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Why Study Light ?

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1 Introduction

Light is the means by which we have come to understand the universe, galaxies, and stars. Everything that we know about the origin of the universe and the evolution of stars has been learned by analyzing the light from these distant objects. Most of what we know about the Sun, including solar phenomena that directly affect radio communications, has been learned by studying light emitted by the Sun. Light from the Sun creates Earth's ionosphere. Refraction and dispersion of light explains to a large extent how HF radio signals propagate through the ionosphere.

Understanding the nature of light is fundamental to our understanding of radio waves. Light and radio waves are the same thing. What applies to one also applies to the other. The advantage of studying visible light is that we can see it reflect, refract, and diffract as it encounters various types of medium, giving us a visual understanding of these mechanisms. We can not see radio waves, but they act the same way.

Light and radio waves are both electromagnetic waves. The only difference between them is their wavelengths. Radio waves are at the bottom of the electromagnetic spectrum with wavelengths of more than 100 meters as illustrated in Figure 1. The wavelength of visible light ranges from 700 down to 400 nanometers (nm), while Gamma rays are at the top of the spectrum with wavelengths on the order of 0.0001 nm.

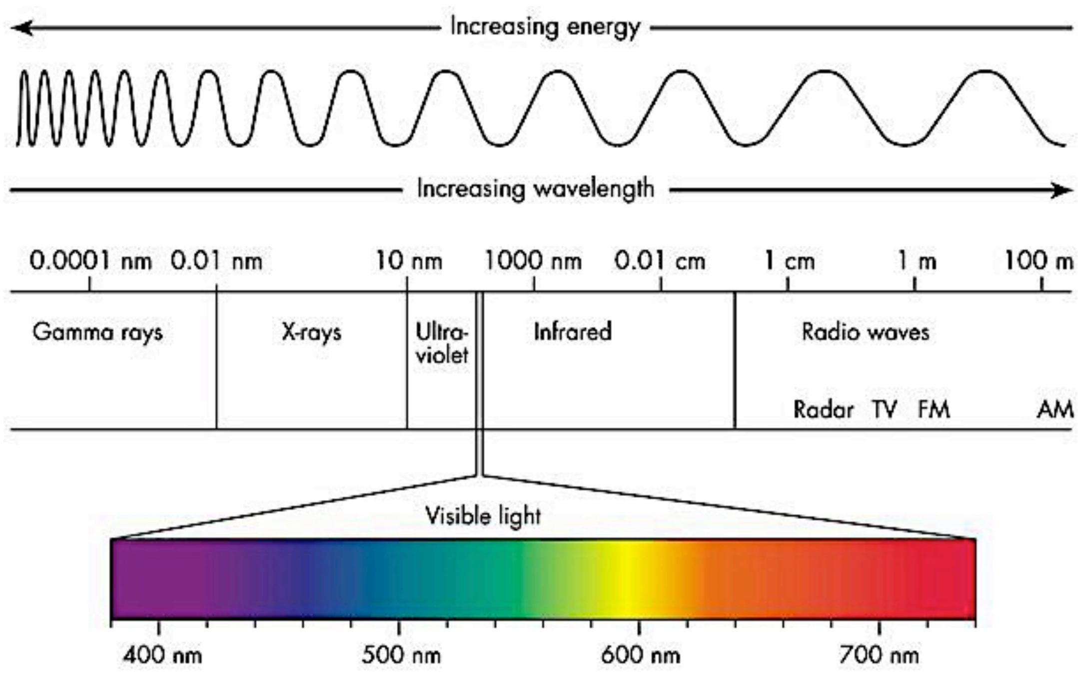

Figure 1 Electromagnetic Spectrum (source: Cyberphysics)

1.1 Isaac Newton - Color and Purity of Light

Isaac Newton (1643 – 1727) discovered the visual spectrum of sunlight in 1666 while working at home during the plague. He received his bachelor's degree from Cambridge University in April 1665, just prior to the university closing its doors. Newton returned to the university in 1667 when the school reopened following the plague. Newton was appointed to the university's prestigious Lucasian Chair Of Mathematics in 1669. Optics was the subject of his first lecture course in January 1670

