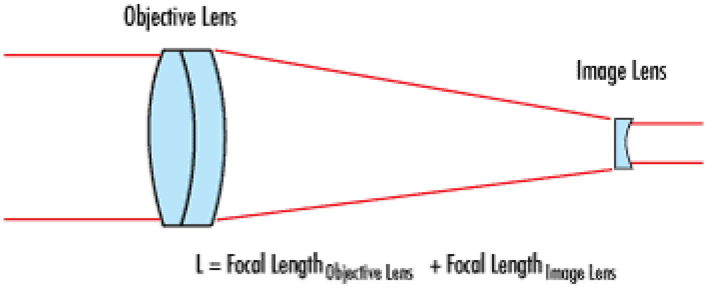
Telescope Optics (“Optics III”)

References:
Telescopes and Techniques, C. R. Kitchin, Springer pub.

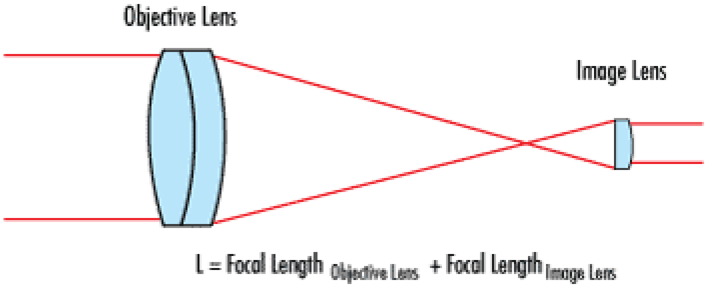
Telescope Optics

It is worth noting that when observing through a telescope, beyond the primary lens or mirror, there are at least two more sets of lenses through which light passes: the eyepiece and the eye. In optical instruments (such as microscopes, telescopes and binoculars) the lens (or mirror) that the light first encounters is referred to as the primary lens or mirror (aka *objective, objective lens, or objective mirror)*. The lens closest to the eye is known as the eyepiece (aka image lens, ocular, or ocular lens). In order to magnify an image properly, both an objective and ocular are required.

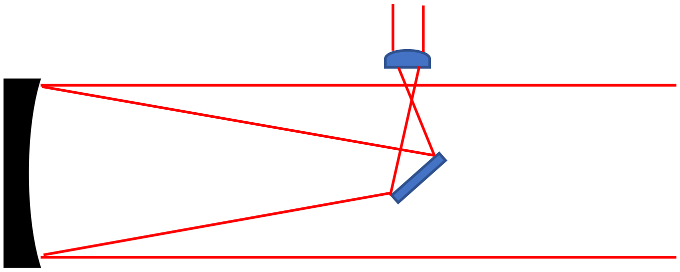
Galilean telescopes use a diverging ocular placed closer to the objective lens than the focal length:



Keplerian telescopes use a converging ocular placed beyond the focal length of the objective lens. Virtually all refracting telescopes use this arrangement where a removable eyepiece is used as the imaging lens.



Reflecting telescopes produce a similar optical design as the Keplerian, except a mirror is used as the objective. The first design was is attributed to James Gregory in 1663 (Kitchin). He used a spherical secondary mirror, and did not get good results. Sir Isaac Newton designed his reflector telescope about 5 years later. He used a flat secondary mirror. Most amateur reflector telescopes are Newtonian designs. The image lens (removable eyepiece) is placed beyond the focal point of the mirror. His primary mirror was only 30mm diameter (Kitchin), smaller than even the cheapest of modern reflectors. There are variations on reflector telescopes including the Herschelian telescopes, which avoid a secondary mirror by viewing the primary mirror off-axis. These are not widely used in astronomy, but are used it microwave wavelengths in telecommunications.

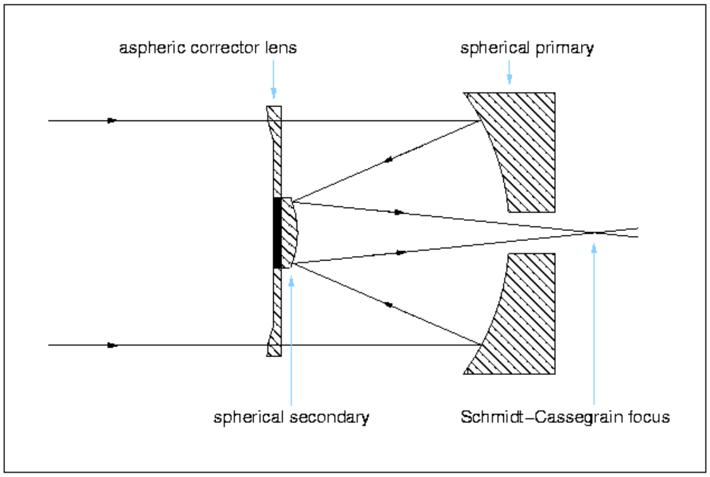


Newtonian telescope (parabolic primary mirror, flat secondary mirror at 45 degrees)

