ALL ABOUT OPTICS

For hundreds of years we've used optics such as **binoculars** and **spotting scopes** to enhance our vision and to see our world in new and exciting ways. A **binocular** is essentially a hand-held double-barreled telescope and a **spotting scope** is a shortened, single-barrel telescope. Both are multi-purpose instruments that expand our own eyes' abilities to see and are useful for a number of different activities including (but certainly not limited to):

- Hunting
- Birdwatching
- General nature observation
- Hiking & camping
- Astronomical observation
- Sporting events & concerts

Although perceived as technical in nature, there are really only a few things you need to know about binoculars and spotting scopes in order to make an informed decision and purchase.

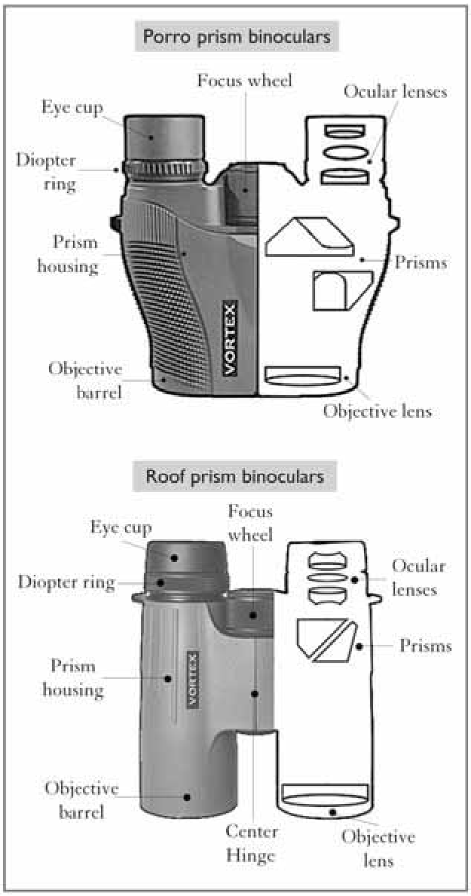
What are binoculars & spotting scopes for?

Binoculars and spotting scopes exist to both magnify and clarify images viewed through them. They make things look bigger and images viewed through them are clearer, have finer detail, and have a more three-dimensional appearance than when seen with the unaided human eye.

Chapter 1: Beginning Optics

Basic ideas, general design, function, and features of binoculars and spotting scopes

Binocular anatomy



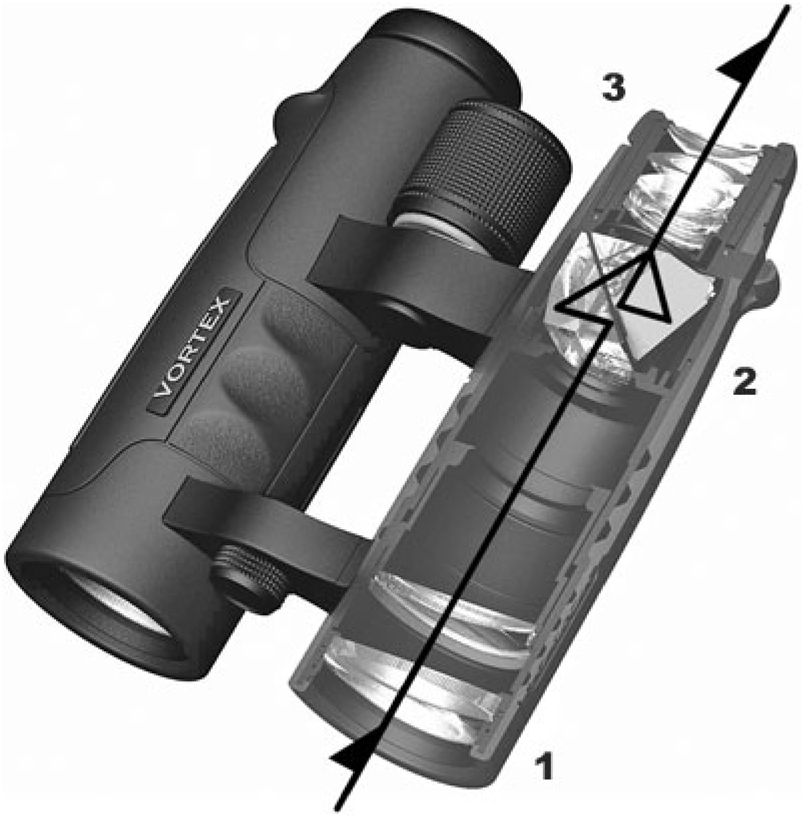
How do binoculars work?

