Aurora Borealis

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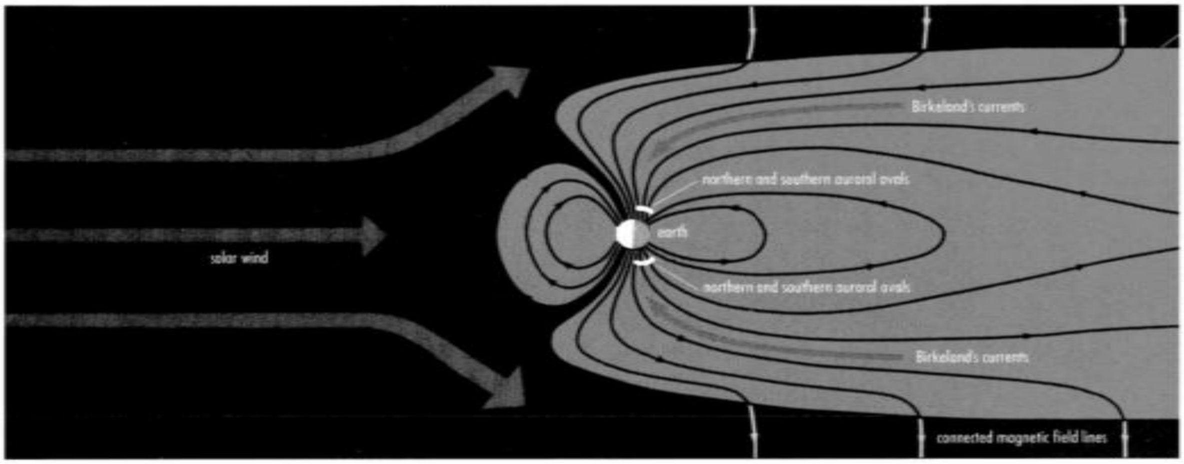
The Aurora Borealis, or Northern Lights, is a beautiful phenomenon that has intrigued people for years especially the red aurora that happened about fifty years ago. Clouds of green, red, and blue lights appear in the sky at both ends of the poles of the Earth. They are known as the aurora borealis and aurora australis which occur in symmetric ovals around the northern and southern magnetic poles of Earth forming the polar lights. When electrons and protons are steered by the Earth's magnetic field toward the poles in the atmosphere, the aurora is formed. The particle hit atoms and molecules in the upper atmosphere where some of the energy in these particles is transformed into light visible to humans, et cetera, and it makes up the aurora. For an aurora to occur there must be an atmosphere so that there are atoms for the particles to transfer energy to. Second, there must a magnetic field so that the particles are directed towards the Earth into the atmosphere. Next, there must a source of energy (the Sun) to provide the particles with a sufficient amount of energy. There also needs to be a method to transfer that energy from the Sun to the particles which is solar wind.

The reasons there are auroras is because the Earth has an atmosphere (a thin gas cover) and plasma (fast charged particles) which are moving around in space above it. Auroras take place those particles which come from the ionosphere with an extremely high velocity due to the solar wind, come into the Earth's atmosphere and strike other atoms and molecules. When the particles collide, that energy which was used to give velocity will change into a light which is the aurora. The Earth’s magnetic field steers the particles poleward. When a particle reaches the atmosphere it collides with one of the many present atoms such as oxygen and nitrogen. When this happens, the atom takes attains some of the energy that had given the particle its velocity.

This process of colliding with other particles continues until it has no more kinetic energy and this happens around 100km above the surface of the Earth. When there are many particles colliding at the same time, an aurora forms.

“The energy source for the aurora is 149 million kilometers (93 million miles) from Earth at the sun” (Slanina 2007). Protons and electrons for the most part also known as plasma, which are the byproducts of thermonuclear reactions occurring inside the sun and is imprinted with solar magnetic force are constantly emitted by the sun. “These charged particles make up the solar wind, which travels away from the sun through space at speeds ranging from 300 to 1,000 km/sec making it so that the solar particles can reach the Earth in two to three days” (Slanina 2007). At Earth, the steady solar wind is deflected by Earth's magnetosphere for the Earth is an obstruction to the solar wind. The solar wind flows around the magnetosphere in a way that produces a stretched and elongated comet shape with a long tail, instead of symmetric set of magnetic field lines. “These floods of electrons, which link the magnetospheric dynamo with the ionosphere, are called field-aligned, or Birkeland, currents. Their symmetry accounts for the mirroring of northern and southern auroras” (Savage 1995).

Figure 1. Birkeland currents showing the symmetric currents producing similar northern and southern auroras (Savage 1995).

