How Does a Solar Nebula Stay Together?

At the center of our solar system is a star that we call the sun. Nine planets and other smaller objects move around the sun. Most planets have one or more moons that move around them.

The ingredients for building solar systems, such as ours, are in areas that seem to be empty space. Just as there are clouds in the sky, there are clouds in space. These clouds are called nebulas. A nebula is a mixture of gases and dust. The gases are mostly hydrogen and helium, and the dust is made of other elements, such as carbon and iron.

GRAVITY

The gas and dust of nebulas are made of matter. The force of gravity holds matter together. In a nebula, the force of gravity is weak because the particles are small and far apart. Nebulas are less dense than the air around you. The force of gravity is just enough to keep atoms and molecules in the nebula from moving apart.

The figure below represents a close-up view of a nebula. Notice that the particles are far apart so there is little gravitational attraction between them. The particles are also moving slowly so the nebula is cold.
PRESSURE

Because gravity pulls particles together, you might expect that it would cause the nebula to collapse. However, this doesn’t happen, because there is another force that works against gravity. That force is pressure. The particles in the nebula are in constant motion and they crash into one another. These collisions cause pressure. 

As particles move faster, pressure and temperature increase. In a nebula, outward pressure balances the pull of gravity and keeps the nebula from collapsing.

The figure below shows how the particles within a nebula behave as the pressure increases and also when pressure and gravity are balanced.

As particles move closer together, collisions cause pressure to increase and particles are pushed apart.

If the inward force of gravity is balanced by outward pressure, the nebula becomes stable.

**What Happens When Gravity and Pressure Become Unbalanced?**

The balance between gravity and pressure can be upset if two nebulas collide. It can also be upset if a nearby star explodes. These events compress, or push together, small regions of the nebula. As these regions come together, gravity pulls them into a tight mass.

As the mass tightens, particles in the mass move faster, and the temperature increases. The stage is set for a star to form. The **solar nebula**, the cloud of gas and dust that became our solar system, may have formed this way.

**How Did the Solar System Form?**

On the next page you will see the events that could have occurred during the change from the solar nebula to the solar system. As the solar nebula collapsed, it began to rotate. The center of the rotating cloud became hotter and denser. The gas and dust around the center formed a disk that began to cool and form bigger particles. The pull of gravity caused the particles to come together and form even larger particles.
**The Formation of the Solar System**

**TAKE A LOOK**

7. **Describe** In which part of the solar nebula is matter more densely packed, the edges or the center?

8. **Identify** What causes planetesimals to stay together, forming planets, when they collide?
PLANETESIMALS AND PLANETS

As the particles collided and grew, they formed planetesimals, bodies the size of boulders and asteroids. As they grew, the gravity of these planetesimals pulled more and more matter toward them. Eventually, they grew large enough to become planets and moons. The sun, the planets, and the moons are mostly spherical. That is because gravity pulls equally in all directions from the center.

THE BIRTH OF A STAR

As the planets were forming, gravity pulled matter to the center of the nebula. The center became so hot and dense that hydrogen atoms began to fuse, or join together, to form helium atoms. The energy released by fusion pushed outward and balanced the pull of gravity. The gas stopped collapsing and the sun was born.

The diameter of the sun is more than 100 times the diameter of Earth. At the sun’s surface, its temperature is about 5,500°C. The core of the sun, where energy is generated, is much hotter than that. The figure below shows the structure of the sun and the layers below its surface.

The Structure and Atmosphere of the Sun

9. Identify What is the shape of dense bodies the size of planets or larger?

10. Define What does the word fuse mean?

11. List Place the following parts of the sun in order from the center outwards: chromosphere, core, corona, radiative zone.
How Does the Sun Produce Energy?

The sun has been producing energy and shining on Earth for about 4.6 billion years. How could it stay hot for such a long time?

The answer to that question came early in the 20th century. Albert Einstein figured out that energy and matter can be changed into each other. Einstein's famous formula is \[ E = mc^2, \] in which \( E \) is energy, \( m \) is mass, and \( c \) is the speed of light. Because the speed of light is a very large number, this equation states that a tiny amount of matter can be changed into a lot of energy. This explains the large amount of energy produced by the sun.

NUCLEAR FUSION

Scientists now know that the sun's energy comes from nuclear fusion. Nuclear fusion is the process in which two or more low-mass nuclei join together to form a larger nucleus. When nuclei fuse, energy is released. Stars begin to generate energy when hydrogen nuclei fuse to form helium. There is a balance between the extremely high pressure from this energy and gravity due to the star's mass. This balance, shown in the figure below, gives a star its spherical shape.