In his study of light, Newton reached the conclusion that sunlight was not a simple entity. Every philosopher and scientist since Aristotle had believed that sunlight was "pure". However, chromatic aberration, caused by imperfections in the lenses of refracting telescopes, suggested to Newton that perhaps sunlight (technically white light) was not pure at all, but instead made of several different colors. Chromatic aberration causes faint colored "rings" to appear around the periphery of the object being viewed. When Newton passed a thin beam of sunlight (Figure 2) through a glass prism he discovered that white light was separated into a spectrum of seven distinct colors: red, orange, yellow, green, blue, indigo, and violet, as illustrated in Figure 3. Others claimed that the spectrum obtained was the result of the "pure white light" being corrupted as it traveled through the prism glass. The more glass that the light passed through, the more corrupt the light would become.

To disprove this, Newton passed light through two prisms as illustrated in Figure 4.

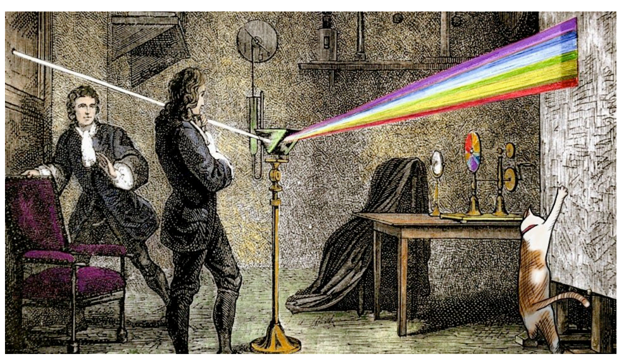

Figure 2 Passing a beam of light through a prisim (source: pinterest)

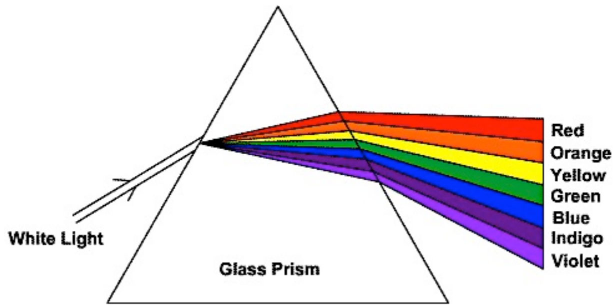

Figure 3 Spectrum of White Light

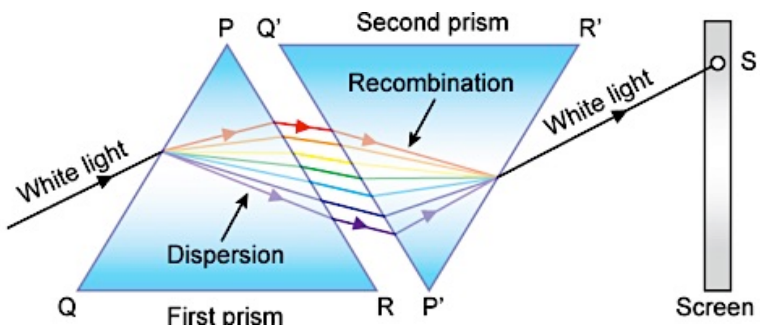

Figure 4 Recombining of light spectrum

The white light was separated into the color spectrum after passing through the first prism. The spectrum was then passed through a second prism rotated 180 degrees with respect to the first prism. Instead of further corrupting the light, the second prism instead recombined the spectrum back into white light. This experiment proved that white light was not "pure", as commonly believed, but instead made up of a spectrum of colors.

Using his understanding of color, Newton designed a reflecting telescope that minimized much of the chromatic aberration present in refracting telescopes. Instead of using lenses Newton utilized mirrors. He placed a concaved mirror at the base of the telescope tube and a flat mirror at an angle of 45^o at the top end of the tube. The concaved mirror focused the light coming into the telescope while the flat mirror directed it into the eye piece.

