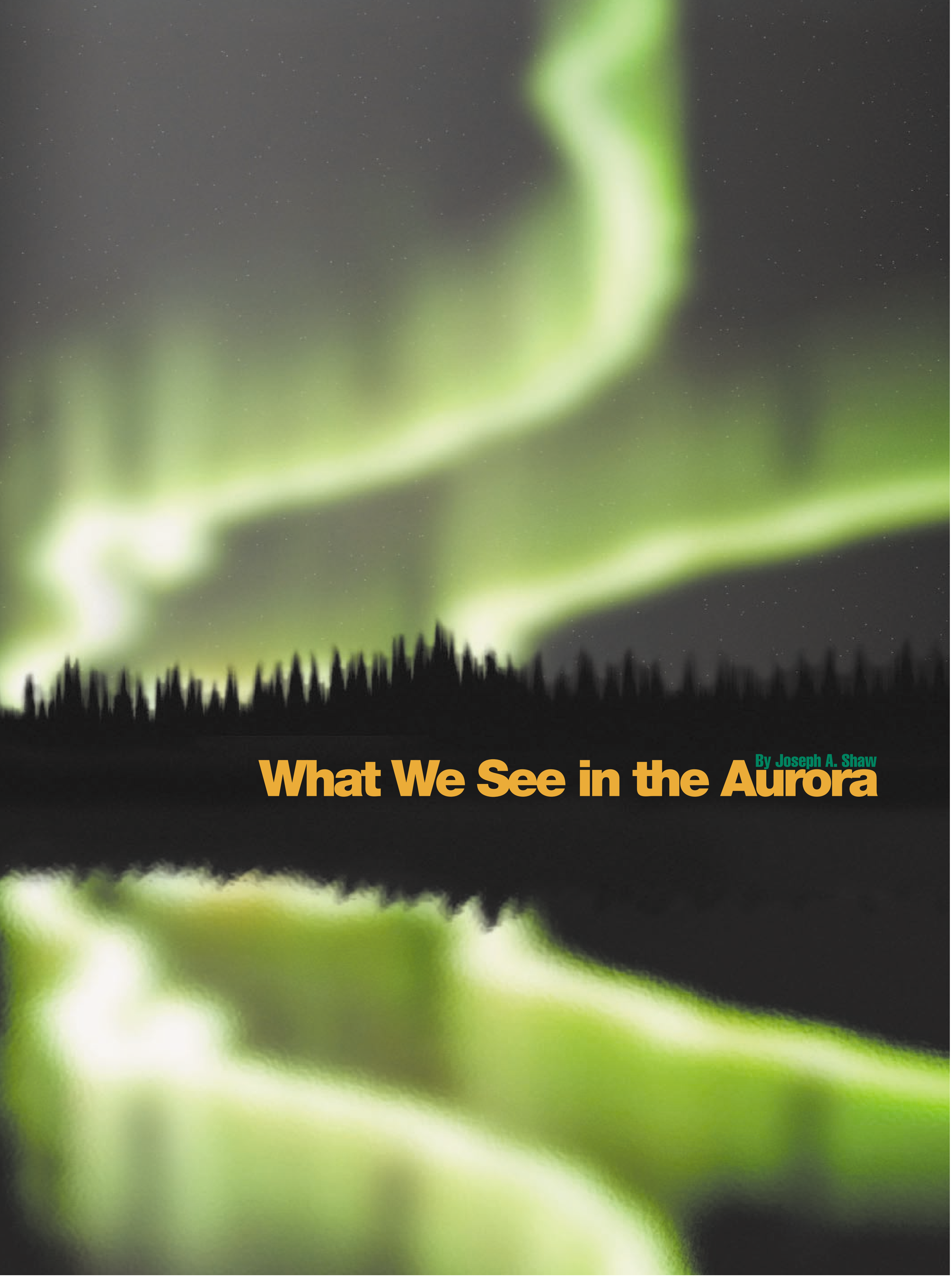


What We See in the Aurora

By Joseph A. Shaw

Of all nature's optical splendors, the aurora may be the most spectacular. The aurora captures audiences like few other natural phenomena because of its relative rarity in populous regions, since it occurs primarily at high latitudes, near midnight. The best time to see an aurora is during fall, winter and spring, when the sun is scarce. For this reason, even the large number of visitors to places like Alaska rarely see auroras because they tend to plan their trips in the summer, when the sun lights the night sky. The next few winters should offer greater opportunities for viewing the aurora because the eleven-year sunspot cycle, to which auroral activity is closely correlated, is reaching its maximum.

