Aurora Borealis

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Lab: H2

The Aurora Borealis is one of the world's greatest wonders. However in the past there was much more wonder about the Aurora Borealis than there was actual knowledge about these "Northern Lights." Through the years many different theories have come and gone, including a few incorrect guesses by the inventor and scientist Benjamin Franklin. It was not until mankind achieved a better understanding of the physics of the universe that the theories began to describe plausible causes for the Aurora Borealis. As scientist began to study topics dealing with Earth's magnetic field and the Sun and the solar winds that it created they were scratching the surface of what made the Aurora Borealis such a mystery for so many centuries.

The Northern Lights were first referred to as the Aurora Borealis in 1621 by a French scientist named Pierre Gassendi. At this time very little was known about the science behind the colorful lights in the sky considering that John Dalton did not even come up with the first atomic theory until the 19th century. However plenty of research was done on the Aurora Borealis to help gain a better understanding of this phenomenon. In the early 1800's many scientist would map out the different locations the Aurora Borealis could be seen and how many times that it appeared. The Aurora Borealis was seen most frequently at the Earth's North Pole during the winter months when the nights lasted longer. One scientist Fritzer estimated in 1881 that these Northern Lights could be observed around 100 nights in a given year near the North Pole. As years passed many different theories came and went. Benjamin Franklin, himself, wrote in 1779 that the Northern Lights were caused by a large amount of electrical charges that were strengthened by different types of moisture, and once these charges became too great they released an electrical illumination (Franklin 1779). Another theory links the Aurora Borealis to the Radiation Belt, which is a belt of charged particles that encircle the Earth and are held in place by Earth's magnetic field. This theory believed that as the charge grew larger it finally leaked out of the belt and became visible. However this theory was negated since the Radiation Belt could not sustain such a high rate of lost charge. It was not until around 1900 that progress was made on the actual cause of the Aurora Borealis as research was done by the Norwegian physicist Kristian Birkeland.

In the early 20th century Kristian Birkeland did an experiment with a terrella which is a magnetized sphere that is meant to represent Earth and its magnetic field. He then shot a beam of electrons at the sphere and observed as electrons were guided around the sphere by the magnetic fields and went towards the magnetic poles at either end. He concluded from that experiment that the Aurora Borealis was formed in the same way as electrons gathered near the Earth's magnetic poles (Stern 2001). Though it was not until the 1950's that the existence of "auroral electrons" was confirmed by detectors on a rocket launched by a team of scientist at the University of Iowa. It was not for about another decade after the terrella experiment that Kristian Birkeland was the first to come up with a theory about what supplied the large amount of electrons that existed in the Aurora Borealis. He was right again when he predicted that they originated from the Sun and its solar winds. He suggested that the solar winds contained both electrons and positive ions and that these different particles behaved the same way as particles on Earth would when exposed to a magnetic field. Birkeland even proposed that there were polar electric currents that ran along the geomagnetic field lines of Earth into and away from the magnetic poles (Plasmauniverse 2012). In one of his books he included a drawing of these field-aligned currents. These theories of Birkeland were argued about for years because none of them could be confirmed or denied with the level of technology that was present at the time his predictions were made. The only way to check Birkeland's predictions was to make observations in the ionosphere, a region of the atmosphere that is over 85 kilometers above the Earth. In the 1960's the U.S. Navy launched a satellite into the ionosphere and observed these disturbances. They began to map them out and realized they were very similar to Birkeland's drawing and named them the Birkeland currents. Birkeland was soon known as the first "space scientist" and many of Birkeland theories and later findings to back up his different theories form the basis of today's understanding of the Aurora Borealis.

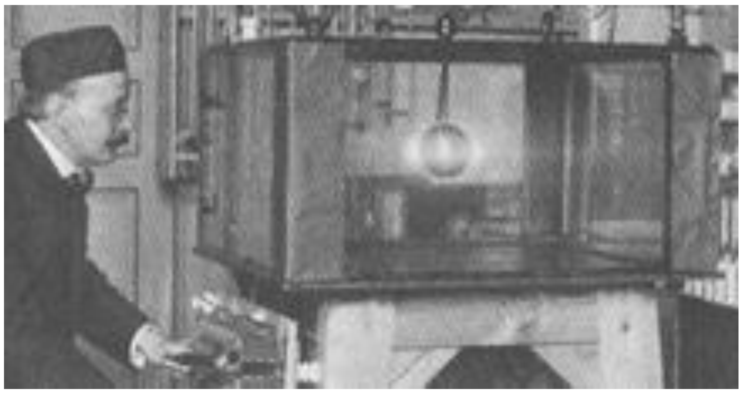

Figure 1: Birkeland and His Terrella (Stern 2001)

