THE SKY CHORUS

Our upper atmosphere is alive with "sounds" generated by particles and waves from the sun and deep space.

BY GARY EGGLESTON

During World War I, the German physicist Henrich Barkhausen discovered a way to tap Allied telephone conversations on the battlefield from behind his own lines. To do it, he inserted two prods into the Earth several hundred yards apart and connected them to a sensitive amplifier. That enabled him to pick up and amplify minute electric currents leaking into the ground from the Allied telephone wires in order to reproduce the communications.

Occasionally, he also heard something else that amazed him. He heard strange whistling sounds that completely swamped the conversations he was trying to listen to. Barkhausen's first reaction was that something was wrong with his equipment. After finding nothing wrong with his apparatus, he decided that the whistles were coming from the atmosphere. He was correct, but it would be many years before anyone understood what the odd sounds were or would care to pay any attention to them.

However, the sounds Barkhausen heard were not in the ordinary radio-broadcasting bands. Instead, they were long-wavelength signals that were so low in frequency, they fell into the audio band. A "whistler" (as the signals came to be called) begins at the upper range of the human ear and decays in pitch, rapidly at first and then more slowly at the lower frequencies. The sound can sweep down through several octaves in a second or two. Since the signals are in the audio range, it is only necessary to string up a long-wire antenna and connect it to the amplifier of a phonograph or radio to pick up one.

The Mechanics. People studying whistlers through the 1920's and 1930's noticed that a whistler often followed a loud click. Apparently there was some connection between the whistle and click. The source of the clicks was also in doubt at the time, but it was a lead. It was known that radio waves of different frequencies travel at different speeds through the atmosphere. Higher frequencies traveled faster than the lower ones. If a click traveled far enough, its frequencies would spread out in time. So a receiver would detect the high frequencies first, followed by the lower ones—just as a whistler behaved. Experiments later proved this theory.

The next theoretical point of interest was the path taken by a whistler. First it was necessary to determine the distance traveled by one. Since distance equals velocity multiplied by time, one would assume that's easy to do. However, while the time between the click and whistler (thus the travel time for the lowest frequency note) was known, the velocity of the wave could vary. A wave's velocity depends in part on the atmosphere's average electron density and the strength of the Earth's magnetic field along the path. By using an average value for the magnetic field strength and assuming the highest electron density, it was possible to estimate the minimum distance. The result was an astonishing figure of 15,000 miles; far beyond what was then thought to be the limit of the Earth's atmosphere, which was assumed to end at the ionosphere.

Thus, Barkhausen's discovery made it possible for us to study the regions beyond the ionosphere from the ground. These regions have been named the "magnetosphere." They begin where the ionosphere thins out so much that it no longer reflects radio waves back to us.

T.L. Eckersley correctly suggested in 1935 that whistlers originated from the energy in lightning discharges. The electromagnetic radiation given off by lightning bolts are commonly called "atmospherics" or "spherics." They travel in the space between the earth and the ionosphere or they penetrate the ionosphere and travel around the magnetosphere. When they traverse the magnetosphere the radiation produces a whistler, as you'll see.

It remained for the English physicist L.R.O. Storey to fill in the rest of the picture in the 1950's. He discovered that lightning within 600 miles of his receivers invariably produced whistlers. From that distance out to about 1,200 miles the whistlers became weaker. Beyond that distance very few were received at all.

This situation was puzzling because when a lightning flash occurs its electromagnetic waves spread out in all directions. Yet, here were waves that traveled at least 15,000 miles and only returned to a limited area—a circle no more than 1200 miles in radius. What type of mechanism in the atmosphere was producing this focusing?

