EYEPIECES

Eyepieces are the part you look through and are responsible for magnification of the objects you see through the telescope. They come in many different magnifications and types, but it's not rocket science. You will soon learn what eyepieces work well for seeing different astronomical objects.

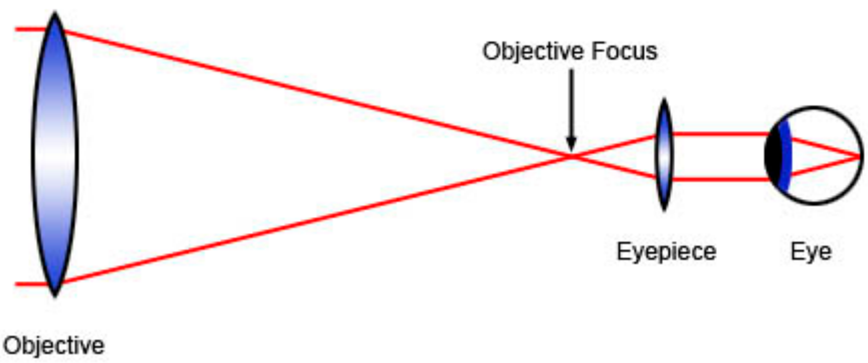
Telescope eyepieces are designed to fit into the focuser of the telescope. Depending on your telescope, they come in generally two sizes 1.25" or 2". There is 0.965" which is an older size and pretty much obsolete, unless you have an old telescope. Most telescopes can be fitted with adapters so both eyepiece sizes can be used. Eyepiece sizes is covered later.

Eyepieces determine the magnification and field of view of a telescope. Different eyepieces are used to view different objects. Some objects, such as nebulae and star clusters, appear quite large and are best viewed at low magnifications (which give a wider field of view), whereas planets appear very small and are normally viewed with high-magnification eyepieces. One of the most common misconceptions in amateur astronomy is that magnification is the most important aspect of a telescope. In reality, the diameter (aperture) of a telescope determines its power and different eyepieces are used to get the best view of a given object. Often the best view is at a low magnification.

How Eyepieces Work

Why are eyepieces even necessary? A telescope is an optical system that creates an image, just like a camera lens creates an image on film. In fact, placing a camera at the focus of a telescope will also capture an image, since the telescope becomes the camera lens. But, placing your eye at the focus point of a telescope does not produce an image. Why not? Because your eye is also an optical system. Your eye focuses light just like a telescope does, and it cannot focus on a *real image* such as that created by a telescope. It requires a *virtual image*, which is what an eyepiece creates.

Take a look at the diagram below. It shows that both a telescope and your eye focus light to a point. Placing an eyepiece at the focal point of a telescope then creates a light beam which is neither converging nor diverging. Your eye can then focus the light beam exiting the eyepiece.



Above: *How an optical system consisting of a telescope, eyepiece, and eye creates a final image*

Magnification

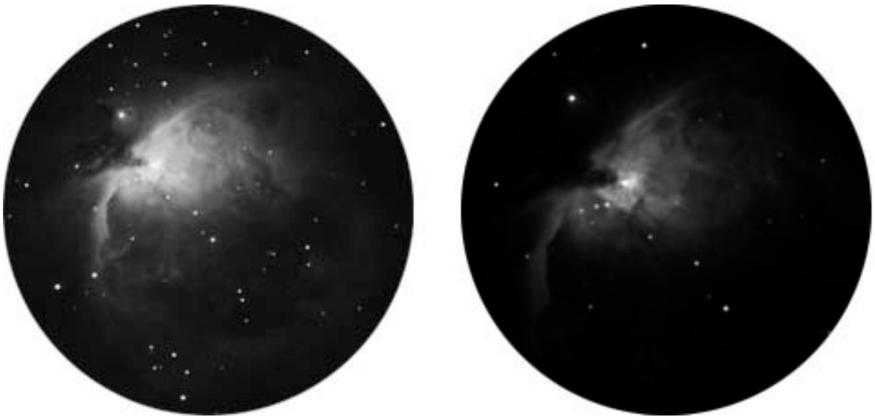
The most important eyepiece characteristic is focal length. This is the number, in millimeters, written on the side of every eyepiece. It allows you to determine the magnification an eyepiece gives in combination with a given telescope. Magnification is determined simply by dividing the focal length of the telescope by the focal length of the eyepiece.

$$\text{Magnification} = \frac{\text{Telescope Focal Length}}{\text{Eyepiece Focal Length}}$$

> Example : for a telescope of focal length 1500mm and an eyepiece of 10mm, then the magnification will be x150.

