What Fuels A Star?

Standard 1, Objective 2:
Analyze Earth as part of the solar system, which is part of the Milky Way galaxy.

Terms to know

- black hole
- main sequence star
- neutron star
- red giant
- supernova
- star

Lesson Objectives

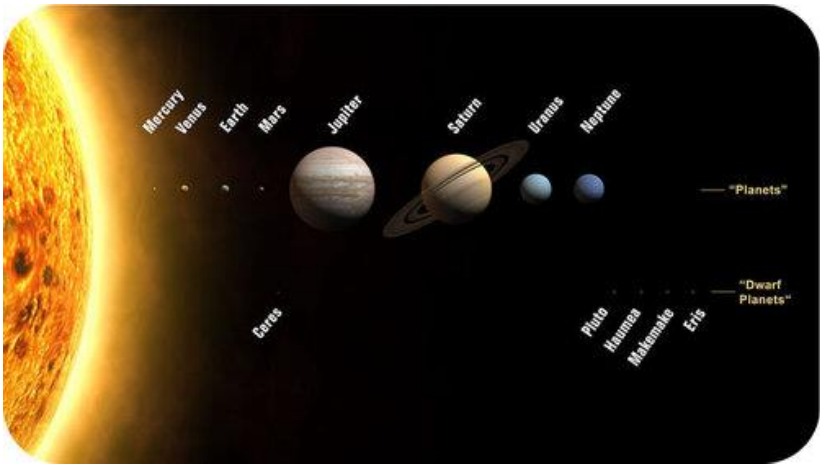
- Relate the composition of objects in the solar system to their distance from the Sun.
- Compare the size of the solar system to the Milky Way galaxy.
- Compare the size and scale of objects within the solar system.
- Evaluate the conditions that currently support life on Earth (biosphere) and compare them to the conditions that exist on other planets and moons in the solar system (e.g., atmosphere, hydrosphere, geosphere, amounts of incoming solar energy, habitable zone).

Section 1: Our Solar System

Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects (See the figure on the following page). These objects move in regular and predictable paths around the Sun.

Distances in the Solar System

Distances in the solar system are often measured in astronomical units (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km (93 million miles). Listed below is the distance from the Sun to each planet in AU (Table below). The table shows how long it takes each planet to spin once on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus! Our solar system is about 100,000 AU across from the Sun to the Oort Cloud or 1.87 light-years.



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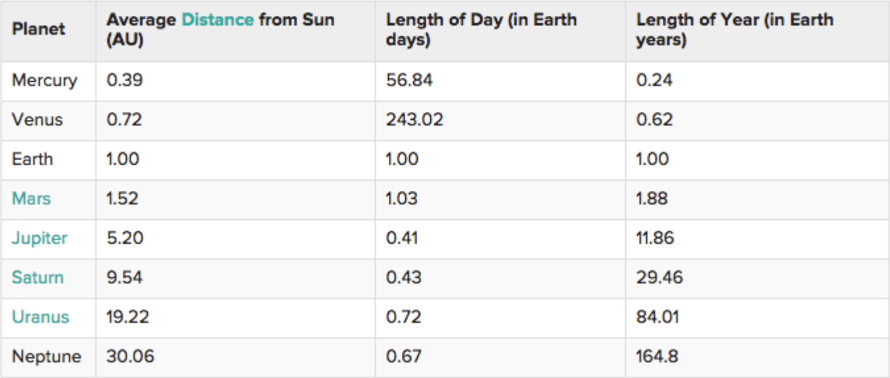
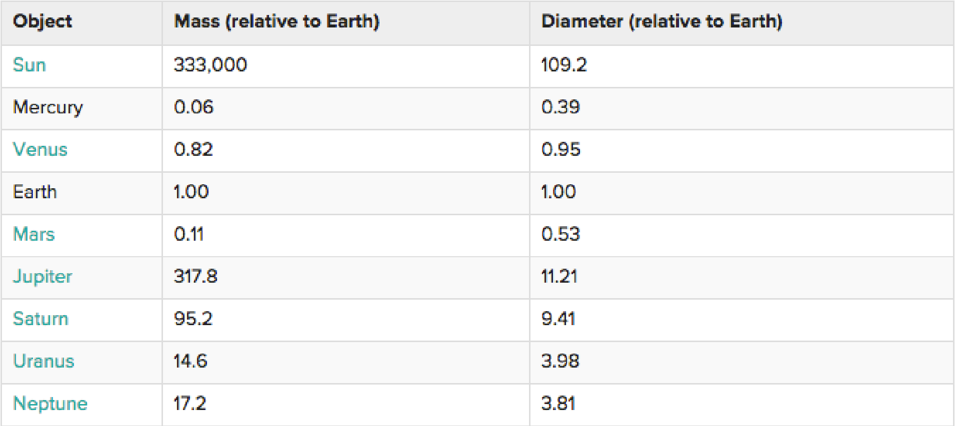


Planet	Average Distance from Sun (AU)	Length of Day (in Earth days)	Length of Year (in Earth years)
Mercury	0.39	56.84	0.24
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Planet Sizes

