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Research Paper

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The Composition of the Sun

Seven centuries ago, people looked up towards the sun and held their hands to worship it and just hoped that it would not burn them down. But our understanding of the sun has improved since then. The Sun is the star at the center of our solar system. It has a diameter of about 420,000 miles and a surface temperature of 10,000°F. The Sun shines as a result of thermonuclear fusion reactions in its core, and the energy produced by these reactions heats the gas in the Sun's interior enough to prevent the weight of its own matter from crushing it down. This energy also is the source of heat and life on Earth, and small variations in the Sun's energy output, or even in the features present in its atmosphere, may be sufficient to conveniently affect terrestrial climate. Although the Sun is by far the nearest star, the processes causing solar variability are still challenging to the astronomers. The sun dates back to be about five billion years old. The Sun is about 90 million miles away from Earth. It is modest by stellar standards, although it is over 100 times larger than the earth and over 300,000 times more massive. (Hall "Sun." 3900)

The sun has been always in the people's mind and studies have been conducted since ancient times to understand its existence. The ancient Egyptians considered the sun to be a god and for anyone who felt its warmth and watched the renewal of crops it brought in the spring realized it was a bringer of life. (Hall "Sun." 3900) Ancient beliefs said that the sun orbited the Earth. But in 1543, Nikolaus Copernicus published his heliocentric theory that said that the sun

was in the centre and the Earth orbited the sun. After Nikolaus, many others tried to come up with their own theories but all were rejected. However in 1608, serious studies about the sun started when Lippersheim invented the telescope. Using the telescope, the early sun explorers, including Galileo, found dark spots on the sun which they later named sunspots. (Hall "Sun." 3900). Around 1802, using an improved spectrograph, Fraunhofer discovered 547 additional dark lines which he called the solar spectrum. The origin of these strange features on the Sun, were explained in 1859 by Kirchhoff and Bunsen, as the selective absorption of light from the hot solar surface that is directed toward Earth, by the cooler atoms in the Sun's atmosphere. By 1929, the chemical composition of the Sun was known as a result of the pioneering work of Hale and Russell and many others (Chupp 711). Hale also discovered that the sun's magnetic field reverses itself with each 11-year cycle, so that there is a more fundamental 22-year magnetic activity cycle behind the sunspot cycle. Since then solar research has followed two lines of investigation. First, a huge observational database has been created. The national solar observing facilities of the United States are located at Sacramento Peak. They study solar spectrum, solar radiation, the erupting volcanoes, solar granulation and more. The other line of investigation is the theoretical analysis of the Sun and in its atmosphere. The goal of this work is to explain why the various features seen on the Sun appear. (Hall "Sun" 3901). Science has helped us in explaining how the sun works, what it is made of, and many more interesting questions.

The million dollar question in everybody's mind was, "How did the sun get that hot and what really does go on in there?". We finally have an answer to how the sun uses its components to power itself. Nuclear fusion is the source of the sun's power. Eddington in 1920 was the first person to theoretically understand the process. After a lot of criticism he was found to be right. The sun is generally composed of hydrogen and helium. The nuclear fusion cycle starts with the

thermal collision of two protons (${}^1\text{H} + {}^1\text{H}$) to form a deuteron (${}^2\text{H}$), with the simultaneous creation of a positron and a neutrino. The deuteron collides with another proton to form a Helium-3 nucleus and gamma ray. Two such Helium-3 atoms combine to form a helium-4 alpha particle and other gamma rays. There is a difference in the masses of initial hydrogen atoms and the final helium atoms. This difference in mass is released into space as energy in the form of radiation. And as we all can see, the amount of heat as a part of the radiation is immensely huge. (Lang 27).

Although Eddington contributed immensely in the field of astronomy, he started out as a physicist. During the year of 1915, Eddington was impressed with Einstein's theory of General Relativity. He analyzed his papers and was ready to personally help into the theory. He experimented the theory on an island during the solar eclipse when he noticed that the stars near the sun appeared to be nearer because the light from them was curved due to the sun's strong gravitational force. 1920s onwards, Eddington was inspired by Einstein and started looking for the universal formula for unifying all the forces of nature but failed in doing so. Although he and Einstein followed their own paths to find the formula, they both had a good work relationship. (Macmillan 170).

We know the process that takes place in the sun, and so it is important to learn about the layers (rather zones) of the sun that form the physical composition. The sun is usually illustrated to have a series of concentric shells pertaining different physical and chemical characteristics. There are four layers of the sun. They are the core, the radiation zone, the convectional zone and the photosphere.

