LOOKING FOR THE MAGIC EYES:
A COMPREHENSIVE GUIDE TO CHOOSING BINOCULARS

K. K. Lai

Physics Department
Universiti Brunei Darussalam
Brunei Darussalam BE 1410

ABSTRACT: This article explains in detail the principles of binoculars and some terms and jargons that a potential buyer or user may come across. Various aspects that should be considered when choosing a pair of binoculars are discussed at length with a view to educate the reader rather than simply offering recommendations. Some general guidelines are given to help choosing binoculars for various situations.

Keywords: Choosing binoculars, principles, guidelines.

Introduction

Star watching, of the non-Hollywood type, is probably one of the oldest branches of science. One can imagine our ancestors on a starry night, lying on a warm boulder in front of a cave shelter, trying to make sense out of the maze of twinkling points of light which seemed forever out of reach. How fortunate it is that we, their modern descendants, have so many toys and gadgets at our disposal which magically show us things in the sky that we cannot see with our naked eyes. In 1986, when Halley’s Comet was in the sky, I happened to be accompanying some visiting astronomers to Mount John Observatory in New Zealand. It is hard to describe the sense of awe I experienced when I look my first ever look through the observatory’s 1-meter telescope and saw Saturn and its rings floating in space. If the ancients were, able to see the rings, they might have invented the hula loop before we did.

Many people think that a telescope is absolutely essential for stargazing. It is true that a telescope allows you to see very faint stars and other celestial objects. However, many of the deep space objects like galaxies and star clusters can also be seen using a pair of binoculars. For greatly extended objects like comets, the view through a pair of binoculars may be more spectacular than a small telescope, as the larger field of view allows you to see the comet’s tail in relation to its head. With binoculars of 50 mm diameter or larger, up to seven of the planets can be observed, and also four of Jupiter’s moons forming a row with it. You can see how the moons change their positions nightly with respect to Jupiter as they revolve around it. At high magnification, it is also worth trying to make out the rings of Saturn. Our moon, of course, is an easy target.

Bird watching, of whatever kind, will be difficult without the aid of a pair of binoculars. On the other hand, with the availability of giant display screens, few fans will bring binoculars to an open-air concert just for looking at their idols on stage. For some, it is far more interesting to watch the watchers who have come to watch the concert.

The uses of binoculars are many and varied. So are the manufacturers (no less than 25 from Japan, Europe & US) and models on the market. How do you choose a pair that suits your needs? Should you simply rely on the salesman’s recommendation?
I wouldn’t, and neither should you. In the following sections, I will try to explain the many terms that you are likely to encounter, describe the features to look out for and list some general guidelines in selecting binoculars.

Then there is the matter of language. In British English, “binoculars” is a plural noun and the reference is “a pair of binoculars”. Some Americans however, argue that two oculars make one “binocular", as in “bicycle", and so use the reference “a binocular” or the short form “a bino”. The Oxford Advanced Learner’s Dictionary does not list the word “binocular”, but still the choice is yours.

Types of Binoculars

There are three basic designs of binoculars: Galilean binoculars, porro-prism binoculars and roof-prism binoculars. Galilean binoculars are also known as opera glasses or field glasses. They are small and inexpensive. Each barrel contains a convex lens at the front and a concave lens at the back. You look through the concave lens to get a magnified view. The optical system is very simple and the magnification is low, not more than five times (5 X). In the rest of this article, I will concentrate on the more common prism binoculars.

How Prism Binoculars Work

A pair of binoculars consists of two identical barrels, each of which contains the following optical elements: at one end is a large lens called the objective, at the other end is the eyepiece, through which you look, and between these is a pair of prisms. Both the objective and the eyepiece are usually made up of two or more lenses.

