Telescopes
by Ken Graun

1 meter = 1000 mm
1 yard = 914.4 mm
1 inch = EXACTLY 25.4 mm

Telescope overview
There are two basic ways to focus light—using either curved lenses or curved mirrors. The two basic telescopes are refractors that use lenses and reflectors that use mirrors. There are telescopes that are a combination of lenses and mirrors (discussed later). Eyepieces, which are used to change magnification, always consist of lenses.

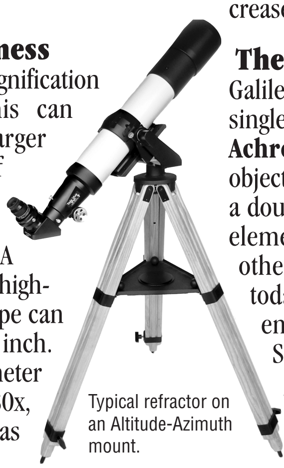
Short history
The telescope was invented in 1609, and it was a refractor using eyeglass lenses. Galileo discovered how to increased the magnification of these first scopes to make them useful and thus used one with increased magnification to published his observations of our Moon, Jupiter's moons and stars early in 1610.

It was Isaac Newton who in 1668 made the first reflecting telescope, known today as a Newtonian, and it is the most popular reflecting telescope that is used by amateurs.

Some terms
The telescope lens or mirror that is used to enlarge distant objects is called the ***objective*** and can be either a curved lens or curved mirror. The size or diameter of the objective is refered to as the ***aperture***.

Magnification craziness
The very highest useful magnification is around 400x and this can be achieved only with larger telescope diameters of 6-inches or more and on nights with very steady atmospheric conditions. A good rule of thumb for the highest magnification a telescope can achieve is 60x per aperture inch. So, a 3-inch (75mm) diameter objective can get you to 180x, NOT 400x, 600x or 1000x as is sometimes advertised!

Useful magnifications for Deep Sky Objects ranges from 50x to 250x. For the planets, the range is 50x to 400x. Usually, the atmosphere limits the highest useful magnification. There are nights when going above 100x is not practical.



Typical refractor on an Altitude-Azimuth mount.

Telescope focal length . . .
. . . is usually expressed in millimeters and is the distance from the objective, lens or mirror, that a distant object comes to focus. This varies from about 4 to 15 times the diameter of the objective (but it can be less or more).

Telescope Magnification =
Telescope Focal Length ÷ Eyepiece Focal Length

Example: If, your telescope has a focal length of **780mm** and your eyepieces have focal lengths of **6, 15 and 20mm**, what are your magnifications?

6mm ➡ 780 ÷ 6 = **130x**
15mm ➡ 780 ÷ 15 = **52x**
20mm ➡ 780 ÷ 20 = **39x**

Lens/Mirror shapes
Lenses. The actual shapes of the curves on *lenses* is usually spherical, that is, it follows the shape of a sphere (circle). This applies to the individual elements of the objective and in eyepieces, too. For lenses, the curve can be convex or concave.

Mirrors. The shape of the mirror in Newtonian telescopes is a concave parabola, which has a deeper center than spherical. The reason they are parabolic is because the shape of a parabola will focus all the light rays to the same point while a sphere does not do this. When they make a parabolic mirror, they first make it spherical and then with finesse, change it to a parabola. Other reflectors like the Cassegrain employ mirrors with different types of curves (not spherical or parabolic) to achieve specific image corrections, like a decrease in coma. (see Optical Defects on back)

The Refractor telescopes
Galileo's telescope front objective lens was a single lens/element. This is not used today.

Achromat. The achromat refractor has an objective that consists of two elements/lenses, a doublet (2 lenses next to each other). One element/lens is made of flint glass and the other is crown glass. These are still made today and are satisfactory with a long enough focal length (f/10+, *see back*). Some lenses today use different types of glass (often called ED glass meaning Extra-low Dispersion) for the two lenses to improve color quality and help shorten the tube length. Manufactures like to call these APOs, and they are good but not as good as an actual APO. ED scopes are more expensive than achromats.

APO stand for Apochromatic and these objectives consist of 3 elements/lenses, a triplet. These refractors provide some of the best color correction/imagery and are usually expensive.

Quadruplet. There are other refractors that employ a doublet for the front objective as well as a second doublet farther down the tube to provide color and/or other corrections—usually expensive.

