the allowable ratios for its combinations with other substances.

Figure 6



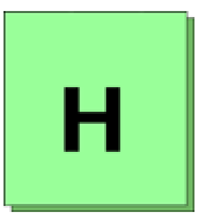
Model of Covalent and Ionic Bonds

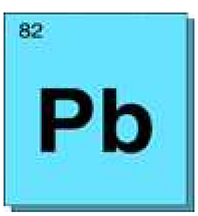
An element is a substance made up of a single type of atom. It can't be broken into simpler components by chemical processes. There are 92 naturally occurring elements. They may be solids, liquids, or gases.

WHAT IS THE PERIODIC TABLE?

The Periodic Table of the Elements is an organized way of displaying information that is known about the approximately 100 chemical building blocks of the universe. It often appears as a roughly rectangular chart with individual squares containing information about each element.

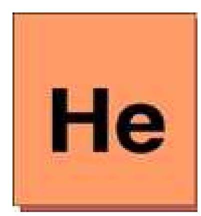
ATOMIC SYMBOLS





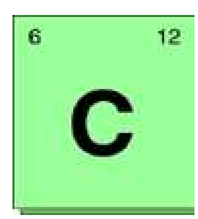
Atomic symbols are a symbolic way for people to refer to elements in the periodic table. For instance, the box on the top left contains information about the simplest chemical element, hydrogen. The symbol of this element is H.

Note: The atomic symbol is made up of the first letter of the word hydrogen. This is not always the case. The element helium must use the first two letters in its name to avoid confusion. The first letter is always capitalized and the second letter is always lower case.



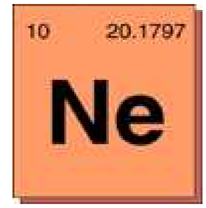
Lithium is third element shown on the table with an atomic symbol Li. Using this same system it would seem that lead would be Le. However, lead has the atomic symbol Pb which stands for the Latin word for lead which is plumbum.

ATOMIC NUMBERS



The number that is in the upper left hand side of the box for lead is the atomic number for this element. In this case, lead has an atomic number of 82. Atomic numbers represent the number of protons in one atom of the element. Therefore, each lead atom has 82 protons in its nucleus. The term "periodic" refers to trends in values that change in a regular pattern from left to right across a row and from top to bottom down a column of the periodic table. For instance, the second row across the periodic table contains the elements lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, and neon. Their symbols are Li, Be, B, C, N, O, F, and Ne. From left to right, their atomic numbers increase from three to ten, meaning that lithium atoms have three protons, beryllium atoms have four, and so on, up to neon's ten.

ATOMIC MASS AND MASS NUMBERS



If you add the number of protons and neutrons for an atom, the sum will be the atom's mass number. This does not show the actual mass of the atom, just information about the atom's nucleus. Most periodic tables show atomic mass, not mass numbers for each element. The mass of an atom or particle is expressed in **atomic mass units** or amus. One atomic mass unit is a very small amount of mass. An amu is 1/12 the mass of one atom of ^{12}C carbon or about 1.66×10^{-27} kg. Only carbon has an atomic mass value that is an integer. It is used as a reference. The mass of carbon is exactly 12. The mass of an atom of another element is the ratio of its mass to the mass of a carbon atom. The mass number for neon is 20 but the atomic mass is 20.1797. The mass of the atoms increases from left to right across the table.

SOLID, LIQUID, OR GAS?

Elements can be solid, liquid, or gas at room temperature. Some periodic tables show this by use of a color code or other key. Neon is a gas at room temperature. Neon belongs to a family of elements that are all gases at room temperature. They are referred to as the noble gas family. There are eleven elements that are gaseous at room temperature. They include: hydrogen, helium, nitrogen, oxygen, fluorine, neon, chlorine, argon, krypton, xenon and radon. There are three elements that are liquids at room temperature and they include mercury, gallium, and bromine. The rest of the natural elements (76) are solid at room temperature. There are over twenty synthetic elements that have been produced by humans.

GROUPS OR FAMILIES

The modern periodic table of the elements contains 18 groups, or vertical columns. Just as members of a family have similar characteristics but are different individuals, elements in a group are different but have similar chemical and physical properties because they have the same number of outer electrons. For instance, the noble gasses have their outermost orbit filled and therefore atoms from this family do not bond with other atoms.