To see how a pair of binoculars works, let’s suppose we use one pair of 8 X 50 designation to look at an elephant from a distance of 100 meters. When we point it at the elephant, the objective lens focuses the light from the elephant to form an inverted (top→down and left→right) image inside the barrel in front of the eyepiece. This image is real, in the sense that if you were to place a screen there, an inverted and greatly reduced image of the elephant would appear on the screen. This is the same as in a camera; the screen is the negative. In order to correct for the orientation of the image, a pair of prisms is inserted to flip the image the right way up. So now, we have a real and upright image inside the barrel.
The eyepiece, made up of a few small lenses, is designed to function as a high power magnifier. For a magnifier to work, the object being looked at must be closer than a few centimetres. The real elephant is 100 m away, so obviously we cannot use the eyepiece to look directly at it. But we can use it to look at the reduced image! So, the image formed by the objective lens becomes the object for the eyepiece.

But of course, we don’t have a screen inside the barrel to render the image visible. In other words, if we open up the side of the barrel and look inside, we will not see any miniaturised elephant! What happened is that the light continues on past the plane where the image would appear if you place a screen there, and diverges to enter the eyepiece. Thus, the light that enters the eyepiece appears to come from a miniature elephant. In other words, optically, it is as if we are using the eyepiece to examine a real miniature elephant. Finally, the light exits from the eyepiece and is focused by the lens in our eye to form an inverted image on the retina. Our brain then interprets this as an upright elephant.

Although the miniaturisation of the first image is great - the magnifying power of the eyepiece over compensates for it and results in a net gain in magnification of 8 times. Therefore, our eye sees an enlarged final image of the elephant. The brain then combines the images from the two eyes into a stereoscopic perception of an elephant at roughly 1/8 of the distance, i.e. 100 / 8 = 12.5 meters away.

**Porro Prism vs Roof Prism**

Prism binoculars make use of a pair of prisms to flip the image so that it is oriented the same way as the object. There are two types of prisms used: roof prisms and porro prisms.

Roof prisms are small and the design of the binoculars can be compact, in the form of paired straight tubes (H shape). Because of more stringent requirements in the optical alignment, a really good pair tends to be more expensive to produce than its porro-prism equivalent. However, they will never out-perform porro-prism binoculars of the same designation. Their distinct advantage is in being compact in design and lighter in weight.

Porro prisms, on the other hand, are bigger and need to be oriented in a specific
Magnification and Diameter (Aperture)

Binoculars are designated as "7 X 50" or "10 X 50" etc. The first number is the magnification and the second number is the diameter (aperture) of the objective lens in mm.

The objective lens is the large lens oriented towards the object. The bigger the diameter, the greater the resolving power (see below), and the more light it will collect. The latter can influence the image brightness (see Relative Brightness). The light gathering power goes up as the square of the diameter, e.g., a 50-mm objective gathers twice as much light as a 35-mm objective. This is especially relevant if the binoculars are to be used for looking at stars. For this purpose, the diameter should preferably be 50 mm or larger.

Strictly speaking, the magnification refers to the increase in angular spread of the object. The increase in linear size is slightly greater, but usually taken to be the same. Thus, an 8 X magnification would make a 1 m x 1 m square appears as an 8 m x 8 m square. Visually, this is equivalent to the 1 m x 1 m square appearing at 1/8 the distance. Usual magnifications are in the range 6 X to 15 X. At magnifications higher than 10 X, any tiny hand movement will be greatly amplified. This may make the visual field unstable unless the unit has built-in image stabiliser, or it is mounted on a tripod or other structure. Some models come with zoom feature, which allows you to vary the magnification over a range. Binoculars with magnifications of 20 X to 45 X are also available for people who crave for high power.
Resolving Power and Resolution Limit

You may have noticed that for a given diameter, the choice of magnification is limited. For example, you will never find a pair of 35-mm binoculars with 20 X magnification. This has to do with the resolving power of the objective lens and of our eye.

*Resolution limit* is usually expressed as the smallest angular separation of two points that can be seen as distinct. Smaller angle means higher *resolving power*. The resolution limit of the eye is inversely proportional to the size of the pupil. For example, when the pupil is 2.5 mm in diameter, the eye has an angular resolution of 0.0154° (or 55.4″). When it is 7.0 mm in diameter, the angular resolution improves to 0.0055° (or 19.8″).