Kristian Birkeland is one of the main physicists credited for mankind's understanding of the Northern Lights. His effort is seen in his numerous Nobel prize nominations. Nonetheless his theories only began to touch on the many varying aspects behind what makes the Aurora Borealis appear in the skies of the Northern Hemisphere. The Aurora Borealis contains much more detail than what Kristian Birkeland predicted and discovered by himself.

One of the key factors in the occurrence of the Aurora Borealis is the solar wind. The solar wind is simply a stream of negative electrons and positive ions that get ejected from the Sun's solar spots and out into the atmosphere. As the solar winds vary over time so does the intensity of the Northern Lights. It was record that in 1859 after an apparently large amount of particles were released by the solar wind at high speeds it caused an aurora that lit up the sky in

Boston at 1 o'clock in the morning (Armstrong 2012). This impressive display was all thanks to a release of solar energy.

The Sun's solar energy is constantly released in the form of solar wind. The particles that are part of the solar wind have energy levels just under 10 kilovolts. They use their high levels of energy to escape from the pull of the Sun's gravity and accelerate through the solar system due to solar magnetic fields. The particles usually have to reach a velocity of around 400 km/s to escape the corona which is the outer atmosphere of the sun. Once these particles escape they form the solar wind. The solar wind travels along the Sun's magnetic field lines until some of them reach a region where the particles of the solar wind experience a "magnetic connection." At this point the Earth's magnetic field lines and the field lines of the Sun couple together and the solar winds enter into a part Earth's atmosphere called the magnetosphere. This area where the magnetic field lines couple together is usually over the Earth's polar caps. Here the solar winds surround the magnetosphere and begin to interact with Earth's magnetic field. It is these interactions with Earth's magnetic field that eventually leads to the visible display of the Aurora Borealis in the northern hemisphere.

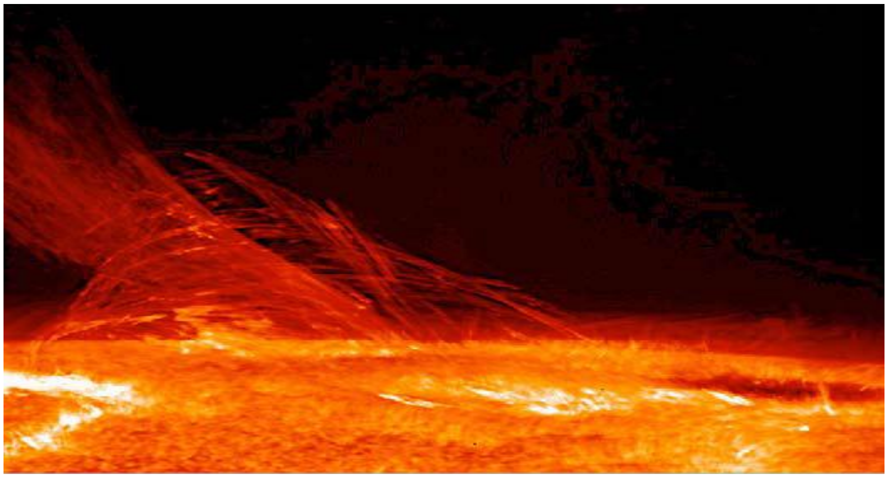

Figure 2: Solar Spot on Sun (Paretzke 2009)

Since the solar winds are one of the main sources of the Northern Lights it makes sense that as the solar winds vary so do the lights. In the same way that climate can vary based on the amount of solar activity present, the brightness and area covered by the Aurora Borealis changes continually. There are locations on the Sun's surface called sunspots where there is a large amount of magnetic activity occurring. These sunspots can cause different events in the Sun's atmosphere such as solar flares which is a large amount of energy being released from the Sun, anywhere up to 60,000,000,000,000,000,000,000 kilojoules of energy. The sunspots and the solar flares are usually followed by an occurrence called a coronal mass ejection. This mass ejection is simply an enormous amount magnetic fields rising above the corona atmosphere and an equally large amount of solar wind being released out of the Sun's atmosphere. The amount of solar wind depends heavily on the sunspots and these sunspots are actually on a cycle. The sunspots on the Sun's surface are on an eleven year cycle and at the peak of this cycle the Aurora Borealis will cover a much larger region than is normal for it due to the high quantity of solar wind that escapes the corona from the sunspot activity. The present cycle is actually set to peak sometime in the year 2013 (Armstrong 2012).

