Earth Space Science : **08 Our Solar System** : **08.03 Physical Properties of Our Sun**

Objectives

How can we compare our sun to other stars and their characteristics?

At the end of this lesson, you will be able to:

- describe and explain the physical features of the sun
- compare and contrast types of nuclear reactions
- discuss the sun's dynamic nature and connection to conditions and events on Earth and its impacts on human-made technology systems

Earth’s outer atmosphere is constantly bombarded by particles from the sun. This results in interactions called space weather. Space weather can be particularly damaging during times of intense solar activity, called solar storms. Space weather even affects life on Earth. Solar storms can disrupt our technology systems, causing billions of dollars in damage.

Helopphysics:

Scientists worldwide have studied the Earth and sun system for centuries. The sun’s gravity and radiation influence the entire solar system. The study of the interactions of the sun with Earth and the rest of the solar system is known as **heliophysics**.

Career Connections: Heliophysicist

A heliophysicist may, for example, look at how ejections of matter from the sun can affect life on Earth. A heliophysicist advises rocket engineers on when to schedule rocket launches so that astronauts are less affected by intense radiation above Earth’s atmosphere.

08.03 Physical Properties of Our Sun

How the Sun Affects Technology

A diagram illustrating some of the ways in which solar activity affects technology on and around Earth:

Astronaut Safety: Astronauts in space can be exposed to excess doses of radiation from the sun.

Solar Cell Damage: Solar cells are devices used to collect and convert solar energy into electricity. Satellites in space rely on solar cells for power. These can be damaged by too much solar activity.

Computer Problems: Strong streams of radiation from the sun can damage sensitive computer equipment and electronics in space.

Radio Wave Disturbances: Radio waves bounce back and forth between the atmosphere's upper layers, allowing long-distance communication. Solar storms can disrupt the upper atmosphere, interfering with such communication.

Navigation Systems Disrupted: Computer-controlled navigation systems in aircraft can be disrupted by solar storms.

Electricity Grid Disruption: A solar storm can disrupt electricity flow in a power grid, leading to widespread blackouts. A powerful solar storm can affect the direction of compass needles. It can also induce electric currents in soil. In 1859, electricity generated by a solar storm shocked workers operating a telegraph and set offices on fire.

Physical Characteristics

Scientists do not know what exactly causes solar storms. By studying many aspects of the sun, we are steadily gaining clues. The basic physical characteristics of the sun are outlined in the next activity. As you complete the activity, take notes on the basic structure of the sun.

Basic physical characteristics of the sun:

Plasma: The sun is made of plasma. Plasma is the fourth state of matter. It comprises electrons and charged atoms, known as ions.

A diagram shows how particles are arranged in different states of matter. In solids, atoms are arranged close together to form a shape that doesn't flow or change to fit the shape of its container. In liquids and gases, atoms are spaced farther and farther apart. In plasma, positively charged ions and negatively charged electrons are spaced even farther apart and move very quickly. As temperature or energy increases, a substance will move from solid to liquid to gas to plasma; as temperature decreases, a substance will move in the reverse direction.

Gases: The sun is made up mostly of hydrogen and some helium. The sun makes up 99.9 percent of all the matter in the solar system. In other words, every planet, every dust and gas particle, and every moon in the solar system only accounts for a thousandth of the total mass of the solar system.

An image shows a close-up view of the sun. Hydrogen gas and plasma form arches on the surface during a solar storm.

Size: If you picture the sun as the size of a basketball, Earth is about as big as a pea. At 1.4 million kilometers wide, the sun is nearly 110 times wider than Earth. About 1 million Earths would fit inside the sun. But our sun is not exceptional as stars go. Astronomers have found stars more than 1,000 times the size of our sun!

A diagram compares the relative sizes of each planet in the solar system to the sun, which has a diameter of approximately 1.4 million kilometers. In contrast, Earth's diameter is less than 13,000 kilometers.

Temperature: The surface of the sun has a temperature of about 5,500 degrees Celsius. At the sun's core, temperatures are about 15 million degrees Celsius.

