# ***The Basic Function of an Eyepiece.***





An eyepiece (Ocular in upperclass Optical jargon) is simply an interface between some optical instrument and the eye. It modifies a set of rays so the eye can accept and form sharp images of the original object, eg, a star, which has been pre-imaged by some other primary lens or mirror system.

We can use an optical instrument without an eyepiece ! Try viewing the image from a telescope without an eyepiece. The moon forms a bright easily found image ideal for this trial.

(a) Remove eyepiece

(b) Move head back about 1 foot behind eyepiece position

(c) Manoeuvre head and try to focus the eye on a spot just forward of where the eyepiece should be.

The view is unmagnified. The field of view is very narrow! This immediately shows us the unquestioned importance of the eyepiece interface, whether a modern Nagler or an antiquated Huygens or Ramsden.

The eyepiece has much in common with a simple 'magnifying glass' but it has evolved differently. Magnifying glasses and eyepieces place different demands on the design.

Before considering how an eyepiece must massage and condition incoming beams of light, what type of rays are required by the eye.

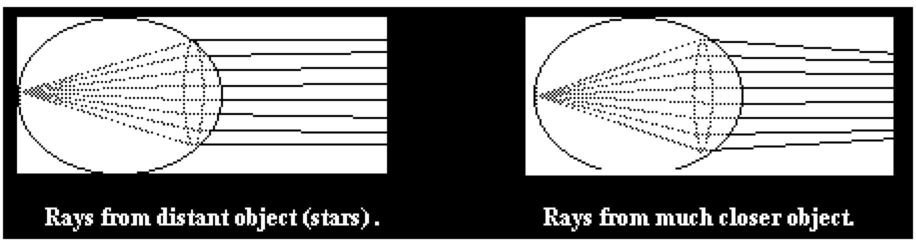


Fig 1

Distant objects (eg. stars) give 'parallel' ray bundles while closer objects result in slightly diverging ray bundles reaching the eye.

The closest object a normal eye can handle is about 10 inches (250 mm). Aged eyes lose the ability to adapt the organic eyelens so it can focus on close objects.  Muscles in the eye change the shape of this lens which changes its focal length. This process is called accommodation.

The eye's pupil ranges between about 7-8 mm for a fully Dark Adapted eye to 2 mm in extremely bright light. This changes with advancing years. The range of pupil size diminishes. The angle of divergence handled successfully by the eye's internal lens varies from 7 min to 50 min depending on pupil size. This small angle seems surprising at first but a little thought will confirm it. Only small departure from these acceptable angles renders incoming light unintelligible to the eye. The rays must focus on the retina to be useful.

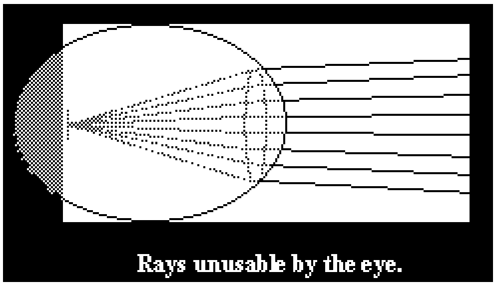


Fig 2.

Converging rays do not exist in nature. Thus the eye has no need to image convergent bundles of rays. Not surprisingly, the eye has never evolved along these lines and only a minutely convergent ray bundle can be successfully focussed on the retina by the organic eyelens. When using an optical instrument, the emerging rays are changed from converging to diverging by focusing the eyepiece back and forth.

Of course, many stars or other objects may be visible simultaneously. The bundle of rays from each has arrived from different directions even though each ray bundle is composed of parallel rays.

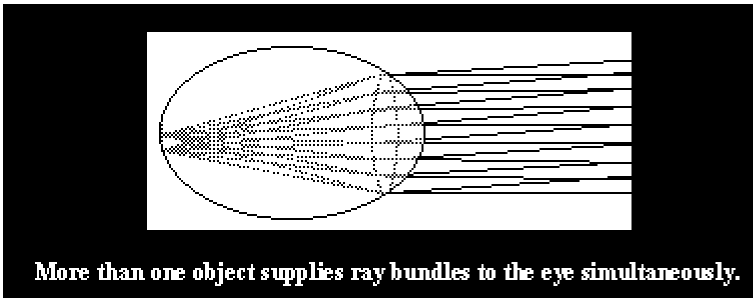


Fig 3.

Each ray bundle will be parallel or very slightly diverging. The extreme spread of bundles of rays an eyepiece can supply to the eye is the apparent field of view of the eyepiece and may range from about 20 to 100 degrees. It is common for designers to specify the half field. You must look carefully at the field angle specifications as a 40 degree half or semi field eyepiece is very different from a 40 degree full field.

