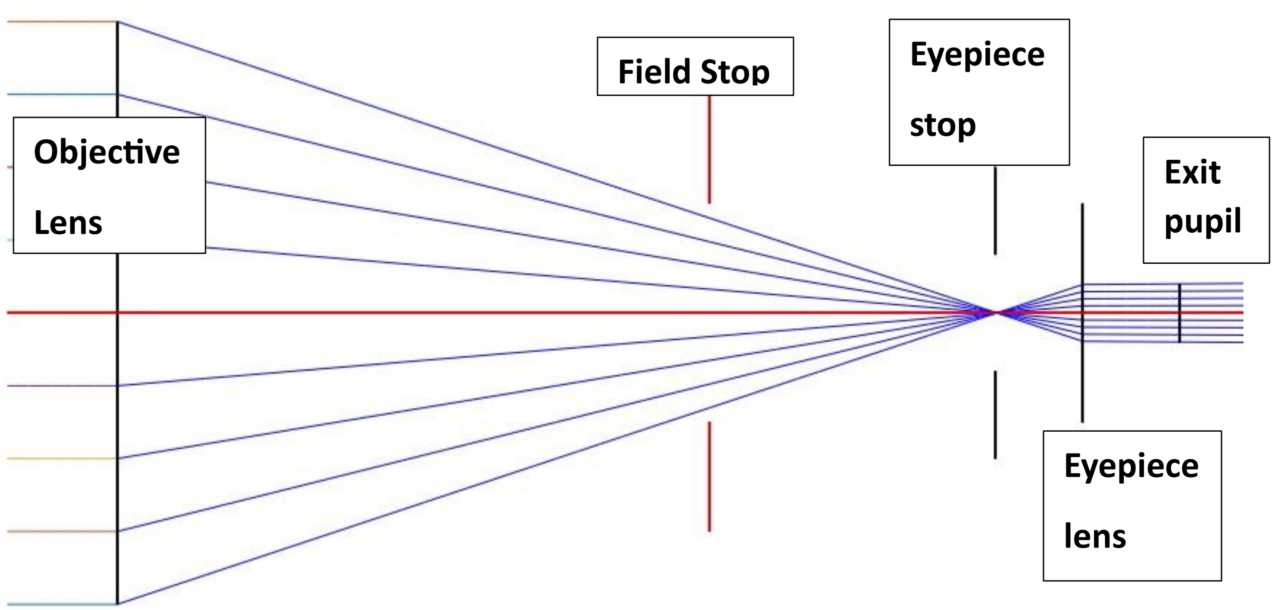
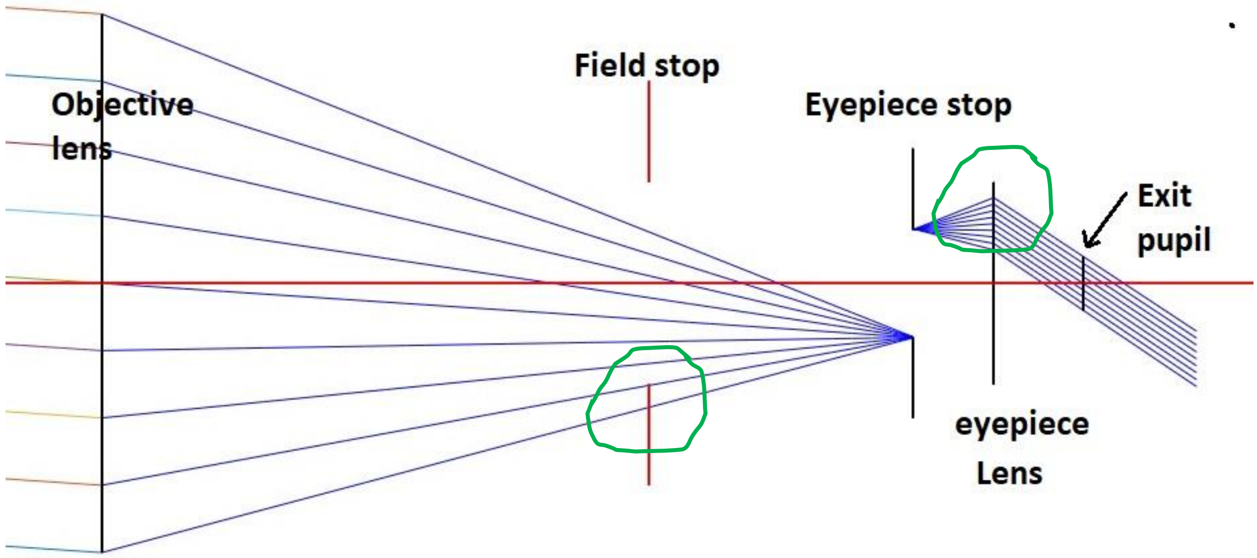
Vignetting in Binoculars (Part 1)

