National Academy of Opticianry

Continuing Education Course

Understanding Telescopes and Binoculars

National Academy of Opticianry
8401 Corporate Drive #605
Landover, MD 20785
800-229-4828 phone
301-577-3880 fax
www.nao.org

National Academy of Opticianry

Understanding Telescopes and Binoculars

Author:

Diane F. Drake, LDO, ABOM, NCLEM, FNAO

Course Level: Intermediate to Advanced

Prerequisite: The learner should have an understanding of mirrors and lens refraction.

Course Description:

This course will present information regarding telescopes and binoculars. Telescopes and binoculars can assist in managing low vision patients. Information will include different types of telescopes and binoculars and how they benefit the low vision patient, as well as special visual needs. Information will examine the differences and applications of the various types.

Learning Objectives/Learning Outcomes

At the completion of this course, the student should have:

- An understanding of the different types of telescopes
- An understanding of differences in telescopes
- An understanding of the numbers associated with binoculars
- A knowledge of low vision applications for telescopes and binoculars

National Academy of Opticianry
8401 Corporate Drive #605
Landover, MD 20785
800-229-4828 phone
301-577-3880 fax
www.nao.org

Understanding Telescopes and Binoculars

Introduction

This section will introduce telescopes and binoculars. While they are optical devices, what we use them for primarily in the optical field is for low vision patients. However, to understand the technology a little better and introduce interest in the topic, we will give some information on the history, types, and applications of telescopes and binoculars.

While the two most common types of telescopes used today are the Galilean telescope and the Keplerian telescope, there were others introduced first that were quite useful. Telescopes are optical devices that are designed using an arrangement of lenses or lenses and curved mirrors whereby rays of light (electromagnetic radiation) are collected and focused, resulting in a magnified image. Their purpose is to make distant objects appear nearer. Let's discuss these two inventors just a bit with relation to telescopes.

Known as a highly influential Italian astronomer, physicist, and philosopher, Galileo Galilei was born on February 15, 1564, near Pisa, Italy. A son of a musician, he developed an interest in medicine and started to study medicine at the University of Pisa, later changing to philosophy and mathematics. He became a professor of mathematics at Pisa and later moved to the University of Padua, becoming a mathematics professor there, a position he held until 1610. During this time, he worked on a variety of experiments, including the speed at which different objects fall, mechanics, and pendulums. In 1609, he heard about the invention of the telescope by Hans Lippershey in 1608, and even without having seen an example, he constructed a superior version. He made many astronomical discoveries, including mountains and valleys on the surface of the moon, sunspots, the four largest moons of the planet Jupiter, and the phases of the planet Venus. His work on astronomy made him famous and he was appointed court mathematician in Florence.

Known as a German mathematician, astronomer, and astrologer, Johannes Kepler was born on December 27, 1571, in Weil der Stadt, Württemberg, in the Holy Roman Empire. He was born into a poor family and had a sickly childhood. His great intelligence earned him a scholarship to the University of Tübingen to study for the Lutheran ministry. He became a mathematics teacher at a seminary school in Graz, Austria, and later became an assistant to the great astronomer Tycho Brahe. After the death of Brahe, he became the imperial mathematician to Emperor Rudolf II and later Matthias and Ferdinand II. Using the precise data that Tycho had collected, Kepler discovered that the orbit of Mars was an ellipse. Living in an era with no clear distinction between astronomy and astrology, Kepler incorporated religious arguments and reasoning into his works. In 1610, after hearing about the spyglass invention of Galileo, he acquired a telescope. Using the precise data that Tycho had collected, Kepler discovered that the orbit of Mars was an ellipse. He identified that all of the planets traveled in an ellipse as opposed to a circle. In 1611, he described how a telescope could be made with a convex objective lens and a convex eyepiece lens known as the Keplerian Telescope.

Some History of the Telescope

Telescopes of today are identified as one of two basic types. One type is a refractor or refracting telescope, which focuses light (electromagnetic radiation) using lenses. The other type is a reflector or reflecting telescope, which focuses light (electromagnetic radiation) using mirrors. The reflecting telescope is basically used exclusively in professional astronomy today.

A Google search on the history of the telescope will provide a plethora of information.