The only ray bundle really sharply imaged by the eye is the centre one. Resolution of the eye outside the small central area is quite poor. Eyepiece designers often take 1 minute of angle as the visual acuity near the centre but accept 5 minutes as the best an eye can resolve at the edge. For detailed observation, the eye always swivels to an incoming bundle of rays, so the image is moved to the centre of the retina.

It is tempting to consider an eyepiece as nothing more than a magnifying glass used to view another image. Certainly, rays are handled similarly by both eyepieces and magnifying glasses but the rays captured by each are different.

Magnifying glasses are always the first optical device any rays hit. The front surface of a magnifying glass captures all rays from the object that approach the lens surface. If the magnifying glass is thin, nearly all of these rays reach the last lens surface and pass out of the magnifier. The entrance pupil is the front surface of the magnifier. Unless limited by some internal stop all of these rays will pass through the lens. The cone of rays is wholly determined by the working distance and lens diameter.

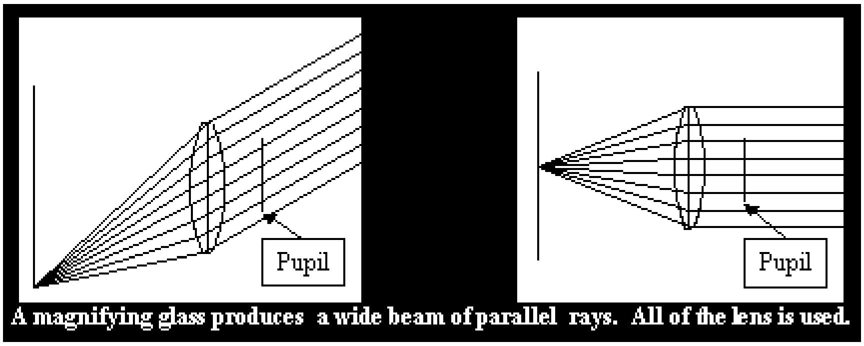


Fig 4.

Because there is nothing except the size of the front lens to limit the rays, a very wide bundle of parallel rays passes through the lens. This is typically much wider than the pupil of the eye which can be moved around and still capture enough of these parallel rays to form an image of the magnified object. Only a few of these parallel rays are sufficient for the eyelens to form a useable image. Of course, the more rays captured by the eye, the brighter the image on the retina.

Eyepieces in an optical system only ever receive a cone of rays emanating from other optical elements in an instrument such as the objective lens of a telescope. Entrance pupil is now predetermined by the telescope objective diameter and position. Typically, the cone of rays fed into the eyepiece may be limited to 2° by a small F:10 objective lens.

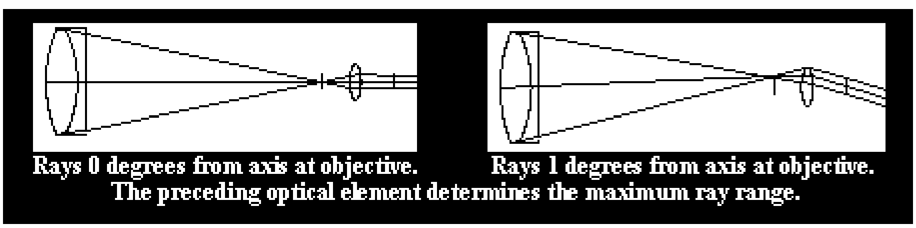


Fig 5.

Note how only a section of the eyepiece is pierced by these ray bundles. This diagram represents rays supplied by an objective of about F:2 which is almost impossibly short and wide.

A more realistic case for very high quality images from a refractor may be F:10. The following diagram superimposes ray bundles arriving at an F:10 objective lens 2 degrees apart. Because of a magnification of 10X by the eyepiece, the range of angles presented to the eye is 20° . The area of the lens pierced by these rays is very small.

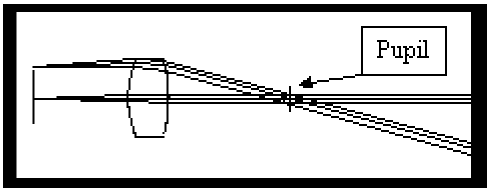


Fig 6.

A narrow ray bundle make design easier for eyepieces which are used in optical systems of high F:NUMBERS. Only small areas of the glass surfaces are used by any one ray bundle. At F:32 (such as a 2 inch - 64 inch focal length objective) nearly any simple lens used as an eyepiece will produce a respectably sharp image. Very few modern optical instruments except for microscopes, periscopes and borescopes have such narrow ray cones.