Telescope Diameter	Magnitude Limit[1]	Resolution Limit in Arc Seconds[2]
Eye 7 mm or 0.276"	6.0	60
50 mm = 2"	10.3	2.28
60 mm = 2.4"	10.7	1.90
75 mm = 3"	11.2	1.52
80 mm = 3.15"	11.3	1.45
100 mm = 4"	11.8	1.14
130 mm = 5"	12.3	0.91
150 mm = 6"	12.7	0.76
200 mm = 8"	13.3	0.57
250 mm = 10"	13.8	0.46
300 mm = 12"	14.2	0.38

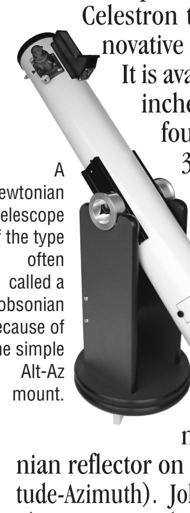
[1]Brightness *decreases* with larger numbers. Polaris has a magnitude of 2.0

[2]Compass degrees. 1 arc degree = 60 arc minutes. 1 arc minutes = 60 arc seconds. Moon spans 30 arc minutes.

Reflector/Catadioptric telescopes
The Newtonian reflector is the most popular reflector used by amateurs today. However, there are other types of reflecting telescopes. All of the other types have a hole cut through the center of the mirror with the eyepiece placed behind it—viewing is from the back end, like with refractors. A hole-in-the-mirror telescope designed in 1672 that is still made today is the **Cassegrain**.

Catadioptric telescopes utilize a combination of lenses and mirrors and usually, the primary is a mirror with a hole in its middle. The two most common catadioptric telescopes are the **Schmidt-Cassegrain Telescope (SCT) and Maksutov (Mak).** The SCT is a very popular scope for amateurs, was designed in the early 1900s, but did not become mass produced until the late 1960s by Celestron telescopes—it required innovative manufacturing techniques. It is available in apertures up to 14-inches. The Maksutov is usually found having diameters of just 3 to 4 inches.

There are other reflector-type designs but that gets beyond the basics.



A Newtonian telescope of the type often called a Dobsonian because of the simple Alt-Az mount.

What is a Dobsonian telescope?
A Dobsonian telescope is nothing more than a Newtonian reflector on a simple Alt-Az mount (Altitude-Azimuth). John Dobson (1915–2014), a "hippie," popularized this style of telescope on the sidewalks of San Francisco. He shared the objects in the sky with others using large inexpensive telescopes/mounts. Dobson's real contribution was the simple alt-az mount that was not used in the amateur community at the time (1960s). The Dobsonian is a common configuration for a Newtonian telescope today.

Common telescope sizes

For us amateurs, the diameter of a telescope size is limited by the telescope type and portability.

Refractors. Generally, the largest refractors are 6-inches in diameter. 3 to 4 inches are most common. It is rare to see diameters at or over 6-inch because the optical glass is difficult to obtain and these telescopes need big, steady, heavy mounts.

Newtonian Reflectors. A common size is 6 to 8 inches. In the past 12-inches was considered the granddaddy but today, amateurs use diameters of 20 inches or more. Most Newtonian reflectors, especially the largest, utilize simple alt-az mounts.

SCT (Schmidt-Cassegrain Telescope). The common diameter is 8-inches. 10-inch diameters and larger start to get heavy. It is difficult for a person (relatively strong guy) to lift a 14-inch SCT on to its mount. The 6-inch is a nice portable size. Celestron is prefered over Meade.

Big vs small diameter telescopes

The greater the diameter of your lens/mirror, the fainter the stars or objects that you can see—see front table. Also, it is possible to see greater detail in larger scopes. Reflector telescopes around 10 to 12 inches or larger are considered bigger scopes. A 6-inch *refractor* is considered large for its type.

The biggest disavantage with larger telescopes is that they are physically bigger and heavier than smaller ones and usually require more muscle and more setup/take down time.

Reflectors around 8 inches and smaller and refractors around 5 inches or smaller are more manageable with size and weight and setup. I tend to use telescopes around 6-inches or less and I can see a lot with these scopes.

f-number/ratio (focal ratio). . .

. . . is in regards to your telescope's focal length. You will often see telescopes and camera lenses described with an "*f*" number like *f*/4, *f*/6, and *f*/8. This *f* numbers refers to the focal length of your telescope in terms of your telescope's diameter. For example, if your telescope mirror is 6-inches in diameter (150mm) and has a focal length of 1200mm, then your *f*-ratio is *f*/8 (1200÷150=8).