There is a third common telescope optical design: catadioptric. Catadioptric telescopes use multiple curved mirrors and/or lenses. The result is a compact telescope with a very long focal length objective. There are various differing details, but effectively, all catadioptric telescopes look like the sketch below. They are a variation/refinement of James Gregory's reflector design.

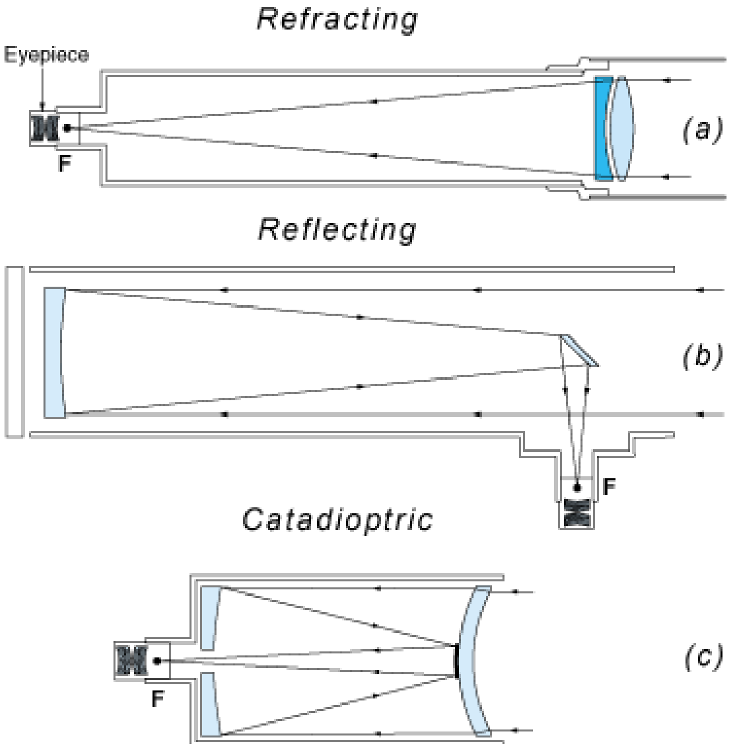
Wikipedia: *The Cassegrain telescope (sometimes called the "Classic Cassegrain") was first published in a 1672 design attributed to Laurent Cassegrain. It has a parabolic primary mirror, and a hyperbolic secondary mirror that reflects the light back down through a hole in the primary. Folding and diverging effect of the secondary creates a telescope with a long focal length while having a short tube length.*

Examples: Schmidt -Cassegrain's and Maksutov-Cassegrains are both common catadioptric designs, but they have slightly different optics. Both have two spherical mirrors (the primary and secondary). Spherical lenses by themselves would result in spherical aberration (distorted image). The difference between these two designs is the corrector plate details. Schmidt-Cassegrain's have a very thin, slightly aspherical corrector lens, where as Muskutav-Cassegrain's have a thicker spherical corrector lens. Both produce very clear images.



Catadioptric design (specifically, Schmidt-Cassegrain).
http://evointee.blogspot.com/2013/06/catadioptric-telescopes.html

The following image shows all three general telescope optical designs. And as noted above, there are subtle but important detailed variations in all of these basic designs. “F” indicates where the focuser is located. The focuser moves the eyepiece closer/further from the objective optics to bring the image into focus for your eye.


Refracting

Reflecting

Catadioptric

http://evointee.blogspot.com/2013/06/catadioptric-telescopes.html

Optical Properties
We have discussed two important optical properties for lenses: the index of refraction and dispersion (how much the index of refraction is a function of wave length). One other important optical property for lenses is spectral transmission.