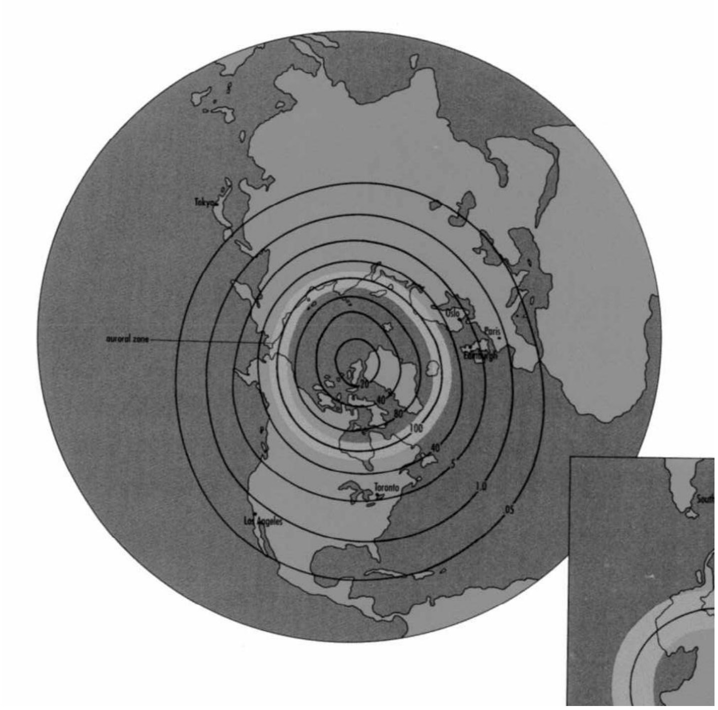


A disturbance in the solar wind is caused by a disturbance of the sun which is caused by a solar flare or something of the like. "The solar wind powers the gigantic electrical discharge process, causing the magnetosphere to behave as a generator that produces up to ten million megawatts of electrical power"[5]. A disturbance in the balance between the solar wind and Earth's magnetic field is then produced. The solar wind particles striking the boundary at an angle of incidence θ exert a pressure on the boundary given by the relation $p = knmv^2 \cos^2 \theta$ where n, m, and v are the particle concentration, mass and velocity, and k is a constant The angular factor of that equation is the most important nonetheless. The surface currents in the boundary are related to B since $B = \mu_0$j and the pressure is balanced by the magnetic pressure of $B^2/2\mu_o$ of the tangential field on the other side of the boundary (Jones 1974). Because disturbance between the solar wind and magnetic field, the electrons and protons are accelerated within the magnetosphere which these charged particles are forced to the magnetic field lines. These accelerated particles will travel down Earth's magnetic field lines and collide with the atoms and molecules in the upper atmosphere where the magnetic field lines come down to Earth's surface around the north and south magnetic poles. The rate at which ions are produced can be given in a simple approximation where the rate at which "ions are produced is n_i, ions are lost at a rate, L, shown by $L = \alpha n(M^{+})n_e$ where the alpha is the effective recombination coeficient, n(M^{+}) is the ion concentration and n_e is the electron concentration. An equation governing the electron concentration is $\frac{dn_e}{dt} = \frac{n_i}{1+lambda} - \alpha n_e^2$ and when it is in the steady state is is $n_{e\infty} = \sqrt{\frac{n_i}{(1+lambda)\alpha}}$ " (Jones 1974).

This is now when an enormous amount of energy hits the magnetosphere in the space of a second; however, just a small fraction of that energy even reaches the magnetosphere to go into producing the aurora "The auroral light is produced by a high-vacuum electrical discharge" (Geophysics 2006). So, when the particles from the magnetosphere collide with the atoms and molecules of the atmosphere, the particle's energy can be transferred to the atoms and molecules (typically O, N, and N_2) of the atmosphere forming excited states of O, N and N_2. When these finally release their energy and return to their normal ground state, they give up energy in the form of light. This is the light that we see from the ground as an aurora (Slanina 2007).

Auroras form in an oval band centered at each magnetic pole. The width of the band ranges from 10 to 1,000 kilometers and it is approximately 3,000 km from the magnetic pole during quieter solar periods. Auroras stay above 95 km because at that altitude the atmosphere is so dense that they finally come to rest at this altitude. On the other hand, auroras typically do not reach higher than 500-1,000 km because at that altitude the atmosphere is too thin to cause a significant number of collisions with the incoming particles.

Figure 2. Auroral oval band centered at one of Earth's poles (Savage 1995).