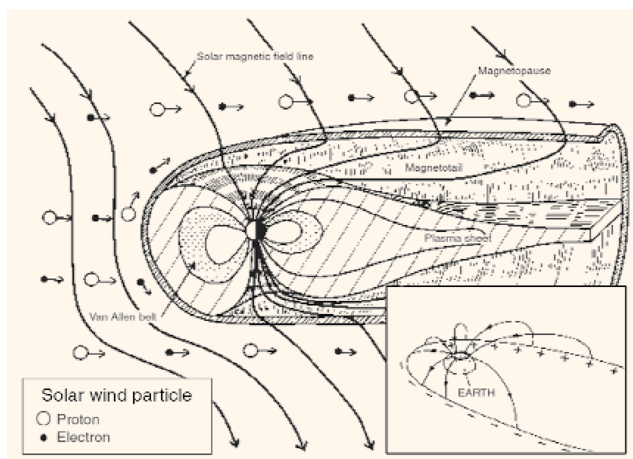
The aurora is a particularly spectacular optical phenomenon because of its great variety: the aurora's color, shape, and motion change, sometimes slowly, sometimes rapidly, before the viewer's eye. On some long, quiet Arctic nights, the aurora takes the form of a dim green glow on the horizon; on other nights, the colors of the aurora swirl and dance overhead like a grand ballet. Even people who have lived long under the aurora's splendor pause on such nights to stare skyward.

What causes the aurora

The aurora[1–5] occurs at high latitudes in both the Northern and Southern Hemispheres. The Aurora Borealis (Northern Lights) and Aurora Australis (Southern Lights) occur simultaneously, and as mirror images. Charged protons and electrons in a plasma called the solar wind stream out from the sun, and throughout the solar system, at a speed of about 500-1,000 km/sec. The electrically conductive solar wind is deflected by the earth's magnetic field so that it flows in a long, cylindrical region around the earth; this region is called the magnetosphere (Figure 1). Sometimes, when the solar wind blows it causes the sun's magnetic field lines to stretch out and interconnect with the earth's magnetic field. Charged particles of the solar wind blowing through these interconnected magnetic fields generate huge quantities of electricity, up to a million megawatts (the largest man-made generators produce about a thousand times less). The interaction of the solar wind with the geomagnetic field causes electrical currents to flow in a great circuit, incorporating a vast region of space around the earth. These currents intersect the ionosphere in a large, nearly oval region centered approximately on the Geomagnetic Poles.

At this point the charged particles begin colliding with atmospheric gas molecules, creating bursts of light; the colors of these bursts of light are determined by the energy emitted in the collision. These collisions occur as part of a process similar to that which takes place inside a neon light. In a neon sign or other low-pressure gas discharge tube, high voltage is applied to the electrodes at each end of a glass tube. The tube contains a small amount of gas at a low level of pressure, similar to that which characterizes the upper atmosphere where auroras occur. Inside the tube, electrons collide with gas molecules as the electrical discharge current flows from one electrode to the other. Light is emitted as a result of these collisions; the color of the light is determined by the energy of the process, and therefore by the type of gas involved in the collision. The colors of the aurora are determined by a similar process, except that in this case the electrons strike atoms or molecules of oxygen and nitrogen in the upper atmosphere, and the colored patterns wander freely with the geomagnetic field in complex patterns.