Layers of the Sun:

Beyond the external characteristics of the sun, scientists have deduced that the sun's interior is structured in layers. Because of the way energy cycles within the sun, the light from the sun you see today was produced in the center of the sun at least 200,000 years ago.

Use the following activity to investigate the layers of the sun:

- Subsurface Flows

  As material from the convective zone rises, it flows on what can be called the sun's "surface." Below the "surface" are the inner core, radiative zone, and convective zone. Above the surface, the photosphere, chromosphere, and corona make up the "atmosphere" of the sun.

- Photosphere

  The sun's visible light is emitted in the photosphere. Its average temperature is 10,000 degrees Fahrenheit.

- Chromosphere

  The chromosphere is the middle layer of the sun's atmosphere, comprising a red, ionized layer of hydrogen gas. It is visible only when using special photographic techniques. The visible light released from the photosphere prevents us from seeing the chromosphere. Its average temperature is 7,800 degrees Fahrenheit.

- Convection Zone

  Hot gases from the sun's interior move outward. The gases rise when hottest and sink when coolest in a process known as convection. The average temperature of the convective zone is 3.5 million degrees Fahrenheit.

  Image of a diagram that shows the process of convection within the sun. The hydrogen core makes up 25 percent of the sun's diameter. Gases rise from the core to the boundary of the radiative zone; from the core to the boundary of the radiative zone makes up 70 percent of the sun's diameter. The gases then begin to cycle between the radiative zone and the surface; this convective zone makes up the final 30 percent of the sun's diameter.

- Radiative Zone

  The radiative zone moves energy from the inner core through thermal conduction. Its temperatures range from 4 million to 12 million degrees Fahrenheit.

- Inner Core

  The inner core of the sun is made of dense gas in its plasma state. At the sun's core, hydrogen atoms fuse, forming helium. It represents 35 percent of the sun's total mass but less than one percent of the sun's total volume. Inner core temperatures are about 28 million degrees Fahrenheit making it the hottest part of the sun. The inner core produces all the heat and light we receive on Earth.

- Corona

  The outermost layer of the sun's atmosphere is a region of hot, ionized gases. The plasma surrounds the sun and extends millions of kilometers into space. It is only visible during solar eclipses. Coronal temperatures measure in the millions of degrees Fahrenheit.

  Scientists have used satellites and Earth-based telescopes to take countless images of the sun. The sun's appearance differs according to the wavelength of the light. Galileo Galilei was the first scientist to look at the sun with a telescope. With his telescope, he meticulously tracked changes in the sun. His data showed for the first time that solar activity changes over time.

<u>Solar Energy</u>

The sun's energy makes life on Earth possible. **Nuclear fusion** occurs deep in the sun's inner core and generates solar energy. When atoms collide under conditions of sufficiently high pressure and temperature, they fuse together to form new elements but also release enormous amounts of energy. In contrast, **nuclear fission** results when atoms split apart. This process also releases energy. Nuclear fission is most often used in nuclear power plants.

<u>Magnetism</u>

The Earth's atmosphere protects it from much of the sun's dangerous radiation. Earth's magnetic shield, known as the **magnetosphere**, also protects us from radiation. As depicted in the image below, Earth's magnetic field surrounds the planet. The magnetic force deflects the sun's radiation, protecting Earth. The magnetosphere reaches 36,000 miles into space.

Streaming plasma from the sun, known as the **solar wind**, travels toward Earth at about 1 million miles per hour. Plasma material is sensitive to magnetic fields and tends to travel along magnetic-field lines. The plasma from the sun interacts with and changes Earth's magnetosphere.

The sun has a powerful magnetic field. Changes in the sun's magnetic field influence the strength, timing, and direction of solar storms. On the side of Earth opposite the sun, the magnetosphere is elongated as the plasma streams react with and change the magnetic-field lines. As solar storms intensify, they change the magnetosphere accordingly.