PERIODS

In the modern periodic table 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. 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 from two elements in period 1 to eighteen elements in periods 4-6. The last period is not complete yet because new exotic or synthetic elements are still being made in laboratories. The classification of elements in the periodic table helps scientists understand known elements and predict the properties of new synthetic elements.

MENDELEEV AND YOU

Mendeleev did not construct a table in the way described above. Rather he arranged what we call periods vertically and groups horizontally. Your students will act very much like Mendeleev in the interactive simulation of the periodic table. They will be organizing information by classifying and grouping elements based on physical and chemical properties. Students will then have the opportunity to arrange the elements in a way that makes sense to them. Afterwards they can compare their results with Mendeleev, the modern periodic table and some other variations listed below. This should help your students better understand why the periodic table exists and why it is necessary to organize data.

OTHER VIEWS

The arrangement described above represents the most familiar arrangement of the modern periodic table of the elements. This is not the only way it can be represented. The following pages show other arrangements of the periodic table. What are the strengths and weaknesses of each type? Which do you prefer?

http://chemlab.pc.maricopa.edu/periodic/spiraltable.html
A periodic table shaped as a spiral.

http://chemlab.pc.maricopa.edu/periodic/stowetable.html
An unusually-shaped periodic table designed for use by physicists.

http://chemlab.pc.maricopa.edu/periodic/triangletable.html
A periodic table shaped as a triangle.

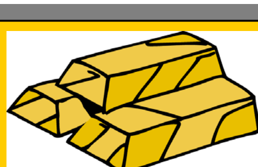
http://www.shef.ac.uk/chemistry/web-elements/pdf/periodic-table.html
A modern periodic table that can be printed using Adobe Acrobat Reader.

The elements are distributed unevenly, with some much more common than others. The ten most abundant elements on Earth make up more than 99% of our planet.

Figure 7

Element	**Symbol**	**Relative % of Earth's Mass**
Oxygen	O	46.6
Silicon	Si	27.7
Aluminum	Al	8.1
Iron	Fe	5.0
Calcium	Ca	3.6
Sodium	Na	2.8
Potassium	K	2.6
Magnesium	Mg	2.1
Titanium	Ti	0.4
Hydrogen	H	0.1

The Ten Most Abundant Elements



A bar of gold can be shaved into gold dust, and still be recognizable as gold.

Gold is one example of an element.

How fine can the dust become and still be considered gold?

The smallest particle that would still have the properties associated with gold is an atom. To get an idea of how small an atom is, consider that a small gold coin may contain over 20,000,000,000,000,000,000,000 atoms.

ISOTOPES

Figure 8

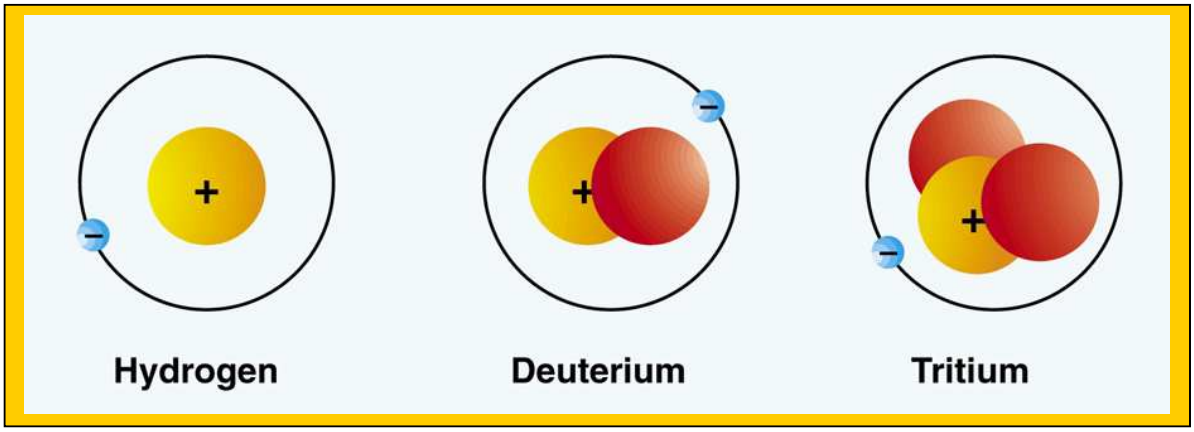
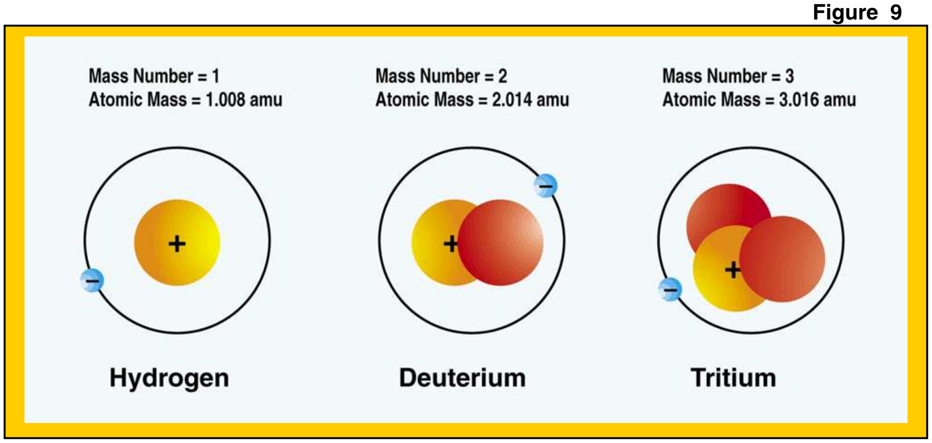