This means that a smaller number on an eyepiece gives a higher magnification. A 10mm eyepiece would provide twice as much magnification as a 20mm eyepiece. It also means that the same eyepiece gives different magnifications on different scopes. A 10mm eyepiece would be low power on a short-focal-length scope but high power on a long-focal-length scope. For example, on an 80mm short-focal-length refractor, a 10mm might only provide 40x magnification, but the same eyepiece on a 10" Schmidt-Cassegrain telescope would give 300x.

A typical eyepiece collection would include 3 eyepieces: one low power, one medium power, and one high power. The usual magnification range depends on the telescope, but for most scopes the normal range might be from 50x to 250x.



Above: *Increasing the magnification makes the image larger, but the image gets dimmer and the field of view gets smaller. The image will get dimmer due to less light gathering capabilities at higher magnification.*

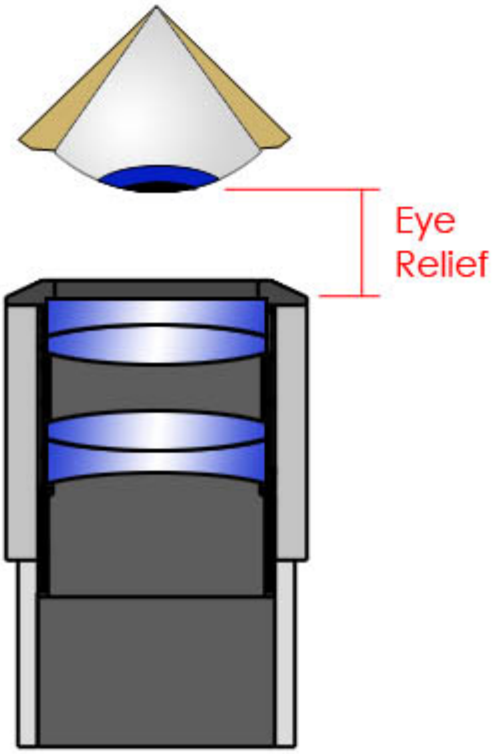
As **power increases**, **sharpness and detail decreases** - because you're pushing your telescope to the limits of its capability, the exit pupil will decrease in size resulting in darker images. Higher powers are used mainly for lunar, planetary, and binary star observations, as they emit a larger amount of light. Be wary of manufacturers that advertise ridiculously high-powered telescopes (e.g. 750x) with a mere 6mm aperture. Both false and misleading, these manufacturers leverage the fact that most consumers are in the dark about how telescopes operate. They pander to the common misconception that magnification is the most important thing in astronomical telescopes.

A word of warning

There are practical upper and lower limits for telescopes. Determined by different optical laws and the nature of the human eye, there are maximum limits to which you'll be able to push your telescope. As a rule of thumb, the Maximum Usable Power (or Highest Usable Magnification) of your telescope will be 60x its aperture (in inches) under normal conditions.

Eye Relief

This is an important aspect of many eyepieces. Eye relief is the distance from the eyepiece to the observer's eye. The shorter this distance, the more difficult it can be to observe. Also, if the observer must wear eyeglasses, short-eye-relief eyepieces can be very difficult or impossible to use. Long-focal-length eyepieces (usually low power) inherently have long eye relief, so they do not need to be specially designed to increase eye relief. Short-focal-length eyepieces (usually high power), on the other hand, do not inherently have long eye relief and must be specially designed to make them easier to use.

