The Aurora Borealis

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The Aurora Borealis, found in the northern hemisphere—or the Aurora Australis as it is called in the Southern Hemisphere—is most easily explained colored lights that appear in the sky due to the combination of solar winds and the earth's magnetic field. For years the phenomena has been observed by cultures around the world. These strange occurrences were named and explained in many different ways by each of these cultures. In Ancient times, Auroras were often believed to be caused by magic, spirits, or a sign from the gods. The oldest account of the Aurora Borealis is thought to lie within the Old Testament, where a few possible references to auroras are made. One reference is believed to be in Ezekiel chapter one, where Ezekiel recounts a vision he saw in the clouds in which he describes "brilliant flashing lights". Aristotle believed that they were formed when heat from the sun caused steam to rise from the ground, which then hit the fire element, ignited, and created the Aurora (Finland: History 2). When King Philip II of Macedonia planned to dig under the walls of Byzantium, his plans were foiled when the bright lights from the Auroras blew his men's cover (Finland: History 3). It would be a long time before people were anywhere close to being able to explain this mysterious event.

As for actual scientific research, it would be the 17th century before the term "Aurora Borealis" was coined by French scientist Pierre Gassendi (this is contested though, since there is some evidence that links Galileo as the one who named it) (Polar Aurora 1). It wasn't until 1716 that there would be any accurate scientific statements about the auroras. Sir William Halley, an English scientist famous for the discovery of "Halley's Comet" predicted that "Auroral rays are due to the particles, which are affected by the magnetic field; the rays are parallel to Earth's magnetic field and the vault like shape is due to perspective phenomena" (Finland 6). Over the years, many theories proposed that the light had something to do with gases. This was proven true by Anders Angstrom, a Swedish physicist and one of the founders of spectroscopy. Angstrom focused much research on the solar spectrum, which led to his conclusion that the sun was composed of Hydrogen and other gases. He then focused his research on the Aurora Borealis in 1867, when he discovered the characteristic bright line in its yellow green region. Finally, in the late 1950's, it was proven that "the particles which excite the atoms and molecules are mostly electrons" (Anders 1). The aurora's many different forms, physical features, and other elements culminate in an amazing display of physics.

The more complicated explanation for what causes the aurora—that the aurora results from an electrical discharge process which is powered by the solar wind-magnetosphere dynamo (Akasofu 1)—is what I will attempt to simplify. First, we must define what the "dynamo" is. Dynamo theory is the explanation of how a body in space generates its own magnetic field. The Earth is one such body in which "if an electric conductor moves with velocity, V, in the presence of an inducing magnetic field, B, an electromotive force (emf), VxB, is set up by which in general drives electric currents" (Roberts 1). In plain English, this means that in order for a planet to produce a magnetic field, it first must be composed of a liquid that can conduct electricity. Then, the planet must be able to "churn" the liquid (caused by its spinning) which produces an electric current. This current then feeds the magnetic field. The entire process can be thought of somewhat like a motor. To reiterate, it is believed that:

> "Fluid motion in the Earth's outer core moves conducting material (liquid Iron) across an already existing weak magnetic field and generates an electric current. The electric current, in turn, produces a magnetic field that also interacts with the fluid motion to create a secondary magnetic field. Together, the two fields are stronger than the original and lie essentially along the axis of Earth's rotation" (Britannica 1).

It is important to note though that this may not be the case for all planets, as scientists believe that moons, or satellites, may also be able to create a dynamo. (Britannica 1)

The entire process of the aurora borealis begins millions of miles away, at the Sun, with solar winds. Due to the extreme temperatures of the Sun's corona, a pressure that is greater than the force of gravity is exerted. This force pushes out charged particles composed mainly of electrons, but contains neutrons and protons as well. This plasma is shot into space in all directions. This plasma can travel as fast as 300 – 1200 $^{km}/_{s}$ (Finland: Splendor 2). This stream of plasma is then called a solar wind. As this solar wind approaches a planet with a strong magnetic field, such as the Earth, it encounters the magnetosphere.

To understand the idea of the magnetosphere, one must remember that the Earth is really just a gigantic magnet. As such, the Earth produces invisible field lines around itself that extend out into space in the same manner that a magnet on earth would. For the Earth, these