Solar Activity

Increased solar activity is related to the **solar cycle**. The solar cycle is a pattern of increased solar activity that repeats every 11 or 12 years, though this time period has varied historically. When the sun is most active, it is at **solar maximum**. When the sun is least active, it is at **solar minimum**. Magnetic changes in the sun cause the excess releases of plasma and radiation from the sun.

Information detailing various solar features that occur during increased solar activity

CME: A coronal mass ejection, also known as a CME, is a bubble of solar-wind gases ejected from the sun's surface. During solar maximum, two to three CMEs can be released from the sun each day.

Prominence: A prominence is a loop-shaped plasma ejection formed in the sun's atmosphere.

Sunspots: Each sunspot is a location where the magnetism of the sun creates a cooler region we perceive as a dark "blemish" on the sun's photosphere. The sunspot is still shining, just not as brightly as the rest of the sun.

Solar Flares: A solar flare is a sudden explosion of charged particles from the solar atmosphere. A solar flare can be so violent that earthquake-like waves can cause the sun to shudder and shake. An average solar flare releases enough energy in two hours to power the United States for 10,000 years!

On Earth, when solar activity is at a maximum, various space weather events can take place, including the production of auroras. As solar activity increases, the magnetic interactions between the sun and Earth cause auroras to appear at lower latitudes than normal. Therefore, solar activity is linked to atmospheric phenomenon on Earth. In fact, scientists have investigated the connection between global climate and the activity of the sun.

What is space weather? Take notes as you learn more about its effects on Earth.

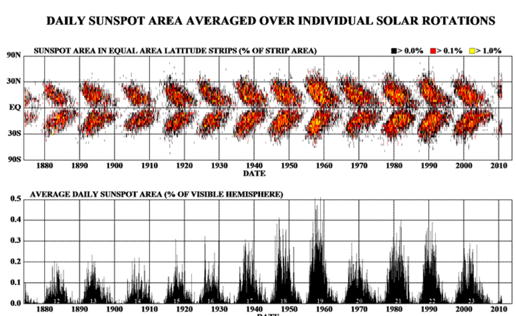
Space Weather

- Solar flares may seem like far-away events, but they can damage satellites and even ground-based technologies and power grids. Every 11 years, as the sun reaches its maximum activity, they become bigger and more common, and that increases the chances that one will significantly affect Earth.
- So what are these solar eruptions? A solar flare is basically an explosion on the surface of the sun ranging from minutes to hours in length. Large flares can release enough energy to power the entire United States for a million years. Flares happen when the powerful magnetic fields in and around the sun reconnect. They're usually associated with active regions, often seen as sun spots, where the magnetic fields are strongest.

- Flares are classified according to their strength. The smallest ones are B-class, followed by C, M, and X, the largest. Similar to the Richter scale for earthquakes, each letter represents a ten-fold increase in energy output. So an X is ten times an M and 100 times a C. Within each letter class, there is a finer scale from one to nine.
- C-class flares are too weak to noticeably affect Earth. M-class flares can cause brief radio blackouts at the poles and minor radiation storms that might endanger astronauts. It's the X-class flares that are the real juggernauts. Although X is the last letter, there are flares more than ten times the power of an X1, so X-class flares can go higher than nine.
- The most powerful flare on record was in 2003, during the last solar maximum. It was so powerful that it overloaded the sensors measuring it. They cut out at X17, and the flare was later estimated to be about X45. A powerful X-class flare like that can create long-lasting radiation storms, which can harm satellites and even give airline passengers flying near the poles small radiation doses. X flares also have the potential to create global transmission problems and worldwide blackouts.
- The seriousness of an X-class flare pointed at Earth is why NASA and NOAA constantly monitor the sun. NASA's Heliophysics fleet of spacecraft can now see the sun from every side and in many different wavelengths. This unprecedented coverage is enabling scientists to predict and detect space weather events like flares and CMEs with ever greater accuracy. With advance warning, governments and companies can take steps to protect their technological infrastructure, so that the worst scenarios will never happen.