The theoretical resolution limit of the binoculars is determined solely by the size of the objective. Like the eye, it is inversely proportional to the diameter. Since the latter is always larger than the eye pupil, the inherent resolution limit is correspondingly smaller. Therein lies the magic of binoculars. When a pair of binoculars enlarges the size of an object, details too fine to be seen by the naked eye but resolved by the binoculars is also enlarged. If we increase the magnification until the eye can just resolve all the enlarged details, the maximum benefit would have been obtained. It turns out that this occurs at a so called, "useful magnification", given by the ratio of the diameter over the eye pupil size.

\[
\text{Useful Magnification} = \frac{\text{Diameter}}{\text{Eye Pupil Size}}
\]

At the useful magnification, the exit pupil (see below) is identical in width to the eye pupil, and the eye will see the maximum possible amount of details. Higher magnifications (smaller exit pupils) increase the visual size of the image but not the details seen. In fact, at excessively high magnifications the image inevitably becomes blur. For this reason, excessively high magnifications are referred to as 'empty magnifications'. Lower magnifications (larger exit pupils), on the other hand, result in under utilisation of the binoculars' resolving power.

The eye pupil changes size from 2 mm to 7 mm according to lighting condition and age. Therefore, for a given diameter D, the useful magnification cannot be smaller than \(D/7\) or greater than \(D/2\). As an example, for a 35-mm objective, the useful magnification lies between 5 and 17. However, a more practical range is 6 - 10.
A pair of binoculars should be used with its specified magnification as the useful magnification. This is the case if your eye pupil matches the exit pupil (see below) in size.

**Exit Pupil and Eye Relief**

After the light beam exits from the eyepiece, it first converges to a waist, where the diameter is the smallest, before it diverges. The waist is called the *exit pupil*, referred to by its diameter in mm. It occurs at the *eye point*, a short distance from the eyepiece. This distance, measured in mm, is called the *eye relief*. The eye relief is determined by the optical design of the eyepiece and is not related to the magnification.

To see the exit pupil, hold the pair of binoculars level at arm’s length. You should see a perfectly circular hole at the centre of each eyepiece. The exit pupil can be calculated as follows:

\[
\text{Exit Pupil} = \text{Diameter} + \text{Magnification}
\]

Ideally, the exit pupil should match the pupil size of the eye (see Magnification and Diameter). If the eye pupil is smaller than the exit pupil, part of the light beam will be blocked by the iris, an effect called vignetting. This will result in a lesser amount of light entering your eye, a wastage of the light gathering power of the objective lens.

In bright light, the pupil of a human eye may be as small as 2 mm. In dim light, it can dilate to 7 mm or so. Binoculars are designed with exit pupils ranging from 3 mm to 7 mm. As a person ages, the dilated size gradually decreases and may be only 4 or 5 mm after middle age. Therefore for older folks, do not choose binoculars with an exit pupil of 6 or 7 mm as the extra cost is money wasted.

To collect the light that exits from the eyepiece, the eye pupil should be placed at the position of the exit pupil, i.e. at the eye point. This ensures that the best view is obtained. Therefore, a long eye relief will be more comfortable than short eye relief, especially for people wearing eyeglasses. Placing the eye further out than the eye point results in “keyhole” perspective.

**True and Apparent Fields of View**

The true field of view (or angle of view) is the angular spread of the part of the naked-eye view that the pair of binoculars magnifies. It may be stated in degrees, or as the width in feet (m) at a distance of 1000 yards (1000 meters), e.g. 6.8°, or “360 ft @ 1000 yds”, or “120 m @ 1000 m”. Use the table below to convert between the various figures:

<table>
<thead>
<tr>
<th>degree → meter</th>
<th>degree → feet</th>
<th>meter → degree</th>
<th>meter → feet</th>
<th>feet → degree</th>
<th>feet → meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>x 17.5</td>
<td>x 52.4</td>
<td>x 0.0573</td>
<td>x 3</td>
<td>x 0.0191</td>
<td>÷ 3</td>
</tr>
</tbody>
</table>

When you look through a pair of binoculars, the visually perceived angular spread of the view is called the **apparent field of view**, and is usually of the order of 50°. If it exceeds 60° it is referred to as “**wide-angle**”, as then the visual perception is considered wide. The apparent field of view is determined by the eyepiece design. It is constant for normal binoculars but is variable for zoom binoculars. Although not normally stated by the manufacturer, it can be calculated as follows:
Apparent Field = True Field \times Magnification

True field of view ranges from the narrow field of 2°-3° (35-53 m @1000 m) to the wide field of 6°-9° (105-158 m @1000 m). The latter is not to be confused with the 'wide-angle' mentioned earlier. The true field of a pair of 'wide-angle' binoculars with high magnification may be less than that of a normal pair with modest magnification.