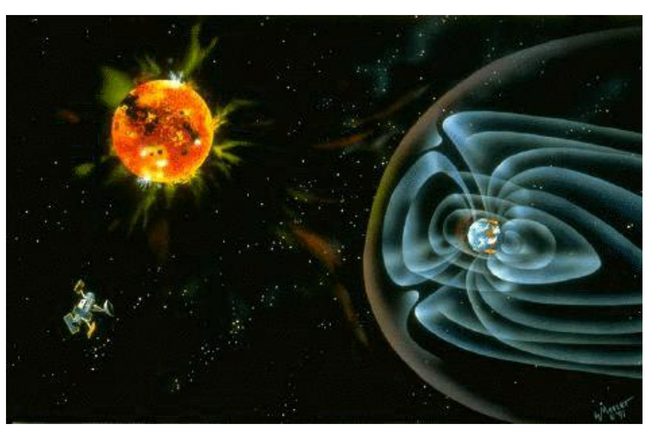
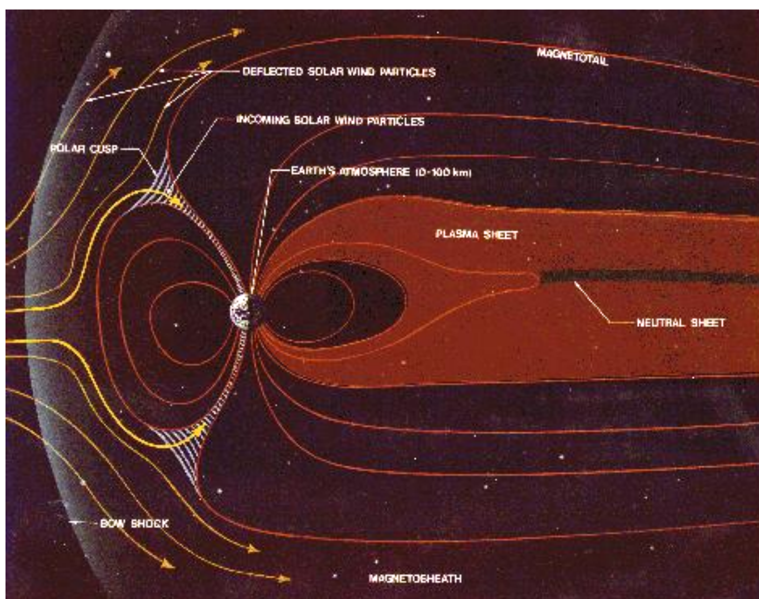


Illustration of solar winds and the magnetosphere.
www.odin.gi.alaska.edu

field lines serve as a line of defense against solar winds which would have already destroyed life on our planet were it not for Earth behaving like a magnet. These invisible lines around the Earth are known as the Magnetosphere. When the solar winds hit the Earth, the Magnetosphere on the side facing the Sun is compressed, which in turn causes those on the opposite side to be depressed, forming what is called the Magnetotail, which can extend many times the Earth's radius out into space (Paintings 2). This can also be thought of in much the same way as when flowing water collides with a rock in a river or stream. "One side is heavily exposed (the daylight side), while the opposite side experiences a vacuum of the flowing material (night side)" (Myths&Facts 3). During this time, most of the particles are pushed sideways by the Magnetosphere, but some are trapped between the Magnetotail and the poles and build up to thousands of volts. They are then discharged towards the north and south poles and follow the field lines down into the Ionosphere (Finland: Splendor 2). The Ionosphere makes up the inside of the Magnetosphere and is where the Earth's atmosphere is ionized by the solar winds (Ionosphere 1). Here, the fast traveling electrons collide with the gas



Picture showing different regions of magnetosphere, and other events occurring when solar winds collide with it.
www.science.nasa.gov

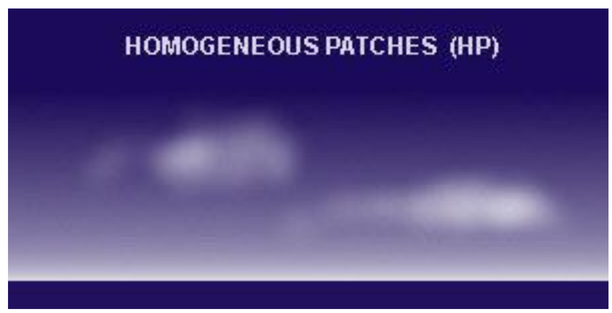
molecules in the Ionosphere, giving them energy and in turn causing them to produce light. Thus, an aurora is created.

To illustrate the effects of not having a magnetic field, let's take a look at Mars. Evidence suggests that it once had oceans which may have supported life. However Mars is now nothing but a barren wasteland. It is also known that Mars currently has no magnetic field, though it may have at one time. If this is true, then it is quite easy to explain what became of the water and life forms that may have inhabited Mars at one time. As was discussed earlier, the magnetic field serves as a shield, protecting a planet from the bombardment of the solar winds. If at some point Mars lost its magnetic field, then the solar winds would ravish the planet and destroy everything. Even if the planet never supported life and never had a magnetic field, then it has been enduring the solar winds since it was created and will likely not be supporting colonization anytime soon, unless of course Mars was to gain a magnetic field. Like Mars, Venus too is without a magnetic field and is in much the same condition.