Sunspots

Taking data from Galileo and others before him, scientists have created a graphical representation of the number and intensity of sunspots over the course of several hundred years. The resulting chart, below, produced a pattern of repeated butterfly-wing shapes. Hence the graph is called the *sunspot butterfly diagram*.



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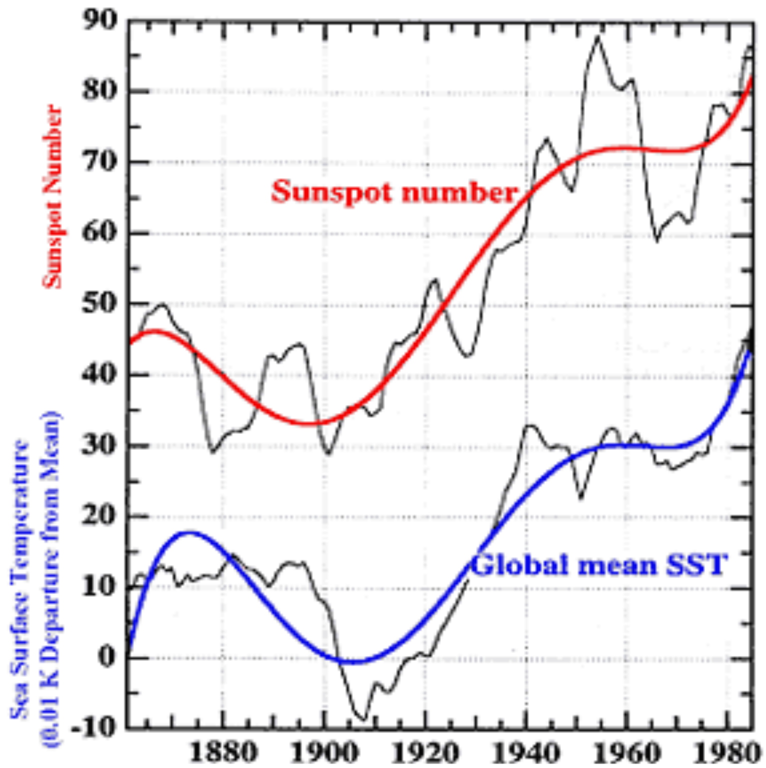
The number of sunspots, as you have learned, can indicate whether the sun is in a maximum-activity period or a minimum-activity period. Some scientists believe this can have an overall effect on the climate of Earth. Though human-induced climate change cannot be eliminated as a possible cause of rising temperatures, changes in solar output over time may be a contributing factor.

For instance, it is generally accepted that changes in the sun cause long-term changes in global climate. The last ice age, which ended approximately 11,500 years ago, was likely due to changes in solar activity. Scientists estimate that global temperatures during the last ice age were about 6 degrees Celsius cooler than they are today [**Source**: NOAA], causing many parts of the world to be covered with glaciers.

As shown in the graph below, ocean temperatures on Earth have corresponded to solar output in recent history.



Exam: 08.03: Physical Properties of the Sun

Question 1
The models below represent nuclear reactions. The atoms on the left of the equal sign are present before the reaction, and the atoms on the right of the equal sign are produced after the reaction.

Model 1: Atom 1 + Atom 2 = Atom 3 + energy
Model 2: Atom 4 = Atom 5 + Atom 6 + energy

Which of these statements is most likely correct about the two models?

a. Both models show reactions which produce energy in the sun.
b. Both models show reactions which use up energy in the sun.
c. Model 1 shows reactions in the nuclear power plants and Model 2 shows reactions in the sun.
d. Model 1 shows reactions in the sun and Model 2 shows reactions in a nuclear power plant.