However when the solar wind finally does reach Earth's atmosphere is it blocked by Earth's magnetosphere luckily, considering the extreme amount of radiation that would reach the Earth if it traveled without any interference. As the solar wind passes the Earth, the magnetosphere begins to gain excessive amounts of plasma and particles. The amount of plasma flowing in the magnetosphere increases as the intensity and speed of the solar winds from the Sun increase as well. However when the Aurora Borealis is viewed it is not this large flow of plasma in the magnetosphere that is seen, but once the solar winds come in contact with the magnetosphere, the Earth's magnetic field lines take over and begin to help create the image of the Northern Lights that so many people have gazed upon.

Once the negative electrons and positive ions that exist in the solar winds reach Earth's magnetosphere they begin to travel towards Earth. As they do this they travel along parallel to Earth's magnetic field lines and begin to interact with Earth's magnetic field. At this point, as Kristian Birkeland said, these charged particles behave the same way as any other particles would when experiencing a magnetic field. These particles feel the same forces, such as the Lorentz Force, in the Earth's magnetic field that a particle would feel placed around a simple 5 tesla magnet. As the charged particles of the plasma continue to travel along the Earth's magnetic field lines they start to get closer to Earth's lower atmosphere. This is due to the fact that Earth's magnetic field lines behave the same way as magnetic field lines of a permanent magnet would behave. The lines are closed loops and exit from the north pole of the magnet, or the Earth, and circle around on all sides and return back to the magnet at the magnet's south pole. The lines tend to be farthest away from the magnet at the center of the magnet and continue to come closer until they exit or enter one of the magnet's poles. However that is only if the magnet has no interference from other objects such as other magnets or magnetic fields created by electricity being run through a current. In the Earth's case there are many different interferences to the Earth's magnetic field mainly they come from the magnetic field of other planets and the Sun and the field is even shaped by the solar winds that come in at such high velocities and bow out the field lines at certain points as seen in Figure 1. Nonetheless the lines still converge at the Earth's magnetic poles and this is where the charge particles of the solar winds continue moving towards until they are low enough that they begin to encounter the particles of Earth's lower atmospheres.

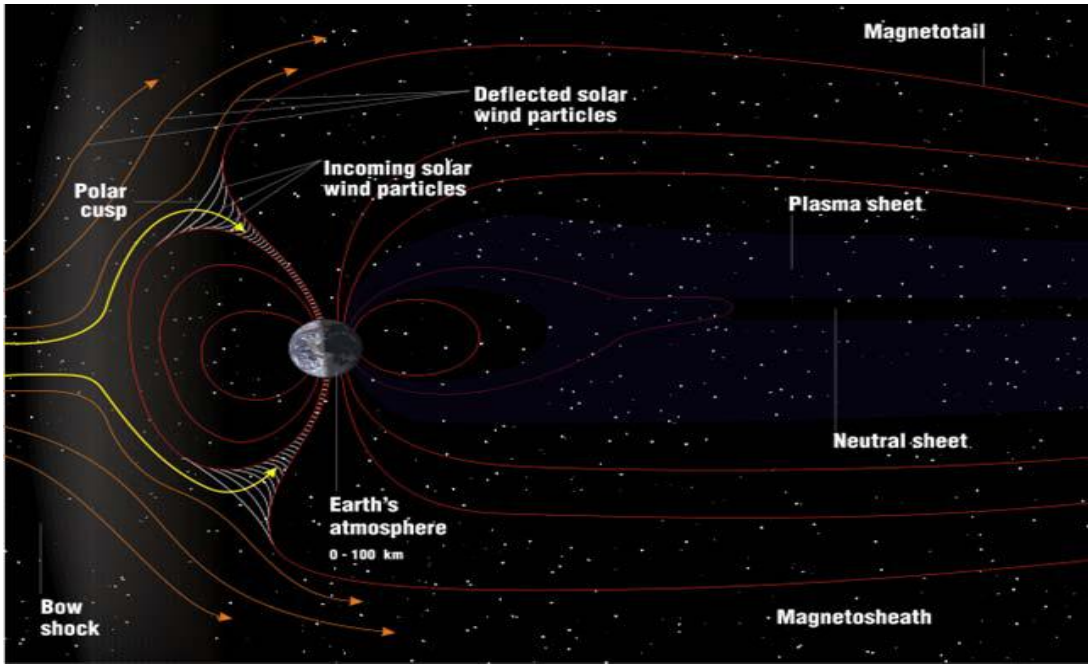

Figure 3: Earth's Magnetic Field (Paretzke 2009)