By Anton Jopko

My major peeve with binocular reviews is the missing discussion of vignetting in binoculars. Vignetting means that not all of the light entering the objective lens (the large front lens) of a binocular reaches the exit pupil and eye. In the figure below, we have a simplified diagram of the optical components of a binocular. The horizontal red line is the optic axis. We imagine a distant star on the far left of the axis emitting a parallel bundle of light rays represented by the blue lines. After passing through the objective lens the rays converge to a point in the focal plane of the eyepiece which is where the eyepiece stop is located. From here the rays diverge until they reach the eyepiece lens where they then form a parallel bundle again passing through the exit pupil. The exit pupil is an imaginary disk through which all light must pass through because it is the image of the objective lens. It is like a fixed open window in space. An observer would then place the lens of their eye at the exit pupil where the eye lens focuses the rays to a single image point on the retina. There is no vignetting in this case since all light entering the objective lens passes through the exit pupil.



In the figure below, we imagine a distant star far to the left again but now it is above the axis. The rays appear broken at the eyepiece stop but only to show the rays after passing through prisms to form an erect image. Notice once again the rays pass through the exit pupil in a parallel bundle but pointing downward which makes the star appear upward as was the original star above the axis. We ignore the rays through prisms for simplicity.



The two green lines show possible vignetting areas. Clearly in lower left case, the field stop is blocking one ray so the light should not be continuing to the right. In the upper right case, you notice that the diameter of the eyepiece lens must be bigger than the diameter of the eyepiece stop so that the light can still be refracted toward the exit pupil. In cheaper eyepieces, the eyepiece stop is the end of a short tube which connects to the eyepiece lens. Clearly there is vignetting when this is the case. Those of you with the $500 eyepieces can let me know what your eyepiece is like. Another source of vignetting not shown above is at the prisms. They need to be large enough to pass all light through them as well. Also note that a diverging beam of light from a point in the eyepiece stop, which is the focal plane of the eyepiece lens, emerges on the other side of the lens as a parallel beam.

In Part 2, I will discuss how to check how much vignetting there is.

Part 2

I think it is fair to say that most aberrations in lenses occur around the periphery. To reduce or eliminate these requires much effort and cost. One benefit of vignetting is that this is an easy way to block these aberrations so to reduce costs but improve the image quality that remains. A major disadvantage of vignetting for astronomers is that you could lose a half magnitude or more of brightness at the periphery of field of view. So quality costs.
Many years ago, I was able to examine a pair of Zeiss binoculars. Zeiss had a reputation for excellent optics. To my dismay I discovered that only the centre of the field of view was fully illuminated. There was much more vignetting closer to the periphery of the objective lens or eyepiece stop too.

In part 2 here I will discuss how to begin to assess the approximate amount of vignetting in your binoculars. I have examined my own binoculars to reach these conclusions but I am sure this applies to most brands.