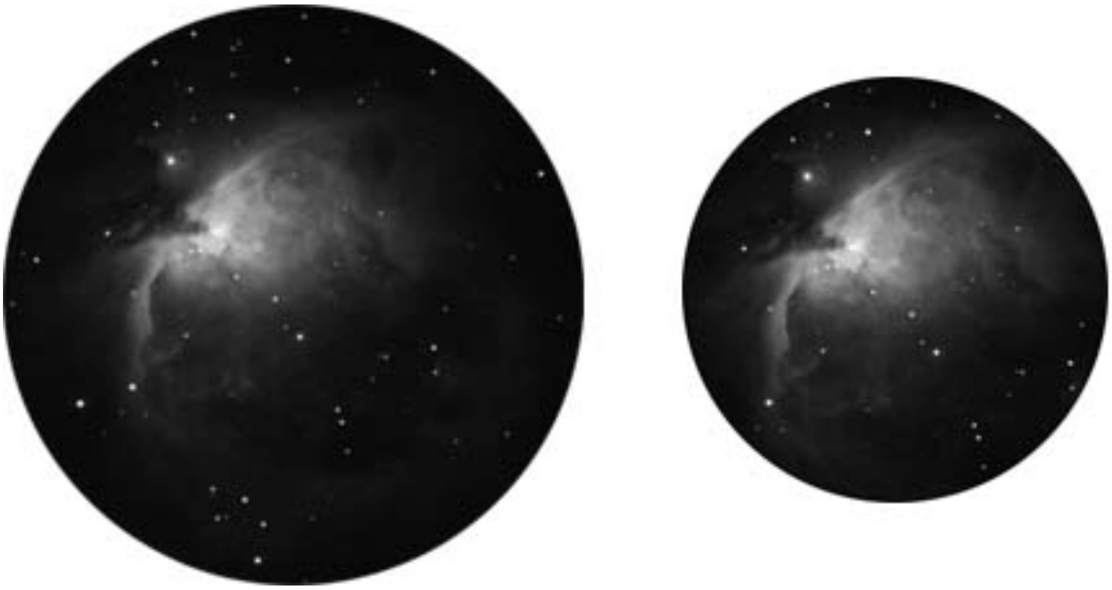


Above: *The eye relief of an eyepiece is the distance from the top lens in the eyepiece to the observer's eye*

Above: *Two short focal length eyepieces, one with normal eye relief and one specially designed with long eye relief. Note the difference in the size of the eye lens.*