Near Focus

This refers to the nearest distance (usually in ft) that you can focus on. It is an important consideration for bird-watchers who might want to look at birds at close range, e.g. in the back yard. Not all manufacturers provide this figure. Near focus is determined by the design of the binoculars and is not directly related to either magnification or diameter. It can range from as close as 2.5 m in some models to the usual 5 m - 10 m for binoculars of diameter 50 mm or less. For binoculars of 60 mm or larger, the near focus may be 13 m to 20 m.

Relative Brightness and Twilight Factor

These two terms are often misunderstood and misleading. For a start, brightness (or luminance in scientific jargon) is a visual sensation that depends on the response of the eye and the interpretation by the brain. The brightness of an object changes as the surrounding changes. A dim object against a bright background appears dark, while the same object against a dark background appears brighter.

To demonstrate the above effect, get ready three or four sheets of white paper. Cut a one inch strip from the edge of one piece, and keep the remainder. Fold the stripe twice so it becomes four layers thick. Now take the small piece in one hand and the pile of paper in the other. Hold the small piece of paper at a comfortable viewing distance away. Look at it against a dark background for a minute or so. Now, without moving the small piece of paper or your eye away from it, use your other hand to slip the large papers behind the small one. You will immediately sense that the small piece of paper has magically becomes darker. Confirm this by sliding the large papers in and out of the background. You need to use three to four layers thick to prevent light leaking out through them.

Now, let's consider a pair of 10 X 30 binoculars with a 5° field of view and an exit pupil of 3 mm. We assume our eye pupil is also 3 mm in diameter. Thus, there is matching in exit and eye pupil sizes. This means that the binocular is working at the useful magnification.
Let’s choose a completely cloudless and uniformly blue sky to look at. If we use our naked eyes, each of the pupils will admit light from a large patch of the sky. Out of this, we denote as $E$ the amount of light collected from a 5° patch.

On the other hand, the amount admitted by each objective lens from the same 5° patch is 100 $E$, as the lens is ten times larger in diameter, and so, one hundred times larger in area. However, when we look through the binoculars, we see a visual field that is ten times larger in angular size, i.e. 50° wide. This converts to one hundred times larger in area. Therefore, the amount of light per 5° patch is $100 \frac{E}{50} = E$, which is the same as the naked eye view! In other words, we get an enlarged view without any change in the amount of light per unit area within the field of view.

Does this mean that the image appears just as bright as the naked eye view? This depends on various factors. The 5° patch is but a small part of what the naked eye sees. If it consists mainly of dim objects surrounded by bright areas outside of the 5° patch, then you may sense the binocular view as being brighter, on account of the reduction in the extent of the bright areas (remember the experiment with papers earlier). Otherwise, you won’t sense any change in brightness.

If the diameter remains the same but the magnification is reduced, e.g. to 8 X, the true field of view will increase to 6.25° and the exit pupil will increase to 3.75 mm. The eye pupil however, remains at 3 mm. In theory, the amount of light per unit area in the binoculars’ visual field will be 156.3% that of the naked eye view. However, the eye pupil, being smaller in size, will admit only 64% of the light that exit from the eyepiece. Thus on balance, you will not perceive any change (1.56 x 0.64 = 1); i.e. the brightness is the same. The pair of binoculars behaves like an 8 X 24.

On the other hand, if the magnification is increased, e.g. to 15 X, the exit pupil (2 mm) will become smaller than the eye pupil (3 mm), which therefore will admit all the exit light. The true field of view (3.3°) will be reduced while the apparent field (50°) remains the same. There is therefore a greater expansion of the image area (225 times the naked eye view). However, the light collected by the objective lens is still 100 times that collected by the eye. Consequently, the amount of light per unit area is reduced to only 44% (100 + 225) of the naked eye view. Therefore the view through the binoculars appears dimmer.