A prime viewing location in the northern hemisphere includes Fairbanks, Alaska. As auroral activity increases, the aurora not only increases in brightness, but it also tends to move further towards the equator. Auroral activity is directly linked to disturbances in Earth's magnetic and electrical current system. These increases in activity are known as geomagnetic storms. Geomagnetic storms and the resulting auroral activity, vary unpredictably throughout the year. Because geomagnetic activity often results from events on the sun, it can be predicted by looking at the sun and solar flares. For this reason, auroral forecasts can only be made two or three days in advance. Since 1979, NOAA's polar-orbiting satellites have been measuring the energy flux of particles into the auroral zones to make such predictions (Slanina 2007). As aurora change in brightness, electric currents associated with and near to them change and create a changing magnetic field. This changing magnetic field generates electric currents in conductive materials such as the earth and in electric power lines and pipelines. The magnetic field generated by the changing electrical currents in the aurora travel quickly to the surface of the earth. Scientists monitor the magnetic field of the earth and the disturbance of the earth's magnetic field by aurora with an instrument called a magnetometer. Using the magnetometer it is possible even during the daytime to determine whether auroras are taking place (Geophysics 2006). A magnetic substorm is a local disturbance in the magnetic field acting in the auroral zone. The storm lasts about 10-30 minutes and is followed by strong auroras. The substorms are due to changes in magnetic fields and charged particles in the magnetotail, which is why they are also called magnetospheric storms (SISP 2009).

The aurora has a variety of shapes, colors, and structures, and can also change rapidly in time. During a typical night, the aurora often starts as a single long arc that stretches in an east-west direction. Near midnight, the arc may begin to brighten. The arc has indistinct edges and is green. Then curls or waves may start to form along the arc. It may also start to have vertical structures that look like thin tall rays of light. Then, just about midnight, the whole sky may become filled with bands and rays that move rapidly from horizon to horizon showing Earth's magnetic field. The length of an aurora arc can be quite large, maybe 1000 kilometres or more, but the width can be as small as 100 metres. This heightened activity can last anywhere from a few minutes to several hours while the most intensive phase of an aurora normally lasts only for about 10 minutes.. As dawn approaches the aurora will typically quiet down and form wispy quiet patches that can last until morning. While this may be a typical night of aurora, any number of variations on this theme may occur. Directly beneath an aurora in the direction of the magnetic field is the corona which is where the rays look like they are all coming from one point and radiating in all directions. The most active auroras occur during sub storms. When the magnetosphere gets rid of most of the surplus energy related to a sub storm you can often see a different type of aurora, pulsating auroras. The sky will be filled with pale light spots that are switched on and off independently of each other and at different speed; the spots are lit for a few seconds. This type of aurora is common after midnight. The most commonly occurring auroras are not so easily noticed, since they have no shape. This is the indistinct aurora that lies like a faint glow across the sky(SISP 2009). They give up this energy in the form of light upon returning to their initial, lower energy state. Also, according to *Aurora* by Allister Valence Jones, when the electrons are colliding with other particles in the atmosphere, there is a loss of energy, producing such reactions called 'quenching reactions' where M is the kth quenching particle and X the excited particle with is quenched from the nth excited state. In the steady state, the excitation rate n(X, n), the quenching term and the radiation transition probability A(n, m) are related by the equation $(X, n) = [A(n, m) + k_Q n(M)] n(X, n)$

which makes $n(X, m) = n(X, n)A(n, m) = \frac{n(X,n)}{1+\left(\frac{k_Q n(M)}{A(n,m)}\right)}$ which is the emission rate per unit volume. The general expression for the emitted intensity of the transition from the nth to the mth state is $n(X, n, m) = n'(X, n)b(n, m)q(n)$ (Jones 1974).

"The two main atmospheric gases involved in the production of auroral lights are oxygen and nitrogen where Oxygen is responsible for two primary auroral colors: green-yellow wavelength of 557.7 nanometers (nm) is most common, while the deep red 630.0 nm light is seen less frequently; and Nitrogen in an ionized state will produce blue light, while neutral nitrogen molecules create purplish-red auroral colors" (Slanina 2007). Very rarely red aurora only happen a few time during solar maximum and have a wavelength of 630 nm, the ordinary green has a 558 nm wavelength from atomic Oxygen, and purple with a 428 nm wavelength from ionized Nitrogen molecules (SISP 2009).

Some people are convinced that the aurora has a sound, while others say that it is impossible. Scientists doubt because the sound is made of waves that travel at a slower speed than the speed of light therefore making it so that the sound could not possibly be heard at the same time as the light is observed for the sound would take about five minutes to reach the Earth.. Nonetheless, people supposedly notice these auroral sounds during calm weather when the aurora has moved quickly and directly above the listening person's head (SISP 2009).

The aurora is a near daily occurrence somewhere on Earth and there is almost always an aurora in the sky (both day and night, but in the daytime it is out-shined by sunlight). It is better to look for auroras at night because they do not have a strong intensity, not to mention they are stronger and therefore brighter at midnight. Also, they are more visible during the winter because its cold, clear, and dark in the northern hemisphere. Auroras also depend on the Sun's rotation of twenty-seven days. There are active spots on the sun which produce a stronger aurora when facing the Earth. The Sun's solar cycle (11years) also plays a part in an aurora's visibility. Every eleven years the sun becomes very active generating more auroras with wider arcs extending further away from its respective pole. Weather, the full moon, and light pollution also affect your ability to see aurora (Slanina 2007).