Diagram Comparing Hydrogen, Deuterium, and Tritium Atoms

When an element has atoms that differ in the number of neutrons in the nuclei, these atoms are called different isotopes of the element. All isotopes of one element have identical chemical properties. This means it is difficult to separate isotopes from each other by chemical processes. However, the physical properties of the isotopes, such as their masses, boiling points, and freezing points, are different. Isotopes can be most easily separated from each other using physical processes.

Most atoms of the element hydrogen contain only one proton in their nuclei. Each of these atoms has a mass of 1.008 amu. There exist atoms of hydrogen that have either one or two neutrons in the nucleus in addition to the single proton. These are called deuterium or tritium, having masses of 2.014 amu and 3.016 amu respectively. Deuterium and tritium are isotopes of hydrogen. An atom of deuterium has two particles in its nucleus, and tritium has three. Since atoms of both deuterium and tritium have only one proton in their nuclei, they only have one electron. They behave, chemically, like other hydrogen atoms.

Figure 9



Mass Number and Atomic Mass of Hydrogen, Deuterium, and Tritium

The sum of the number of protons and neutrons in the nucleus of an atom is called that element's mass number. This is not the same as the element's mass. Since different isotopes of an element contain different numbers of neutrons in the nuclei of their atoms, isotopes of the same element will have different atomic masses. This was shown above for the three isotopes of hydrogen. The symbol for an isotope is the symbol for the element followed by the mass number. Hydrogen is symbolized as H1, while deuterium is symbolized as H2.

What would we call an atom that had three particles in its nucleus, like tritium, but two were protons and one was a neutron? This would be an uncommon isotope of a different element, helium (He3). Because there were two protons in this nucleus, there would also be two electrons in the probability cloud around it. Since it is the outer electrons that determine the chemical properties of an atom, this would be a different kind of atom than hydrogen. The presence of two rather than one electron would cause it to have distinctive chemical properties. Thus, this must be a different element, and it is named helium. The most common isotope of helium (^{4}He) has two protons and two neutrons in the nucleus of each atom.