The most functional early telescopes were introduced as early as 1608. These are credited to

Hans Lippershey. The early designs of these early telescopes consisted of a convex objective lens and a concave eyepiece and were known as refracting telescopes. Galileo used the refracting telescope design in his telescope that was introduced in 1610. We will discuss this design a little more fully later in this section. Galileo devoted much of his time to improving and perfecting the telescope and soon succeeded in producing telescopes of greatly increased power. His first telescope magnified three diameters and finally, one that magnified thirty-three diameters. This last telescope allowed him in 1610 to discover the satellites of Jupiter and soon afterward the spots on the sun, the phases of Venus, and the hills and valleys on the Moon. These brilliant achievements, together with Galileo's immense improvement of the instrument, overshadowed to a great degree the credit due to the original inventor and led to the universal adoption of the name of the Galilean telescope for the form of the instrument invented by Lippershey.

Then, in 1611, Johannes Kepler described how a telescope could be made with a convex objective lens and a convex eyepiece lens. By 1655 astronomers such as Christiaan Huygens were building powerful but unwieldy Keplerian telescopes with compound eyepieces. Hans Lippershey used the Keplerian design and is the earliest person documented to have applied for a patent for the device.

In 1668, Isaac Newton is credited with building the first practical reflector telescope in 1668 with a design that incorporated a small flat diagonal mirror to reflect the light to an eyepiece mounted on the side of the telescope. Laurent Cassegrain in 1672 described the design of a reflector with a small convex secondary mirror to reflect light through a central hole in the main mirror.

The achromatic lens, which greatly reduced color aberrations in objective lenses and allowed for shorter and more functional telescopes, first appeared in a 1733 telescope made by Chester Moore Hall, who did not publicize it. John Dollond learned of Hall's invention and began producing telescopes used in commercial quantities starting in 1758.

Important developments in reflecting telescopes were John Hadley's production of larger paraboloidal mirrors in 1721, the process of silvering glass mirrors introduced by Léon Foucault in 1857, and the adoption of long-lasting aluminized coatings on reflector mirrors in 1932. Almost all of the large optical research telescopes used today are reflectors.

William Gascoigne was the first who commanded a chief advantage of the form of telescope suggested by Kepler: that a small material object could be placed at the common focal plane of

the objective and the eyepiece. This led to his invention of the micrometer, and his application of telescopic sights to precision astronomical instruments. It was not until about the middle of the 17th century that Kepler's telescope came into general use: not so much because of the advantages pointed out by Gascoigne, but because its field of view was much larger than in the Galilean telescope.

The first powerful telescopes of Keplerian construction were made by Christiaan Huygens after much labor in which his brother assisted him. With one of these: an objective diameter of 2.24 inches (57mm) and a 12 ft (3.7 m) focal length, he discovered the brightest of Saturn's satellites (Titan) in 1655; in 1659, he published his Systema Saturnium which, for the first time, gave a true explanation of Saturn's ring founded on observations made with the same instrument.

Chromatic aberration was a concern which limited the sharpness of the image with the Keplarian telescope, for very far viewing, due to the non-uniform refractive properties of the objective lens. Giovanni Cassini was able to overcome this limitation at high magnifying powers by creating objectives with very long focal lengths. Cassini discovered Saturn's fifth satellite (Rhea) in 1672 with a telescope 35 ft (10.7 m) long. Astronomers such as Johannes Hevelius were constructing telescopes with focal lengths as long as 150 feet (45 m). Besides having really long tubes these telescopes needed scaffolding or long masts and cranes to hold them up. Their value as research tools was minimal since the telescope's frame tube flexed and vibrated in the slightest breeze and sometimes collapsed altogether.

In some of the very long refracting telescopes constructed after 1675, no tube was employed at all. The objective was mounted on a swiveling ball-joint on top of a pole, tree, or any available tall structure and aimed by means of a string or connecting rod. The eyepiece was hand held or mounted on a stand at the focus, and the image was found by trial and error. These were consequently termed aerial telescopes and have been attributed to Christiaan Huygens and his brother Constantijn Huygens, Jr. although it is not clear that they invented it. Christiaan Huygens and his brother made objectives up to 8.5-inch (220mm) diameter and 210 ft (64 m) focal length and others such as Adrien Auzout made telescopes with focal lengths up to 600 ft (180 m). Telescopes of such great length were naturally difficult to use and must have taxed astronomers to the utmost and tried the skill and patience of observers. Aerial telescopes were employed by several other astronomers. Cassini discovered Saturn's third and fourth satellites in 1684 with aerial telescope objectives made by Giuseppe Campani that were 100 and 136 ft (30.5 and 41.5 m) in focal length.