The most common auroral color is pale green (optical wavelength of 557.7 nm), due to emission by atomic oxygen approximately 100 km above the earth's surface. Bright red seems to be everyone's favorite auroral color, perhaps because it is relatively rare. The most common red, created by emission from nitrogen molecules, is a pinkish-red fringe at the bottom of a green auroral arc. During particularly intense auroral activity, one might see large regions of bright-red aurora situated above the green emission. This red is emission from oxygen atoms higher in the atmosphere than the green-emitting oxygen. Because of its height and the intensity of the magnetic storms causing it, this relatively rare bright red color can be seen in most auroras visible from mid-latitudes.



Courtesy of the Geophysical Institute, U. of Alaska-Fairbanks

Figure 1. The solar wind consists of charged particles (electrons and protons) streaming away from the sun. This stream is deflected by the earth's magnetic field, creating a long, oval-shaped region called the magnetosphere, which extends for many earth radii beyond the night side of earth and about 10 earth radii in front of the day side. The interaction of the solar wind and the geomagnetic field comprises a magneto-hydrodynamic power generator that is the aurora's energy source. The inset indicates the electrical circuit between the earth and the magnetosphere, intersecting the atmosphere on the auroral oval.

Where and when to see the aurora

The best place to see the aurora is from beneath the "auroral oval," a doughnut-shaped area floating above the earth's polar regions like a loose, rotating crown. It is always tilted away from the Pole, toward the night side of the planet. In the Northern Hemisphere, the oval often lies over central Alaska, Canada, and northern Europe (Figure 2). The probability of seeing the aurora decreases as one travels either south or north of these regions (Figure 3). During intense solar activity, the auroral oval expands, bringing the aurora to locations further south than usual. Also, the oval drops farther south on the east side of the United States than it does on the west, so people living in the northeastern states have a higher probability of seeing auroras than do those in the northwestern states, cloud cover not withstanding.

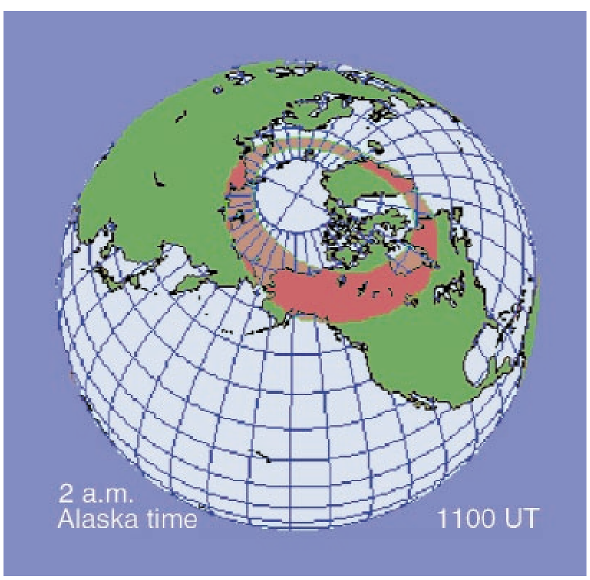
The aurora is most frequently visible at mid-latitude locations during the maximum of the sunspot cycle, which will take place next around 2000–2001. The strong magnetic storms required to bring the aurora to the mid-latitudes occur as a result of intense solar flares near a large group of sunspots. At high latitudes, the aurora tends to occur more frequently in the declining phase of the sunspot cycle, in the years just after the sunspot peak. Besides clouds, other factors influencing auroral visibility include interfering light from cities, the sun or the moon. Unfortunately for human observers, the clear Arctic nights that are best for viewing auroras are also often extremely cold! Because of this, it is nice to have a warm house or a warm vehicle close by—with the lights turned off, of course. To avoid the intense mid-winter cold, the best aurora viewing seasons are late fall and early spring, which offer frequent auroras and sufficiently dark skies, but usually warmer temperatures.