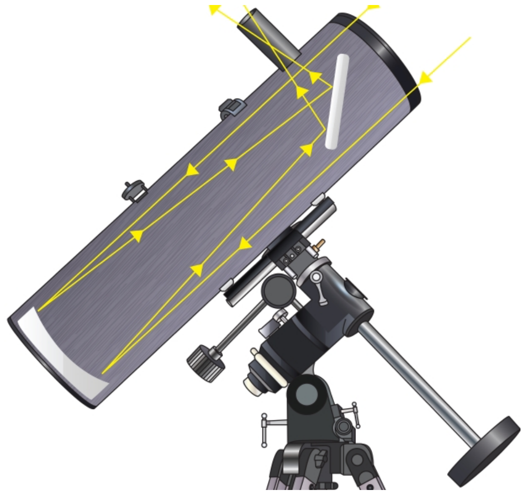

Figure 5 Newtonian Telescope (Source: Space Answers, by Jonathan O'Callaghan)

1.2 Understanding of Light in the Ancient World

The nature of light has been the subject of study and debate since the time of the early Greeks.

1.2.1 Empedocles – Emission Theory of Sight

In the fifth century BC the Greek philosopher Empedocles (~ 492 – 432 BC) postulated that everything was composed of the four elements: fire, air, earth, and water. He was also one of the first recorded philosophers to speculate that light traveled at a finite speed. He claimed that light was something in motion and therefore must take some time to travel. Empedocles further believed that sight was the result of light emitted from our eyes that bounced off objects and back into our eyes permitting us to see an object's size, shape and color. Remarkable as it may seem, this was the perception of vision held by most philosophers and scientists for over a thousand years.

1.2.2 Aristotle – Infinite Speed of Light

Aristotle (384 – 322 BC) has exerted a unique influence on almost every form of knowledge in the Western world. His views on physical science were considered indisputable well into the 17th century AD.

Aristotle argued that light was due to the presence of something, not a movement as Empedocles suggested. Thus light appeared instantly.

Aristotle strongly believed that knowledge came primarily from sensory experience coupled with inductive and deductive reasoning. He sought to collect all available information. He formed hypotheses based on what he saw, and then applied these hypotheses to further observations. However, Aristotle did not perform experiments to prove his hypotheses. For example, Aristotle taught that the rate at which a body falls is directly proportional to its weight, that is, a heavier body falls faster than a lighter body. Aristotle could have easily proved that this hypotheses was wrong by performing a simple experiment. He could have dropped a stone and a heavy rock at the same time and noted that the rock did not fall any faster than the stone. But he didn't. In general, the concept of experimentation was unknown to the Greek philosophers. They were certainly capable of performing experiments, but it simply did not occur to them.

1.2.3 Euclid – Light Travels in a Straight Line

Euclid (~ 325 – 265 BC) lived in Alexandria, Egypt and studied at its great library shortly after the library's construction . Euclid is best know for his extensive study of geometry and number theory compiled in his multi-volume book *Elements*. Like many in the ancient world, Euclid studied multiple subjects, one of them being the study of light and optics. He documented the results of this work in a book titled *Optica*. In the book Euclid extended Empedocles' concept that we see by means of light emitted from our eyes, which became known as the emission theory. In addition to promoting the emission theory, Euclid also postulated that light traveled in straight lines and described the phenomena of reflection from polished metal mirrors. From his book it is known that he worked with spherical and parabolic mirrors in addition to plane mirrors. He states in the book that concave mirrors turned toward the sun will cause ignition, presumably of dried grass and leaves on which the Sun's rays were focused by the mirror.

1.2.4 Lucretius - Hypothesized Light and Heat Came From the Sun

Not everyone believed that sight was the result of light emitted from our eyes. A Roman poet and philosopher by the name of Lucretius (~ 99 – 55 BC), was one of those that questioned that theory. In his poem *On the nature of the Universe* he hypothesized that light and heat from the Sun were composed of minute atoms which traveled at great speed from the Sun through air to Earth. However, his views were not well accepted and the belief continued to be that sight was the result of light emitted from the eye.

