

Unit 4 Study Guide - Extension

Spectroscopy – Elements & Stars

A. The Origin of the Elements

<http://www.teachersdomain.org/resources/phy03/sci/phys/matter/origin/index.html>

All liquids, gases, and solids found on our planet are made from one or more of 92 naturally occurring elements. From what they have observed, scientists have determined that these same 92 elements are found throughout our universe. This suggests that a common process leads to their creation. But how are these elements created? How did they get they so widely disseminated?

Currently, the most popular theory states that the nuclei of hydrogen and helium, the lightest and most abundant elements in the visible universe, were created in the moments following the Big Bang. All other naturally occurring elements were — and continue to be — generated in the high temperature and pressure conditions present in stars. Elements are composed of tiny particles called atoms that are indivisible under normal conditions. However, when exposed to high heat and pressure, atoms can either break apart or fuse together. Under these conditions, the nucleus of one element can fuse with the nucleus of a different element, creating the nucleus of a heavier element. When elements lighter than iron form, the mass of the new nucleus is less than the combined mass of the two original nuclei. The difference in mass between the two is released as energy. In stars, this kind of reaction is referred to as stellar nucleosynthesis, but it is more commonly known as nuclear fusion. Nuclear fusion is used today on Earth in the nuclear explosives called hydrogen bombs. Many people hope that one day nuclear fusion will be used for peaceful energy production.

Stars are fueled by nuclear fusion reactions, which take place in their deep interiors, or cores. Hydrogen nuclei fuse, forming helium nuclei. The energy produced by these fusion reactions prevents the star from collapsing under its own gravity. Mature stars contain enough hydrogen nuclei to last billions of years. When a star's hydrogen fuel supply is spent, however, its core begins to contract. The contraction is so intense that it creates conditions under which helium nuclei fuse. In this way, helium becomes the star's next fuel source. The fusion of helium nuclei produces carbon and oxygen nuclei, and in the process sufficient energy is released to temporarily sustain the star.

Once helium runs out, the nuclei of carbon, oxygen, and other elements begin to fuse. These new fuel sources are depleted at faster and faster rates. Since the heaviest element created in a star by nuclear fusion reactions is iron, a large iron core eventually forms at the center of everything. At this point, gravity becomes overwhelming, the core collapses, and an explosion occurs, during which outer layers of gas and heavy elements are ejected to space. Such explosions, called supernovas, occur about once a century in our galaxy. The energy created by supernovas produces nuclei heavier than iron. This process is known as supernova nucleosynthesis.

Long ago, scientists learned that they could heat atoms of an element to a glow and direct the light through a prism to produce a set of colored lines. These spectral lines are unique for each element: No two elements produce the same colors and line positions along a spectrum. By using instrumentation that reads light signatures from far away — a technique known as spectroscopy — scientists today know with great certainty which elements a planet or a star, or even a star's dispersed remnants, contains.

Discussion questions:

Where are elements created? How are heavier elements created from hydrogen and helium?

What evidence do scientists use to tell which elements are released when a supernova explodes?

How do the elements in the atmosphere of a supernova help scientists identify types of supernovas?

B. The Elements: Forged in Stars

<http://www.teachersdomain.org/resources/ess05/sci/ess/eiu/fusion/index.html>

All matter is made up of atoms -- elements comprised of smaller particles such as protons, neutrons, and electrons. The number of protons within the nucleus -- the central component of the atom -- determines the type of element. An element can have different forms, called isotopes, based on the number of neutrons in the nucleus. For example, an ordinary hydrogen nucleus contains just one proton. But deuterium, an isotope of hydrogen, has one proton and one neutron in its nucleus.

The entire universe shares a common set of elements. In the very early universe, the only elements were hydrogen and helium. But since the formation of stars, lighter elements within the stars began fusing to create heavier elements, producing all the other naturally occurring elements. Under the extremely high temperatures and pressures within the core of stars, atoms collide at high enough speeds to overcome the usual electromagnetic repulsion of nuclei, allowing nuclear fusion to occur.

All stars live by fusing hydrogen into helium. In the first step of the process, two hydrogen atoms fuse to form deuterium. In the next step, another hydrogen atom fuses with the deuterium, creating a rare isotope of helium that has two protons and one neutron in its nucleus. In the third step, two of the rare helium atoms fuse to create a single normal helium atom and two hydrogen atoms. The fusion pathway described above requires six hydrogen atoms to create one helium atom -- however, there are two hydrogen atoms left over at the end of the process. The net result is that it takes four hydrogen atoms to make one helium atom. The energy that fuels a star is a result of the difference in mass between the original four hydrogen atoms and the resulting helium atom. Following Einstein's mass-energy relationship, $E=mc^2$, the missing mass is converted to energy.

At even higher temperatures and pressures, heavier elements are able to form. Many are made from a process called "helium capture," in which a heavier element fuses with a helium atom. For example, helium fuses with carbon to make oxygen, and helium fuses with oxygen to make neon. Heavier nuclei can also fuse with each other, such as when carbon and oxygen fuse to make silicon or two silicon atoms fuse to make iron. Eventually, the interior of a massive star begins to resemble an onion, with different elements being created in different layers. However, elements heavier than iron are only produced in the extraordinary conditions created by the collapse and explosion of a star -- a supernova.