A solar flare is a violent explosion in the Sun's atmosphere with an energy equivalent to tens of millions of hydrogen bombs. Solar flares take place in the solar corona and chromosphere, heating plasma to tens of millions of kelvins and accelerating the resulting electrons, protons and heavier ions to near the speed of light. Electromagnetic radiation across the electromagnetic spectrum at all wavelengths from long-wave radio to the shortest wavelength gamma rays is produced because of solar flares. Most flares occur around sunspots, where intense magnetic fields emerge from the Sun's surface into the corona. The energy efficiency associated with solar flares may take several hours or even days to build up, but most flares take only a matter of minutes to release their energy (Science Daily 2010). While coronal mass ejections can cause larger plasma storms that last for more than 24 hours, deformation of the magnetotail can create smaller substorms that last just a few hours. But scientists disagree on the precise order of events between the solar wind and the substorm. Some say that the key step is a disruption, which occurs about 60,000 kilometres away from the Earth, in the electrical current that travels across the magnetotail. However, some other scientists say that the first step is actually a realignment of the Earth's magnetic field some 120,000 kilometres away, roughly one-third the distance to the Moon (Dance 2008).

Research with rockets and satellites has been done in such a way that makes viewing the particles of the aurora easier. Particles that make auroras possible do not reach the ground-they are stopped by the Earth's atmosphere which this makes it difficult to study those particles. To study the behavior of the particles, instruments must be sent to make measurements in the higher atmosphere. The instruments payload are sent into space with a rocket or satellite. The upper atmosphere contains, at the lower edge of the aurora, a thin and partly ionized layer called the ionosphere. Reflected by the ionosphere, radiowaves can propagate great distances by bouncing between it and the ground. In space, data is translated into radio signals from the different instruments which are then are transmitted to a receiver on Earth, where magnetic tapes record them. Usually, the ground station can only reach the satellite during a period of its orbit; therefore, the data is often stored in memory banks on the satellite until the next contact with

Earth. Measurements from the ground are also very important. Ground measurements are more advantageous than space measurements in that all the measurements can be performed at the same location where the rocket or satellite would be constantly moving, and it is possible to repair the instruments if they break down[4]. Scientists are able to measure the gyrofrequency, Ω, of the particle which is related to the angular frequency and propagation constant of the wave, ω, and k respectively, by the equation $\omega = \Omega k v_R$. The phase velocity of the wave is ω/k. The expression for the wave velocity the energy for interaction, E_R is found to be $E_R = \left(\frac{B^2}{2\mu_o n_e}\right)(\frac{\Omega_e}{\omega})(1 - \left(\frac{\omega}{\Omega_e}\right)^3$ where n_e is the plasma density which controls the wave velocity. And the wave amplitude can be shown to increase as ext(*y*t) where

$\gamma = \pi\Omega_e \left(1 - \frac{\omega}{\Omega_e}\right)^2 n(v_R)(A - 1/((\Omega_e/\omega)\text{-}1))$ where n(v_R) is approximatley the fraction of the electrons per unit parallel velocity interval in the neighborhood of the resonant velocity (Jones 1974).

The Aurora will never cease to mystify the casual observer nor the experienced, knowledgeable scientist. Still, its secrets have yet to be unfolded, but each day brings something new to the table. What was once fact can be disproven as many scientists have done throughout the ages trying to define the auroras.

Notes

1. "Solar Flare," Science Daily, accessed February 26, 2011, http://www.sciencedaily.com/articles/s/solar_flare.htm

2. Dance, Amber. "Aurora's source found by string of satellites" *NatureNews.* (2008)Accessed March 29, 2011, doi: 10.1122/science.1160495.

3. *The Encyclopedia of Earth.* ed. Sjaak Slanina Last revised Date April 17, 2007; Accessed March 29, 2011, s.v. "Aurora Borealis" http://www.eoearth.org/article/Aurora_Borealis

4. Swedish Institute of Space Physics, "Northern lights (Aurora Borealis)." Popular Science. http://www.irf.se/Popular/?docid=1132 (accessed March 29, 2011) (updated November 19, 2009).

5. Geophysics Institute, "The Aurora Explained." Alaska Science Explained. http://alaskascience.com/aurora.htm. (accessed March 28, 2011)(updated 2006).

6. Savage, Candace. *Aurora-The Mysterious Northern Lights.* San Francisco, CA: Sierra Club Books, 1995.

7. Jones, Alister Vallance. *Aurora.* Boston, MA:D. Reidel Publishing Company, 1974.