Users demand short telescopes for portability these days. F:6 is common and F:4 not unheard of. While these short telescopes are a technological masterpiece one cannot but question if a slightly longer telescope may be a better compromise. Exotic glass types would not be as necessary. Certainly, in a hostile environment, more common glass types may survive while the exotics gradually degrade. Money saved could be spent on special eyepieces.

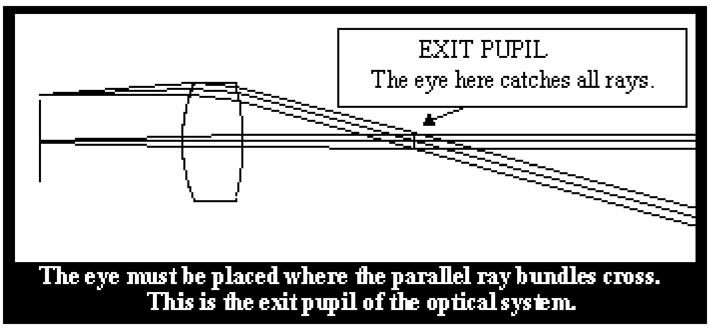


Fig 7.

With a magnifying glass the eye can wander over a large area and receive samples from all ray bundles. When using an eyepiece, the limited cone of rays, predetermined by preceding optics, limits the eye position to a small, well defined exit pupil. This is the image of the objective formed behind the eyepiece. If you have not noticed this, hold a pair of binoculars facing the sky (not the sun) and place a piece of tissue paper a few mm behind the eyepiece. By moving it backwards and forwards the eyerelief distance and exit pupil diameter can be measured.

Strictly speaking, an eyepiece by itself has no defined exit pupil.

*The size and position of the exit pupil is determined by both eyepiece and preceding optical elements and apertures as a system.*

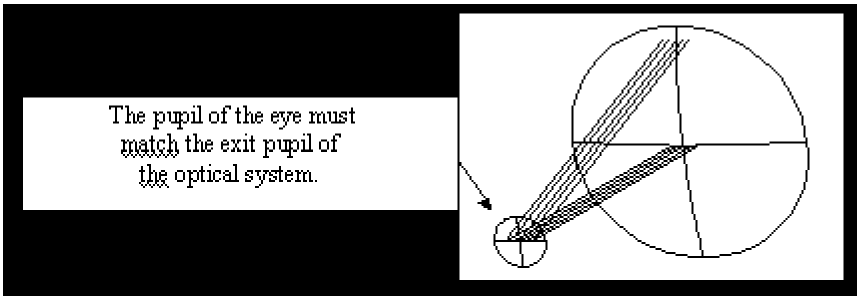


*Fig 8.*

Aberrations have so far been ignored. In fact, control of the ray bundles in the previous F:2 diagrams would only be possible with exotic aspheric or non spherical surfaces. In reality, only spherical surfaces are practical although some special wide field eyepieces may use one aspheric surface.

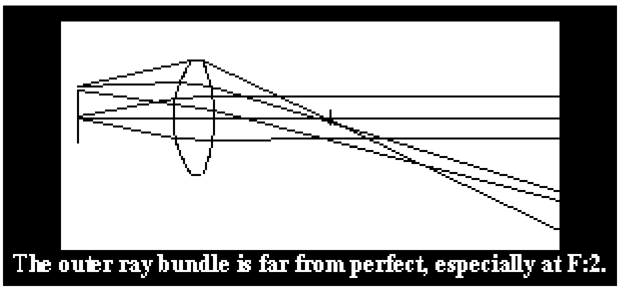


Fig 9.

Obviously, the outer ray bundle contains rays which appear to come from different directions. This will give a blurred image to the eye instead of a point. Since the outer rays come from different directions, the apparent magnification to the eye has also been distorted.

The complexity of modern high performance eyepieces helps to minimise aberrations while retaining especially desirable properties such as wide apparent field of view and comfortably long eye relief. While modern technology can reduce the blurred images below the limit detectable by the human eye, some small blur usually remains at the edge of a wide field eyepiece, and appreciable distortion is usually left uncorrected.

Except for a few special applications, distortion is of little concern. It only appears off axis and observers instinctively centre images for critical examination. In none of the eyepiece prescriptions here has distortion been a driving factor as I consider zero distortion a far lower priority than other faults.