Reflecting Telescopes

The ability of a curved mirror to form an image may have been known since the time of Euclid and had been extensively studied by Alhazen in the 11th century. Galileo, Giovanni Francesco Sagredo, and others spurred on by their knowledge that curved mirrors had similar properties to lenses, discussed the idea of building a telescope using a mirror as the image-forming objective. Niccolò Zucchi, an Italian Jesuit, astronomer, and physicist, wrote in his book Optica Pilosophia of 1652 that he tried replacing the lens of a refracting telescope with a bronze concave mirror in 1616. Zucchi tried looking into the mirror with a handheld concave lens but did not get a

satisfactory image, possibly due to the poor quality of the mirror, the angle it was tilted at, or the fact that his head partially obstructed the image.

Gregorian Telescope

In 1636 Marin Mersenne proposed a telescope consisting of a paraboloidal primary mirror and a paraboloidal secondary mirror bouncing the image through a hole in the primary, solving the problem of viewing the image. James Gregory went into further detail in his book Optica Promota (1663), pointing out that a reflecting telescope with a mirror that was shaped like the part of a conic section would correct spherical aberration as well as the chromatic aberration seen in refractors. The design he came up with bears his name: the Gregorian telescope; but according to his own confession, Gregory had no practical skill and he could find no optician capable of realizing his ideas. After some fruitless attempts, he was obliged to abandon all hope of bringing his telescope into practical use.

Newtonial Telescope

In 1666, Sir Isaac Newton, based on his theories of refraction and color, perceived that the faults of the refracting telescope were due more to a lens's varying refraction of light of different colors than to a lens's imperfect shape. He concluded that light could not be refracted through a lens without causing chromatic aberrations, although he incorrectly concluded from some rough experiments that all refracting substances would diverge prismatic colors in a constant proportion to their mean refraction. From these experiments, Newton concluded that no improvement could be made in the refracting telescope. Newton's experiments with mirrors showed that they did not suffer from the chromatic errors of lenses, for all colors of light the angle of incidence reflected in a mirror were equal to the angle of reflection. To prove his theories, Newton set out to build a reflecting telescope. Newton completed his first telescope in 1668 and it is the earliest known functional reflecting telescope. After much experiment, he chose an alloy (speculum metal) of tin and copper as the most suitable material for his objective mirror. He later devised means for grinding and polishing them but chose a spherical shape for his mirror instead of a parabola to simplify construction. He added to his reflector what is the hallmark of the design of a Newtonian telescope: a secondary "diagonal" mirror near the primary mirror's focus to reflect the image at 90° angle to an eyepiece mounted on the side of the telescope. This unique addition allowed the image to be viewed with minimal obstruction of the objective mirror. He also made all the tube, mounting, and fittings. Newton's first compact reflecting telescope had a mirror diameter of 1.3 inches and a focal ratio of f/5. With it, he found that he could see the four Galilean moons of Jupiter and the crescent phase of the planet Venus. Encouraged by this success, he made a second telescope with a magnifying power of 38X, which he presented to the Royal Society of London in December 1672. This type of telescope is still called a Newtonian telescope.

Cassegrain Telescope

A third form of reflecting telescope, the "Cassegrain reflector telescope" was devised in 1672 by Laurent Cassegrain. The telescope had a small convex hyperboloidal secondary mirror placed near the prime focus to reflect light through a central hole in the main mirror.

Coudé Telescope

Adding further optics to a Nasmyth-style telescope to deliver the light - usually through the declination axis - to a fixed focus point that does not move as the telescope is reoriented gives a Coudé focus (from the French word for elbow). This design has often been used on large observatory telescopes, as it allows heavy observation equipment such as spectrographs to be more easily used.

The Coudé focus was widely used in large telescopes built in most of the Twentieth Century since limits on optical design and fabrication required high-resolution spectrographs in particular to have large collimating mirrors.

According to Wikipedia, in optics, a collimator may consist of a curved mirror or lens with some type of light source and/or an image at its focus. This can be used to replicate a target focused at infinity with little or no parallax.