Question 2

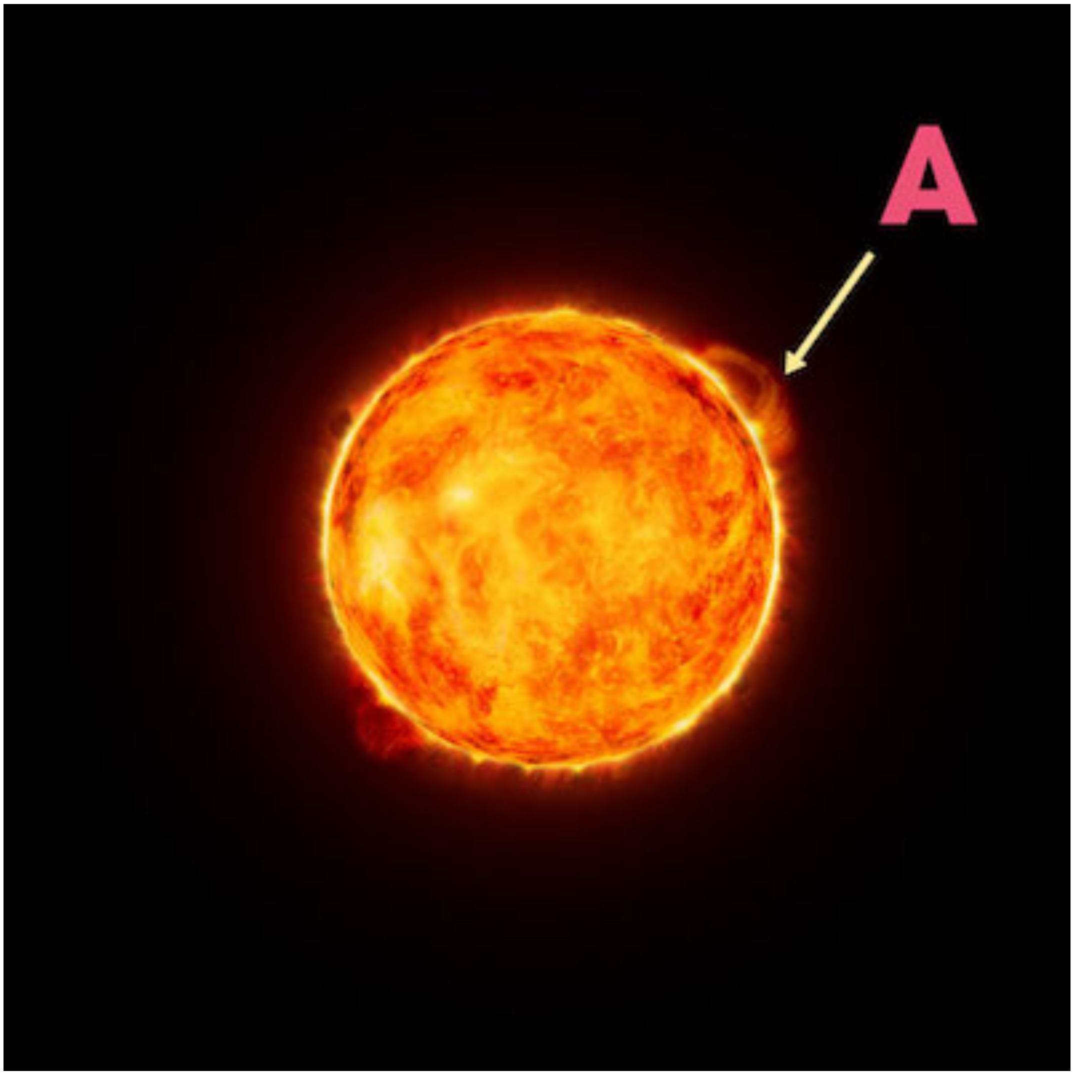
Which list places the layers of the sun in the correct order from outermost to innermost?

a. Chromosphere, convective zone, radiative zone
b. Convective zone, chromosphere, corona
c. Corona, photosphere, chromosphere
d. Radiative zone, corona, convective zone

Question 3

Which of these events is most likely to occur as a result of the solar wind?
a. Cell phone reception is extended.
b. Microwave may stop working.
c. Increased navigation system quality.
d. Radio and television signal disruption.