One final distinguishing feature of modern eyepieces is the inclusion of more than one lens. No matter how complex the design, the reason for this is simple. Inclusion of many different surfaces and materials allows the aberrations to be minimised or eliminated. The designer has more degrees of freedom to balance one aberration against another and arrive at a successful compromise.

The field lens intercepting incoming rays can also be made wider than the last lens in an eyepiece. This allows edge rays to be captured which otherwise would miss a single lens. The wider front lens is often called a field lens and the latter an eye lens.

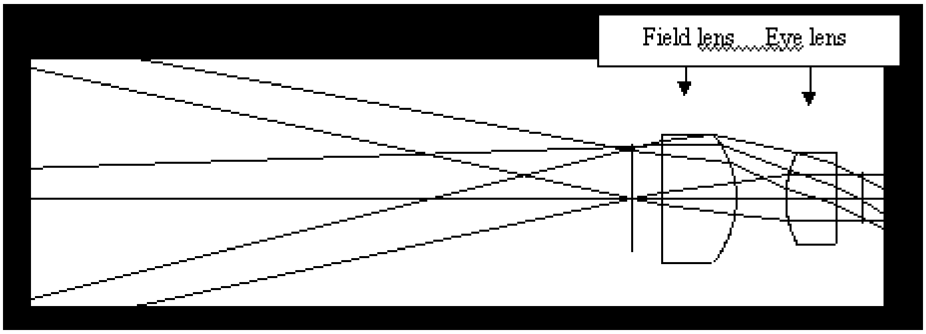


Fig 10.

If some rays miss the field lens, the image will dull annoyingly at the edges. The following diagram shows how 'Vignetting' can occur. The lens may be wider but a better system is to use a wide field lens in conjunction with an eye lens.

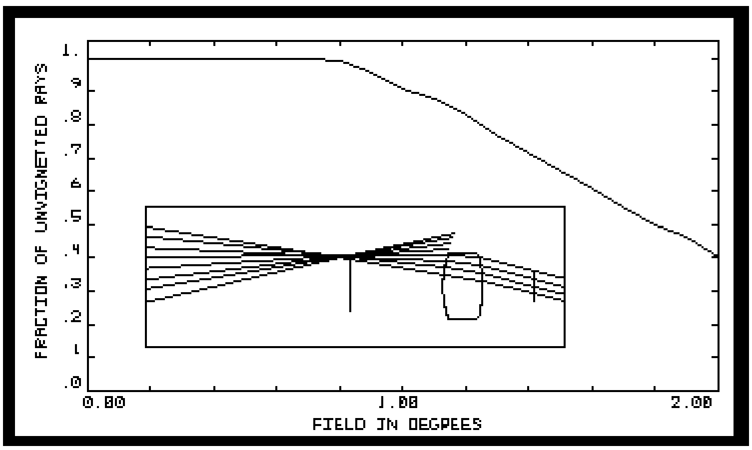


Fig 11.

Extremely wide fields of view require more lens groups. The general idea is represented in the following diagram. Actual designs always use at least one doublet constructed from different glass types.

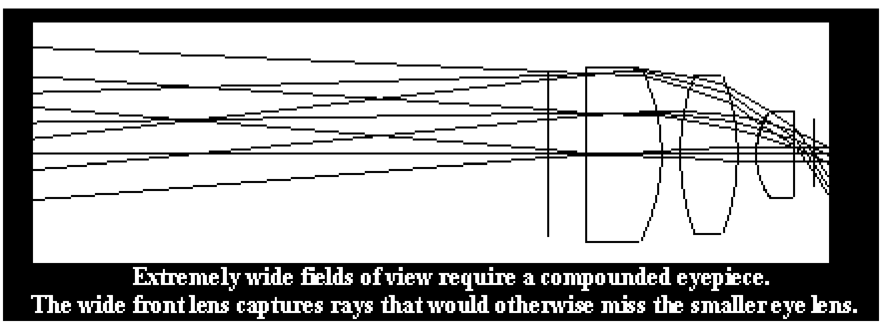

Fig 13.

One feature common to extremely wide apparent field eyepieces is 'kidney bean effect. Note how in the above design extreme rays cross the axis closer to the eye lens. This makes placement of the pupil of the eye difficult to capture all rays at once. Slight movement of the eye favours some rays over others thus selective vignetting occurs. Rays from all objects are still parallel bundles so they appear sharp. Image detail does not suffer but the effect is very disconcerting.

Kidney bean effect is more of a problem when the exit pupil of the eyepiece is larger and the pupil of the eye is reduced in diameter by bright daylight. Very short focal length eyepieces produce a smaller exit pupil because of their high magnification so seldom have this problem.