Ideally, these had the same diameter as the telescope's primary mirror with very long focal lengths. Such instruments could not withstand being moved, and adding mirrors to the light path to divert the light to a fixed position to such an instrument housed on or below the observing floor, and usually built as an unmoving integral part of the observatory building, was the only option. The 1.5m Hale Telescope, Hooker Telescope, 200-inch Hale Telescope, Shane Telescope, and Harlan J. Smith Telescope all were built with Coudé foci instrumentation. The development of echelle spectrometers allowed high-resolution spectroscopy with a much more compact instrument, one which can sometimes be successfully mounted on the Cassegrain focus. However, since inexpensive and adequately stable computer-controlled Alt-az telescope mounts were developed in the 1980s, the Nasmyth design has supplanted the Coudé focus for large telescopes.

Refracting Telescopes

Galileo Telescope

Galileo's telescope used Hans Lippershey's design of a convex objective lens and a concave eye lens. The lens closest to the object is called the objective and the lens closest to the eye is called the eyepiece. The telescope Galileo used was a refracting telescope. It consisted of two lenses, one converging, which causes parallel light from the sun to converge to a focal point, and one diverging, which causes parallel light to diverge from a focal point. The distance between the two lenses is determined by the difference in their focal lengths. By design, the Galilean telescope will be shorter and has weigh less than the Keplerian telescope.

A feature of the telescope constructed in this way is that the image will be right-side-up. Remember Galileo initially saw the military and other terrestrial uses for the telescope where this would be significant. However, you will see that the field of view is not very large and that you might not be able to see the entire moon at once. However, you will be able to make some of the surface features such as craters.

Keplerian Telescope

For astronomical purposes, you will probably find it more satisfying to use a Keplerian telescope rather than a Galilean one. The Keplerian telescope uses two convex lenses, the objective lens is a lower dioptric power than the ocular lens. The distance between the lenses is the sum of their focal lengths. This telescope will not focus at the same place that the Galilean one does. You will have to adjust it differently to get a clear image. Having done so, you will find that this telescope inverts the image, but at the same time gives you a larger one – it does not magnify more but it gives a larger field of view. You may be able to fit the entire moon into your field of view. So, to invert the image, an erector or prism is used which makes it longer and heavier. However, since the visual field is greater and the image is better, it generally is more costly.

The first lens (the objective) will focus the object just beyond the focal point of the second lens (the eyepiece). This creates a real intermediate image. This intermediate image is now the object for the eyepiece. In astronomical use, the object is at a very large distance so that the intermediate image is very close to the focus of both lenses. Because this object is within the focal point of the eyepiece, the final image will appear magnified and inverted as shown. One can also see from this diagram that the field of view is significantly increased from the previous image and that the Keplerian telescope will show a much larger part of the image, not a larger magnification. The magnification of both of these instruments is the ratio of the objective focal length to the eyepiece focal length. For these telescopes the magnification is 700mm/50mm = 14X.

Surgical Applications of Telescopes

Telescopes used in surgical applications are routinely referred to as surgical loupes, and they enlarge images when the surgeon/technician is working on or conducting precision operations. There are a number of factors that you will need to consider when assisting your patient with a surgical telescope/loupe. Remember that the higher magnification will also make the focal length shorter, so select the lowest magnification possible for the required working distance. How wide must the field be and how will weight affect the wearer? The longer the focal length, generally the wider the field of view, which will reduce eye strain and fatigue. They must have adjustable pupillary distances or you will need to be able to place them on glasses according to your patients working PD.

There are three basic types of loupes available today. The first is a single lens loupe for simple, low-magnification applications. A photographer or jeweler might use this style. The second style is the Galilean loupe designed by Galileo Galilei during the 17th century. Galilean loupes use multiple lenses and offer magnification between 2.0X and 3.0X. These are easy to use, lightweight and affordable for your patients. For greater magnification up to about 8.0X, Keplerian prismatic loupes are available. Designed by Johannes Kepler during the 17th century, prismatic loupes use a series of lenses and prisms to magnify the subject. They offer greater magnification, sharp resolution, and a greater depth of field.

There are also telescopes/loupes available that will simply clip on to existing eyewear.

Applications of Telescopes in Low Vision

Telescopes may help patients with low vision in improving their quality of life. For example:

- For watching TV
- For watching sporting events
- For going to movies or theatrical events
- For Driving
- For spotting street signs

Telescopic lenses bend rays of light so when they leave the telescope, they appear to be coming from the same direction as an object closer to the eye; thus, the object appears much larger.