CONDITIONS THAT CAUSE FUSION

Under normal conditions, two hydrogen nuclei cannot get close enough to one another to fuse. That is because they each have a positive electric charge. Like charges repel one another, just as like poles on a magnet repel one another. However, in the center of the sun and other stars, the temperature and pressure are extremely high.

The high pressure and rapid motion of particles are enough to overcome the force of repulsion. Hydrogen nuclei are forced together, and the hydrogen fuses into a different element, helium.
What Happens During Fusion in the Sun?

There are three steps in the fusion of hydrogen in the sun, as shown in the figure below.

Step 1: Two hydrogen nuclei, also called protons, collide and fuse. This process emits particles and energy, and one of the protons becomes a neutron. The proton and neutron combine to form deuterium, a heavy form of hydrogen.

Step 2: Another proton combines with the deuterium nucleus (one proton and one neutron). This forms a nucleus with two protons and one neutron, known as helium-3. This process also releases energy.

Step 3: Two helium-3 nuclei collide and fuse. As this happens, two protons are released. The remaining two protons and two neutrons combine to form a nucleus of helium-4, usually just called a helium nucleus. The mass of the helium nucleus is a tiny amount smaller than the mass of the original protons. This very small amount of mass has been converted into a large amount of energy.

Critical Thinking

15. Identify How do you know that deuterium is a form of hydrogen, not a form of helium?

16. Fill In Label the three nuclei shown in the illustration.
How Are Distances Between Planets Measured?

One way that scientists measure distances in space is by using an astronomical unit. One astronomical unit (AU) is the average distance between the sun and Earth. This distance is about 150 million km. This unit is normally used to refer to distances within the solar system. For example, the average distance from the sun to Neptune is about 30.1 AU. So, Neptune is $30.1 \times 150$ million km = 4,500 million km from the sun.

Another way to measure distances in space is by using the speed of light. Light travels at about 300,000 km/s in space. In one minute, light travels about 18 million km. Light from the sun takes 8.3 minutes to reach Earth.

It takes light over 4 years to reach Earth from the nearest star (other than our sun). That is why distances to stars are measured in light-years. Light travels about $9.5 \times 10^{12}$ km or 9,500,000,000,000 km in one year. A light-year is about 63,000 times farther from Earth as our sun is.

How Is the Solar System Divided?

Astronomers divide the solar system into two main parts, as shown in the figure below. These parts are called the inner solar system and the outer solar system. The inner solar system contains the four planets that are closest to the sun—Mercury, Venus, Earth, and Mars.

Jupiter is the first planet in the outer solar system. The distance between Mars and Jupiter is much larger than the distance between Earth and Mars. The outer solar system contains four planets—Jupiter, Saturn, Uranus, and Neptune.

CALIFORNIA STANDARDS CHECK

8.4.c Know how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.

17. Analyze Ideas If an asteroid is found to be 300 million km from Earth, how many astronomical units is this?

TAKE A LOOK

18. Identify What planet is farthest from the sun?
**Section 1 Review**

**SECTION VOCABULARY**

<table>
<thead>
<tr>
<th><strong>astronomical unit</strong></th>
<th>the average distance between the Earth and the sun; approximately 150 million kilometers (symbol, AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>nebula</strong></td>
<td>a large cloud of gas and dust in interstellar space; a region in space where stars are born or where stars explode at the end of their lives</td>
</tr>
<tr>
<td><strong>solar nebula</strong></td>
<td>the cloud of gas and dust that formed our solar system</td>
</tr>
</tbody>
</table>

1. **Identify**  What are the two forces acting on the particles inside a nebula that affect its balance? How do they affect particles?

2. **Classify**  Fill in the blanks to complete the table.

<table>
<thead>
<tr>
<th>Layer of the sun</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Core</td>
<td>very dense region surrounding the core, about 300,000 km thick</td>
</tr>
<tr>
<td>Convective zone</td>
<td>the part of the sun that we can see from Earth</td>
</tr>
<tr>
<td>Corona</td>
<td>thin region below the corona, about 30,000 km thick</td>
</tr>
</tbody>
</table>

3. **Apply Concepts**  Why are all the large bodies in the solar system, the sun and the planets, shaped like spheres?

4. **Identify**  What unit is used to measure distances in our solar system? How large is this unit?

5. **Identify**  What unit is used to measure distances to stars? How large is this unit?