All binoculars, regardless of their size and shape, function in the same, straightforward way:

1. Light comes to and moves through the objeective lenses.

2. Light then travels through the prisms (which correct the image orientation in all directions; up-down, left-right).

3. Finally, light moves through the eyepieces (which magnify the images) and then on to the user's eyes.



What determines image quality?

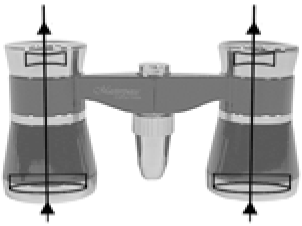
1. Optical glass - The quality of optical glass that is used in binoculars will make a difference in how bright, sharp, and colorful the view will be. Quality binoculars use dense optical glass that is painstakingly designed, shaped, and polished to eliminate flaws. The more sophisticated the glass and techniques employed in its design, the better the images.

2. Anti-reflection coatings - Binocular lenses are coated with anti-reflection coatings to eliminate internal reflections and light scattering, reduce glare and produce sharper images with more detail. The type of coatings and the number of coatings applied to the binocular lenses matter tremendously to how brilliant and crisp the view will be

3. Exit pupil - The exit pupil is the beam of light that exits each eyepiece of the binocular and enters the users' eyes. The larger the exit pupil, the brighter and more superior the image will appear, especially under low light conditions (when comparing optics of similar quality). The exit pupil is measured in millimeters, and is calculated by dividing the objective lens by the magnification. An 8x42 binocular, for example, has a 5.25mm exit pupil (42/8=5.25).

Binocular Design

Though they may look different on the outside, on the inside binoculars can only be designed in a few ways:



Galilean design

Used almost exclusively in opera glasses, the Galilean design is very primitive and uses only lenses (no prisms).

Porro prism design

Named after their Italian optical designer, Porro prism binoculars are characterized by the objective lenses being spaced wider apart than the eyepieces. The design is reversed in compact binoculars, with the eyepieces spaced wider than the objectives.

Roof prism design

Named for the "roof-like" appearance of the prisms, the more modern Roof prism design features a more complicated design, resulting in the objectives and eyepieces being positioned in a slim, straight line.

Porro prism or roof prism?

What do the numbers mean?

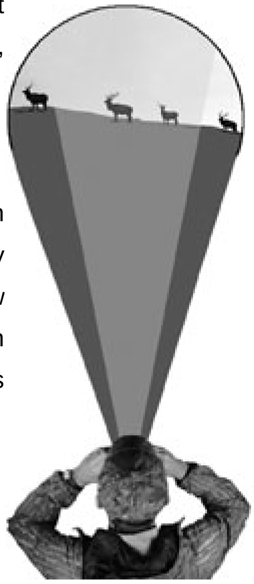
When you look at a pair of binoculars, you'll notice a few numbers printed on the binoculars, such as 8x42 (read as 8 by 42), or 12x50. What do these numbers mean? What do they refer to?

1. Magnification

With a pair of 8x42 binoculars, as in our example, the first number, 8 (often expressed as 8x), refers to the magnification the binoculars provide, or how many times larger an object will appear. Binoculars vary in magnification from 4x up to 12x and even higher, but 8x and 10x are most common. Higher magnification is not necessarily better. As magnification increases, users may have trouble holding the binoculars steady, causing the image to become blurry. An increase in magnification will also generally cause a decrease in image brightness and clarity. 7x / 8x magnification is considered adequate for woodland settings, while 10x is preferred for viewing at greater distances.

2. Objective lens size

The second number in our example binocular, 42, refers to the diameter of the objective lens (the lens farthest from your eyes) in millimeters. Objective lenses vary in size from 15mm to 50mm and beyond. The size of the objective lens determines how much light the binoculars can receive and hence how bright and clear the resulting images can be. The size of the objective lens also affects how large or small a pair of binoculars will be. Let your needs and desires help you decide what size objective lenses are right for you. If you use your binoculars only during the brightest times of day or in well-lit areas, then smaller objective lenses (say, under 25mm) will do just fine. If, however, you want the brightest possible image and will be using your binoculars during near-dark conditions (such as at dawn, dusk, or in heavy forest cover), you'll want to choose larger objective lenses, from 35mm to 56mm. The greatest factor in determining the weight of a binocular is its objective lens size; the larger the lenses, the heavier the binoculars will be. Again, let your desires dictate what weight is comfortable for you. Compact binoculars can weigh between a few ounces to under a pound, while modern full-size binoculars will weigh from twenty ounces to around two pounds.



3. Field of view

Another important number to know is the is the field of view. The field of view is the widest dimension from left to right that you can see when looking through the binoculars. This specification is usually measured either in linear feet at a distance of 1000 yards, or in angular degrees. A wider field of view is desirable for many reasons, including but not limited to: following fast moving action, and when scanning in denser backgrounds (grasslands, woodlands, etc.). Note that when magnification is increased, the field of view narrows (sometimes considerably).