Telescopes with low f-numbers like around f/4 are called RFTs for Rich Field Telescope. Traditionally, these provided lower powers and greater fields-of-view but that is not exactly the case anymore with the larger diameters of 12-inches or more for Newtonians.

Cheap/Closet Telescopes

Yes, we tend to buy inexpensive telescopes for our kids which may not work well and discourage them. And, there is your scope which may end up in the "closet" because it does not work well and/or telescope viewing is not your thing.

Aiming a telescope, Finders!

It is not easy to aim a telescope without the aid of a "finder" which can be a small telescope or a gizmo that projects a red dot or reticle. To see how hard it is, try aiming a telescope without the aid of a finder.

I have found that the red-dot pointer (technically called a reflex finder or pointer) is the easiest to aim a scope—the little telescopes used for finders are too restrictive in their fields-of-view and magnify/invert images. My favorite "red-dot" is the Telrad but it is big and so is not suitable for smaller scopes. **Remember, you need a finder!!**

Image Orientation

Most telescopes used for astronomical observation are not best suited for terrestial viewing because images can be upsidedown, sideways and/or reversed, like in a mirror. Most refractors using a "regular" 90° diagonal present mirror images (left and right reversed). There are special diagonals that will make images correct. The SCT produces the same imagery as a refractor. On reflectors, the image is correct but its orientation can be sideways depending on where the observer is standing and the orientation of the eyepiece focuser.

A 6-inch SCT (Schmidt-Cassegrain Telescope) by Celestron on a altitude-azimuth fork mount (half fork) that is motorized and computerized to automatively move to and find any object using the hand controller once the scope has been aligned to at least 2 bright stars.

Collimation • Alignment of optics

Telescopes work the best when all the mirrors, lenses and eyepieces are in alignment. If they are not, the images of stars will not be pinpoints.

Usually, telescopes get out of alignment from setup/takedown bumps and vibration from travel.

Newtonian reflectors will require more frequent collimation/alignments than any other scope, a process that is not difficult but will be confusing at first, and ideally, it needs some specialized "tools."

Many amateurs say that refractors don't need collimation but this is not true. Yes, they are more robust in keeping their alignment but the vibration from travel will certainly cause misalignment. All of my refractors have needed collimation—some can be performed by owners and others have to be done by the "factory."

Focusing a telescope

Every telescopes has to be "focused" so the image is sharp, that is, the stars are pinpoints, when looking through the eyepiece. Focus varies from person to person because of differences in eyes (the eyes are optical systems).

For most refractors and Newtonian reflectors, eyepieces are inserted into a focuser where there are knobs that are turned to move the eyepiece—to focus. For almost all SCTs, focusing is accomplished by turning a knob on the back of the telescope which actually moves the mirror and not the eyepiece.

Optical "defects"

There is NO optical system that provides *perfect* color correction AND eliminates image distortion of stars (especially towards the edge of the fields-of-view)—each system is a compromise.

For achromat refractors, the two inherent optical defects are called chromatic aberration (color fringing) and spherical aberration (fuzzy focus at the edge of the field-of-view).

Newtonian reflectors are mostly plagued by coma (elongated stars at the edge of fields-of-view). Coma is very pronounced for lower f-ratios like f/4 and lower. As a note, mirrors do not suffer from any form of color aberration.

Most abberations can be greatly alleviated but not totally eliminated.

Little about Binoculars

Binoculars are nothing but two side-by-side refractors. They are *always* identified by magnification and objective/lens diameter. For example, 7x35 indicates 7 times magnification with a front lens diameter of 35 millimeters. 10x magnification is the limit to hold binoculars steady. 7x50 or 10x50 are great for astronomy but any binoculars will do!

How many telescopes should I get?

For those who stay with the hobby and become somewhat crazed, you will probably own, buy and sell several telescopes. But starting with one is good enough.

Best Telescope!

The best telescope is simply the one you use the most. People who stay in the hobby often have or go through several telescopes. And, they will discover that the telescope they use the most is often a smaller telescope that is easy to setup, use and store.

Telescope Companies/Brands

For 6 to 8 inch Dobsonian reflectors, visit Orion Telescopes & Binoculars and Explore Scientific (online). For refractors, stick with Explore Scientific, Vixen, Takahashi and Tele Vue. Celestron is generally preferred over Meade for a Schmidt-Cassegrain Telescope (SCT).

Starizona, a telescope store in Tucson on Oracle near Orange Grove, is a great place to get a scope and expert advice.