If the pair of binoculars were used for stargazing the situation would be very different indeed. Stars, being so far away from us, always show up as points of light. Therefore, in the current example, the amount of light collected from each star is independent of the magnification and remains at 100 times more intense than the naked eye view. However, as discussed above, at the useful magnification, the background remains the same as the naked eye view. Therefore, against this, the stars appear brighter and stars previously too faint for the naked eye now become visible.

At a lower than useful magnification, (larger exit pupil), some of the exit light is blocked by the iris. Although the stars are still brighter than the naked eye view, the brightness is not as good as in the previous case. Some of the faint stars seen earlier may no longer be visible. In fact, the pair of binoculars functions as if the diameter of the objectives has been reduced to that given by the eye pupil size times magnification. For example, at 8 X, it functions as if it has a 3 x 8 = 24 mm diameter, i.e. the 8 X 30 behaves like an 8 X 24. Therefore, for folks above 40 years of age, whose maximum eye pupil size is 5 mm, it makes more sense to buy a pair of 10 X 50 rather than paying more for a pair of 10 X 70, as the extra money will be wasted.

At a higher than useful magnification (smaller exit pupil), the same amount of light as in the first case is collected from each star, but the background sky is dimmer for reasons discussed earlier. Thus the visible stars appear even brighter and also, some of the fainter stars may become easier to see. However, the field of view is smaller and there may be deterioration in the image sharpness and a greater amplification of hand-trembles. The benefits (wide field of view, hand-held etc.) of binoculars may be lost and it is then better to switch to a small telescope.

To help customers compare the image brightness offered by binoculars, manufacturers have introduced the term relative brightness, a number equal to the square of the exit pupil. It is commonly claimed that a relative brightness of 25 (exit pupil 5 mm) is 2.8 times brighter than one of 9 (exit pupil 3 mm). As we have seen, this is not necessarily so as the ratio of the eye pupil to the exit pupil is the
determining factor. If your eye pupil is at 3 mm or smaller, the view through either pair of binoculars would be equally bright, so the relative brightness is misleading. As a rule, comparing relative brightness is meaningful only if your eye pupil is at least as large as the largest of the exit pupils.

Twilight factor is the square root of the product of diameter and magnification. This is used principally by bird watchers as an indicator for performance under dim light conditions. Again, it is often misleading. For example, 8 X 50 and 10 X 40 binoculars have respective exit pupil of 6.25 mm and 4 mm but identical twilight factor of 20. For a person whose pupil size is 4.0 mm, both binoculars are equally bright, but the 10 X 40 binoculars gives the sharpest image. On the other hand, for a young person whose eye pupil size is 6.25 mm, the 8 X 50 is not only 2.4 times brighter than the 10 X 40, its image is also sharper.

Anti-Reflection Coatings

Each time light passes through an air-glass interface in either direction about 4% of the light is reflected and lost. In a typical pair of binoculars, the light beam may pass through 10 or more such interfaces. Thus, potentially 30% - 50% of the light may be reflected and lost. The reflected light bounces around inside the barrel and causes glare. Although good binoculars have their internal surfaces blackened to reduce light scattering, the amount of light lost is still objectionable.

Fortunately, modern technology has offered us a solution making use of the laws of physics. An extremely thin layer, less than a thousandth of a millimetre, of magnesium fluoride or other compound, is vacuum deposited on the lens surface. The thickness is carefully controlled so that reflection is inhibited because of interference effects. A single layer coating can reduce reflection to about 1.5%, averaged over all wavelengths of visible light.

Anti-reflection is improved further in multi-layer or broad band coating, which consists of several layers of different materials on top of one another. The reflection per lens surface can be reduced to 0.5% or less. This results in an overall light transmission of 95% or better in porro-prism binoculars. In roof-prism binoculars the maximum possible light transmission is slightly less because of the use of an aluminised prism surface.