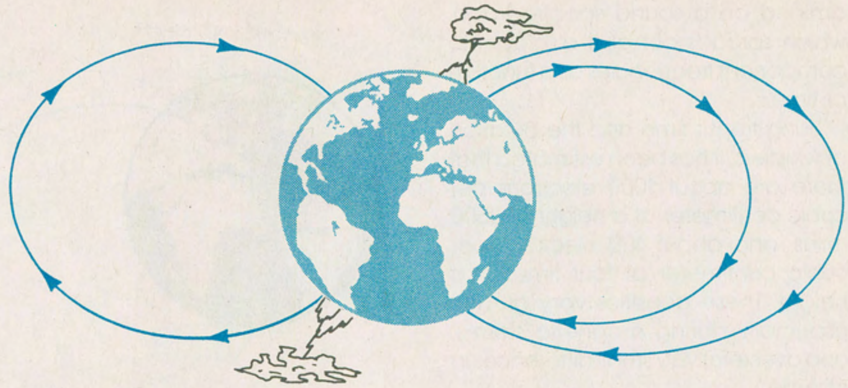

Fig. 1. The energy from a lightning bolt follows the geomagnetic lines, bouncing from hemisphere to hemisphere, as it is draw out into a whistler.

As it turns out, most of the electromagnetic waves that strike the ionosphere are reflected back to Earth and are confined to a conical space between the earth and the ionosphere. As a result, some of the energy from the lightning stroke is concentrated in a relatively narrow vertical beam. This generates a new kind of wave, named after its discoverer, the Swedish physicist Hannes Alfven, which travels into the magnetosphere. As it rises, the beam does not continue in the vertical direction. Instead it follows the lines of the Earth's magnetic field.

Figure 1 illustrates this concept. The wave's intimate association with a magnetic line of force explains why whistlers travel along the Earth's magnetic-field lines.

If indeed the wave does follow a line of the Earth's magnetic field, we can figure its path with ease and see if it adds up to at least 15,000 miles. From the earth's surface in England, for example, a line of force swings southward, crossing the magnetic equator at a height of 7,000 miles. It comes down again at its "mirror point" in the southern hemisphere. Such a path is a little more than 15,000 miles long.

When the wave comes back down to the ionosphere above the mirror point, some of the energy is reflected back into the magnetosphere. Meanwhile, some of the energy penetrates down to the ground where it can be picked up on a radio receiver. Since it originated in the opposite hemisphere, such a whistler is not preceded by a click. The click, traveling in the lower atmosphere, is absorbed before it reaches the receiver. This is called a "short whistler" for reasons that will become obvious shortly.

The energy reflected at the mirror point is reflected back through the magnetosphere again, following the same magnetic field line until it reaches the area of the original lightning discharge, give or take 1200 miles. There, some of its energy reaches the ground in the form of what is called a "long whistler." It gets its name from the fact that it has traveled twice the distance of a short whistler and is therefore twice as long in duration.

An additional kind of whistler has recently been discovered: the "nose" whistler. It is phase retarded in both the high and low frequencies. That tells us that time delays occur at the high as well as the low end of the frequency range.

What We've Learned. Whistlers have told us and continue to tell us much about the electric and magnetic fields above us. They especially reveal the distribution of electrons in the upper regions. Sounding rockets, balloons, and satellites have also done their part in this area, but are expensive and are not always located where they are needed at a given time. Besides, Earth satellites that directly measure electron densities have generally confirmed what has been learned from whistlers anyway.

Since lightning is always flashing somewhere on the globe and whistler equipment can remain on duty 24 hours a day, much can be learned in this way. Also, since whistlers and other atmospherics generate signals in the audio-frequency range, they can be recorded on magnetic tape and examined on a sound spectrograph, which spreads out and displays the component frequencies as a function of time.

Using transit time and the duration of whistlers, it has been estimated that there are about 1000 electrons per cubic centimeter at a height of 3500 miles, and about 100 electrons per cubic centimeter at four times that height. These densities vary greatly, especially during magnetic storms, and over relatively small differences in altitude.

Detectable numbers of electrons have been found at great distances from the Earth. It has been observed that there are measurable numbers of electrons all the way out to the Moon. Thus, in a loose sense, the Moon can be considered to be within the Earth's "atmosphere."