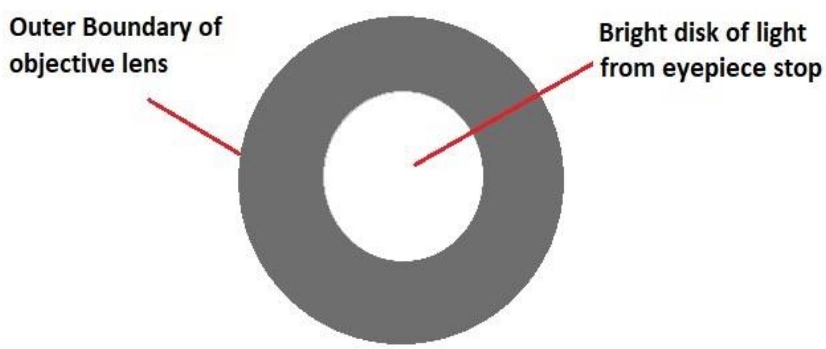
The first thing we need to do is measure the diameter of the exit pupil on the optical axis direction. In this case the light passing through the exit pupil is a parallel bundle and also parallel to the axis. You should mount the binoculars on a tripod, focused at infinity and pointing toward the bright sky outdoors. You also need a small plastic see-through ruler. Place the ruler at the location of the exit pupil and measure the diameter of the exit pupil which is a bright disk.

Without any vignetting the theoretical diameter of the exit pupil equals the diameter of the objective lens divided by the power of the binoculars. So, for 10X50 binoculars, the diameter of the exit pupil is 50 mm/10 = 5 mm. If the diameter is less than this, say 4mm, then you have vignetting even on the axis. The central image point is not fully illuminated. So, you really only are using 10 x 4 mm = 40 mm of your objective lens, instead of 50 mm. So, lets assume now that the diameter of the exit pupil is as large as it theoretically should be. Now we look for off axis vignetting.

For the remaining tests, we turn the binoculars around and look into the objective lens holding the binoculars about a foot from your eyes. Also aim the binoculars at the bright blue sky outdoors. In figure 1 we show the view when the eye is on the axis of the binocular. The large grey disk is the inside of the binocular and the white disk is the light through the eyepiece stop coming from the eyepiece lens behind it. If you move your eye up close to the objective lens you will see more of the eyepiece lens through the stop. It is sometimes difficult to separate out what you are seeing. In my binoculars, I can see a square region which is the back opening of the prism. In side this square is a bright disk fully inside the square.

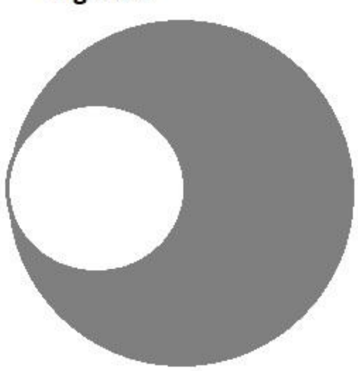
If you see a dark region surrounding the bright disk then this is part of the lens mount. This implies the eyepiece lens is too small. The eyepiece lens diameter should be about one third larger than diameter of eyepiece stop.

Figure 1



Now go back to holding the binoculars a foot from your eyes again while looking at the bright disk as in figure 1.

Figure 2



Now move your eye slowly to the left edge of the objective lens. With no vignetting, the view would be as in Figure 2. The bright disk is tangent to the outer boundary of the objective lens. This is extremely **unlikely** to be the case however. Anything less implies some vignetting around the periphery of the objective lens or eyepiece stop too. In Part 3, we will examine the alternative in more detail.

Part 3

In part 2 we showed that when looking into the objective lens of the binocular, held a foot from your eye, and on the axis of the binocular, then the bright disk was at the center of view, concentric with the boundary of the objective lens.

For what follows it is important to realise that two incident parallel rays will intersect on the other side of the lens at some point in the focal plane of the lens. This is why you hold the objective lens a foot or so from your eyes.

Now slowly move your eye to the left and observe what happens to the bright disk. The disk also moves to the left. Eventually you reach a point where the edge of the disk starts to disappear. This is indicated by point A. For the red curved line in figure 4, light is blocked on the left side but light from the right side reaches the left edge of the eyepiece stop.

You should stop at this point and note the position of point A as a fraction of the lens diameter from the left edge. You could place a ruler across the objective lens to measure the position closely. In this example I would say the fraction is about 1/6 or 16%. This means there is vignetting at the edge of the eyepiece stop as shown in figure 3 on the next page.

We will investigate the exact shape of the curve of the red line in part 4.