Other useful specifications

The following specifications and definitions will aid in your understanding of how binoculars can function best for you and provide you with the maximum benefit out in the field.

Eye relief

The term eye relief refers to the furthest distance behind the binoculars' eyepieces at which the whole field of view can be attained, and is measured in millimeters.

The eye relief measurement is of great importance to those that must wear eyeglasses/sunglasses while looking through binoculars, but is also important to anyone planning to use binoculars for long stretches of time.

Binoculars with long eye relief will satisfy the above considerations, and will have an eye relief measurement of at least 15mm

Close focus

The minimum distance to which a pair of binoculars can be focused is called its close focus. Some users desire binoculars that will focus down to 10 feet or less.

Weatherproofing

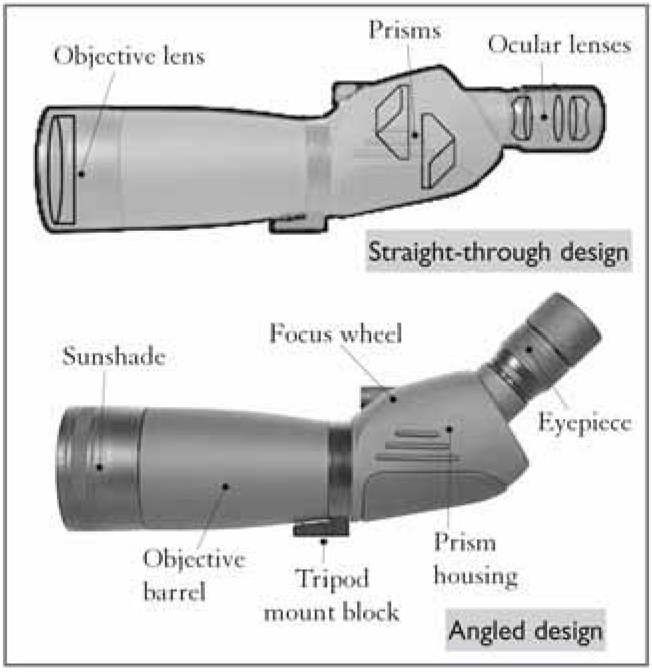
Binoculars that effectively keep out the elements will inevitably last much longer and keep you satisfied.

Waterproof / fogproof binoculars are sealed with O-rings at all open points to inhibit moisture, dust and debris. The inside of the binoculars is then purged of its atmosphere, which is replaced with an inert gas that has no moisture content. This process, called purging, ensures that the binoculars will not fog internally from high humidity or altitude changes. Nitrogen is the most common gas used when purging optics. A more unique gas, Argon, is utilized in select optics to provide a higher level of anti-fogging protection that is maintained over a longer time period.

Warranty

A manufacturer's included warranty ought to be considered a feature of the binoculars, especially if you plan to get a lot of use out of them in the outdoors where anything can and usually does happen. Most manufacturers offer a warranty limited only to initial defects, which do not protect you if anything accidental happens in the general course of using your optics. More progressive warranties keep you covered in literally any situation, regardless of what happened or who is at fault.

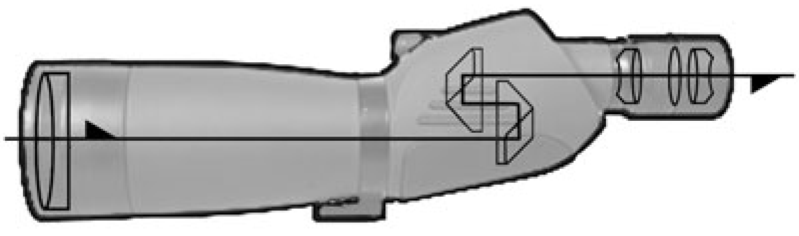
Spotting Scope Anatomy



How do spotting scopes work?

A spotting scope functions essentially the same way a binocular does:

1. Light is gathered and moves through the objective lens of the scope.
2. Light moves through the prisms (which correct the image orientation in all directions; up-down, left-right).
3. Light moves through the eyepiece (which magnifies the image) and then on to the user's eye.



Spotting scope specifications

Spotting scopes are essentially small telescopes designed primarily for land viewing at longer distances. A spotting scope features greater magnifications and a larger objective lens than those offered with binoculars, and as such requires a tripod to be used effectively. The light gathering power of a spotting scope is determined by the width of the objective lens, typically between 50 and 80 mm. All else being equal, the larger the objective, the more heavy and expensive the telescope.

- **50-60 mm spotting scopes** are fairly portable and compact and will offer good image quality for a generally lower price.