Question 4



Which statement describes the solar feature labeled A?

a. A brief eruption of intense high-energy radiation from the sun's surface
b. A dark spot appearing from time to time on the sun's surface
c. An envelope of plasma surrounding the sun
d. A stream of glowing gas that shoots out from the sun in an arch

Question 5

Which of the following is a result of interaction of particles from the sun and Earth's magnetic field?

a. Aurora
b. CME
c. Solar flare
d. Solar wind

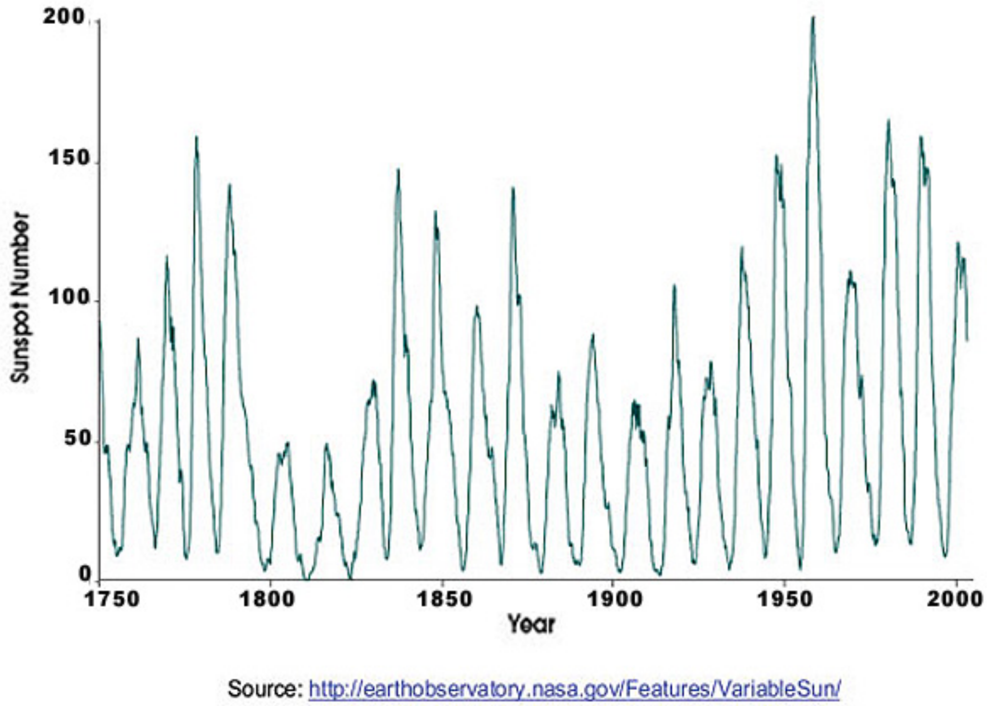
Question 6

Which of these is most likely to happen during a solar storm?

a. All places on Earth will experience severe thunderstorms.
b. Satellites and solar cells will be damaged.
c. Electricity grids will produce surplus power.
d. Hurricanes will flood all coastal locations.

Question 7

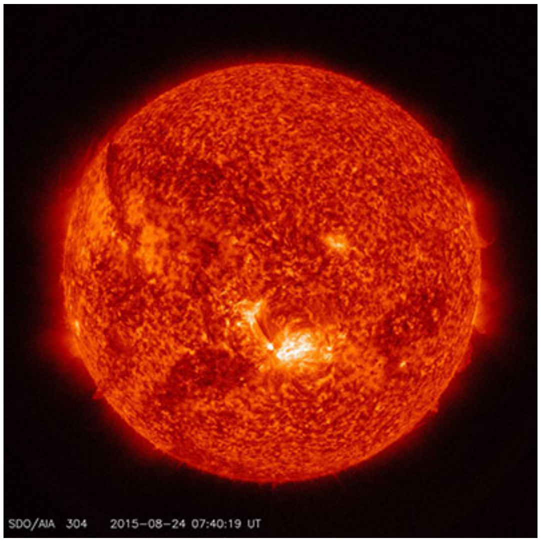
The graph below shows the number of sunspots observed between 1750 and 2000.