Figure 10

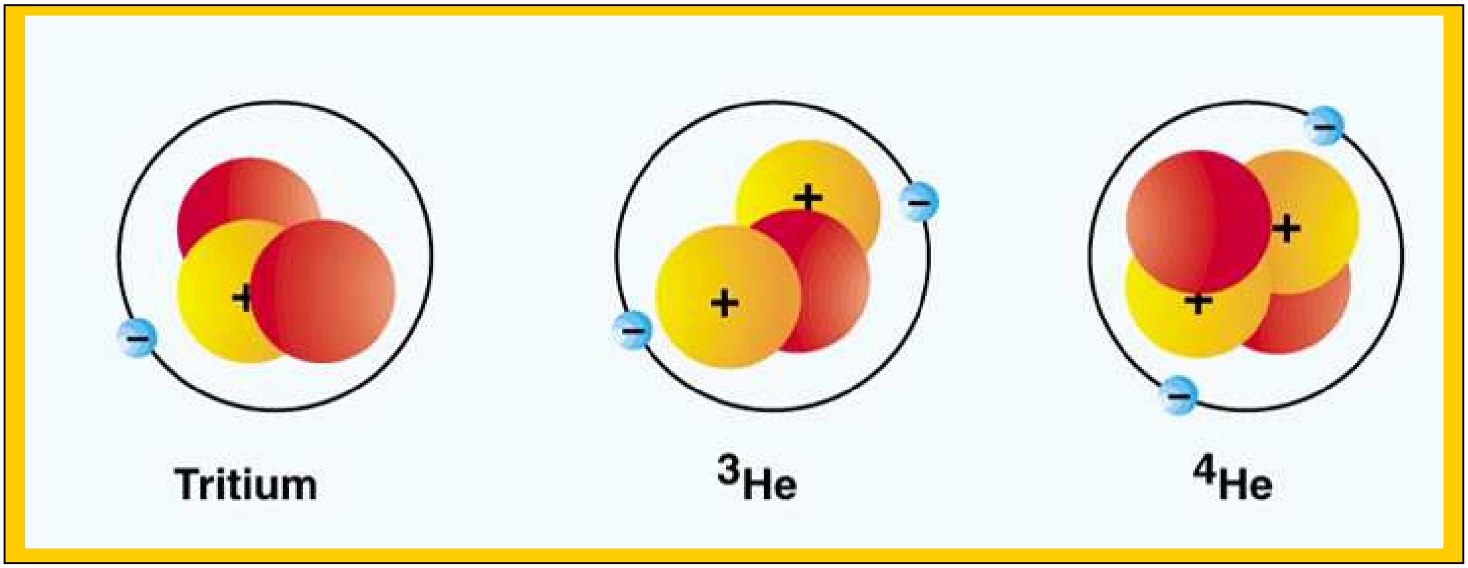


Diagram of Tritium, ^{3}He, and ^{4}He

To distinguish between elements, we often refer to their atomic numbers. The atomic number is the number of protons in the nucleus of an atom of that element (which is equal to the number of electrons around that atom's nucleus). Hydrogen's atomic number is 1, while helium's atomic number is 2. Gold has an atomic number of 79, which means it has 79 protons in its nucleus. The modern periodic table of the elements shows the different elements arranged in increasing order of atomic number.

There are 92 elements found in nature and several more exotic, manmade elements. Based on their chemical and physical properties, scientists have invented a tool to show relationships among these elements. It is known as the periodic table of the elements.

Figure 11

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	—— VII		——	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	11 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Families of Elements

Each element in the periodic table has distinctive properties.
When elements have similar properties they are grouped into families.

- **Alkali Metals**
- **Alkali Earth Metals**
- **Transition Metals**
- **Rare Earth Metals**
- **Other Metals**
- **Nonmetals**
- **Halogens**
- **Noble Gases**
- **Metalloids**

Observations show that the same elements exist throughout the known universe. We organize information about the elements in the form of a periodic table. The elements and their interactions are studied in all disciplines of science, as chemicals form the basis of life science, physical science, and earth and space science. As the American Association for the Advancement of Science wrote in *2061, Science for All Americans*, “All humans should participate in the pleasure of coming to know their universe better."

OXYGEN ISOTOPES AND THE GENESIS MISSION

The Genesis spacecraft will return samples of solar wind particles from outside the Earth's magnetosphere. Among the isotopes to be examined is oxygen. An important goal of planetary science is to discover and interpret the possible variations in oxygen isotope ratios across the solar system. Understanding the process of formation of the planets from the solar nebula probably cannot occur without understanding the origins of these variations.

There is a relatively large variation of isotopic abundance of the element oxygen in planetary materials. The amounts of the three oxygen isotopes (^{16}O, ^{17}O, and ^{18}O) have been measured for available samples of materials from the Earth, the moon, Mars, asteroids, and meteorites. The most common isotope is ^{16}O, so ratios are developed that compare the amounts of ^{17}O and ^{18}O to the amount of ^{16}O. The cause of the possible variations between solar and planetary oxygen isotope abundance is unknown.

Since the sun contains over 99% of the mass of the solar system, its importance is without question. Understanding the isotopic composition of oxygen atoms in the sun plays a key role in the interpretation of planetary formation. Oxygen isotope ratios for the sun have been estimated, but the uncertainties are unacceptable to scientists. For this reason, measurement of the oxygen isotope composition of the sun is the highest priority for the Genesis mission.