- **80 mm spotting scopes** will be much brighter than a 60mm scope but will also generally be heavier and potentially bulkier. An 80mm scope will deliver very good image quality at up to 60x magnification.

- s**potting scopes** that are **90mm or higher** have enormous light gathering capability that create a bright and clear picture in nearly all viewing conditions, including twilight. There are several spotting scopes with lens diameters over 90x on the market, including the Yukon 6-100x100 High Power Spotting Scope, which has a dual channel optical system with a 100mm lens that provides a high quality image at magnifications ranging from 6x to 100x.

Spotting scopes are often made available in two body styles, a straight-through design (where the eyepiece is in-line with the objective lens) and an angled design (where the eyepiece is set at a 45-degree angle). One design is not better than the other, but each design does offer some distinct advantages.

Straight-through design advantages:

- Works well with a car window mount;
- Provides a natural line-of-sight.

Angled design advantages:

- Allows for lower mounting height; improves stability, enables for smaller, lighter tripod;
- More comfortable for extended times of viewing.

As with binoculars, there are other specifications (such as eye relief, weatherproofing, warranty, etc.) that you may want to think about. Eyeglass wearers should look for scopes with at least 15mm of eye relief, and for using your equipment in inclement weather, all Vortex spotting scopes are fully waterproof and fogproof. As with binoculars, a scope that carries a more progressive warranty, will offer more piece of mind when out in the field

What determines image quality?

Most spotting scopes use a Porro prism design that offers a rich three-dimensional view with good image quality. Similar to binoculars, spotting scope image quality is derived from the types of optical glass and optical coatings that are employed in its design. The better the glass and optical coatings, the better the image quality.

Some spotting scopes are offered in two different versions of glass; a “standard” version, and a “high-grade” version. The standard versions employ regular optical glass in their design, and generally offer good to very good image quality. The high-grade versions make use of more exotic (and more expensive) glass types that deliver heightened resolution and color. Consider the high-grade versions (if available) if you desire the best possible image in all lighting conditions.

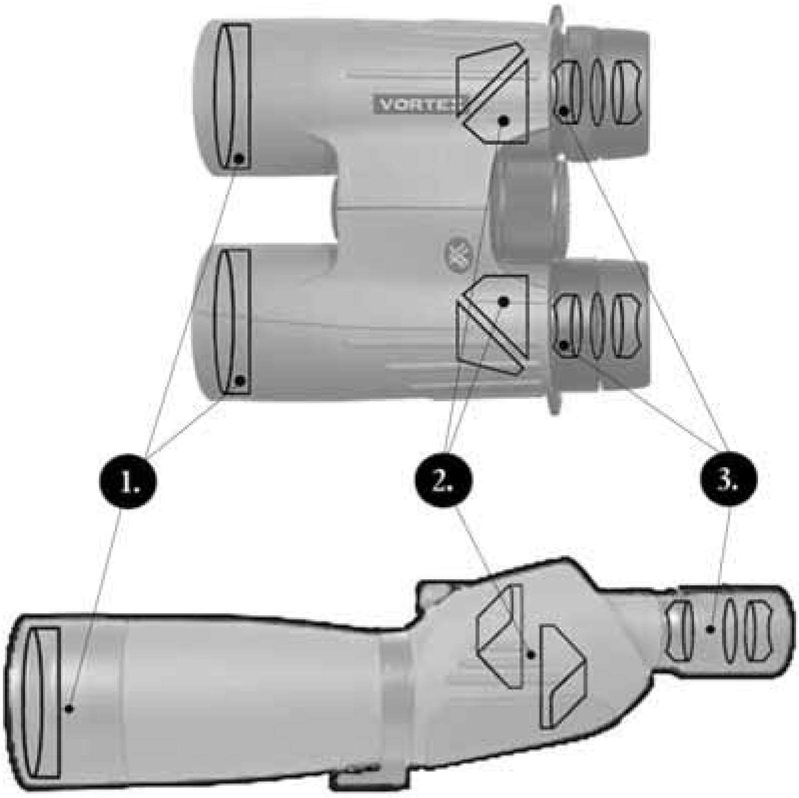
Chapter 2: Advanced Optics

In-depth, technical instruction on the design, function, and features of binoculars and spotting scop es

Advanced Optical Design

Binocular and spotting scope optical design is comprised essentially of three components:

1. **Objective lenses**
2. **Prisms**
3. **Ocular lenses**



1. Objective Lenses

The objective lens has one job, to gather light and transmit it to the user's eyes. In order to gather more light, an objective lens must be made larger. Transmitting more light (which is just a fancy way of saying “delivering” more of the light to the user's eye) can be achieved by using a higher density optical glass that is carefully cut and polished (and also by applying anti-reflective coatings, which are discussed later). With the relatively small objective lenses in binoculars, high-quality images can be obtained using standard optical glass.

