
Odd Radius Halos Are Real

Confusion and doubts

Hexagonal prismatic crystals—essentially the model of Mariotte—can account for many halos quite well, but they cannot explain the odd radius display of Helmut Weickmann, in which several circular halos have radii other than the usual 22° and 46° (Figure 1.1). Weickmann's display is not unique, and even as early as the seventeenth century there were occasional rumors of odd radius halos. Later, as halo observations continued to accumulate in the eighteenth and nineteenth centuries, a persistent small fraction of them would report odd radius halos. There was little consensus, however, regarding the observed radii of the halos. In fact, there was a nearly continuous range of reported radii running all the way from about 6° up to 28° , with scattered larger radii as well. Perhaps nobody believed all of the reports to be accurate, but nobody could say for sure which ones to reject. Thus the reported radii were difficult to evaluate. Photographs of odd radius halos, which could have confirmed the existence of the halos and given reliable radius estimates, were not forthcoming until recently. On the subject of odd radius halos the observational record was equivocal at best.

It turns out that most odd radius halos are caused by ice crystals having pyramid faces (Figure 7.1). Such crystals are called pyramidal (or pyramid) crystals, whether or not they also have prism and basal faces. Pyramidal crystals seem to occur only under cold conditions, and it is unlikely that any of the early halo workers, working in, say, Paris, would have seen one. But already in the seventeenth century Mariotte had recognized that pyramidal crystals were a theoretical possibility, and he had considered and then rejected them as the

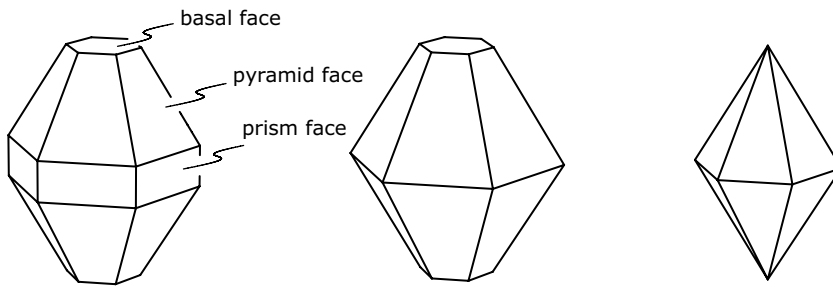


FIGURE 7.1 Some conceivable pyramidal crystals. The left-hand crystal has two basal faces, six prism faces, and twelve pyramid faces. The middle crystal is the same but with no prism faces, and the right hand crystal is the same but with neither prism nor basal faces. We cannot recall seeing a naturally occurring pyramidal ice crystal with no basal faces.

cause of the 22° halo.¹ Much later—in the mid-nineteenth century—Bravais used pyramidal crystals to explain odd radius halos. By then, Scoresby [66] had made some very explicit drawings and descriptions of pyramidal crystals that he had seen in the arctic. Although Scoresby’s crystals may have been bullet crystals (Figure 2.7) rather than true pyramidal crystals, in one respect it did not matter: halo theorists, including Bravais, could believe that pyramidal crystals were real, at least for the time being. Still, the exact shape of the crystals—in particular, the crucial inclination angle between the crystal axis and the pyramid faces—was not evident from Scoresby’s observations. But about the same time as Scoresby, Edward Daniel Clarke [12] reported seeing rhombohedral ice crystals. The crystals were growing on bridge timbers and had apparently formed in mist from a river. They were huge—about an inch long—and the crystal faces were good enough that the interfacial angles could be measured with a goniometer. Rhombohedral crystals should in some ways not be so different from pyramidal crystals, and Bravais used Clarke’s results to infer the likely shape of pyramidal crystals. Although Clarke’s results influenced Bravais and others after him, even well into the twentieth century, we—Tape and Moilanen—do not know what to make of Clarke’s observation; we ourselves have never seen anything quite like it. In any case, when photographs of ice crystals began to appear in the literature in the late nineteenth and early twentieth centuries, no pyramidal or rhombohedral crystals were to be seen. The observational record of pyramidal crystals was as murky as that of odd radius halos.

The ambiguous observational record, both of odd radius halos and of pyramidal crystals, made for a poor foundation for the theory of odd radius halos, and the

¹ Mariotte even claimed to have seen some pyramidal crystals, but his claim seems to have been forgotten, deservedly so.

theory was for a long time, well, a mess. As a result, even as late as the 1970's one sometimes heard doubts about the existence of odd radius halos. But by that time there were emerging signs of order amidst the chaos, and more such signs were on the way.

Making some headway

The crystallographic ratio c/a of ice, to be explained later, is a crucial parameter for halo theory. Together with the hexagonal symmetry of ice, the c/a ratio determines which crystal faces are likely to occur. What it determines is not the relative sizes of the faces but rather their relative orientations, hence the interfacial angles. The interfacial angles in turn determine the radii of any resulting circular halos. In short, the c/a ratio determines the likely halo radii.