Based on the graph, which of these periods most likely witnessed the highest average amount of solar radiation??

a. 1750 to 1800
b. 1800 to 1850
c. 1850 to 1900
d. 1950 to 2000

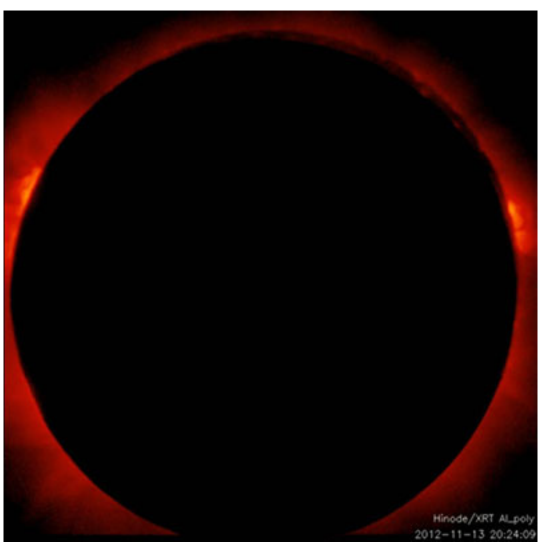
Question 8



Which bright solar feature is shown in the picture above?

a. Convection zone
b. Prominence
c. Solar flare
d. Sunspot

Question 9



Which layer of the sun seen above is visible during this solar eclipse?

a. Convective zone

b. Corona
c. Photosphere
d. Radiative zone

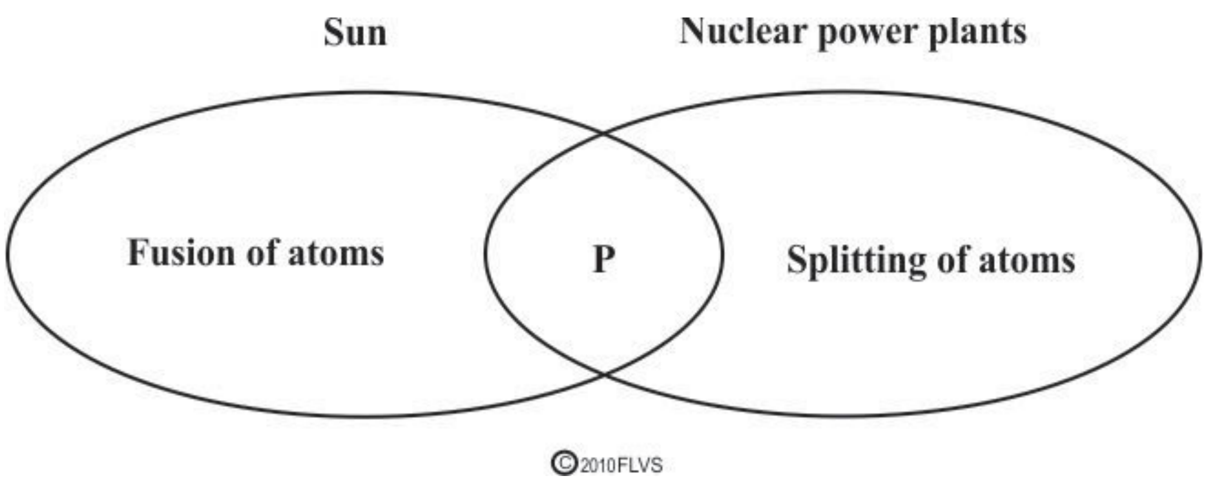
Question 10

Which statement describes the motion of the sun?

a. The sun does not rotate at its poles.
b. The sun rotates faster at its equator.
c. The sun rotates faster at its poles.
d. The sun rotates more slowly at its equator.

Question 11

The Venn diagram shown below compares the nuclear reactions in the sun and nuclear power plants.



Which of these would best describe the process labeled P?

a. Absorption of elements
b. Absorption of heat
c. Formation of new elements
d. Formation of solar energy