High-quality glass types reduce or eliminate the inherent problem of chromatic aberrations. Chromatic aberrations are the result of a physical reality of color; different colors move at slightly different wavelengths, which means they will have slightly different focal lengths when they pass through optical glass. Chromatic aberrations diminish the resolution and color fidelity of normal binoculars and spotting scopes. They show up as green and/or purplish ghost images, and are especially apparent under low light conditions.

2. Prisms

The prisms in a binocular or spotting scope have two jobs:

- They revert the image, which would otherwise be presented to the user upside-down and backwards.

- They shorten binocular length (light bounces in the prisms; its path is shorter through the whole of the binocular than it would be without them).

Porro prism or roof prism?

Porro prisms have rich depth and wide field of view and usually employ large prisms. However, Porros aren't very rugged and many people feel they handle poorly. Porros are generally heavier than roof prisms due to the prism size and the use of larger prism housings (the housings are larger due to the bigger prisms, but also from the optical design of the binoculars). Roof prisms can achieve image quality similar to porro prisms, but it costs more (and involves phase correction coatings, discussed later). Also, most roof prisms generally can't replicate the 3-D feel of good quality Porros. However, roof prisms are generally more popular because of their ruggedness and superior handling (more streamlined and lighter weight).

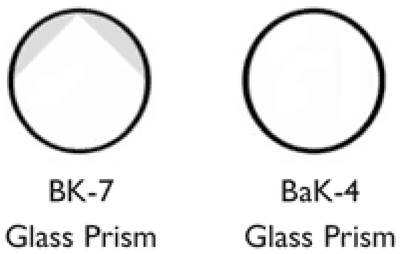
What determines prism quality?

The density of prism glass is important in determining its ability to deliver high-quality images. Also important is the care taken in grinding and polishing the prisms. There are two kinds of glass used to make Porro prisms; boro-silicate (more commonly known as BK-7) and barium-crown (known as BaK-4) glass. BK-7 glass is of inferior quality to BaK-4 glass, and is commonly used in the less expensive binoculars.

The type of glass used in roof prisms is of less consequence than with Porro prisms. Roof prisms involve more complicated engineering and stricter tolerances on their design - these factors have a greater determination on quality. Many manufacturers use BaK-4 glass in their roof prisms, but some manufacturers don't release any information on the prism glass type used - it's a trade secret.

Determining prism glass type

BK-7 glass prisms transmit a distinctive light beam shape, seen when you see the exit pupil of a binocular or scope at a distance of about 8 inches from your eye. BK-7 prisms lose some light as it passes through the prisms.



BaK-4 prisms (or other more exotic prism types) transmit more of the light through the prisms, and hence feature exit pupils with a clearly defined circle.

Phase correction?

Many modern roof prism binoculars advertise “phase-corrected roof prisms”, but what are those? This special kind of coating corrects for an inherent flaw in all roof prism designs.

After light passes through the objective lens, it is reflected off the mirrored surfaces of the roof prism and split into two out-of-phase beams of light. Light reflected from one roof surface is 1/2 of a wavelength different from the light hitting the other roof surface. This is sometimes referred to as “out of phase” or “phase shift”. Although the light waves are subsequently forced back together when they reach the viewer's eye, there is a slight reduction in image resolution and contrast.

The phase correction coating, which is applied to the mirrored surfaces of the prism, forces the light beams back into phase, thus improving a roof prism's resolution and contrast. The coating also enhances color fidelity.

3. Ocular lenses

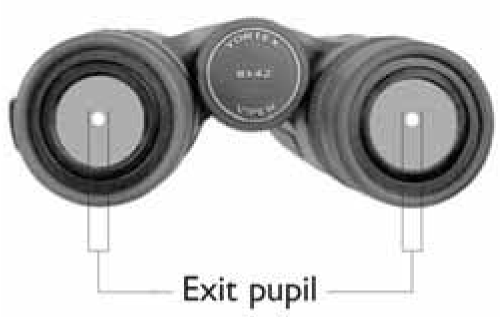
The ocular lenses magnify the images that the objective lenses have transmitted. Ocular lens design incorporates between three-to-six different lenses, but overall quality is determined mostly by the care in manufacturing and polishing of the glass and also the quality and quantity of anti-reflective coatings employed.

Many of the important optical specifications (such as field of view, eye relief, etc.) are determined primarily by the design of the ocular lenses.

Advanced image quality elements

Exit pupil

The shaft of light that meets your eye when you use a binocular or scope is its exit pupil. The exit pupil is seen by holding the binocular or spotting scope a short distance from your face.