Photographing the aurora

If you wish to capture the aurora on film, you will need at least a tripod and a camera with a "bulb" setting that allows you to lock the shutter open for a long time. It is best to use a camera not entirely dependent on battery power; otherwise you will have to find a way to keep the battery warm. Most modern, electronic 35 mm cameras last minutes, at best, outside on cold winter nights before the battery freezes. Because of this, I prefer to use older manual cameras with a shutter-release cable; other options are heating pads or external battery packs that can be kept inside your coat.

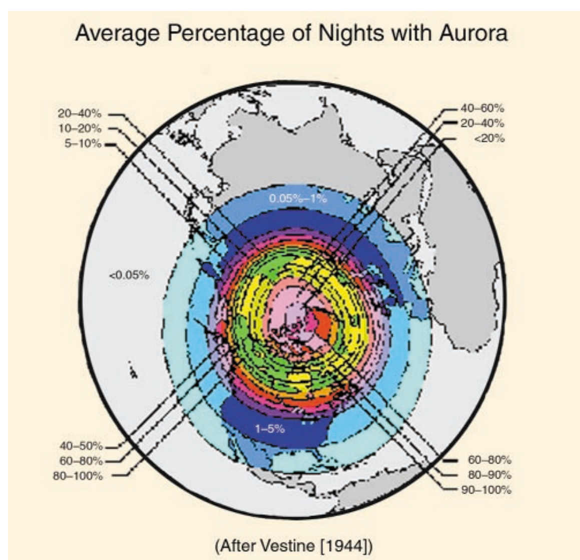
Reasonably fast film and lenses help you capture the aurora with minimal blurring, especially during rapidly moving displays. The photographs in Figures 4 through 6 illustrate the variety of auroral colors and forms, and also give an idea of the photographic technique employed. Figure 4 shows a calm, sweeping, green aurora photographed with a Nikon EL2 camera and a 28 mm f/3.5 lens in October 1998 at Fairbanks, Alaska (65° N); the exposure was 40 seconds on Ektachrome ISO 1600 film. Figure 5 is a more dramatic aurora, showing vertical ray structure and high-altitude red emission: it was photographed with a Canon AE1 camera and a 24 mm f/2.8 lens, on Ektachrome ISO 1600 film, with a 15 second exposure, in February 1990 in Snow Lake, Manitoba, Canada (~55° N).

Figure 6 should provide motivation for mid-latitude photographers to watch carefully for auroras during the next few years. This photograph was taken at Nederland, Colorado (~40° N), in the Rocky Mountains just west of Boulder, on June 4, 1991. The exposure (~30 s, f/1.8 on ISO 1600 film with a Canon 50-mm lens) may enhance the color intensity somewhat beyond what can be seen with the naked eye, but this is an impressive example of the best aurora I have seen photographed at such southern latitudes. Not only did this display occur at a modest latitude, it also occurred during the summer. At the Alaskan and Canadian locations that were the sites of the photographs depicted in Figures 4 and 5, this aurora would not have been visible because of the bright, sunlit nocturnal summer sky. This photograph was taken during the declining phase of the solar cycle, immediately after the last sunspot maximum in about 1989–90. Despite its intensity, this aurora would not have been readily apparent in proximity of bright city lights.



Courtesy of the Geophysical Institute, U. of Alaska-Fairbanks

Figure 2. The aurora occurs within an oval region centered on the earth's Geomagnetic Poles (both north and south). Shown here is a depiction of the northern auroral oval, extended further south than normal due to modest auroral activity. During periods of quieter solar activity, the oval's southern edge retreats northward.



Courtesy of the Geophysical Institute, U. of Alaska-Fairbanks

Figure 3. Average percentage of nights with aurora over the Northern Hemisphere. To calculate the probability of seeing the aurora, you must also consider the percentage of clear nights and the phase of the eleven-year sunspot cycle.