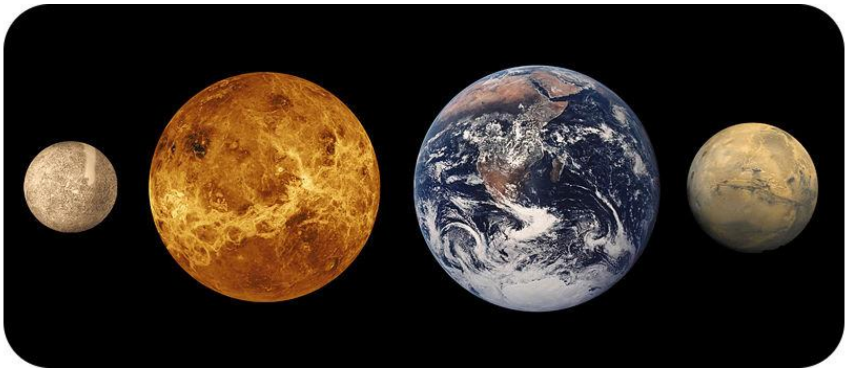
The Sun is just an average star compared to other stars. But it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Listed below is data on the sizes of the Sun and planets relative to Earth (table below).



Object	Mass (relative to Earth)	Diameter (relative to Earth)
Sun	333,000	109.2
Mercury	0.06	0.39
Venus	0.82	0.95
Earth	1.00	1.00
Mars	0.11	0.53
Jupiter	317.8	11.21
Saturn	95.2	9.41
Uranus	14.6	3.98
Neptune	17.2	3.81

The Inner Planets

The inner planets are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. The figure below shows the relative sizes of these four inner planets.



Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings. The inner planets are generally smaller than their outer planet relatives.

The Outer Planets

The four planets farthest from the Sun are the outer planets. The figure on page 31 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called gas giants.

Milky Way Galaxy

The Milky Way Galaxy is our galaxy. Home, sweet home. The Milky Way is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 billion to 400 billion stars and is 100 – 120 million light-years across.

Section 2: Stars, an introduction

When you look at the sky on a clear night, you can see hundreds of stars (or thousands, if you're away from city lights). A **star (**A self-luminous celestial body consisting of a mass of gas held together by its own gravity) is a giant ball of glowing plasma that is very, very hot. Many **stars** are like our Sun, but most are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Energy of Stars

Only a tiny bit of the Sun's energy reaches Earth, but that light supplies most of the energy at Earth's surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

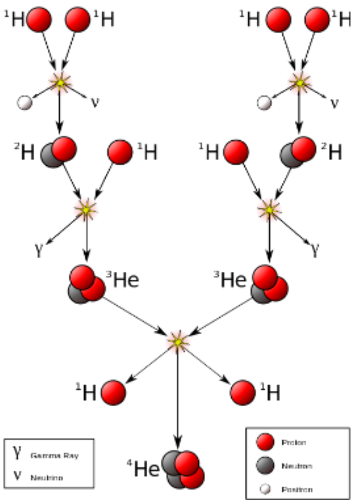
Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star heats the plasma to extreme temperatures of millions of degree. This combination of high temperature and pressure causes nuclear fusion reactions.

We call it nuclear fusion because under these conditions, the collision of atomic nuclei causes them to fuse (join) together. In stars like our Sun, four hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.

Energy from Nuclear Fusion

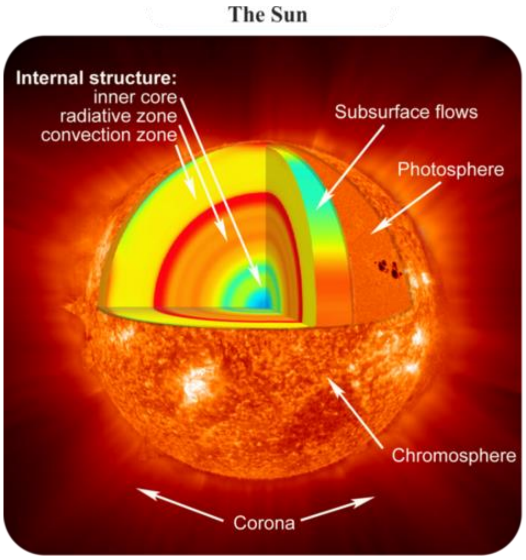
In fusion, two or more small nuclei combine to form a single, larger nucleus. An example is shown in the Figure at the right. In this example, four hydrogen nuclei fuse to form a helium nucleus. A great deal of energy is also released. When nuclei lighter than iron undergo fusion, energy is released. Energy is absorbed when iron or nuclei more massive than iron undergo fusion.



In this nuclear fusion reaction, nuclei of four hydrogen nuclei fuse together, forming a helium nucleus and energy.