This diagram shows how vital of a role the Earth's magnetic field plays in the occurrence of the Aurora Borealis in the northern skies. It is the Earth's magnetic field that traps in all these particles and brings them into Earth's atmosphere close enough that they can interact with the particles in the air of Earth's atmosphere. Without the Earth's magnetic field lines accelerating the particles to the Earth's north and south pole, the particles and plasma from the solar winds would simply flow right past the Earth having very little influence on the skies of the northern hemisphere where the Aurora Borealis can be viewed. It is also thought that the Earth's magnetic field not only brings the particles that help form the Northern Lights, but once the auroral rays begin to form that they are shaped by the field lines of Earth's magnetic field. The rays of light from the Aurora Borealis tend to line up parallel to any local magnetic field lines and the electrons and other charged particles that tend to be constrained to the field lines.

As it has been explained the Sun and the solar winds that are emitted from it bring the electrons and positive ions to Earth magnetosphere. Then these charged particles get carried into the Earth's magnetic field lines and follow the lines along towards the Earth's magnetic poles. Once these particles come in contact with Earth's atmosphere they begin to interact with the particles, such as nitrogen and oxygen, that make up the air of Earth's atmosphere. It is a collision between these charged particles and the atmospheric atoms that will cause a transfer of energy from the particles to the atoms and then from the atoms the energy is released and viewed as the display of lights of the Aurora Borealis.

When the collision between the different particles and the atoms in Earth's atmosphere happen they usually occur in a region called the auroral oval which is centered around the magnetic north pole. This region typically has a diameter close to 3000 kilometers when conditions are normal but this value can become even greater when large amounts of solar winds escape the Sun's gravitational pull. This auroral oval has a tendency to exist on average between 95 to 1,000 kilometers above Earth. The atmosphere below 95 kilometer is too dense and the auroral particles will come to a rest. However once the particles reach the atmosphere above 1,000 kilometers the atmosphere is too thin and there are not enough collisions to release a considerable amount of energy from the atmospheric atoms. The actual structure of the auroral rays comes in many different shapes and sizes. The main types of shapes of the Aurora Borealis are what are called arcs or curtains. These curtains are made up of several separate auroral rays of light that extend straight upward, and the curtains are enhanced by "folds" in the curtains that give them a wavering shape as they extend through the sky. The curtain of the Aurora Borealis can be only 100 meters in length while some nights it can extend from one side of the sky all the way across to the other side. As the night continues the curtains gain a sparser look and do not have a continual flow as they are known to have at the peak of the night. As these are the usual conditions to expect from the Aurora Borealis, it has become very clear over the years that no one can predict the Northern Lights.

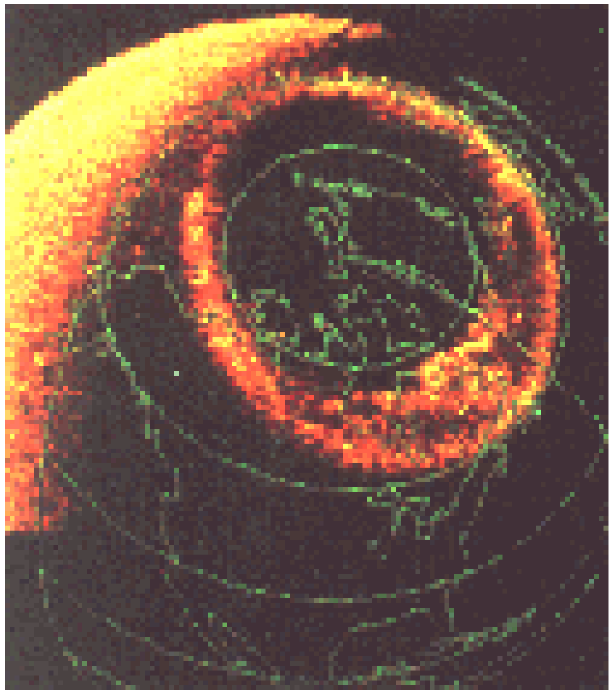

Figure 4: Aurora Oval around North Pole (Paretzke 2009)