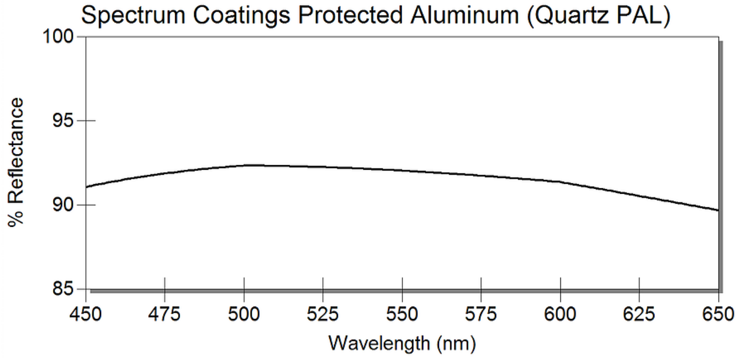
Spectral transmission describes how much of the light’s energy is transmitted through the glass at various wave lengths. Ideally, we would like 100% of all light frequencies to pass through the lens, but that is never the case. All materials “absorb” some amount of light, and the amount absorbed is a function of wave length (frequency).

Many telescope lenses and eye piece lenses have special coatings over the glass to increase transmission (decrease reflection). High quality eye pieces often have several different coatings on each surface. In product literature, high quality lenses will state that “all surfaces are multi-coated”.

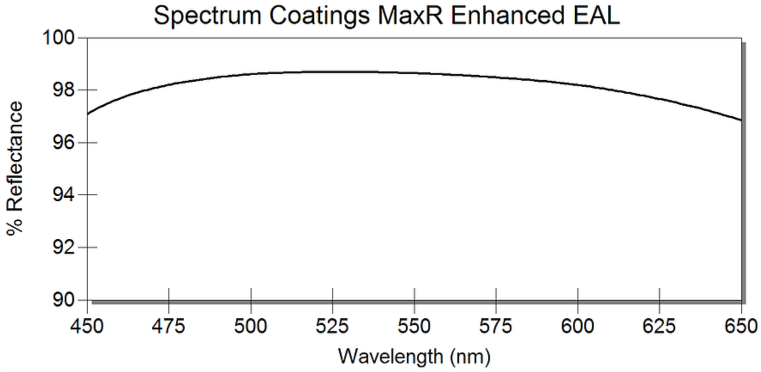
Anti-glare eyeglasses reduce reflection (and presumably increase transmission)

We will discuss more about spectral transmission later, but in a different context. Lenses are not the only material through which star light must pass.

The primary optical property of telescope mirrors is the spectral reflectance. Like spectral transmission, the amount of light reflected off of a mirror is a function of wave length (but the angle of reflection is nota function of wave length). Most amateur (and perhaps professional telescopes – Lulay does not know) are a thin aluminum coating applied over glass. A thin hard coating (such as SiO_2) is applied over the aluminum to increase the reflectance and provides a harder surface. Reflectance is typically around 92% to 98% depending upon specific coating materials and methods (in other words, 8% to 2% of the light energy is not reflected).



Aluminum with SiO_2 overcoat. *https://www.spectrum-coatings.com/coatings*



Aluminum with SiO_2 /TiO_2 overcoat. This is a somewhat more expensive process than SiO_2 alone, but increases reflectivity. *https://www.spectrum-coatings.com/coatings*

Physical Properties of Optical Materials

As mentioned above, most telescope mirrors are made from aluminized glass (glass with a thin aluminum coating). If the light reflects off of the aluminum coating, why is the mirror surface made from glass? The answer is that it is easy to “manufacture” into a paraboloid. Glass is a hard, brittle material, which means it is relatively easy to grind. Soft, ductile materials, like aluminum are easy to machine, but problematic to grind – it “smears” too much. Imagine trying to sandpaper on something very soft like clay. It doesn’t work very well. Glass, on the other hand, can be sanded relatively easily. The grinding process used to make high precision optics is effective on glass. But glass has high transmission, and very low reflectance; therefore, a thin aluminum coating is applied to the glass surface once it is the appropriate optical shape (such as a paraboloid).

Hardness is an important property, not just for manufacturing, but also important in-use. Being used outdoors, it is not possible to prevent dust from getting on the optical surfaces. Harder surfaces are less prone to scratching, and therefore, desirable.

Telescopes operate over a range of temperatures; therefore, coefficient of thermal expansion (CTE) of lenses and mirrors is important. If an optical surface expands or contracts due to temperature change, then its shape (and hence, optical performance) also changes. Pyrex was developed to have very low thermal expansion, and is a nice choice for telescope mirrors.

Density becomes an issue with larger mirrors. The weight of a mirror can be sufficient to cause the mirror to distort. For amateur telescopes, density of material is generally not something to consider when selecting a material. However, mirror weight and proper support are important aspects of design.

Chemical stability affects material selection of amateur telescopes. Silver has very high reflectance and was commonly used on telescope mirrors. However, silver quickly oxidizes causing reflectance to seriously decrease. That is why aluminum has become the common mirror coating.