Telescope Basics

Astronomical telescopes have three main purposes:

1.   To gather light (because most astronomical objects appear very faint, due primarily to their great distance)

2.   To magnify (because most astronomical objects appear very small, due primarily to their great distance)

3.   To resolve detail (allowing us to split binary stars, see features on moons, planets, nebulae, galaxies, etc.)

Light gathering is accomplished by the **objective**, a lens or mirror which collects light over a wide area and funnels it into a small area in order to enter the eye. Telescopes which have objective lenses (usually converging lenses) are called **refractors**; those with objective mirrors (usually concave mirrors) are called **reflectors**.

The light-gathering power (LGP) of a telescope depends on the *area* of the objective. As objectives are normally circular, the area can be specified in terms of the **aperture** (D) -- the diameter of the objective. $LGP = 4\pi D^2$. Thus, the LGP increases as the square of the aperture.

Because light gathering is the most important purpose of an astronomical telescope, the *aperture* is the principal specification for a telescope. A 6-inch telescope has an aperture of 6 inches and gathers $(6/3)^2 = 4$ times as much light as a 3-inch telescope. A 12-inch telescope would gather $(12/6)^2 = 4$ times as much light as the 6-inch and $(12/3)^2 = 16$ times as much light as the 3-inch.

Magnification is accomplished by the **eyepiece** (in its simplest form, a converging lens), which functions as a magnifying glass and enlarges the image created by the objective. The magnifying power (M) of a telescope thus depends on both the objective and the eyepiece; it can be defined as the ratio of the angular size of the image to the angular size of the object.

In practice, magnifying power is calculated from the ratio of the focal lengths of the objective (f_o) and the eyepiece (f_e): $M = f_o/f_e$. For example, a Celestron 8 has an objective focal length of 2000 mm. A 40 mm (focal length) eyepiece used with it will produce a magnification of 2000/40 = 50x; a 20 mm eyepiece would yield a magnification of 2000/20 = 100x. The same two eyepieces used with the C11 ($f_o =$ 2800 mm) would give magnifications of 70x and 140x, respectively.

Resolution depends on the telescope aperture and the wavelength of light being used, being better for larger apertures and shorter wavelengths. Resolving power is specified as an angle -- the minimum angular separation which the telescope can resolve. Once this limit is reached, increasing the magnification will *not* improve telescope performance: binary stars with separations less than the telescope's resolving power will not be split by increasing the magnification.

Resolving power for small telescopes is normally obtained from the Dawes limit: $\alpha = 4.56/D$, where α is the resolving power, in arcseconds, and D is the aperture, in inches. For example, a 3-inch telescope should have a resolving power of about 1.5" while an 8-inch telescope has a resolving power of about 0.57". For comparison, the human eye has a resolving power of about 2 arcminutes.

The Dawes limit is a theoretical value, which agrees reasonably well with practical tests; however, resolution depends on a number of other factors, including the relative brightnesses of the pair of stars, the seeing, the sharpness of the observer's vision, etc. Even though this estimate of resolving power is not a firm limit, the Dawes limit does provide some idea of what to expect from a given telescope.

The principal specifications normally given for small telescopes are aperture (D) and f-number ($\# = f/D$). The combination of aperture, speed, and focal length for a given telescope determines its capabilities, in terms of the types of objects which can be easily observed with it. The following chart gives a simplistic illustration of these effects for small telescopes:

	small aperture (low LGP, poor resolution)	**large aperture** (high LGP, good resolution)
short focal length (low magnification)	medium speed **big, bright objects** Sun Moon Orion Nebula bright comets	fast speed (low #) **big, faint objects** wide, faint binaries nearby galaxies (M31) diffuse nebulae (M8) open clusters
long focal length (high magnification)	slow speed (high #) **small, bright objects** wide, bright binaries planets lunar surface features sunspots	medium speed **small, faint objects** close, faint binaries planetary nebulae globular clusters distant galaxies