Figure 4

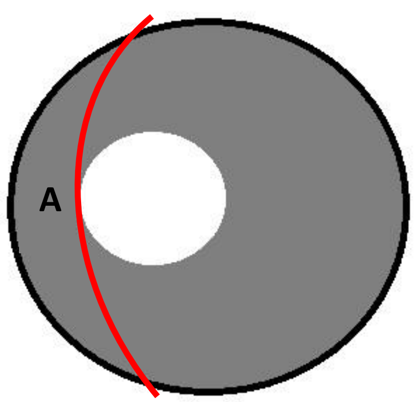
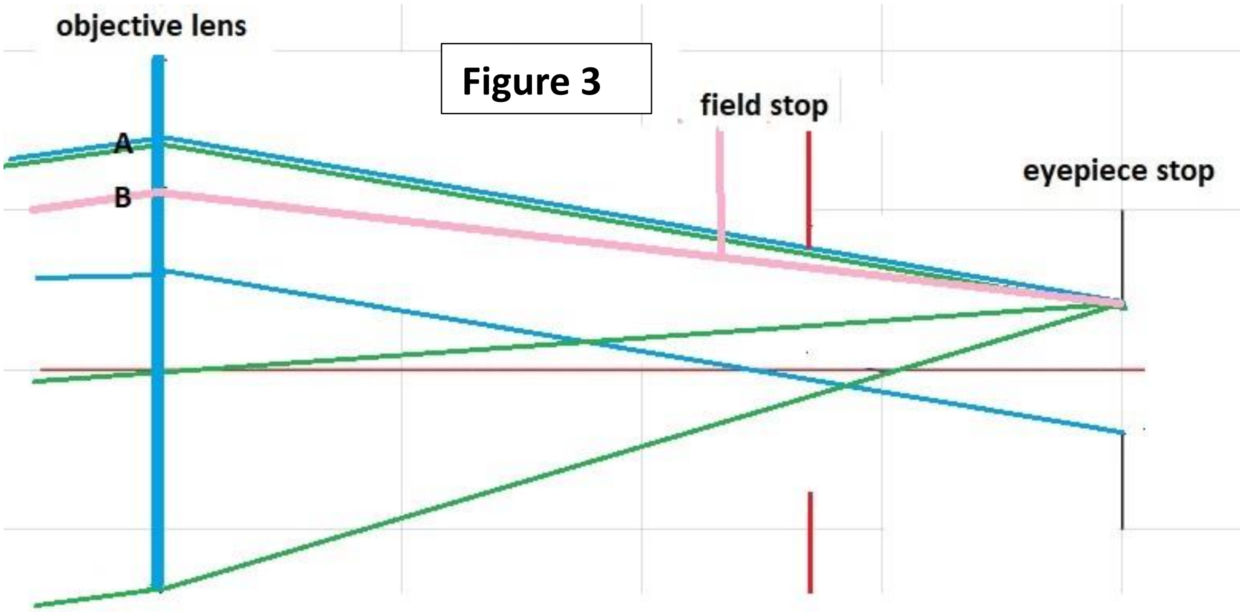


Figure 3 on the next page is a very complicated one. Point A, which was determined above, is near the top of the objective lens. There are two field stops shown in red and pink with the pink one lower than the red one. We will compare these two. We focus first on the red one. The top most ray enters the objective lens at point A and continues to the top of the eyepiece stop just clearing the red field stop. Only rays lower than this can still converge at the top of eyepiece stop. I have shown 3 green rays that do this.

Now focus on the pink field stop. The ray that enters the lens at B now also passes through the top of the eyepiece stop and just clears the lower end of the pink field stop. So as the field stop protrudes lower toward the axis, less of the objective lens allows light to reach the top of the eyepiece stop.



The next question now is to know how much incident light will pass through the objective lens below point A or B compared to the total area of the lens. This corresponds to the area in figure 4 which is on the right side of the red curve. This depends on the location of point A and how much the red line is curved in figure 4 on the previous page. It turns out that the shape of the red curve depends on the location of the field stop between the objective lens and eyepiece stop.

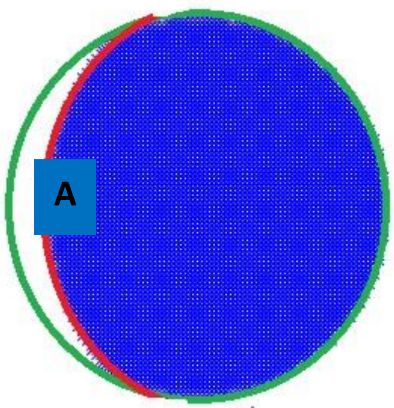
We will examine this in much more detail in part 4.