The Power of Stars

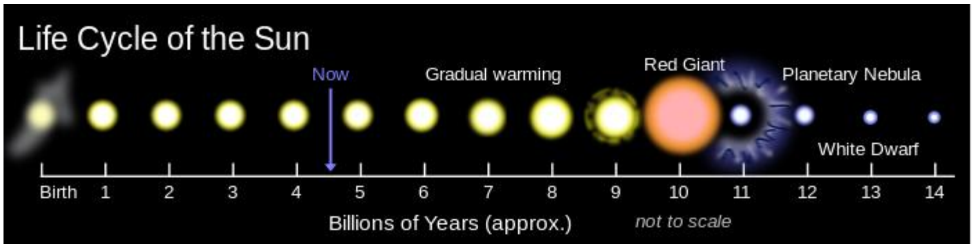
Nuclear fusion of hydrogen to form helium occurs naturally in the sun and other stars. It takes place only at extremely high temperatures. That's because a great deal of energy is needed to overcome the force of repulsion between positively charged nuclei. The sun's energy comes from fusion in its core, where temperatures reach millions of Kelvin (Figure left).



The extremely hot core of the sun radiates energy from nuclear fusion.

What happens when a star dies? We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.

Stars have a wide range of size, temperature and brightness. The properties of a star are determined by the star's mass. While most stars appear white, some stars have a slight blue or red color. The color relates to a star's temperature. Reddish stars are cooler than white stars and bluish stars are hotter.



http://en.wikipedia.org/wiki/File:Sun_Life.png CC BY SA

Section 3: Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in the Figure left.

Stars form in a nebula like this one in Orion's sword.

For a star to form, gravity pulls gas and dust together. As mores gas continues to accumulate, the material becomes denser, the pressure and the temperature increase. When the temperature at the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Main Sequence Stars

A star is a **main sequence star** (hydrogen nuclei fuse to form helium nuclei) for most of its life. The mass of a main sequence star determines its properties such as how hot it is, how bright is, how big it is, and how long it will exist. Stars with more mass are hotter, brighter, and have shorter lives than lower mass stars.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star may be on the main sequence for tens to hundreds of billions of years.

Red Giants and Element Production

A star like our Sun will become a **red** giant (a very large star of high luminosity and low surface temperature) in its next stage. When a star uses up its hydrogen, the star’s core starts to collapse inward and the core temperature increases. When the temperature is high enough, helium fuses into heavier nuclei like carbon and oxygen. As the core collapses, the star's outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.

Eventually a **red giant** fuses all of the helium in its core. At this point the star has a core filled with carbon and oxygen. Surrounding the core are two separate layers where fusion still occurs - an inner layer of helium and an outer layer of hydrogen. Nuclei within the helium-burning shell can be changed into heavier nuclei by capturing neutrons. Extra neutrons can make a nucleus unstable and one of the neutrons will suddenly change into a proton. In larger stars, this process can produce some elements as heavy as bismuth with 83 protons.

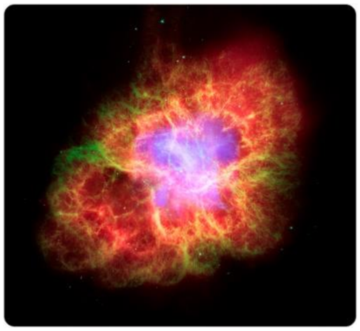
White Dwarfs

What happens next depends on the star's mass. A star like the Sun stops fusion and the core becomes a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. The outer layers of the star are blown into space carrying with them many of the heavier elements produced in the star. After a very long time, a white dwarf will cool down and its light will fade. This is the potential end of our star, the Sun, based on its mass.

Supergiants and Supernovas

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse.

In a red supergiant, fusion does not stop with carbon and oxygen. These elements fuse into heavier ones until iron nuclei form. Fusion of iron does not produce energy to sustain the star. With no more energy from fusion, the core will rapidly collapse. Collapse of the core creates a shock wave that moves outward and the star explodes violently. This is called a supernova (a star that suddenly increases greatly in brightness because of a catastrophic explosion that ejects most of its mass) explosion. The incredible energy released fuses heavy nuclei together. Astronomers think gold, uranium and other heavy elements may form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time. The heavy elements are blown into space as shown in Figure below.



A supernova remnant, as seen by the Hubble Space Telescope.

Neutron Stars and Black Holes

After a supernova explosion, the star's core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star (celestial object of very small radius (typically 18 miles/30 km) and very high density, composed predominantly of closely packed neutrons.). This type of star is made almost entirely of neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter. Research indicates that a collision between two neutron stars could also be the source of many heavy elements such as gold.

A teaspoon of matter from a neutron star would weigh 10 million tons on Earth. If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core collapses to become a black hole (a region of space having a gravitational field so intense that no matter or radiation can escape.). Black holes are so massive that not even light can escape their gravity. For that reason, we can't see black holes. How can we know something exists if radiation can't escape it? We know a black hole is there by the gravitational effect that it has on objects around it. Also, if a black hole is pulling in matter, collisions between particles can heat the matter to high enough temperatures for the matter to give off high energy radiation like x-rays. A black hole isn't a hole at all. It is the tremendously dense core of what was once a supermassive star.