Nowadays, most binoculars have at least some kind of coating on the objective lens. This will show up when you view the lenses at an angle. The lenses appeared to be coloured instead of clear. The colour seen depends on the coating material used. However, this does not tell you whether it is multi-coated or, more importantly, whether the other optical elements inside the barrels are similarly coated. The only way to find out is to look at the manufacturer’s printed specifications. Generally, you may encounter four different descriptions:

- **Coated**: Most likely only a single layer coating on the outside of the objectives and the eyepieces.
- **Fusy Coated**: Single layer coating on all surfaces of lenses and prisms.
- **Multi-Coated**: Usually means multi-layer coating on the outside surfaces of the objectives and eyepieces only, and single layer coating on all other lenses and prisms.
- **Fully Multi-Coated**: This is supposed to mean multi-layer coating on all surfaces. However, some manufacturers may cheat by using single-layer coatings on selected internal surfaces.

To get the most enjoyment out of your binoculars, go for fully multi-coated models if you can afford them. They are more expensive, but their image quality will be the best.

Waterproof Binoculars

These come in various grades. Those advertised as water-resistant or shower proof may fog up or leak when immersed in water. Only nitrogen-purged and hermetically sealed models are really fog proof and fully waterproof. Because of design constraints, most fully waterproof models have individual focusing for the eyepieces.
Image Stabiliser

To tackle the problem of shaky hands, some manufacturers have introduced vibration-proof binoculars. These usually have the internal prisms decoupled from the housing. By moving the prisms to compensate for any small movements of the housing, the stabilising mechanisms can ensure a steady view. The stabilisers may be purely mechanical (cheaper), or electrically driven actuators (more expensive) controlled by an electronic circuitry with motion sensors.

For example, Zeiss offers a 20 X 60 stabilised model that they claim can be hand-held. Other models e.g. 12 X 36, are available from Canon. Note that severe vibrations may still cause the view to shake. Stabilised models are particularly useful if you have to use the binoculars from a moving vehicle. However, they tend to be expensive.

Lens Aberrations

Lenses are not perfect in their light bending properties. Depending on their shape and material, there can be up to six types of image defects. These are: astigmatism, coma, curvature of field, distortion, spherical aberration and chromatic aberration. By cementing two or more lenses of different shapes together to form a compound lens, most of these effects can be corrected or reduced. However, you should still look out for distortion around the edge of the visual field. If the periphery appears out of focus when the centre of the field is well focused, then there is excessive curvature of field. Some manufacturers incorporate a special optical system to correct for this, resulting in sharp edge-to-edge view.

In recent years, a small number of manufacturers have incorporated aspherical lenses in some models of their binoculars. Usually, lenses are produced from blanks by grinding to yield the desired shapes and smoothness. The grinding process limited the types of surface curvature to either planar or spherical, i.e. being part of a sphere. Such lenses suffer from one or more of the aberrations mentioned earlier. However, advances in technology have made it feasible to produce aspherical lenses, which are lenses with at least one surface being of parabolic shape. These are precision moulded, not ground, to the design profiles that minimise aberrations. Thus, fewer lenses are needed, resulting in higher light transmission and better image quality. The industry leader in this technology is perhaps Docter-Optic of Germany (with a subsidiary in the U.S.).

Checking for Proper Lens and Barrel Alignments

Hold the pair of binoculars level at arm’s length. You should see a perfectly circular hole at the centre of each eyepiece. If either hole is not round, fuzzy or offset to one side, it means that the lenses in the barrel have not been aligned properly. You should reject outright such binoculars.

Look through the pair of binoculars and focus on an object. Ideally, the image should be sharp and clear from edge to edge. For most models, there may be a very slight blur near the very edge and this is perfectly acceptable. However, if the blur is substantial, reject the pair outright, no matter how cheap it may be.

To check for barrel alignment, focus on an object, correct for dioptr (see below) and adjust to get the sharpest image. Then look elsewhere to rest your eyes for 20-30 seconds. Block one of the objectives with one hand and look with both eyes through the pair of binoculars at the same object; then quickly drop the hand. The image should stay sharp throughout.
If the barrels were not aligned with one another, the image would blur as you drop your hand and then slip back into focus. This is because your eyes have unconsciously compensated for the differences between the barrels. Prolonged use of such a pair can cause eyestrain.