The "bad side" of the aurora

The same electromagnetic processes that produce wonderful auroral displays in the sky can create severe problems for human activities ranging from radio communication to electric power transmission. The incoming charged particles that cause the auroral colors also modify the earth's ionosphere (an atmospheric layer containing charged ions, existing between altitudes of approximately 80 and 400 km). High-frequency (HF) radio communications can exploit the reflectivity of the ionosphere to bounce radio waves over distances that are much longer than the allowable line-of-sight propagation. Indeed, before communications satellites, this was the primary method of long-distance communication. Solar disturbances which lead to aurora also greatly increase the ion density in the lower ionosphere, resulting in absorption of radio waves before they can be reflected. The process leading to auroras can also generate low-frequency radio waves, which are reflected by the ionosphere back into space, creating an intense radio signal that could be detected at long distances from earth much more easily than the visible aurora.

Another problem is what happens to electric power systems as a result of the fluctuating geomagnetic field associated with the aurora. Maxwell's equations, the mathematical basis of electromagnetic theory, tell us that an electric field is created by a time-varying magnetic field. Therefore, fluctuations in the geomagnetic field can induce electric currents to flow in any electrically conductive system that is grounded at different locations: examples are long-distance electrical power transmission lines and pipelines. During periods of intense auroral activity, the induced quasi-direct current can trip breakers or even burn out large electrical transformers, as well as promote corrosion in pipelines. One of the most famous examples of this kind of incident took place in March 1989, when Hydro Québec lost a major transformer during a particularly intense aurora: the result was a sweeping power outage throughout the region and the need to replace a very expensive transformer. As an undergraduate student at the University of Alaska-Fairbanks, I helped build and install instrumentation to measure geomagnetically induced currents in the Anchorage-Fairbanks intertie system that allows the exchange of power between the two primary population centers of Alaska. Today, this remains an active area of research.[6]

Figure 4. Mild green aurora in 1998 at Fairbanks, Alaska.

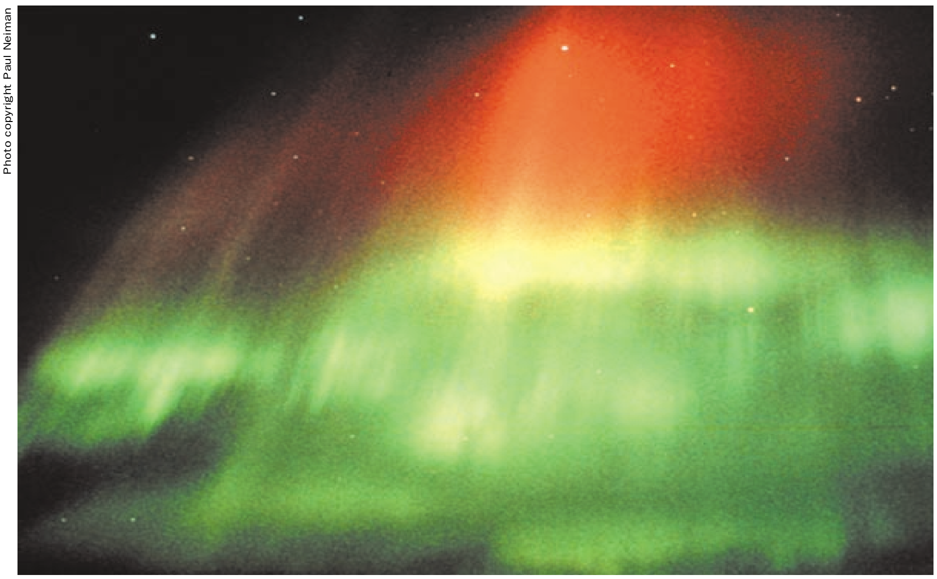


Figure 5. Active green and red aurora in 1990 at Snow Lake, Manitoba, Canada.

Teaching about the aurora

If you wish to teach students some basic principles, begin by demonstrating electricity generation with a conductor moving back and forth through a magnetic field. Point out that in similar fashion, auroral power is generated by the motion of charged particles carried by the solar wind through a magnetic field. In this case, the magnetic field arises from the interaction of the earth's magnetic field with the magnetic field carried from the sun by the plasma flow of the solar wind. The main point is that the charged particles flow across magnetic field lines, thereby generating electrical energy. Some of this energy then flows in a great circuit and discharges in the upper portions of earth's atmosphere, creating light.