The exit pupil should appear as a clear circle surrounded by a uniformly dark background. Exit pupil is calculated by dividing the objective lens by the magnification and is measured in millimeters. An 8x42 binocular will have an exit pupil of 5.25mm.

$$\text{Exit pupil} = \frac{\text{Objective lens}}{\text{Magnification}}$$

Why does exit pupil matter? The human eye pupil (which is controlled by the muscles of the iris) can change in size from roughly 2-8mm in diameter, depending on the lighting situations. The eye pupil dilates to about 2-3mm in regular lighting conditions, dilates out to about 4-5mm in lower light situations, and further dilates to 7-8mm in near-dark conditions. A binocular will appear brightest when its exit pupil is equal to or larger than your eye pupils. This is most important when viewing in low-light conditions.

Optical coatings

When you look at the lenses of a binocular or spotting scope, you'll notice tints in the glass that are usually purplish/greenish in color. What you are seeing are the anti-reflective coatings that have been put on the lenses. These coatings serve to reduce light reflection and scattering at the air-to-glass surface. When light strikes uncoated glass, a percentage of it (4-5%) is reflected back from the surface, and with 10-16 air-to-glass surfaces in a pair of standard binoculars or a spotting scope, almost 50% of the light passing through uncoated optics would be lost! By applying just one layer of anti-reflection coating, loss due to reflection can be reduced to 2-3%, and by applying multiple layers of coatings, light loss can be reduced to a mere .5% per surface!

Optical coatings are made from certain metallic compounds (including the compound Magnesium Fluoride) that are vaporized and applied to the optical glass in very thin layers (measured in microns; millionths of a meter) inside a vacuum chamber. The quality and quantity of optical coatings matters a great deal in determining how bright and sharp a binocular or spotting scope will be.

There are some standardized terms concerning the level of coatings applied to binoculars and scopes. With optical coatings, more is better! With more coatings comes increased resolution, contrast, color fidelity, and increased light transmission.

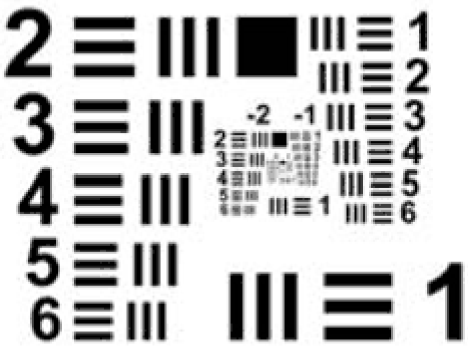
- **Fully coated optics**: all air-to-glass surfaces are coated with an anti-reflective coating film. Many modestlypriced binoculars offer fully coated optics and have good but not great image quality.

- **Multi-coated optics**: one or more surfaces are coated with multiple anti-reflective coating films. Image quality with multi-coated optics can be quite good, except perhaps in lower light settings.

- **Fully multi-coated optics**: all air-to-glass surfaces are coated with multiple anti-reflective coating films. Fully multi-coated optics offer the highest image quality.

Important optical terms

Resolution: The ability of a binocular/spotting scope to separate and distinguish thin lines with clarity. Resolution is essentially the same as image sharpness.

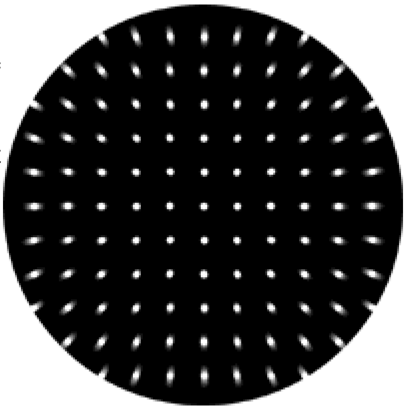


Resolution test: A chart on paper containing a series of sets of lines at progressively smaller spacing and used to ascertain the limiting number of lines per millimeter that a binocular or spotting scope is capable of resolving clearly.

Contrast: The ability to distinguish differences in brightness between light and dark areas of an image. Because we see much of the color spectrum, contrast also refers to the ability to distinguish differences in dimensions of hue, saturation, and brightness or lightness. Optics with superior contrast transmit colors that appear very dense and saturated.

Transmission: The percentage of light that passes through the binocular or spotting scope and reaches the user's eyes. With expensive optics (those that have more and better optical coatings, better optical designs, and better glass) the light transmission will be higher than it will be in more modestly priced optics. There is currently no universal industry standard for measuring and comparing light transmission.

Chromatic aberrations: Because different colors move at slightly different wavelengths, they will come to focus at slightly different lengths when they pass through optical glass. The resulting false colorations (seen most often as purplish and greenish ghost images) diminishes resolution and color fidelity. Chromatic aberrations will be negligible with binoculars and scopes that use better optical coatings and/or higher quality glass.