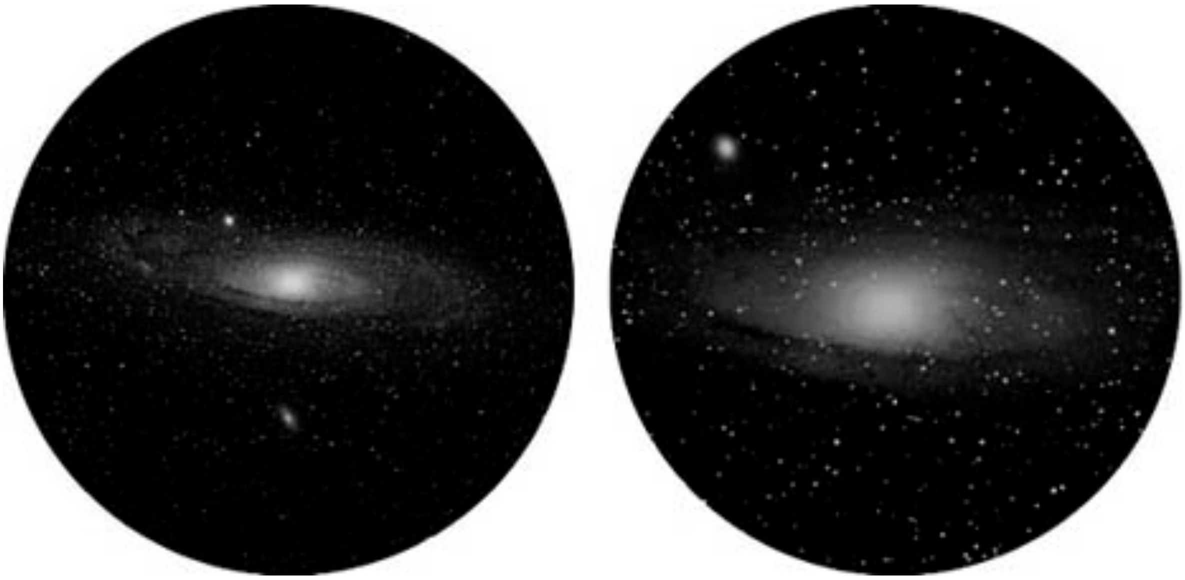
Field of View

The amount of sky seen through an eyepiece (called the true field of view) is determined by both the magnification and the eyepiece's apparent field of view. Apparent field of view is a design characteristic of an eyepiece design. Some eyepieces have narrow apparent fields and some have wide apparent fields. If the magnification is kept the same (i.e., the eyepieces have the same focal length), an eyepiece with a wider apparent field will have a wider true field.



Above: *Changing the apparent field but not the magnification changes the field of view but not the object size*

You can also change field of view by simply changing magnification. If the apparent field is kept the same, a lower power eyepiece will give a wider field of view. To view very large objects such as the Andromeda Galaxy or Pleiades star cluster, you need a very large field of view and hence a very low magnification. Field of view is very important for getting the best view.

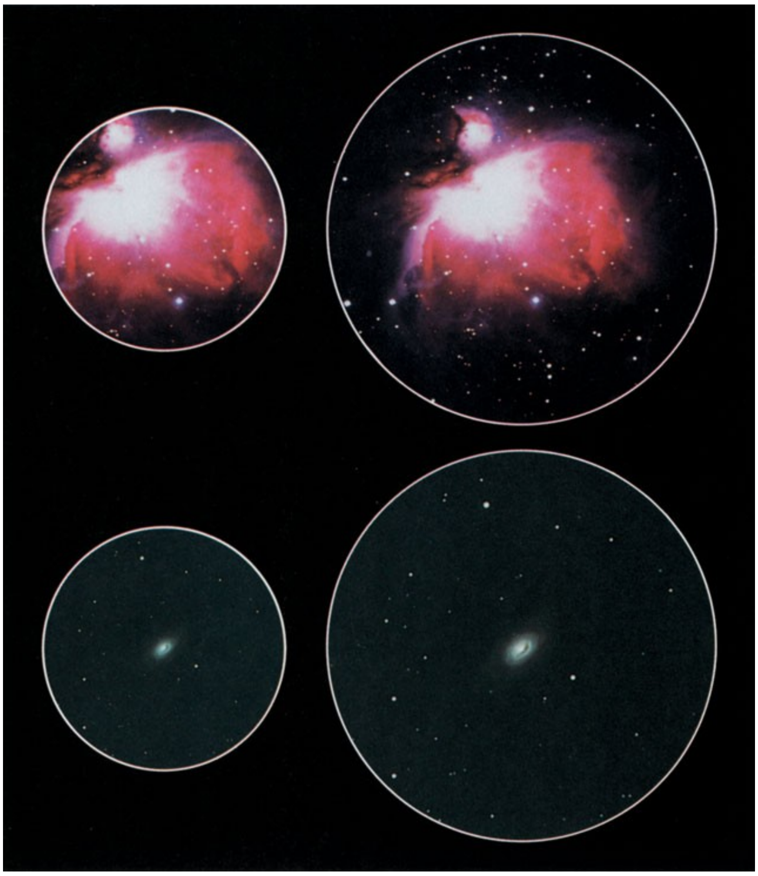


Above: *Increasing the magnification may not always result in a better view, especially if the object being viewed is very large*

Simulation of views through a telescope using different eyepieces. The center image uses an eyepiece of the same focal length as the one on the left, but has a wider *apparent field of view* giving a larger image that shows more area. The image on the right also has a shorter focal length, giving the same *true field of view* as the left image but at higher magnification.