1.2.5 Lucius Seneca – First Mention of Magnification

Roman philosopher and statesman, Lucius Seneca, better known as Seneca the Younger, (4 – 65 AD) was a tutor and later an advisor to Emperor Nero. In a comment regarding magnification, Seneca wrote "letters, however small and indistinct, are seen enlarged and more clearly through a globe or glass filled with water". It is said that Emperor Nero watched gladiator fights by holding a green emerald to his eye. While the truth of this claim is questionable, it suggests that polished transparent gems were being used for magnification, a precursor to “seeing stones”.

1.2.6 Heron of Alexandria – Angle of Incidence Equals Angle of Reflection

Around 60 AD Heron of Alexandria (~ 10 – 75 AD) showed by geometrical methods that light reflected from a flat polished metal mirror takes the shortest possible path from the object (the light source) to the mirror and finally to the observer. Using this result, he concluded that the angle of reflection from the mirror must equal the angle of incidence on the grounds that this would yield the shortest path. He also concluded that the distance from the object to the mirror was equal to the apparent distance of the image behind the mirror. In addition, Heron argued that the speed of light was infinite because stars appeared immediately when opening one’s eyes.

1.2.7 Early Roman Glass Mirrors

The Roman glass industry underwent rapid technological growth, including the introduction of glass blowing techniques, during the first century AD. Large scale manufacturing of glass, primarily in Alexandria, resulted in glass becoming a commonly available material, much like plastic today. However, the building of flat glass mirrors was difficult and expensive due to the inability to produce flat glass of uniform thickness and problems of applying hot reflective metal to the glass without cracking it. The clarity of the glass was also a problem due to impurities in the glass. Consequently, highly polished metal mirrors continued to be manufactured.

1.2.8 Ptolemy – Reflection, Refraction, and Color

It was also during this time that Alexandrian astronomer, mathematician, and geographer Claudius Ptolemy (~ 85 – 165 AD) studied the properties of light including reflection, refraction, and color. Ptolemy described a stick appearing to bend when partially immersed in a pool of water, and accurately recorded the angles he observed. He discovered that water and glass have different angles of refraction. He studied reflection by performed experiments with plane, concave and convex mirrors constructed from polished iron. In addition, he explained that magnification occurred when light passed through transparent curved objects. Ptolemy continued to promote Empedocles’ emission theory (sight is the result of light emitted by the eyes).

1.2.9 Hunayn ibn Ishaq – Ten Treatises on the Eye

Hunayn ibn Ishaq (809 – 873 AD) was the most productive translator of Greek medical and scientific treatises in his day, translating the documents first into Syriac and then into

Arabic. In addition he wrote a book titled *Ten Treatises on the Eye* which was influential in western European until the 17th century.

1.2.10 Abbas ibn Firnas – Colorless Glass and Magnifying Glass

Abbas ibn Firnas (810 -887 AD) was an inventor, physician, chemist and engineer residing in Spain. His work included manufacturing colorless glass and developing a magnifying glass (a reading stones) for improving vision.

1.2.11 Ibn Sahl – First to Describe Law of Refraction

Islamic mathematician and physicist Ibn Sahl (~ 940 – 1000 AD) is the first known Muslim scholar to have studied Ptolemy's *Optics* and wrote his own optical treatise around 984. His book was an important precursor to the *Book of Optics* written by al-Haytham some thirty years later. Ibn Sahl studied the optical properties of curved mirrors and thick lenses constructed from transparent material to understand how they bend and focus light. In the process he described a law of refraction mathematically equivalent to Snell's law.

1.2.12 Al-Haytham – The First to Understand the True Nature of Light

Around 1,000 AD, the Muslim mathematician, astronomer, and physician al-Haytham, (also known as Alhazen) made considerable strides in the understanding of light. al-Haytham is believed to have been born in Persia (now Iraq) around 965 and probably died in Egypt in 1040.

al-Haytham rejected the Greek idea that sight was the result of light emitted by the eye. In his *Book of Optics*, written from 1011 to 1021, al-Haytham maintained that sight was the result of light reflecting off objects and then entering ours eyes. He backed up his claim with a number of very persuasive demonstrations.