The c/a ratio of ice was not reliably known until the 1920's, when William Howard Barnes [3] and others measured it using X-ray diffraction techniques. But from then on, halo theorists could in principle predict the radii of the most likely odd radius circular halos. Steinmetz and Weickmann did so, in 1947 in their article *Zusammenhänge zwischen einer seltenen Haloerscheinung und der Gestalt der Eiskristalle* [72],² in which they analyzed Weickmann's odd radius halo display of 1940. They assumed that the responsible ice crystals had the simplest crystallographically possible pyramid faces, the so-called $\{10\bar{1}1\}$ faces (Chapter 9). Using Barnes' c/a -value, they calculated the interfacial angles on the crystals, and then they used the interfacial angles to calculate the expected halo radii. Their calculated radii agreed passably well with the crude observational estimates of radii that Weickmann had made during the display. In the next two chapters we will essentially repeat the calculations of Steinmetz and Weickmann.

Weickmann had not been able to get a good look at the crystals during the display, but he and Steinmetz did see pyramidal crystals at other times. The crystals were not bullets but had good planar faces—the crystals were truly pyramidal. Some, at least, of the crystals had shapes that were similar to those of the hypothetical crystals that they had used to explain the halo display—the pyramid faces appeared to be the $\{10\bar{1}1\}$ faces.

Still missing was any photographic documentation of odd radius halos, but it came eventually. Turner and Radke [80] in 1975 and then Tricker [79] in 1979 published unequivocal photographs of odd radius halos. Somewhat later Neiman [50] published photographs of a spectacular and long lasting odd radius display in Boulder, Colorado. Today we have hundreds of good photographs of odd radius halo displays. Odd radius halos are real, and so are the pyramidal crystals that make them.

² The Relation between a Rare Halo Phenomenon and the Form of the Ice Crystals

Most of the measurements of halo radii that have been made from photographs are consistent with the values predicted by Steinmetz and Weickmann. But the measurements are often imprecise, for a variety of reasons, and we in fact need more good measurements of halo radii. For those who wish to measure halo radii from their own photographs, Appendix C has some suggestions for taking the photographs.

In hindsight we tend to see the Steinmetz and Weickmann article as a turning point in our understanding of odd radius halos. But their theory was not immediately embraced. It was not widely known, especially in the English speaking world, and where it was known, it did not get much attention. Perhaps some skepticism was justified initially, given the lack of photographs of odd radius halos at the time. In any case, the historical evolution of our understanding of odd radius halos is more convoluted and tortuous than the above summary suggests. In Chapter 11 we will take another look at it.

How rare are odd radius halos?

Since good documentation of odd radius halos was so long in coming, you might think that odd radius halos are impossibly rare. Indeed they are rare, at least in most geographic locations, but not as rare as might be imagined. One of the odd radius circular halos—the 9° halo—is close to the sun and therefore easily missed, even when it is fairly bright. Two of the odd radius circular halos—the 23° and 24° halos—are often difficult to distinguish from the ordinary 22° halo, and the 18° and 20° halos are often difficult to distinguish from each other. And, like any halos, the odd radius halos are easy to miss when faint. When halos are present we recommend scanning the sky using a \$1.59 circular rearview mirror, the sort that is sold in many auto supply stores under the name blind-spot mirror. The mirror compresses the halos and dramatically increases contrast, thus increasing the chances of detecting faint halos. Photographs of displays can also be scrutinized for faint halos; we are still embarrassed on occasion to find halos in our photos that we did not see when the display was in progress. Finally, practice helps enormously. The dentist sees more in the dental X-ray than does the patient, the geologist sees more in the rock outcrop than does the passing hiker, and the seasoned halo observer will see more in the sky than does the novice, even though both are looking at the same sky. Still, in most localities even an experienced and persistent observer will be lucky to see more than a handful of odd radius halo displays per year.

How rare are pyramidal crystals?

Odd radius halos are normally an indication of pyramidal crystals in the atmosphere, but it does not work the other way around. That is, you can have pyramidal crystals without having odd radius halos. Pyramidal crystals are therefore more common than you would guess from the frequency of odd radius halo displays. In our ice crystal samples collected at temperatures below about -20°F we often see a few pyramidal crystals, though usually not enough to make perceptible halos. Our Fairbanks, Alaska, crystal samples collected at temperatures below about -30°F are often dominated by pyramidal crystals (e.g., Figure 10.14), but below about -35°F the crystals are usually too small to make good halos. These remarks are an oversimplification, and we would not want to have to make a living predicting crystals or halos on the basis of temperature (or anything else).³ Nevertheless, our experience is that pyramidal crystals require cold conditions.

Reports of pyramidal crystals are nearly non-existent in the many published studies of atmospheric ice crystals. One reason that few scientists have seen pyramidal crystals is that they were working in relatively warm places, especially Japan. But lots of crystals have been collected from aircraft flying through cold clouds, lots of crystals have been collected at the ground in cold places, and lots of crystals have been grown under cold conditions in laboratories. We really do not understand why pyramidal crystals are not being seen more often in these studies.

You will probably never see a pyramidal ice crystal in, say, St. Louis, since it is not cold enough there. But there can be pyramidal ice crystals nearby—within ten miles of downtown—even in July. They are straight up, of course, and when there are enough sufficiently large ones, you will see their characteristic signature in the sky—the odd radius halos.

³ Indoors in the laboratory the dependence of crystal habit on temperature and humidity is relatively well defined, though complex [2]. Outdoors any such dependence is much more elusive.