Apparent Field Of View (AFOV)

The apparent field of view is the field of view advertised by eyepiece suppliers. It's the angle your eye sweeps out when you look at one edge of the field in the eyepiece and then look to the opposite edge. The greater the AFOV the more of the sky you will see, many of todays most highly regarded eyepieces are ones with a large AFOV, this is because it gives a more emersive feeling to the observer. With a larger field of view it also enables higher magnification to be used and still encompas quite large objects, the picture below shows two views at the same magnification, the one on the left has a 50° AFOV the one on the right an 80° AFOV, as can be clearly seen the one on the right frames the subject better.



However, the main problem associated with getting a wide AFOV is the cost. To get a wide field of view, that is well corrected, requires numerous lenses to be incorporated in the eyepiece. Every additional lens impacts light transmission, so to limit the impact of these lenses they must be of top quality and well coated and this raises the cost. Many of today's best wide field eyepieces are prohibitively expensive for the average amateur astronomer. Eyepieces can be roughly divided into four categories around AFOV: -

Narrow Field 30°-45° (some specialist eyepieces appear in this category, notably some specifically designed for planetary observation where a large field of view is not necessary but maximum transmission is)

Normal Field 50°-60° (there are many good quality, fairly inexpensive eyepieces with this AFOV)

Wide Field 65°-72° (there is an increasing number of eyepieces appearing in this category and the prices are decreasing while quality is increasing)

Ultra Wide 78°+ (the number of lenses needed to provide a well corrected field of view this size make it difficult to produce eyepieces of this AFOV cheaply so most are quite expensive)

True Field of View (TFOV)

The True Field of View (TFOV) is the actual amount of the sky we see when we look in the eyepiece. To work out the exact True Field of View requires you to know the exact size of the field stop, this information is, in most cases, not readily available. However the exact True Field of View is not really necessary for most observers, a good approximation of the TFOV can be obtained by dividing the stated AFOV by the magnification being used.

Eyepiece Sizes

There are two standard sizes of telescope eyepieces. The sizes are determined by the diameter of the eyepiece barrel that fits into the telescope. The two standard sizes are 1.25" and 2". A third size, 0.965", is a smaller standard that is usually best to avoid (see below).

1.25" Eyepieces
Almost all telescopes are designed to be used with 1.25" diameter eyepieces. Most telescopes will include at least one 1.25" eyepiece. Accessories such as Barlow lenses and filters are designed to thread into the barrel of these eyepieces, so such accessories are also distinguished by size. Good 1.25" eyepieces typically cost £30-£200, although there are more and less expensive models.

2" Eyepieces
The second standard size is the larger 2" diameter. Many telescopes will accept these eyepieces, though some telescopes will require an optional adapter. Not all telescopes work with 2" eyepieces. 2" eyepieces are wide-field, low-power eyepieces. Above a certain magnification (which depends on the design), 2" diameter barrels are not required, so not all wide-field eyepieces are 2"--some will still be 1.25" and this is not a disadvantage, just a function of the design. This is a common misconception. Accessories such as filters and Barlow lenses are designed for 2" eyepieces as well.

Above: *A 2" wide-field eyepiece compared to a standard 1.25" eyepiece. Both are 26mm eyepieces.*

0.965" Eyepieces
The final eyepiece size is the one to avoid. 0.965" eyepieces are the standard size for "department store" telescopes. These inexpensive telescopes often frustrate new stargazers, and one of the primary reasons is that viewing through 0.965" eyepieces is all but impossible. Also, standard accessories such as Barlow lenses and filters are not normally available for these eyepieces. And you are usually stuck with the eyepieces that come with the scope since 0.965" eyepieces are rarely sold separately. The difference between a scope with 1.25" eyepieces and one with 0.965" eyepieces is usually the difference between a scope that ends up in the yard showing you the wonders of the universe and one that ends up in the closet collecting dust.

Below are rough guides and are dependent on the telescope you use:

2mm-4.9mm Eyepieces: These are very high magnification and very difficult to use unless seeing conditions are perfect and the object observed is very bright, like the moon.

5mm – 6.9mm Eyepieces: These are good on bright objects such as the moon and bright planets, but are still very high power and work best with steady seeing conditions.