Part 4

In this part we will examine how much vignetting there is around the periphery of the objective lens or consequently the periphery of the eyepiece stop and consequently the field of view.

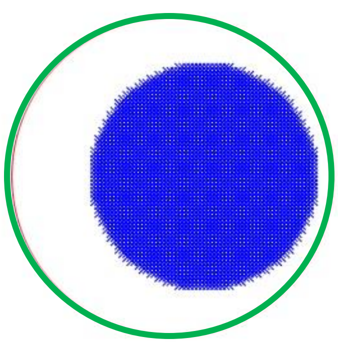
The figures on this page were calculated as follows. First choose the fraction of the diameter of the objective lens that point A is from the left edge of the objective lens. In the first figure below, it is 10%. I then placed the field stop half way between the objective lens and eyepiece stop. Then I chose a radius of the field stop which just touches the ray from point A to the left edge of the eyepiece stop. I then shot rays of light through the lens which will end up at the left edge of eyepiece stop. If the ray was able to pass through the opening in the field stop I put a blue X at the spot on the lens where it came from.

Point A is the same point as in previous parts and the dark red curve also.

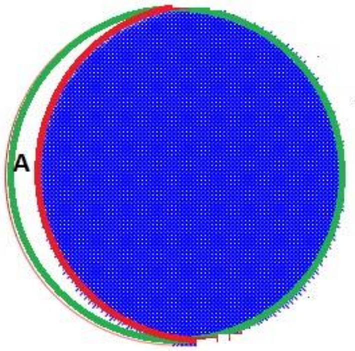


This point A and red curve applies similarly to the other 3 figures below.

For this case, 87% of the light was able to reach the left edge of eyepiece stop. The green circle is the outline of the objective lens.



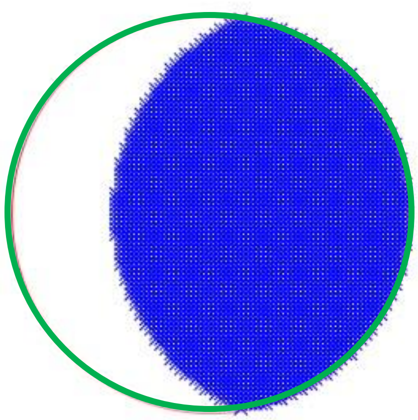
For this figure, point A was chosen 25% of the lens diameter from the left edge. Now only 48% of the light shown in blue was able to reach the left edge of eyepiece stop.



For the two figures on this page, I put the field stop ¾ of the distance from the objective lens to the eyepiece stop. For the first figure point A is 10% distance from edge of objective lens. The same as the first figure on previous page.

Now 91% of the light from the objective lens reached the left edge of the eyepiece stop. This is slightly more than 87% for the first figure at top of last page. So, when there is little vignetting, it does not really matter where the field stop is located.

For the figure below, point A is 25% of the distance from the edge of objective lens. 69% of the light was able to reach the left edge of the eyepiece stop.



Compare this to second figure on last page where 48% of the light reached the edge of the eyepiece stop.

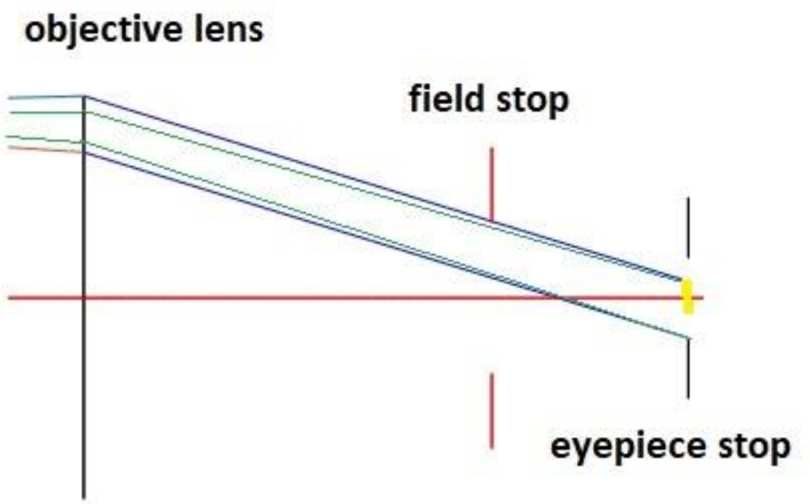
We conclude that more light passes through the objective when the field stop is closer to the eyepiece stop. In part 6 we will show how to estimate at what longitudinal position, called f, in the binocular the field stop is located.