The label indicates the power and field of view ex: 7X20, 7.5. The image is 7 times larger than normal, objective lens is 20mm, and the field of view is 7.5 degrees

Mounted Telescopes

- For distance viewing
- May be fit with reading cap for near
- Can be mounted into the upper part of standard distance lens
- Advantages:
    - The only low vision aid which provides distance magnification
- Disadvantages:
    - Reduced field of view
    - Exaggerated movement of objects viewed
    - Spatial orientation

Binoculars

What do the numbers on binoculars mean?

As an example, a pair of binoculars may have 10x42mm listed as a technical specification. The "10 refers to the magnification power of the binoculars, that is, objects viewed will appear to be 10 times closer than when they are viewed by the naked eye.

The second number in our example is 42mm. This refers to the diameter, in millimeters, of the objective lenses on the binoculars. The objective lenses are located on the end of the binoculars furthest away from the eye when viewing.

As with the aperture of a camera lens, the size of the objective lens determines the amount of light that can enter the binoculars. If the binoculars are going to be used during low light - hunting and astronomy are good examples – there must be large objective lenses.

Another important number describing binoculars is called field-of-view.

A field-of-view of 390' indicates that the width of the sight picture is 390 feet at a distance of 1000 yards. Field-of-view is determined by magnification and the focal lengths of the objective and eyepiece lenses.

More magnification always means less field-of-view. This specification is sometimes expressed in degrees. A field-of-view of 6.5 degrees equates to 341' (6.5 times 52.5 equals 341).

How well binoculars will serve in low light conditions is described as Twilight Performance. Although many things, such as overall design and quality of glass impact this specification, magnification and objective lens diameter are the chief components.

A quick way to determine the Twilight Performance of binoculars is to multiply the magnification power (first number) times the objective lens diameter (second number). The higher the result, the better the Twilight Performance will be. As an example, 10x42mm binoculars will have better Twilight Performance than 8x50mm binoculars (420 versus 400).

While compact binoculars weigh as little as a pound, by using them you will undoubtedly sacrifice performance. If performance is your main consideration, full-sized binoculars are preferred.

The greater the magnification, the narrower the field-of-view. If field-of-view is important, don't purchase the most powerful binoculars. This becomes very important when viewing objects that move quickly such as antelope, racehorses, shooting stars, or race cars.

There is no such thing as one-size-fits-all when it comes to sporting optics. If you have multiple uses for binoculars, you will most likely end up with multiple pairs of them.

How do you choose binoculars for astronomy, binoculars for birding or binoculars for a child? Why does the binocular lens size matter?

Binoculars truly are a twin set of refracting telescopes. The size of the objective (or primary) lens is referred to as the aperture.

Just as with a telescope, the aperture is the light-gathering source which plays a key role in the applications binoculars are suited for.

Theoretically, more aperture means brighter and better resolved images, yet the size and bulk increase proportionately. To be happiest with your choice, you must ask yourself what you'll be viewing most often with your new binoculars.

Binoculars with aperture less than 29mm are small and very portable. For well-lit situations such as sporting events and concerts, these will make great companions for bringing the view a little bit closer.

Binoculars with apertures between 30-39mm are a great mid-range size that can be used for multiple applications. At this size, a higher magnification becomes a little more practical. This allows for better views of birds in lower light situations, such as in shadows, leaves or twilight/daybreak illumination.

Binoculars with 40-49mm aperture are also a great mid-range size. Again, increasing the objective lens size means brighter images in low light situations, but these models are a bit bulkier. They are very well-suited to birding applications and wildlife studies, but the larger models may require a support such as a tripod, monopod, or car window mount for extended viewing.

50mm aperture binoculars are pushing the maximum amount of weight that can be held comfortably by the user without assistance. Available in a wide range of magnifications, these models are for serious study and will give crisp, bright images across all lighting situations.

Binoculars with apertures larger than 56mm are some serious aperture. For wildlife studies of dawn and dusk critters, these are the perfect size allowing for bright images at high magnification. For astronomy applications, these will definitely open a whole new vista to your observing nights. The wide field of view allows for a panoramic look at the heavens.

What you will notice that is included on all good quality telescopes and binoculars is that they use good quality glass to avoid chromatic aberrations. They also include AR coatings to eliminate reflections.

National Academy of Opticianry
8401 Corporate Drive #605
Landover, MD 20785
800-229-4828 phone
301-577-3880 fax
www.nao.org