7mm – 9.9mm Eyepieces: These are very comfortable high magnification eyepieces and are excellent for observing brighter objects, a must for any eyepiece collection.

10mm – 13.9mm Eyepieces: These work well for all objects including brighter nebula and galaxies a good mid/high range magnification.

14mm – 17.9mm Eyepieces: These are a great mid range magnification and will help resolve globular clusters, galaxy details and planetary nebulae.

18mm – 24.9mm Eyepieces: These will work nicely to show wide field and extended objects, great mid-range magnification for objects like galaxy clusters and large open clusters.

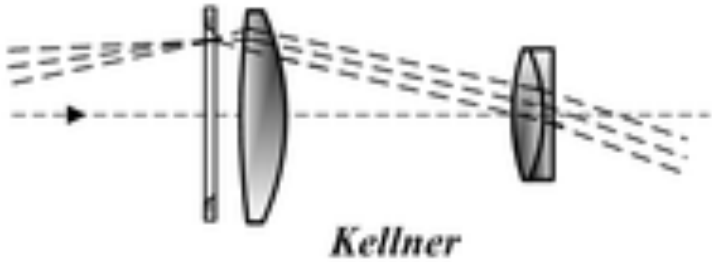
25mm – 30.9mm Eyepieces: These are wider field eyepieces for large nebula and open clusters. A good finder eyepiece for locating objects before moving to higher powers.

31mm – 40mm Eyepieces: These are excellent for extended views and large star fields and make excellent finder eyepieces before moving to higher powers.

Types of Eyepiece

There are eleven or twelve types of designs in eyepieces. Here is a short summary of the most popular eyepieces listed and described by Wikipedia, along with a glimpse of the higher end of the market. Generally speaking, the more elements that an eyepiece has, the better its performance should be, providing that it is made well and originates with a good manufacturer.

Kellner or "Acromat"



Carl Kellner designed this first modern achromatic eyepiece in 1849, also called an "achromatized Ramsden". Kellner eyepieces are a 3-lens design. An achromatic doublet is used to correct the residual transverse chromatic aberration.

The biggest problem of Kellner eyepieces was internal reflections. Today's anti-reflection coatings make these usable economical choices for small to medium aperture telescopes with focal ratio f/6 or longer

Illustrated opposite is a Celestron 25mm Kellner eyepiece, note designation KE, however, many Kellner eyepieces have the single designation of 'K'. Used on the the correct aperture scope these eyepices are simple in construction and can give good images, aperture f/6 or f/8 is better.

Price range: £12 - £16 each

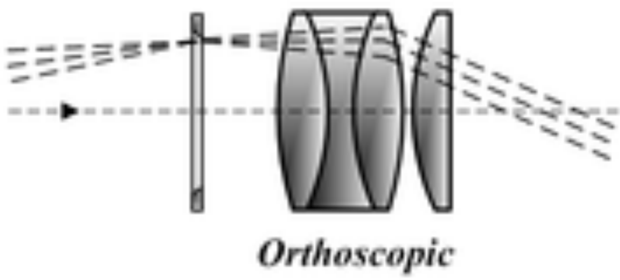
Modified "Acromat" or standard 3-element eyepieces

The standard modified "acromat" 3-element eyepiece is similar to the Kellner and has a FOV - 52° or better. The Modified Achromatic design has an optical advantage over the Kellner and is often used in entry-level telescopes. Th eyepieces, sometimes marked 'MA' or similar generally have good all-round performance and good eye relief, but lac the sharp contrasty images of 4 and 5 element designs.

The eyepieces are extremely good for beginners and offer the range of focal lengths that allow you to test the ability c your telescope in relation to its aperture. These eyepieces work particularly well on 'fast' scopes (f/5 and lower) but or SCT's and ranges above f/8 would possibly lose the sharpness of more detailed exploration

Price range: £10 - £15 each. A boxed set of 5 from Meade will cost about £72.