The creation of different colors through electric discharge can be demonstrated simply by connecting gas discharge tubes (e.g., neon lights) to a power supply: the color produced depends on the type of gas the tube contains. Finally, if you have one to spare, an old television or computer monitor and a handheld magnet can be used to demonstrate how a moving magnetic field deflects the electron beam, resulting in a warped image on the screen.

Conclusion

These are just a few examples of what can be seen in the northern skies if you brave the cold. If you have always wanted to visit the far north or south, I recommend doing so in the next few years (or 11 years later). And avoid going in the summer! If you live at the northern end of the mid-latitudes, keep your eyes on the sky during clear winter nights, especially over the next few years. Long-term auroral predictions are not practical, so if you plan a vacation to view the aurora, be sure to allow plenty of time. A strong solar wind can reach the earth in about two days, so periods of intense sunspot activity suggest good auroras within a few days time. If you want to watch for auroras where you live, keep an eye on the solar activity forecast web page posted by the National Oceanic and Atmospheric Administration's Space Environment Center (http://www.sec.noaa.gov /forecast.html).

Acknowledgments

I gratefully acknowledge assistance from Professor Syun-Ichi Akasofu, Director of the International Arctic Research Center at the University of Alaska-Fairbanks, Professor Glenn Shaw of the Geophysical Institute, University of Alaska-Fairbanks, and Paul Neiman of the NOAA Environmental Technology Laboratory, Boulder. The graphics in Figures 1–3 were provided by the University of Alaska's Geophysical Institute (Figures 2 and 3 by Don Rice), and the photographs in Figures 5 and 6 were provided by Paul Neiman of NOAA/ETL in Boulder.

I dedicate this article to the memory of Professor Robert P. Merritt (1924–1999), who first taught me at the University of Alaska how the aurora affects electrical systems. Any errors in this article are mine, not his.

References

1. S.I. Akasofu, "Why do auroras look the way they do?" *EOS* (American Geophysical Union) **80** (17), 193, 198-99 (1999).
2. S.-I. Akasofu, "The Dynamic Aurora," *Scientific American*, **260** (5), 90-97 (1989).
3. S.-I. Akasofu, "The Aurora: new light on an old subject," *Sky and Telescope*, 534-37 (1982).
4. S.-I. Akasofu, *Aurora Borealis: The Amazing Northern Lights*. Alaska Geographic **6** (2), (1979; 1994 reprint). ISBN 0-88240-124-6.
5. T.N. Davis, *The Aurora Watcher's Handbook*. University of Alaska Press (1992). ISBN 0-912006-59-5 cloth, 0-912006-60-9 paper.
6. J.D. Aspnes, R.P. Merritt, and B.D. Spell, "Geomagnetic disturbances and their effect on electric power systems," *IEEE Power Engineering Review* **9** (7), 10–13 (1989).

Web Resources

Among the many great web sites for learning about auroras are those maintained by the Geophysical Institute at the University of Alaska-Fairbanks (http://www.gi.alaska.edu/ pfrr/aurora; http://gedds.pfrr.alaska.edu/aurora/); NOAA's Space Environment Center in Boulder (http://www.sec. noaa.gov/); the Public Northern Lights Planetarium in Norway (http://www.uit.no/npt/homepage-npt.en.html); and Michigan Technological University (http://www.geo.mtu. edu/weather/aurora). Be sure not to miss the great photographs by Jan Curtis at the University of Alaska's Geophysical Institute (http://climate.gi.alaska. edu/Curtis/ curtis.html). Photographs taken by the author and his colleagues will also be posted soon on the education/outreach portion of the NOAA Environmental Technology Laboratory web page (http://www.etl.noaa. gov).

Joseph A. Shaw (jshaw@etl.noaa.gov) is an electro-optical engineer for the NOAA Environmental Technology Laboratory in Boulder, CO.

Figure 6. Aurora with a large amount of red emission in 1991 at Nederland, Colorado.