Once the charged particles, especially the negatively charged electrons, collide with the atmospheric atoms they tend to excite these neutral atoms or even strip the atmospheric atom of one of its electrons and create a positive ion from this collision. When these atmospheric atoms get excited their valence electrons reach a higher energy state and as these electrons return to their lower, normal energy state the energy from the electrons gets released in the form of photons which is then viewed as light. This same process is very similar to what happens when a neon light or a television screen gets lit up by photons from neon gas or photons from different types of chemicals that cover a television screen. The colors that are seen in the display of the Northern Lights depend on which atmospheric atom collides with the charged particle and it also depends on which energy state it gets excited to by the charged particle. The two primary atoms that cause the colors of the Aurora Borealis to show up are oxygen and nitrogen since they make up a large percentage of the particles in the atmospheric air. Oxygen tends to cause a green color with a wavelength of 557.7nm and also a red with a wavelength of 630nm. The nitrogen can release a red and also a bluish-violet color as well around a wavelength of 427.8nm. As the altitude of the air changes so do the proportion of oxygen atoms to nitrogen atoms, so as the auroral rays travel higher or lower their color will change depending on the mixture of nitrogen and oxygen that is in the air (Paretzke 2009). At times people can even see what looks like the waves of green light from the oxygen being chased by the red light rays from the nitrogen atoms. This is due to the delay between their excited states. While nitrogen tends to emit its light fairly instantaneously the oxygen remains in an unstable state for about a second before it begins to return to its lower state and release its high energy.

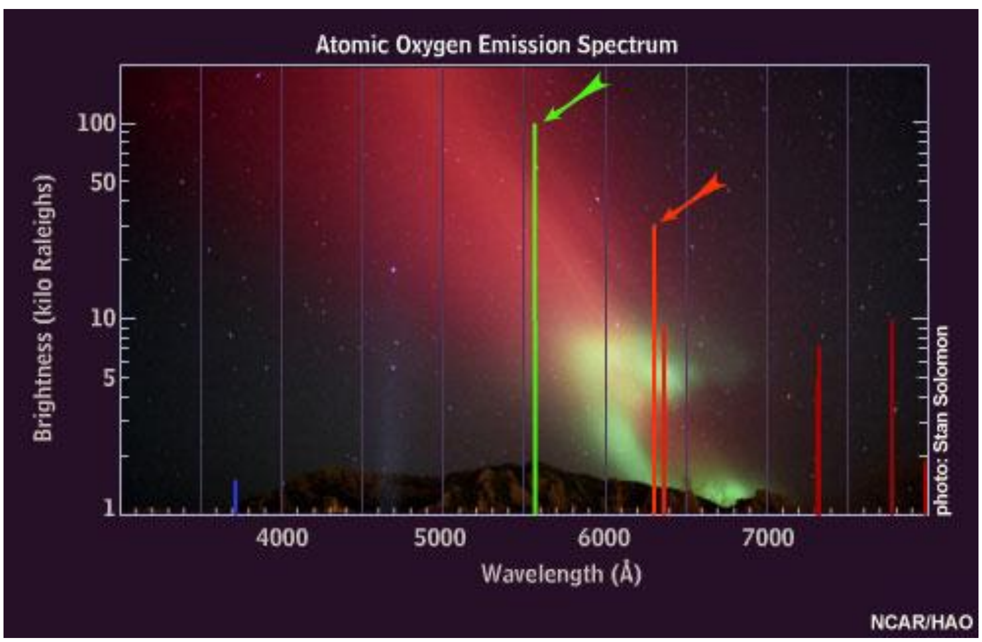

Figure 5: Emission Spectrum of Oxygen (Paretzke 2009)

All of these different aspects of the Aurora Borealis come together and eventually lead to the beautiful display of light that people have come to recognize all over the world. For so many years the truth behind what made the Northern Lights so amazing was simply a secret to everyone. However as years have passed and people's knowledge of physics has grown with different discoveries, they have been able to apply these new lessons to help make the mystery of the Aurora Borealis go away. Now mankind can truly understand the wonder behind what drives these magical lights in the sky.

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