Discussion questions:

- How does a star get its energy to glow?
- What elements make up young stars?
- What causes a star to become a supernova?
- Why do you think it takes a tremendous amount of heat and pressure to create helium (and then carbon, etc.)?
- What could you infer about the age of a star if you were to find evidence of iron being present?

C. Birth of a Supernova, Type Ia

<http://www.teachersdomain.org/resources/phy03/sci/phys/matter/nova1/index.html>

The most massive stars in the universe end their lives in cataclysmic explosions called supernovae. Of the four supernovae types, the two that occur most commonly are Type Ia and Type II supernovae. The more powerful Type Ia supernovae occur in what's called a binary system, in which a pair of stars orbit one another. By contrast, Type II supernova events involve very large individual stars called supergiants.

Any medium-mass or larger star, from one about 40 percent the size of the Sun to one several times greater, relies on energy produced in its core to offset the enormous force of gravity pulling matter toward its center. Nuclear fusion produces this sustaining energy. When hydrogen nuclei -- a star's primary fuel supply -- fuse with one another, helium nuclei are created. Although helium is heavier than hydrogen, the mass of the single helium nucleus is less than the total mass of the two hydrogen nuclei from which it formed. The difference is released as energy. A star will blaze away as long as there is enough hydrogen to fuel the reactions. Depending on its mass, this can range from a few million years for the most massive stars to several billion years for less massive stars, including the Sun.

A star between 0.5 and 1.4 times the size of our Sun does not explode when it has used up its fuel supply. Instead, it evolves into a smaller, denser, and cooler body called a white dwarf. After one of the stars in a binary system has become a white dwarf and the second star exhausts its fuel, the white dwarf's gravity field draws in the gases escaping from its dying companion. The white dwarf increases in mass until its core can no longer support itself, and it collapses in a huge explosion.

Supernovae are rare -- so rare that only three or four can be expected to occur in our galaxy each century. One was last observed in the Milky Way in 1604. However, thanks to continual improvements in telescope and instrument technology, astronomers can more easily detect and monitor supernovae in other galaxies. And although they cannot predict when a star will explode, observing the event and its aftermath can provide important clues to the workings of the universe. All Type Ia supernovae fade in a characteristic manner: rapidly at first, then more slowly. By analyzing the light they emit, scientists can measure distances to faraway galaxies and the speed at which the universe is expanding. They can also identify the elements from which the stars were made. And as the explosion fades to obscurity in a year or two, a gas remnant continues to mark where it occurred. From recent Hubble research, we know that Type Ia supernovae are not all of the same brightness, as was previously postulated.

Discussion questions:

- What is a red giant? What is a white dwarf?

- What happens to the core of the red giant? Why?

D. Birth of a Supernova, Type II

<http://www.teachersdomain.org/resources/phy03/sci/phys/matter/nova2/index.html>

The most massive stars in the universe end their lives in cataclysmic explosions called supernovae. Of the four supernovae types, the two that occur most commonly are Type Ia and Type II supernovae. Type Ia supernovae occur in what's called a binary system, in which a pair of small stars orbit one another. By contrast, Type II supernova events involve very large individual stars called supergiants.

Any medium-mass or larger star, from one about 40 percent the size of our Sun to one several times greater, relies on energy produced in its core to offset the enormous force of gravity pulling matter toward its center. Nuclear fusion produces this sustaining energy. When hydrogen nuclei -- a star's primary fuel supply -- fuse with one another, helium nuclei are created. Although helium is heavier than hydrogen, the mass of the single helium nucleus is less than the total mass of the two hydrogen nuclei from which it formed. The difference is released as energy. A star will blaze away as long as there is enough hydrogen to fuel the reactions. Depending on its mass, this can range from a few million years for the most massive stars to several billion years for less massive stars, including the Sun.

When a star at least four times more massive than our Sun runs out of hydrogen, gravity's influence becomes predominant, and the star's solid core begins to contract. As it contracts, it heats up. If it reaches a high enough temperature, a different type of fusion begins. At this point, the helium nuclei act as fuel and begin to fuse with one another. As the star swells to become a supergiant, the gravitational force is once again opposed by the outward pressure of energy from the material undergoing fusion. After the supply of helium is exhausted, the star repeats this process using the carbon and oxygen nuclei produced by helium fusion as its next source of fuel.

The cycle of producing and using heavier and heavier elements continues until all possible fuel sources are exhausted. When this happens, the core instantaneously collapses, and an enormous shock wave ripples outward through the star. This massive explosion, or supernova, jettisons solar gases and heavy elements into space. Depending on the size of the star, the remains of the collapsed core form either an incredibly dense,

spinning neutron star or a black hole. Unlike Type Ia supernovae, which fade in a characteristic manner -- rapidly at first, then more slowly -- Type II supernovae fade differently from one event to another.

Discussion questions:

- Why does the fusion of the first few elements release energy while that of iron does not?
- What is the composition of the dense core that is left behind when the star explodes?
- What are the different courses of events in the birth of Type Ia and Type II supernovae? What are the similarities between the two processes? (for both Type Ia and II resources)

Additional Resources:

*Watch these **Chandra X-ray Observatory Podcasts** at*

<http://chandra.harvard.edu/resources/podcasts/>

- Supernovas: When Stars Die
- Until Their Dying Day: Stars on the Brink