% Point A from edge	% illumination f =1/2	% illumination f =3/4
0	100	100
10	87	91
20	63	77
25	48	69
30	35	61
35	25	53

In the chart above, we summarize the cases for the field stop at f = ½ and f = ¾ the distance from the objective lens to the eyepiece stop. Interpolate % point A for values not in chart.

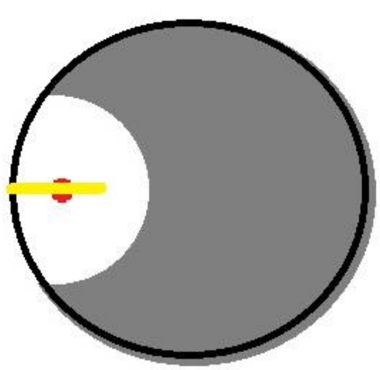
Part 5

In this part we will investigate what portion of the eyepiece field stop that is fully illuminated. That is, there is zero vignetting there. That is, all the light from the objective lens ends up in this area. The figure below shows the geometry. The observer's eye is off the left side of the diagram. The top blue solid line enters the objective lens at the top edge, and just clears the field stop. The lower parallel blue line also just touches the lower edge of the eyepiece stop. The two pairs of close lines exit the objective lens on the left as parallel bundles and enter the observer's eye-pupil located a foot or so from the objective lens.



The short yellow line is the portion of the field of view that is fully illuminated.

Figure 3



The figure left shows the view looking into the objective lens with the white disk as close to the edge of the lens as possible. Now locate the exact center of the disk as shown by an imaginary red dot.

The yellow line is the portion of the eyepiece stop that is fully illuminated. The portion is a disk with diameter equal to the short yellow line. The distance of the yellow line from the left edge to the central red dot is equal to the same distance on the right side of the red dot because of axial symmetry. In this case about 50% of the central diameter of eyepiece stop is fully illuminated. That is, it has zero vignetting.

Figure 3

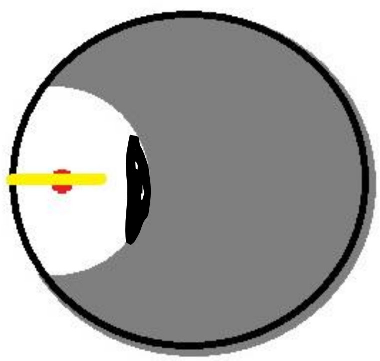
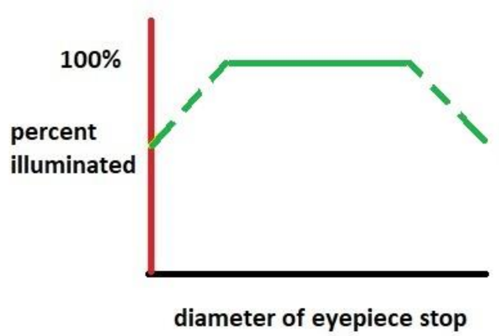


Figure 3 is repeated here to show you what else you may sometimes see during this test. The right edge of the eyepiece stop is dark and blurry, shown as the thin vertical black strip. This means the opening at the back of the eyepiece (closest to your eye) is too small so you are seeing the edge of this opening as the black strip which also increases vignetting.

Finally, the percent illumination across the eyepiece stop or field of view is summarised in the figure below. A portion of the center is usually fully illuminated at 100% and the sides may decrease to 50% or less. 50% illumination corresponds to a magnitude loss of 0.75. 40% illumination is about magnitude loss of 1.