**Adjustments on Binoculars**

Most binoculars have a knob on the hinge between the two barrels. This is for adjusting the focus of both eyepieces in tandem. On one of the eyepieces, usually the right, is a diopter adjustment to correct for any differences in the strength of your eyes. The rubber eyecups help to block light from the side and also place your eyes at the eye point. If you wear eyeglasses, fold the rubber eyecups down.

To use the binoculars, set the diopter adjustment to zero, place your eyes on the eyecups and adjust the two barrels to merge the images into one. Close your left eye and adjust the centre focus to get a sharp image. Then open both eyes and adjust the diopter to re-sharpen the image. Once the diopter correction has been done, all subsequent adjustments of the centre focus will maintain that correction.

Some binoculars have no centre focus. Instead the eyepieces are focused individually. This is usually found in waterproof and marine binoculars.

When the magnification is high, the image tends to be unstable, as any tiny movement of the hands will be greatly amplified. In this case, the binoculars should be placed on a tripod or other support structures, or you can rest your elbows on the roof of a car. If you are sitting on the ground, then pull in your legs and rest your elbows on the knees.

**General Guidelines**

**All Purpose Binoculars**

Generally, these are used in daylight, so look for small exit pupils of 3-4 mm. Then decide either on the desired true-field-of-view or the magnification (up to 10 X). The diameter will work out to be less than 40 mm. For eyeglass wearers, look for eye relief of 15 mm or longer.

**Bird Watching**

If solely for daytime viewing, the exit pupil should be less than 4 mm. If for twilight conditions, get a pair with a large diameter and an exit pupil of 5 - 7 mm (5 mm for folks above 40 years of age). A good compromise is 5 mm. For a given diameter, choose one with the largest exit pupil consistent with the above. Alternatively, for a given magnification, select a pair with the largest diameter consistent with the above.

For example, for daytime use in and out of forests, I would choose 8 X 32 for its small size, and 10 X 40 for its higher magnification, which is necessary if the birds tend to be far away, e.g. on a sea shore. Good choices for twilight use are 8 X 40, 10 X 50 and 10 X 60. A stabilised 15 X 60, or a 20 X 80 mounted on a tripod, is excellent for watching small birds and animals. To ensure high brightness and good contrast in the image, always insist on fully coated optics.

**Boating and Fishing**

Binoculars should be fully waterproof. Some of these come with individual focus for the eyepieces. Magnification can be up to 10 X, but 8 X may provide a less shaky view. The exit pupil should be 3 to 4 mm because of the bright light conditions.

**Hiking**

Lightweight compact roof-prism binoculars are most popular among hikers. The diameter is usually below 40 mm. The magnification can be up to 10 X but it is advisable to keep it to 8 X or lower, to minimise the effect of hand trembling when using the binoculars after a long hike. The binoculars should be at least water-resistant if not fully waterproof.
Outdoor Sports and Concerts

Wide true field of view is recommended for team sport events in stadiums. Magnification can be up to 10 X but lower power would help to keep, for example, a larger part of the soccer field in view. For daytime use, the exit pupil should be kept below 4 mm. Zoom binoculars might offer some distinct advantages if you wish occasionally to zoom in on some actions. If you are prone to sitting in the rain, then waterproofing is important.

Stargazing

In this case, large is beautiful. If possible, go for diameter of 50 mm or larger. Light gathering power goes up as the square of the diameter, so a doubling of diameter means four times as much light is collected.

Since stars are far away, they always show up as points of light no matter what magnifications we used. Magnifications higher than the useful magnification (see the section on Resolution) result in a dimmer background (a smaller true field of view) and so can render faint stars more visible without improving resolution. Since the eye pupil will likely be fully dilated, you should choose binoculars with exit pupil of 5 - 7 mm. However, older folks should avoid binoculars with an exit pupil larger than 5 mm as up to half of the collected light will not make it through their smaller eye pupil; the extra cost will be money wasted.

It is advisable to ensure the optics are fully multi-coated. If you wear eyeglasses, then select a model with long eye-relief. A tripod should be used if the magnification is high, or if you are uncomfortable with holding the pair of binoculars.