Similarly, both the Earth and the Moon may be considered to be within the Sun's corona of electrons. It may be that the clouds of electrons occasionally shot to Earth by the Sun may affect our weather. If so, a better understanding of the ebb and flow of electrons from the Sun, such as those that produce whistlers, may lead to improved weather forecasting.

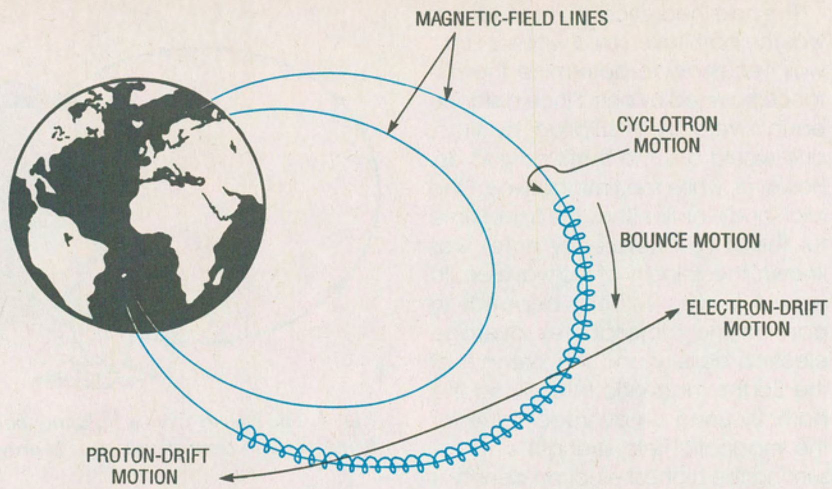

Fig. 3. A charged particle will travel in a bent spiral path along the Earth's magnetic field lines, bouncing back and forth between mirror points.

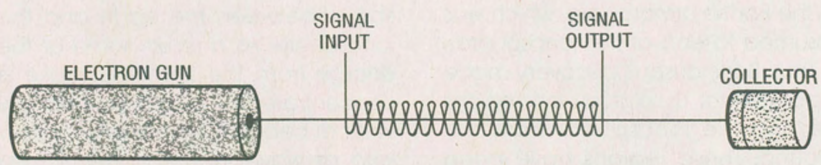

Fig. 4. The ionosphere may act like the traveling-tube amplifier shown here, in that it reduces a waves velocity by making it travel a longer distance over a helical path.

Other Sounds. Electrical "sounds" other than whistlers have also been found in the atmosphere. These take two main forms, both of which are in the VLF range below 30,000 hertz. One is a "hiss" that may continue for a long time, although confined to a narrow range of frequencies. The other is a separate, short noise in which the frequencies are dispersed or spread out in much the same way as in a whistler. Often the tone first falls and then rises, in which case, a "hook" is formed on the spectrograph.

All the suggested explanations incorporate the fact that ionized particles from the Sun are trapped in the magnetic field of the Earth. When a charged, moving particle crosses a uniform magnetic field, the particle experiences a force that tends to deflect it in a direction perpendicular to both its direction of travel and that of the magnetic field. This can be illustrated by the "left-hand rule" (See Fig. 2). If the index finger depicts the field and the middle finger represents the direction of particle movement, then a negatively charged particle will tend to be deflected in the direction of the thumb.

Therefore, an electron that enters the Earth's magnetic field from space will generally be deflected toward the east. If the particle enters at an angle, which is usually the case, it begins to spiral around a magnetic-field line until it reaches the north or south magnetic pole, as illustrated in Fig. 3. At this point, the particle might smash into the Earth, or it will be "squeezed" into close proximity with other electrons at one of the Earth's poles, which is where the field lines come together. The electron may then be slowed to a stop, and sent back along the same route where it might continue to corkscrew back and forth between the magnetic-mirror points of the Earth.