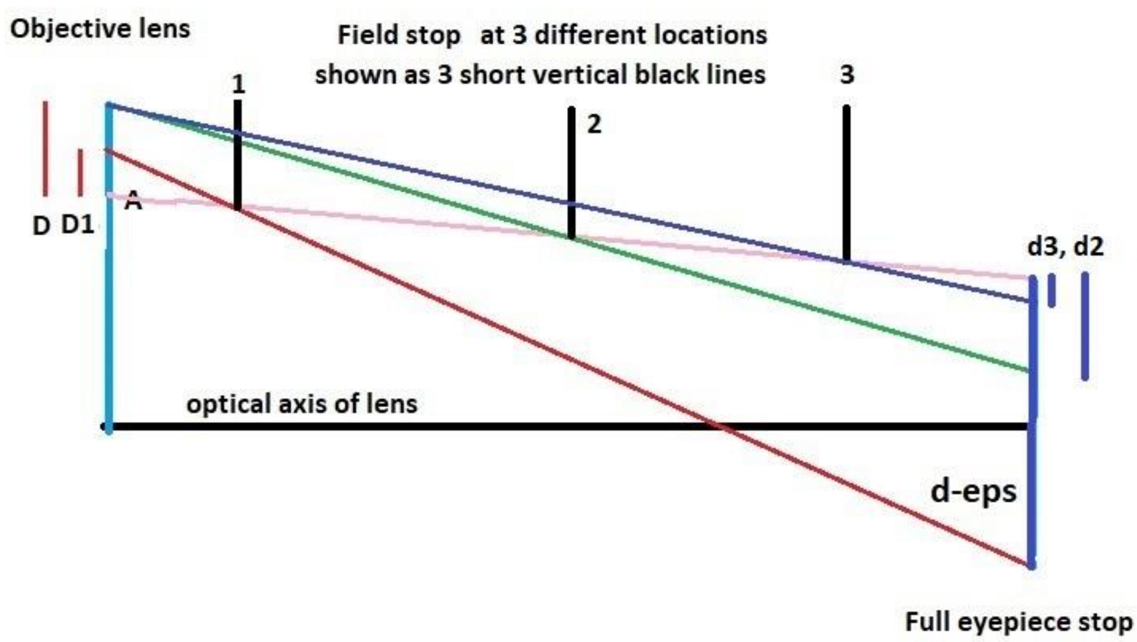


We spent the most time investigating the amount of vignetting at the two outside edges of the eyepiece stop. We do not know the shape of the two dashed green lines so I have drawn them as straight lines but they may not be so. We only know the values at each end. More work could resolve this question.

Part 6

In this part we will show how to get a good estimate of the location of the field stop between the objective lens and the eyepiece stop and estimate the vignetting.

The first step is to measure the diameter of the eyepiece stop using the method in part 3 and figure 4. After placing the ruler across the objective lens then measure the diameter of the eyepiece stop. You could add 10% to this because the ruler is not in the plane of the objective lens. This diameter will be called d-eps (**e**ye **p**iece **s**top) in the figure below. The field stop is placed in one of 3 positions 1,2, and 3 with the property that they all touch the purple line from point A on the objective lens to the top of the eyepiece stop. Recall point A is the location where the edge of the bright disk of the eyepiece stop begins to disappear because its light is blocked. The distance from point A to the nearest edge of the objective lens is called D. At this point we can't determine the location of the field stop. Now move your eye upwards (left as in earlier parts) until the visible portion of the stop is at the top edge (left edge in earlier parts) of the objective lens.



