



Diffraction & the Obscuring Shape

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Users of reflecting telescopes that have vane-supported secondary mirrors are well aware of the connection between the vanes and the diffraction spikes that appear extending from images in the eyepiece. Few, however, understand why the spikes occur or what the geometric relationship is between the spikes and the vanes. Even fewer understand the relationship between an obscuring shape and the diffraction pattern resulting at the focus. The purpose of this paper is to make an explanation without delving into the mathematics of diffraction theory. The diagram above will provide assistance, and we'll begin there naming parts.

The simplest obscuring shape for discussing diffraction is the straight edge, and the straight edge of a razor blade will act as our obscuring shape. A lens behind will focus all rays entering its aperture not obstructed by the razor blade. The lens has a vertex at "V", and its focus falls at "F". The line between these two points is the optical axis of the lens. Light rays enter the lens aperture, and we will presume that they all proceed parallel with the optical axis of the lens just as they pass the

razor. Two rays, “B1” and “B2”, graze the razor’s edge at “A” and are “scattered” oppositely through a small angle with respect to the optical axis V-F. The scattering angle is quite small, so small that one couldn’t detect the angle if the two beams were viewed from above (here the angle is *hugely* exaggerated to better show the effect). The little, two-headed arrow above the lens labeled “C” indicates the direction of the scattering of the rays, and the arrow is oriented perpendicularly to the razor’s edge.

Now we are ready to determine what happens as the rays approach the lens focus at “F”. The situation here may be familiar to those that have knowledge of the 1802 experiment by Thomas Young that verified the wave nature of light. As the experiment is generally reenacted, a slit with a source behind it shines light onto two, closely spaced slits a short distance away. An interference pattern is observed on a projection screen further away as the beams leaving the two slits scatter into each other. This interference phenomenon is called *diffraction* and occurs exclusively as the result of the interaction between two or more waves. Undulations are drawn in the sketch on beams “B1” and “B2” to indicate their relationship to waves. The orientation of the plane of undulations, parallel with the razor’s edge, is the same as it would have been had the beams proceeded through slits parallel with the razor’s edge. This is by no means a necessity (Young used pinholes rather than slits), but it may help to better understand the process.

The lens merely brings the undulating beams to focus at a definite location. Were the lens removed and an observer chose to gaze by the razor’s edge at a coherent source (like a lighted slit), the interference pattern would be seen as bands paralleling the razor’s edge. (Incoherent sources smear the bands since many differing wavelengths and phases of waves “pile” over each other; this explains why diffraction isn’t noticed as a common, everyday experience occurring about all lighted or shadowed objects.) Telescope mirror makers often report seeing bands parallel with the knife-edge that is used as a measuring reference in the testing of the focusing mirrors they have fabricated. Although the bands parallel the edge, the direction of the spread of the pattern is perpendicular to the edge and to the bands contained.

Our rays “B1” and “B2” act just as the rays in Young’s experiment, producing a spread “sideways” containing light and dark bands parallel with the razor’s edge, just as is shown in the sketch. The “center” band in the spread is bright, and is flanked by adjacent, dark bands. Lesser brights follow, and they are followed by dark bands to be followed by even lesser brights, and so on and so until the eye’s ability to detect the faintest

bands drops away. The intensity is something like that shown in the sketch entitled, “Approx. Light Intensity”. The graph is only representative and isn’t accurate enough for scaling, but it does present the concept. Experienced readers may recognize some similarity with a graph plotting the intensity of the disk and rings of the *Airy* pattern, and, indeed, if one were to rotate the interference pattern shown at the focus “F”, one would recognize the Airy pattern. One could think of the Airy pattern, after all, as the interference pattern of many, tiny, straight edges arranged tangentially to form a circular aperture!

The important point is to note that the “spread” of the diffraction pattern is always *perpendicular* to the edge that generates it. The “spike” of a spider vane is the diffraction spread, and the spike is perpendicular to the vane that causes it. The reason that interference bars aren’t seen in the spike is because the sources, planets and stars, are incoherent emitters and their emitted wavelengths are many arriving out of phase. The eye is also a poor detector for faint detail so that the brain registers a smeared streak. In addition, each side of a spider vane acts like one of the slits in Young’s experiment so that the diffraction generated by one edge is reinforced by the diffraction from the other. The effect is that the observed streak becomes brighter as the vane thickness increases. (A similar situation occurs for the increasing diameter of the secondary-mirror obstruction; the first ring of the Airy pattern becomes significantly brighter, even bleeding into the Airy disk itself. Thus, the first ring may set the resolution limit for visual observing rather than the Airy disk.)