The core is the innermost layer of the sun and so the hottest. It has a temperature of close to 13,600,000 kelvins. The core is where the process of the p-p reaction (initial stages of the nuclear fusion reaction) takes place. The origin of the p-p reaction can be explained (two hydrogen protons combining with each other) as there are no atoms in the core. In actuality no atom can ever exist in the immense heat. Hence, all we have in here is a sea of particles. These particles are very excited and travel at immensely high speeds. The process of nuclear fusion then takes place and with the resulting energy and helium atoms, photons are also produced. (Hall "Sun." 3903). These photons are electromagnetic rays that radiate from the sun as light. The high-energy photons released in fusion reactions are absorbed in only a few millimeters of solar plasma and then re-emitted again in random direction—so it takes a long time for radiation to reach the Sun's surface. Neutrinos are also released by the fusion reactions in the core, but unlike photons they very rarely interact with matter, so almost all are able to escape the Sun immediately. (Chupp 715).

The next layer is the radiation zone. The temperature is 4 million kelvins. The density of the radiation zone is much less than that of the core. The radiation zone puts a lot of pressure on the core. Heat travels in the radiation zone via radiation. The photons travel in random direction and so the whole zone is very chaotic in nature. As trillions of photons are radiated through the radiation zone, new and fresh photons get produced in the core through nuclear fusion. (Chaisson, Eric and Steve McMillan, 1993 369).

The layer after the radiation zone is the convection zone. The Convection zone with the radiation zone forms the solar envelope and is responsible to contain the heat and pressure of the core so that nuclear fusion processes can take place. (Chaisson, Eric and Steve McMillan, 1993

369). Almost two-thirds the way to the surface, the gas cools down a little here. Instead of the individual particles, complete atoms can be found here. The solar plasma is not dense or hot enough to allow the transfer of heat through radiation. Hence heat is transferred through the process of convection. Thermal convection occurs as huge cells of circulating gas carry the hot material to the surface of the Sun. (Hall "Sun." 3904). The top of each cell is called a granule and variations in the velocity of the particles in a granule can cause slight wavelength changes in the spectra emitted by the sun. (Chaisson, Eric and Steve McMillan, 1993 369). The thermal columns in the convection zone form an imprint on the surface of the Sun, in the form of solar granulation. The turbulent convection gives rise to a small-scale dynamo that produces magnetic north and south poles all over the surface of the Sun. (Hall "Sun." 3904). After the heat is transferred, the cells get cooler than their surrounding and sink back towards the radiation zone to get more heat and begin the convection cycle again. (Chupp 721).

The Photosphere is the outermost visible layer of the sun. Above the photosphere, sunlight is free to propagate into the space and energy escapes the sun almost completely. The upper part of the photosphere is cooler than the lower part, thus the Sun appears brighter in the center than on the edge or of the solar disk, in a phenomenon known as limb darkening. In places there are great, dark spots, where the temperature is low and matter is constrained to flow along the intense and tangled lines of the strong magnetic fields that permeate the spots. (Chupp 721). Violent eruptions in twisted magnetic fields result in flares, which spray matter and intense radiation into space. This is where most of the solar activity takes place, sunspots are seen and solar winds originate.

Over the photosphere, we find the solar atmosphere. Although not a layer, it plays some role. The solar atmosphere is usually known to have two components- the chromosphere and corona. The chromosphere is much hotter than the photosphere and cannot be seen easily. (Hanslmeier 64) We need filters to see it or we can also see it during an eclipse when the sun gets red portraying the abundance of hydrogen and the chromospheres with the corona becomes very visible. "During a total solar eclipse, depending on the phase of the solar cycle, the light that extends well beyond the disc and the narrow chromosphere takes on different forms and is typically as bright as the full Moon. This "crown" of light is called the solar corona." (Chupp 728). The most dramatic characteristics of the corona are its high temperature and its extremely low density, surprising for such a luminous object. "The changing forms of the corona are associated with the sunspot cycle and the changing magnetic structure. Near the minimum solar sunspot number, the coronal intensity near the poles is depressed relative to that when the solar activity is high."(Chupp 731).

The reason chromosphere is so useful is because it is dominated by a spectrum of emission and absorption lines. Sunlight has a black-body spectrum that indicates its temperature is about 6,000 K, interspersed with atomic absorption lines from the chromosphere. Hence, the solar atmosphere helps us in determining the actual chemical components of the sun. (Hall Sun." 731).

Now that we know the structure of the sun, let's take a look at the chemical composition of the sun. The race to find the chemical compositions of the sun was going on since 17th century with many well known physicists and scientist working day and night. But the bell rang in 1857 when Robert Bunsen and Gustav Kirchhoff found empirical laws of spectroscopic analysis. They

could now determine the physical and chemical composition of the sun. From 1814 the German physicist Joseph von Fraunhofer observed black lines in the spectrum of the Sun. (Hall "Sun." 733). Kirchhoff deduced that these elements were present in the atmosphere of the Sun and were absorbing their wavelengths. Using his knowledge, he published the first atlas of the solar spectrum in 1861. Around 67 elements have been detected in the solar spectrum till now and some of the major ones are:

By mass - Hydrogen 91.2% ; Helium 8.7% ; Oxygen 0.078% ; Carbon 0.043% ; Nitrogen 0.0088% ; Silicon 0.0045% ; Magnesium 0.0038% ; Neon 0.0035% ; Iron 0.0030% ; Sulfur 0.0015% .