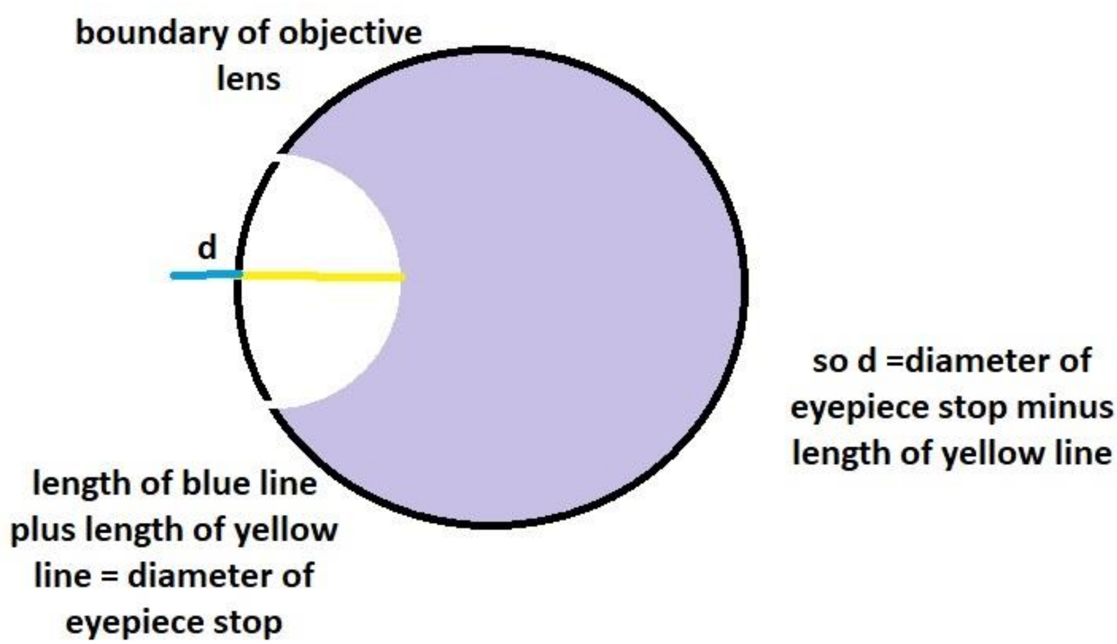
you have to estimate the distances d3, short vertical blue line, for the field stop in position 3 or d2 for the field stop in position 2, knowing that the measured value of d-eps is say 20mm for example. So, if d = d2 is about one third the diameter of d-eps, then d is about 7mm. Then let f be the fraction of the distance to the field stop between the objective lens and eyepiece stop. We can show that

$$f = \frac{D}{D+d}$$ where d is the estimated distance like d3 or d2.

For example, if D = 7mm and d = d2 = 7mm, then f = 7/14 or 50% of distance to eyepiece stop. But if d = d3 = 2mm say, then f = 7/9 = 78%.

The figure below shows the view while looking into the objective lens. Only a portion of the bright light disk from the eyepiece stop is visible. We need to know the length of the short horizontal blue line which is called d below, but is the same as the short vertical blue line on the previous page. However, it is not visible so we have to estimate the length of the blue line as follows. Given the diameter of the eyepiece stop as d-eps = 20mm, then d = d-eps – length of yellow line. In this example the yellow line is about two thirds the diameter of the eyepiece stop so the length of the blue line = 20 – 13= 7mm or so. Thus f = 7/14 = 50% as before.

Finally divide D by the diameter of the objective lens to get the percent distance of point A from the edge of the objective lens. Then go to the chart in part 4 and use this percentage value and that of f to estimate the amount of vignetting at the edge of the eyepiece stop.



Now it may happen, although very unlikely, that the eyepiece stop disappears completely before your eye reaches the top of the objective lens. This case is called D1 in the figure of first page of part 6. In this case no further testing is needed. Just throw the binoculars away or give them to someone who likes to take stuff apart to see what is inside!

In conclusion we have taken a long journey to understand how vignetting in binoculars can be reasonably determined. It takes practice and patience as in most things.
I have prepared another article on checking for vignetting in your binoculars using stars at night. If you know the angular field of view of your binocular, say 6 degrees, then find 2 stars whose brightness differs by 0.75 magnitude or 50% for example, and are which separated by 3 degrees or so in the sky. Then looking at these two stars in your binocular, place the brighter star at the very edge of the field of view and move it around the edge until the fainter star is near the center of the field of view. Then see if the brighter star near the edge of the field of view is the same brightness or differs from the fainter center star. If the brightness is the same then you know the vignetting is 50% at the edge of the field of view. If edge star is still brighter than the central star then you know the vignetting at the edge is less than 50%.

This article will list quite a number of such pairs of stars to use with differing amounts of brightness. This article will be available soon.

Comments and questions welcome at my email:
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