What happens if the object observed isn’t centered in the field as was presumed in the sketch above? The image in the field of an observed object is the location where the object’s light comes to a focus, so all diffraction spikes that are generated from the light of that object occur centered on the object’s image. The center, bright bar in any diffraction spike actually falls on the image of the object that emits the light.

We can now describe the effects generated by various, obscuring shapes placed in the aperture of the telescope. We know that for any shape, only the lengths and the orientations of edges that are exposed to the stream of light rays are important, and that all diffraction spikes generated will be centered at image focus just as is shown in the sketch above. Thus, a three-vane spider, each vane at 120° , will generate six spikes, each spike at 60° from the last. A six-vane spider, each vane at 60° , will have the same number of spikes oriented in the same way, but the spikes will be brighter. Here are other examples:

- 1) A six-edged aperture mask, added to the front of the telescope so that the aperture becomes a hexagon, will generate six spikes centered at image focus just like the spiders discussed, even if the hexagon is not centered. A mask creating an aperture that is an equilateral-triangle produces the same number of spikes.
- 2) A prism with a square obscuration used as the diagonal for a Newtonian will generate four spikes. If the spider that supports it has four vanes and the vanes are parallel with the sides of the prism, four spikes will occur centered at image focus. If the vanes are at an angle of 45° with respect to the sides of the prism, eight spikes will occur centered at image focus with each spike 45° from the last.
- 3) A single post used to support a Newtonian diagonal will generate a single spike centered at image focus perpendicular to the direction of the post.
- 4) A curved spider vane will spread the diffraction generated by it about the general field so that “spikes” cannot be seen, but the instrument’s resolution may suffer because of the general scatter.
- 5) A mask that carries a single, off-axis hole, sometimes used to block out the effects of the obscuring diagonal and spider vanes of a reflector, will appear as a single aperture centered at focus. Multi-holed apertures can be seen to converge from off-axis as the focus is approached, but at focus, they will coalesce into a single aperture. About each bright image in the field, a single, circular Airy pattern will be observed.
- 6) If the mask’s single hole of example 5 above were oval rather than round, the Airy disk and rings would all be oval, but their major axes would all be perpendicular to the major axis of the hole.

These examples should cover most of the situations with which observers are familiar. Sometimes, short spikes may be seen at half angles between the major spikes at full angles. A four-vane spider may generate such short spikes at 45° between the 90° major spikes. These are the result of constructive interference between the major spikes near the bright bars at image center. They may be particularly evident in photographs.

Nothing of any practicality can be done to thwart diffraction, and the real concern is how much the instrument's resolution is diminished because of diffraction's effects. The human eye currently remains the resolution champion as a detector for amateur telescopes, but the resolving powers of CCD's have surpassed that of film and are approaching that of the eye. Still, CCD's remain relatively unresponsive to the loss of resolution at image focus caused by obstructions large enough to affect the resolving power of the comparison, eye-telescope system. But the effects cannot be determined until the characteristics of given, high-resolution CCD's are [contrast-transfer] tested. That has not as yet happened. The resolving power of film, however, is known to be so coarse that an obstruction as large as 60% of the entrance aperture has no detectable effect on photographic images.

Extraneous spikes, however, can be most annoying in printed CCD and photographic images. But as long as the vanes that support detectors are no more than is commonly used to support secondary mirrors, the spikes generated will not differ significantly from what is usually encountered in the image plane of a visual system. The obstructing housings that contain electronic detectors will likely not contribute much to diffraction spikes, certainly not beyond what is generally caused by spider vanes. The buyer of a housed system should verify that the unit he will purchase has the "minimum" number of edges and angles in the housing that will suffice for the CCD-chip support function. Generally, the common circular, squarish, or rectangular shapes are appropriate (but trapezoidal shapes will generate extraneous spikes). Small radii at the corners of jointed sides may be ignored. The "size" of the housing will contribute to loss of resolution for a detector that has the resolving power of the eye, but that detector hasn't yet been marketed. Housings that are located somewhat off-center from the telescope's optical axis will cause no significant addition to diffraction with respect to centered housings of the same size and shape. All diffraction spikes will occur centered on the bright images at system focus regardless of housing shape and location.