Orthoscopic or "Abbe"

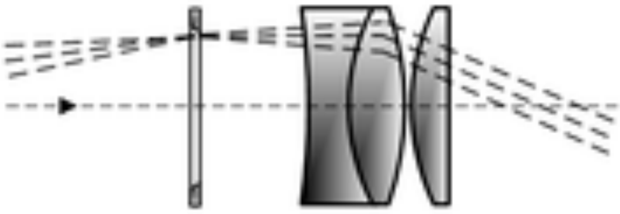


The 4-element orthographic eyepiece was invented by Ernst Abbe in 1880. It is called "orthoscopic" or "orthographic" because of its low degree of distortion. It is sometimes called an "ortho" or "Abbe". The orthoscopic design uses a convex-convex triplet field lens and a convex-flat singlet eye lens. Orthos have nearly perfect image quality and good eye relief, but by modern standards a narrow apparent field of view - about 40°-45°.

Until the advent of multicoatings and the popularity of the Plössl, orthoscopics were the most popular design for telescope eyepieces. Even today these eyepieces are considered good eyepieces for planetary and lunar viewing.

Price range: £25 - £85 each - illustrated is the more expensive Baader Planetarium 'Genuine Ortho'

König



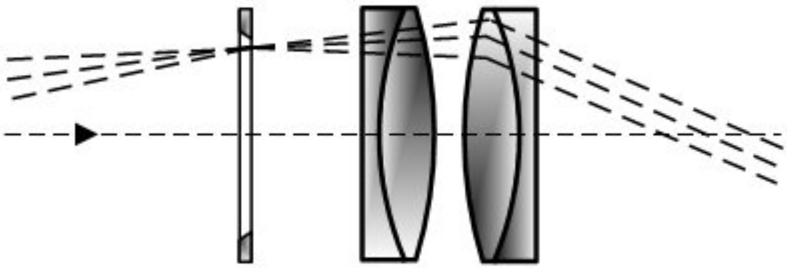
König

The König eyepiece was designed in 1915 by German optician Albert König (1871-1946). The original design is a simplified Abbe, with a leading doublet instead of a triplet. The original design allows for high magnification with remarkably high eye relief - the highest eye relief proportional to focal length of any design before the Nagler, in 1979 The field of view of about 55° makes its performance similar to the Plössl, with the advantage of requiring one less lens.

Modern versions of Königs can use improved glass, or add more lenses, grouped into various combinations doublets and singlets. The most typical adaptation is to add a positive, concave-convex simple lens before the doublet, with the concave face towards the light source and the convex surface facing the doublet. Modern improvements typically hav fields of view of 60°-70° Good for lunar studies.

Price range: £8 - £15 each

Plössl or "Symmetrical"



Plössl (1860)

The Plössl was originally designed by Georg Simon Plössl in 1860, and several versions can be found on the amateu astronomy market. By far the Plössl eyepiece is currently the most widely used design. The name Plössl eyepiece covers a range of eyepieces with at least four optical elements. Usually consisting of two sets of doublets (a doublet lens is a convex and concave element sandwiched together). Since the two doublets can be identical this design is sometimes called a symmetrical eyepiece. The compound Plössl lens provides a large apparent field of view along with relatively large FOV. This makes this lens ideal for a variety of observational purposes including deep sky and planetary viewing. The Plössl, is a good all round eyepiece due to great performance, approximate 50 degree field of view, pinpoint sharpness and good contrast.

The chief disadvantage of the Plössl optical design is short eye relief, which is restricted to about 70-80% of focal length. The short eye relief is more critical in short focal lengths, when viewing can become uncomfortable.

Price range: £14 - £70 each (for multiple-element or better eye-relief)

Multi-element and SWA (Super-Wide Angle) eyepieces since 1979

Up to eight optical elements in 4 or 5 groups. 70º FOV to 100º FOV.

Multi element eyepieces can by expensive but if you have ever had an opportunity to look through such a fine eyepiece then you will realise the huge advantage that these can give both in relation to field of view and in the quality of the image. TeleVue 'Nagler' and 'Ethos' eyepieces are the most expensive on the market and can easily cost more than the telescope itself, with some prices as high as £600 or £700!