He proposed that there were two types of light, primary and secondary light. Primary light came from self-luminous bodies such as "red hot glowing iron". Secondary light was actually the reflection of primary light from a non-luminous object. Both types of light traveled in straight lines.

He believed that sun light consisted of streams of tiny particles also traveling in straight lines. In addition al-Haytham believed that the speed of light was finite arguing that "light is substantial matter, the propagation of which requires time, even if this is hidden from our senses". He maintained that the speed of light was variable, traveling at a slower speed through denser material. In his book he described transparent bodies as objects through which light could pass, for example air and water. Opaque objects were objects through which light could not pass, all though there were degrees of opaqueness as there were degrees of transparency.

Light could be reflected from smooth objects such as highly polished metal mirrors. When being reflected, light traveled in a straight line to the mirror and also in a straight line after being reflected from the mirror. Furthermore, he made the important observation that the angle of incidence, i.e. the angle between the incident ray of light and the line normal (perpendicular) to the mirror, was in the same plane as the angle of reflection.

He pointed out that magnification could be achieved when light passed through transparent curved objects. He observed that a light ray along the central axis of a thick lens passed through the lens without refraction. However, inclined rays were refracted. The amount of refraction depended on the density of the transparent material. While he made detailed measurements of the angle of incidence and the angle of refraction, he was not able to discover the sine law of refraction. One of the important aspects of his work was his use of observations, experiments, and rational arguments to support his findings. He was an early practitioner of what has become known as the scientific method.

1.3 Rebirth of Science in Europe

In the 10th and 11th centuries the Muslim city of Cordova, Spain was an important center of scientific learning, primarily in mathematics, astronomy, medicine, and botany. The learning institutions and libraries in Cordova far exceed anything available in the rest of Europe. Toledo, Spain had one of the finest libraries in Islam. It was from Cordova, Toledo and other Muslim cities in Spain that the European scholars, emerging from the dark ages, re-acquired the knowledge that had been lost following the fall of the Roman Empire. Aristotle's views and the experimental approaches of al-Haytham were introduced to the European scholars via Latin translations of Arabic and Greek texts.

1.3.1 Robert Grosseteste – One of the First European Scholars

English Bishop, theologian, and scientist Robert Grosseteste (1175 – 1253 AD) was one of the early European scholars. In his treaties De iride ("On the Rainbow"), written between 1220 and 1235, Grosseteste mentions the use of optics to "read the smallest letters at incredible distances".

1.3.2 Roger Bacon – Early Scientific Method

Franciscan Friar Roger Bacon (1214 – 1292 AD) was one of the earliest European's to utilize experimentation in the study of science.

Bacon developed a strong interest in mathematics and science while studying and teach at Oxford University in 1247 (at the age of 33). He was strongly influenced by the writings of Grosseteste and embarked on an intense study of languages, mathematics, optics and sciences that would consume him the rest of his life. Bacon read al-Haytham's "Optics" and came to understand the importance of applying mathematics to real world problems. In fact, his most important mathematical contribution was the use of geometry in the study of optics. Bacon planned and carried out systematic observations and experiments with lenses and mirrors in a manner very similar to today's scientific approach. He also promoted the idea of using lenses for magnification to aid natural vision.

Bacon left the University of Oxford in 1251 and entered the Franciscan Friary in Oxford at the age of 37. It is unclear what the reason was for this move. He was a devout Christian who believed that his scientific work would aid in an understanding of the world and God's creation. He spent the rest of his life assigned to various Friary's in England, France, and Italy, not always at his choice. For a while he was imprisoned in Italy, the charge being "suspected novelties" in his teachings. In other works, he expressed views which his superiors disagreed with. However, he was allowed to continue his study of mathematics and science throughout most of his years as a Friar.