If the observer desires to look primarily at the Moon, then a large aperture telescope is unnecessary. But an observer wishing to study galaxies will need a telescope with sufficient aperture to bring them into view.
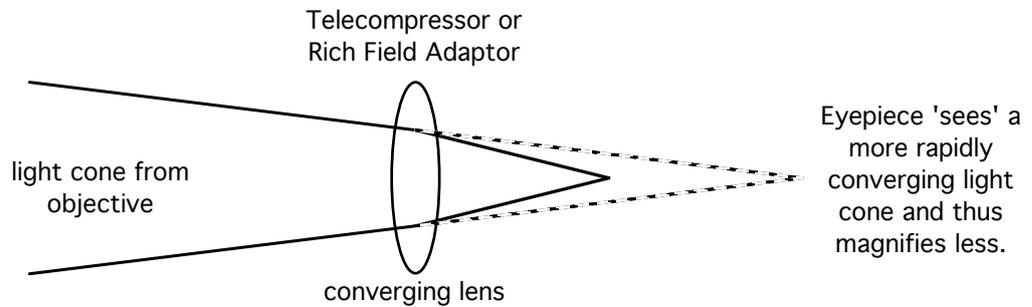
Although the objective of a telescope determines the aperture, speed, and objective focal length, there are ways to modify the performance of a telescope for different applications.

The aperture of a telescope may be stopped down, to reduce the amount of light collected -- useful when observing the Sun.
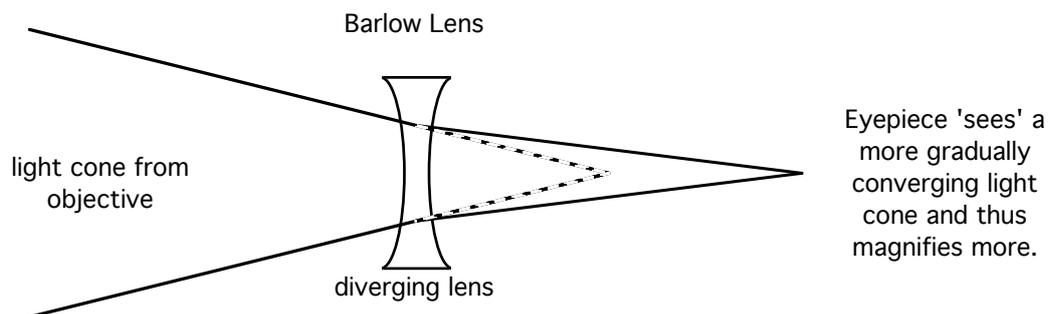
The eyepiece can be replaced with one of a different focal length, giving different magnifying powers.

The *effective focal length* of the objective can be modified by the insertion of appropriate optics in the light path ahead of the eyepiece.

Insertion of a *converging* lens ahead of the eyepiece results in a more rapidly converging light cone, a shorter effective focal length, and an apparently faster system, as viewed by the eyepiece. Magnification is thus reduced and the field of view is enlarged. When used for visual observations, this is called a **Rich Field Adapter** (RFA); when used with a camera, it is called a **Telecompressor**.

Telecompressor or
Rich Field Adaptor

light cone from
objective

Eyepiece 'sees' a
more rapidly
converging light
cone and thus
magnifies less.

converging lens

Insertion of a *diverging* lens ahead of the eyepiece results in a more slowly converging light cone, a longer effective focal length, and an apparently slower system, as view by the eyepiece. Magnification is thus increased and the field of view is reduced. Such a device is called a Barlow lens. Barlow lenses are rated by the factor by which they increase the magnification -- 2x, 3x, etc. A 2x Barlow lens will double the magnification of any eyepiece used with it. For example, a C8 (f = 2000 mm) with a 25 mm lens yields a magnification of 80x. Inserting a 2x Barlow lens ahead of the eyepiece will produce 160x.

Barlow Lens

light cone from
objective

Eyepiece 'sees' a
more gradually
converging light
cone and thus
magnifies more.

diverging lens

Of course there is a limit to the amount of useful magnification. The standard rule of thumb is to use no more than 60x per inch of aperture: a 3-inch telescope should not exceed 180x; an 8-inch telescope should not exceed 480x.