By weight – Hydrogen 71.0% ; Helium 27.1% ; Oxygen 0.97% ; Carbon 0.40% ; Nitrogen 0.096% ; Silicon 0.099% ; Magnesium 0.076% ; Neon 0.058% ; Iron 0.14% ; Sulfur 0.040% . (Chaisson, Eric and McMillan,1997)

The abundance of hydrogen in both the cases just shows the huge amount of nuclear fusion that takes place in the core and accounts on the immense amount of heat and energy that is emitted from the sun.

Also forming a part of the sun are the solar activities, solar winds, and solar prominence (the horrifying solar flares). Solar activity has traditionally referred to dynamic changes in photospheric active regions, where faculae, sunspots are seen. Vast eruptions have been observed in which billion tons of matter have been expelled from the sun in a single event that sometimes has disastrous effects; it is known as coronal mass ejection. These events taking place on the sun are primarily the cause of the strong solar magnetic field. (Chupp 731). Although many were aware of this erratic nature of the sun, very few know that the activities occur in a roughly

periodic cycle. The sunspot cycle was discovered in 1843 by a German amateur astronomer, Heinrich Schwab, who, after only two decades of observation. Schwab originally aimed at discovering intramercurial planets. In 1825, he started observing the sun virtually every day and continues to do so for 42 years. An approximate solar activity cycle is taken to be 11 years long. (Chaisson, Eric and Steve McMillan, 1993 369). The solar magnetic field is usually created due to the convection zone in the sun. The convective circulation functions like a dynamo and generates a dipolar magnetic field for the sun. One activity due to the magnetic field is the solar flares. (Chupp 745). Solar flares or solar prominence are large clouds of gas suspended in magnetic field loops above the Sun's photosphere. It is very difficult to spot them in front of the brilliance of the photosphere but they can be seen clearly during eclipses. They are a product of the solar activity cycle. The hot gas that in the Sun is magnetized, and as the Sun rotates and the heat of its interior, churns its subsurface layer in great convective bubbles. Large magnetic loops burst through the Sun's photosphere and into its atmosphere. (Hall "Sun." 3904). Prominences are typically huge; several Earth-sized could fit inside a typical prominence loop (Hall "Solar Prominence" 3700). The solar wind is basically a stream of matter that is flowing away from the sun. It does not affect the revolution of the sun as the matter leaves very slowly. Solar winds are thought to permeate the entire solar system and beyond. (Hall "Sun." 3904).

The knowledge that we have now is the result of a lot of hard work by many scientists and physicists. There have been many missions to study the components of sun and observe the different activities in the sun. The first observations of the Sun from space were made by Naval Research Laboratory (NRL) scientists in 1946 using ultraviolet (UV) and X-ray spectrometers. Starting in 1962, NASA launched its Orbiting Solar Observatory (OSO) Series, which made many important observations of the Sun through 1975. The OSO 7 carried the first chronograph

and the first white light spectrometer. From 1974 to 1976, the European Helios 1 and 2 solar-orbiting satellites made plasma and high-energy electron and ion observations from the Sun. From 1978 to 1982, the International Sun Earth Explorer 3 (ISEE3) was at the Sun–Earth Lagrangian point (L1) and made numerous valuable solar flare observations. The Solar Maximum Mission (SMM) satellite was launched on 14 February 1980 carrying six instruments for a coordinated study of solar flares covering several spectral regions: the UV, soft and hard X-rays with the hard X-ray burst spectrometer (HXRBS), and gamma rays, with the gamma-ray spectrometer (GRS). In October 1990, the ESA Ulysses was launched carrying instruments to measure the solar wind composition. Around five more have been launched after this to study more about the sun. In April 1998, the Transition Region and Coronal Explorer (TRACE) was launched to image the photosphere, the transitional region, and the corona at various wavelengths. (Chupp 734). Two of the very recent missions were RHESSI (Reuven Ramaty High Energy Solar Stereoscopic Imager) in 2002 to explore the particles and solar flare and STEREO (Solar Terrestrial Relations Observatory in 2006 to use stereoscopic measurements to study the Sun and the coronal mass ejections. (Hanslmeier 25).

Now, we can see how the study of sun has evolved over three centuries. Technology has helped to study the origin of the universe and how the sun and the planets have grown since then. Although our knowledge of the sun has gone quite far, we still do not know everything about it. There are a lot of unknowns to be found and finding these unknowns can be the key to the important question in the minds of mankind. The sun being the star of our galaxy is very vital to our existence and understanding more about the sun can be of great importance to us in the future.

Source citation

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