The saying "no two snowflakes are ever the same" rings true with auroras. Descriptions can be very vague due to the amount of variation, but they are generally categorized into two different groups, which are then further broken down. The first group is made up of forms that appear to have little to no movement at all and contain the same level of brightness over long periods of time. These auroras are very dim and have no defining shape. They produce brighter "glows" that bunch together and give the appearance of clouds. The other group contains auroras that move quickly and whose brightness and shape fluctuate rapidly. This causes the auroras appear to "dance" across the sky. Auroras of this type include heterogeneous arcs without a definite shape or brightness and have rays that branch off the arcs; lone rays at varying distances that point to a single position and thus form a circle; and homogeneous bands with varying brightness and height α width (Angot 32).

1st Form
www.britastro.com

The first form of the first group, the dim auroras with no defining shapes, is considered the least significant of the auroras. They can cover very large distances, or very small ones. Sometimes their light is so low that they are easily missed or mistaken for something else. Next, the second form, or "cloud" auroras, often appears to be smoke, or even cirrus clouds (which are usually difficult to distinguish between, and often accompany one another). They are normally found alone, instead of in the presence of other auroras and often serve as a precursor to other forms. The third form, with clearly defined arcs that appear completely homogeneous, is found near the horizon and rarely strays very far from it. They lay completely motionless and can



2nd Form
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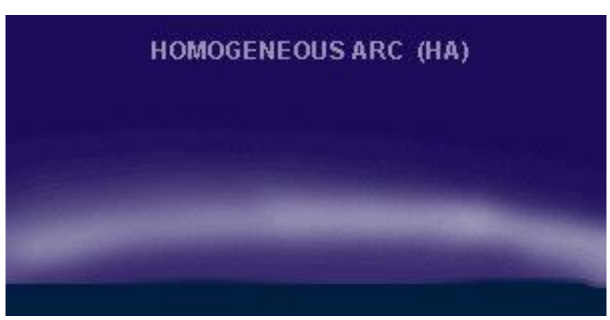

3rd Form
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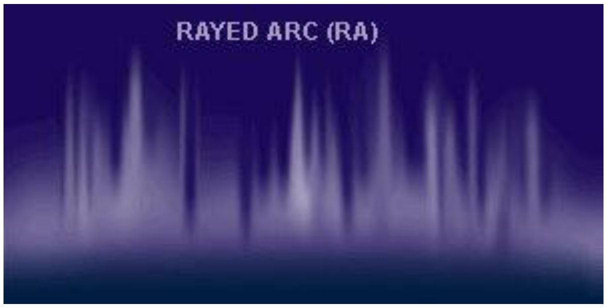
last for days. They range from circular elliptical and may have multiple arcs (Angot 21).



4th Form
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The fourth form, which is part of the second group, contains a heterogeneous arc without a definite shape and can move at fast rates, characteristic of its group. Some have been known to move as much as seventeen degrees per minute. The summit of the arc is generally found to be very close to the magnetic meridian (or line of longitude), varying by just a few degrees. The rays that break off tend to point in the same direction as a magnetized compass. They can also have multiple arcs. Two or three arcs are quite common, though many more have been seen before. The arc appears to move in the same direction as its length. It has been theorized that this is because parts of the arc (i.e. the rays) remain dim, and then, one at a time, will quickly become brilliant, and then fade away. Then, the entire process begins again with the next ray. With enough speed, it would be impossible to discern whether the arc was really moving or not. Another key component of auroras in general, which is often seen in this form, is a dark segment which can be seen before or during an aurora. It appears on the lower portion of the arc of the aurora and is not opaque, because

5th Form
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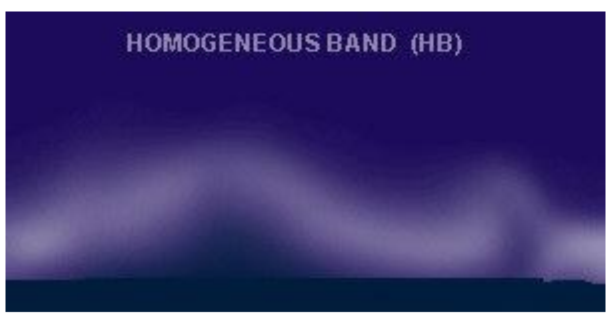
the light from stars can be seen through it. Little is yet known about the dark segment, though a few contested theories exist.