However, fine multi-element eyepieces do not always cost a fortune and following are two highly recommended models to pursue if you have the initial outlay

Price range: £75 - £105 each.

Sky Watcher PanaView 2" eyepieces

Baader Hyperion 68 degree eyepiece

Sky Watcher PanaView 70° eyepiece (Fits 2" barrels only)

Sky Watcher's new 2” PanaView 5-element eyepieces with their impressive high-contrast super-wide views are ideal for low power, deep-sky observing. Available in focal lengths of 26mm, 32mm & 38mm, with apparent fields of view of 70° and eye relief of 20mm, 24mm & 28mm respectively.

NB. You will only ever need one of these in your collection so choose well, I find the 32mm more than adequate, with the 38mm being far too heavy and cumbersome, it is massive! The 32mm or the 26mm will give you the satisfying magnification you need for low power observing and star-hopping.

Baader Planetarium Hyperion 68° eyepiece (Fits 2" and 1¼" barrels)

The Baader Hyperion eyepieces are one of the finest modular eyepieces out there, they will fit 2" and 1¼" barrels and have six elements (eight with the 1¼" extension) and are modular, which means that you can vary the focal length by the addition of optional fine tuning rings (FTR's), however, one or two well-chosen eyepieces will serve you extremely well as these pieces also 'Barlow' very well. (i.e. they can be used to great effect with a x2 Barlow lens)

This means that if you had say a 24mm and an 8mm, these would Barlow down to a 12mm and a 4mm, which gives a very satisfying viewing range, as well as fantastic eye relief. NB. the 24mm cannot be modified by the FTR's, but all others in the series can.

The Hyperion is a comfortable eyepiece with a large field of view that is easily visible even with eyeglasses. A field of view of 68 degrees is regarded as ideal for astronomical observations and is the largest field of view that can be viewed without strain and without turning your eyes.

They come in the following sizes: 3.5mm, 5mm, 8mm, 10mm, 13mm, 17mm, 21mm, 24mm

In Summary

The least you can do without upgrading....

Assuming that your telescope came with one or two eyepieces (a 25mm and a 10mm), the first thing is to buy a 2x Barlow Lens, this doubles the magnification of the eyepieces you already have, so your 25mm becomes a 12.5mm and your 10mm becomes a 5mm. The next thing you should do is buy a Moon Filter so that you can explore the Moon for long periods at a time. It is recommended here that you should buy a ND96 (0.9 or 0.6) Moon filter (The 0.9 and 0.6 by the way refers to the density, the higher the number, the more density. A low density for use with smaller aperture telescopes and a higher density for large apertures, suggest 0.09 for large apertures above 6" and 0.06 for small apertures below 6" - light transmission 13% and 25% respectively), the ND means Neutral Density and therefore optics do not add any false colourization, whereas some Moon filters have a colour bias (usually green). A Barlow lens will cost between £18 & £28, and an ND96 (0.9 or 0.06) filter about £15.

Hot Tip: When buying a Moon filter, always try and buy a metal-framed one, the plastic frames tend to be difficult to screw on in the dark! (ND filters are usually made from metal frames.)

If you want to stop here then this is the least you need to do to expand your enjoyment of the sky at night.

Upgrading your eyepieces

By far the most popular eyepieces amongst amateur astronomers today is the Plössl eyepiece, there are a number of reasons for this but the principle ones are as follows:

- they have a wider FOV than the orthoscopic, however, less than the Konig.
- Plössl multi-coatings are continually being improved and include blackened edges, not so with the Kellner, Konig or MA's.
- They come in four, five and six-element designs, improving in quality all the while, not so with the Kellner, Konig or MA's.
- their popularity has led to lower prices leading to improved affordability, whereas a good ortho can set you back £80

There are good Plössls and not so good. The best advice is to stick to branded Plössls, such as Celestron, Sky Watcher, Meade, Williams Optics, Orion or Baader Planetarium and so on.

Decide on your price range and individual requirements

However, if you’re on a limited budget then I would recommend a 32mm and a 9mm to start with. These would in turn barlow down to 16mm and 4.4mm respectively.