Astigmatism: The lenses used in a binocular or spotting scope usually have a curved shape, and thus all light rays passing through will not converge on the same focal plane. If this physical reality isn't remedied in the overall optical design, a binocular or spotting scope will provide images where either the center image or the edge image is in focus, but not both (without refocusing).

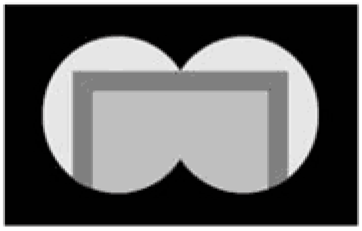
Astigmatism cannot be eliminated completely, but it can be kept to a minimum. Users will want to avoid binoculars or spotting scopes that exhibit too much astigmatism, as it cuts into the image quality.

Distortion: The disability of a binocular or spotting scope to deliver an image that is a true-to-scale reproduction of an object. There are principally two types of distortion to be concerned with; barrel distortion (where images bow outward and look bulged), and pincushion distortion (where images bend inward). In both cases, the distortion is due to a poor or compromised optical design and any binocular or scope that exhibits distortion should be passed up.

Alignment and collimation: In a binocular or spotting scope, the optical components must, for the best performance, be situated as they were initially designed. Poor or rough handling of the equipment can cause any or all of the components to become misaligned, resulting in diminished performance.

In a binocular, the optical components (primarily the prisms) in both barrels must be pointing in the exact same direction, known as collimation. Viewing through binoculars that aren't perfectly collimated (whether they became miscollimated through poor construction or mishandling) can cause great eye strain and fatigue. Porro prism binoculars are much more susceptible to collimation issues than roof prisms.

You can test a binocular for collimation by looking through them at a horizontal line (a door frame at about 15 - 20 feet works very well) and then slowly and carefully pulling the binoculars away from your face so that you can start to see where the two exit pupils intersect. The horizontal lines in each exit pupil should match up correctly. If they do not, they are out of collimation and need repair.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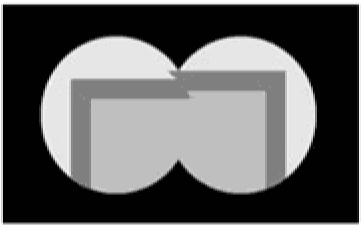
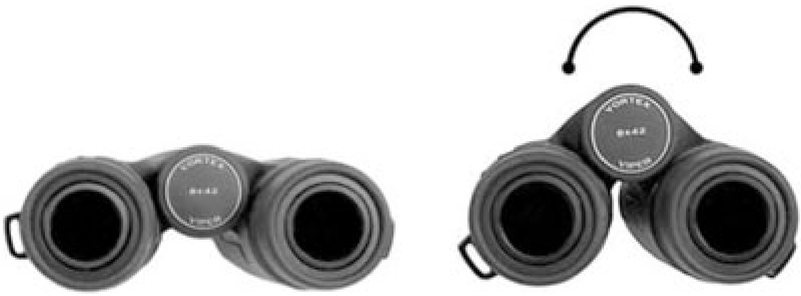

Out of collimation

How to use binoculars properly

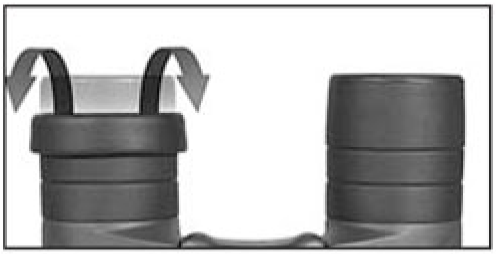
Adjusting for your interpupillary distance

In order to see one singular image, you must adjust the two barrels of the binocular to your interpupillary distance (the distance from left pupil to right). To do this, turn the barrels of the binocular on their central hinge until you see one singular field of view with no disturbing shadows.



Using the eyecups

The eyecups on a binocular or spotting scope aid in maintaining proper eye relief for the user (which allows for the most comfortable and widest view). There are essentially two types of eyecup design: a flexible rubber design (**A**) and a retractable design (**B**) which is usually lightly rubber armored.



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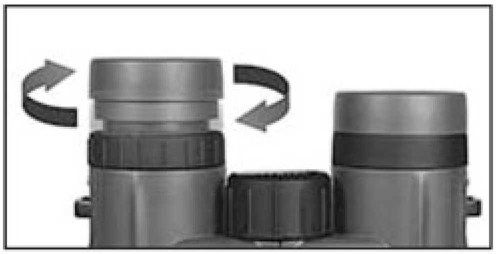

B

If you wear eyeglasses / sunglasses, rest the eyecups of the binocular/scope right up against your glasses. Since your glasses sit away from your eye, they generally provide the proper distance for seeing the full field of view comfortably. The rubber eyecup must be folded down to be able to rest on your glasses. The retractable eyecup will stay flush with the eyepiece to accommodate glasses. If the rubber eyecups aren't folded down or the retractable eyecups are twisted out, it will appear as if you are looking through a tunnel.