In this dizzying dance, the electron is constantly changing direction. However, when an electron changes direction or speed, it emits electromagnetic radiation called "cyclotron" radiation. The frequency of the radiation depends upon the strength of the local magnetic field and the particle involved. However, it is below 1000 cycles-per-second for a proton and is on the order of tens or hundreds of kilocycles-per-second for the lighter and faster-moving electron.

Consequently, cyclotron radiation might explain some of various LF noises. To explain the hooks men-

(Continued from page 92)

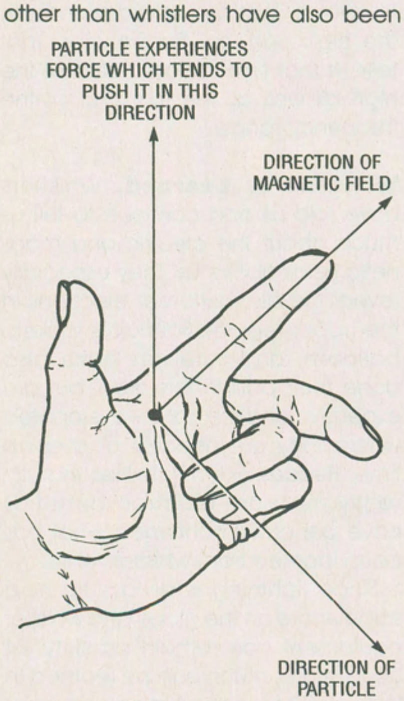

Fig. 2. The left-hand rule is a mnemonic device for remembering how an electron would be affected when traveling through a magnetic field.

THE SKY CHORUS
(Continued from page 48)

tioned earlier, an additional mechanism is required. This may have to do with an effect noticed in 1842 by the Austrian physicist Christian Johann Doppler. The frequency of a source of sound will rise if the source is approaching the listener and will fall if it is receding. The Doppler effect also applies to light, radio waves, and other wave-based phenomena. Since the particles alternately slow down as they approach the poles and speed up as they approach the magnetic equator, the Doppler effect could explain the existence of hooks, provided the electrons travel in bunches. It is not known whether this is the case. However, if they did not travel in bunches, the slowing down and speeding up effects would cancel.

Other possibilities are that the noises start out very weak and are amplified in the atmosphere and involve another somewhat complex phenomenon: the interaction between particles and waves in the ionosphere. If a stream of electrified particles moves along with, and at nearly the same speed as, an electromagnetic wave, the wave can be amplified at the expense of the energy of the particles. This may sound impossible at first since radio waves travel in general at the speed of light. It is true that particles cannot reach the speed of light, but electromagnetic waves can be slowed down to the speed of fast-moving particles.

In fact, that is the principle of the traveling-wave-tube amplifier, as illustrated in Fig. 4. In that type of amplifier, the wave is slowed down by making it travel through a helical or spiral-shaped duct or wave guide.

In the magnetosphere, the wave from a small electrical noise might be slowed naturally by interaction with electrons and the Earth's magnetic field. It is estimated that that would reduce the speed of the wave to about one-tenth of its speed in a vacuum, or to about the speed of the particles coming from the Sun. There are components in the magnetosphere that make a natural traveling-wave-tube, which could take the ever-present but exceedingly weak noises and amplify them.

The last possibility is that these VLF noises are actually the result of lightning discharges, but that they have been changed by some as yet unexplained phenomenon.

It could be that all these possibilities are correct. Each could act alone or in combinations at various times. It is worth noting that all involve the interaction of ionized particles from the Sun with the magnetic field of the Earth. That is supported by the close association found between solar disturbances and noise storms.

New phenomena has been detected beyond the altitude where normal whistler propagation cuts off. A powerful fluctuating noise has been detected with frequencies that extend from 200 to 100,000 hertz. The noise has been observed between five earth radii (about 20,000 miles out) and 25 earth radii out. Emissions have included hiss, chorus, risers, and constant tones. ■