The fifth form of auroras, rays without an arc, often form circles that can extend very large distances. They are shafts of light that follow the Earth's Magnetic field lines and tend to extend vertically (Eather 3). Occasionally, they will form a circle with the rays directed outward. This is referred to as corona, which is Latin for crown. These rays are much more defined and produce enough light to be reflected off of certain material on the ground (i.e. ice, water, etc.). They have irregular movements which give them the appearance of "dancing" across the sky, which has been noted (and is the origin of the names given to them) in many different cultures across the world. Finally, we have the sixth form, auroral bands, which are also said to look like curtains. Bands are varied in form. Generally, they are clearly outlined, display the brightest colors, and

Corona created by Rays
www.britastro.com



6th Form
www.britastro.com

move in a very smooth, wavelike fashion across the sky. Aside from the curtain appearance, they can also be arranged in a long snaking pattern, going back and forth across the sky. Sometimes, they can be a combination of the two arrangements.

There are many physical properties that define the aurora as well. They come in a range of colors that become quite vivid the more defined the aurora becomes. The general color of the aurora depends on the elements that are contained in the air of the ionosphere. The vast composition of air is Nitrogen and Oxygen, which means that most auroras will have a green or crimson hue. However, the air is also composed of small amounts of other elements, which creates the other colors that are visible. Dark to light hues ranging from pink to red and blue to purple are common as well. Another factor of an aurora's color is the height, or altitude, of the aurora (Colors 1). Generally, the lower altitudes tend to produce green auroras more often, while a red hue is often seen in higher altitudes. This is because for a red photon to be produced, it can take nearly two minutes for an oxygen atom to return to ground state, when the photon is emitted. In this time, a collision with another particle will transfer the photon's energy, and thus the photon will not have enough energy to be produced. The higher the altitude, the less dense the atmosphere is; this means there is a greater chance of not colliding with other particles and thus a greater chance of the red hue being emitted (Lummerzheim 4). It is interesting as well to note that some people believe auroras to

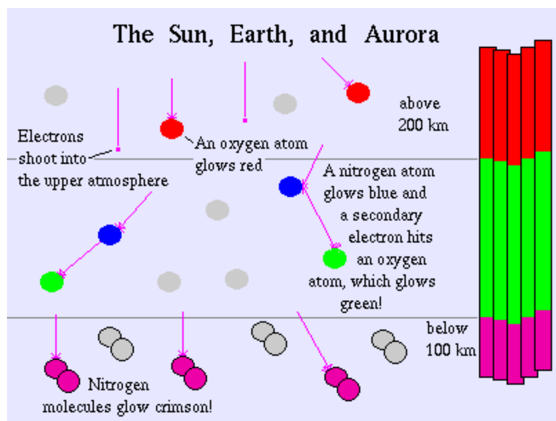


Chart detailing variance Aurora colors, and their variants based on altitude
www.ffden-2.phys.uaf.edu

produce sounds and smells, though this has yet to be proven and is very disagreed upon amongst the scientific community. For the idea of sound, it is generally thought to be impossible primarily because of how high up they occur. At this distance, the atmosphere should be too thin to carry sound waves, plus it would take sound waves about 5 minutes to traverse the distance. Yet, people still claim that they hear something, and is commonly described as having a whistling or hissing sound (Lummerzheim 11).

The secrets of the Aurora Borealis, a phenomenon that has baffled scientist for years, are slowly being exposed thanks to new developments in science and technology. But there are still many questions to be answered about the aurora itself and the earth's magnetic field, and there is lots of research to do in this area. Currently there are no answers to the question of what causes the variation in the different forms of the aurora. It is also unknown what exactly to expect of the coming flip of the poles, expected to occur sometime in the next few thousand years. Will this lead to Earth being vulnerable for a short time, a very long time, or perhaps will there be an immediate switch? Current evidence suggests that while the Earth's magnetic field will likely be very weak for a "short" amount of time, everything should be fine. Fossil records of creatures that went extinct due to a magnetic field switch have yet to be found. This could partially be due to the fact that even with a weak magnetosphere, our own atmosphere is sufficient at blocking out harmful radiation (Odenwald 2). So will life on Earth be able to continue? It should, but only time will tell for sure. The Earth is not the only planet which has magnetic fields and, thus, is not the only one to experience auroras. There is much that can be learned about the Earth's magnetic field, the dynamo theory, and the entire universe itself by studying these planets, which may even lead to a better understanding of what to expect when the poles flip. On Jupiter, the auroras (which are vastly more powerful than Earth's) are believed to be powered by one of its moons, Io, as opposed to being created by solar winds, which are deflected far away because of Jupiter's giant magnetic field. Scientists believe that when volcanoes erupt on Io, they shoot out charged particles, which are then picked up by Jupiter's magnetic field (Anne 2). There is much studying needed to be done on how Jupiter's dynamo is created. The theory is that the motion of Io, which is a conductor, and perhaps other satellites, create part of the electric current that is crucial for the idea of the magnetic dynamo. Regardless of the planet, the aurora borealis is evidence of much larger things at play. And while it is a beautiful sight to behold, it is a reminder of one of the many things that makes life possible.

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