If you don't wear eyeglasses / sunglasses, you will rely on the eyecups to provide the proper distance for seeing the full field of view. The rubber eyecup stays “as is” and fits right around your eyes, while the retractable eyecup must be twisted- or pulled-out fully in order to see the full field of view. If the rubber eyecup is folded down or if the retractable eyecups aren't retracted out, you will note disturbing black “crescents” in your field of view.

Many retractable eyecups offer multiple positions or “stops”. With these eyecups, experiment to see which position is most comfortable for you.

Using the diopter / Focusing your binoculars

Most binoculars feature a center focus wheel and also an adjustment ring (either on the right eyepiece or integrated into the center focus wheel) known as the diopter. The diopter adjusts for differences between your individual eyes (many people have one eye that is “stronger” than the other). The procedure for attaining proper focal balance using the center focus wheel and the diopter is:

1. With your right eye closed (or with your hand over the right objective lens), focus your left eye on an object approximately 20 yards away with the center focus wheel until it is in sharp focus.

2. Now adjust for your right eye. To do this, close your left eye (or, again, place your hand over the left objective lens) and focus your right eye on that same object 20 yards away. Focus using the diopter until the object is sharply focused. Note: Some diopters have a locking feature that you’ll need to unlock before moving the diopter ring.

3. The binoculars are now set for your eyes. Make a note of your diopter setting if you are sharing your binoculars with someone else.

What to disregard and why

There are a number of specifications and product “features” that are often confusing or misleading which should just be ignored or avoided.

Specifications to ignore

Twilight factor:

This specification gives a measure of viewing efficiency in low lighting. The bigger the number, the more efficient (sharper) the binocular is in low light. Twilight factor is calculated by taking the square root of the power times the objective lens diameter, so the value is usually between 12 and 25. Twilight factor is a dubious specification because it says nothing about actual optical coatings or glass quality, nor does it take into account the light transmission of the binocular.

Relative brightness:

This specification is a measure of overall image brightness, and is calculated by squaring the exit pupil of the binocular. Relative brightness is misleading in that there are different binoculars that can have the same values. A 7x35 binocular and a 10x50 binocular will both have a relative brightness value of 25, but the 10x50s gather much more light than the 7x35, and will often present a brighter image. It also doesn't take into account different light transmissions.

“Features” to avoid

Focus-free binoculars:

Binoculars that offer an “instantfocus”, “permanent-focus” or “focus-free” feature are advertised in many department stores. The main reason to avoid this type of binocular is that optical quality is very poor as a result of its focus-free design. Focus-free binoculars are also often difficult to use if you wear eyeglasses.

Ruby coated lenses:

Often advertised in sporting goods stores and department stores, these are seen as bright reddish-orange coatings on the objective lenses of several binocular models. Ruby-coated lenses reflect most red out of the optical system. This skews all colors to the cool end of the spectrum and takes away from the overall brightness of the binocular.

So why use these binoculars? Shortening the color spectrum increases contrast and resolution somewhat. However, better glass and better coatings are capable of excellent contrast and resolution without giving up color and brightness.

Trade-offs

Unfortunately, there is no such thing as the perfect binocular or spotting scope. In the design phase there are many inherent trade-offs that have to be made.

- The main trade off that you have to make involves objective lens size. The larger the objective lenses, the brighter and sharper the binocular/scope, thus the more useful it is, especially under low-light conditions. The larger the objective lens, however, the heavier and bulkier the binocular/scope will be, and unless you plan to hire a porter, remember that you have to carry it!

- Higher quality optical glass is by design heavier, so when it is employed the binocular/scope will weigh more.

- There are a number of trade-offs with binoculars and scopes regarding higher magnification. With higher magnification binoculars comes a diminished field of view, a shallower depth of field, and more chance of image shakiness. With higher magnification spotting scopes comes diminished optical quality with magnified heat waves and atmospheric dust & debris.

- There are trade-offs inherent to some of the optical specifications as well. There is an inverse relationship between eye relief & field of view and close focus & depth of field. The greater the eye relief, the narrower the field of view (the wider the field of view, the shorter the eye relief). Similarly, a binocular with an extreme close focus distance will generally have a shallow depth of field.

More expensive scope eyepiece designs can offer good compromises and give the user very good (but not great) specifications.

The final word

For many people, this guide may be only the beginning of the journey into learning about binoculars and spotting scopes. There is a LOT more information available. Should you have any questions or comments about something you have read in this guide, please contact us at sales@aeon-optical.com and we will be happy to assist you.