1.4 Lenses and Mirrors

Glass mirrors were being made by the 3rd century AD, despite the difficulty of making flat smooth uniform glass. They were made by blowing a glass bubble and then cutting out a small circular section producing concave and convex mirrors. The mirrors were very thin to prevent the glass from cracking when coating the back of the mirror with a molten reflective metal. The mirrors were small, very fragile, often had a green tint due to iron impurities in the glass, and usually produced distorted images. In addition, glass mirrors were very expensive. Because of these problems, metal mirrors, typically made of polished iron, were generally used.

Improved mirrors were being produced in Moorish Span by the 11th century. The glass clarity problem had been overcome by mixing substances such as soda, limestone, potash, and manganese in with the glass. A technique for producing flat uniform glass was finally developed by blowing a glass cylinder, slicing it down the center and unrolling it on a flat hearth.

Reading stones (Figure 6) were invented in the early part of the 11th century. These were primitive plan-convex lenses (flat on one side and convex on the other side) initially made by cutting a polished quartz or beryl glass sphere in half. Reading stones were extensively used by monks as a reading aid for their older brothers and in producing intricate hand drawn copies of the Bible. Over time it became evident that better magnification was obtained by making the reading stones thinner.

Figure 6 Reading Stone (source: Zeiss Optical Museum)

The first eyeglasses were most likely made in Pisa in Northern Italy around 1290. In a sermon delivered on February 23, 1306, the Dominican friar Giordano da Pisa (ca. 1255–1311) wrote "It is not yet twenty years since there was found the art of making eyeglasses, which make for good vision... And it is so short a time that this new art, never before extant, was discovered.". Giordano's colleague Friar Alessandro della Spina of Pisa (d. 1313) was soon making eyeglasses. However, the art of making convex lenses for glasses quickly became a closely guarded trade secrete.

1.4.1 Types of Lenses and Mirrors

There are two types of simple lenses and three types of mirrors:

1. Lenses
    a. Convex,
    b. Concave

2. Mirrors
    a. Convex,
    b. Concave,
    c. flat

as illustrated in Figures 7 and 8

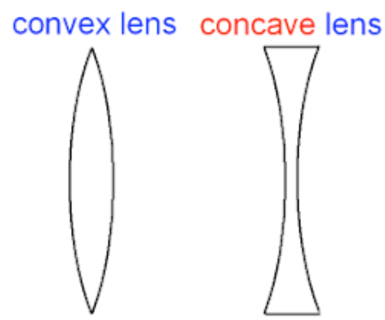

Figure 7 Types of Lenses (source: gcsescience.com)

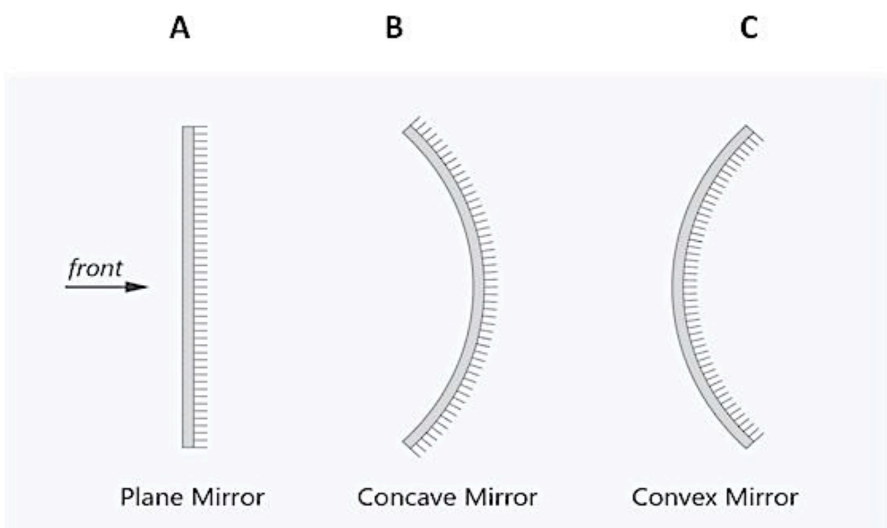

Figure 8 Types of Mirrors (source: Chegg)

1.4.2 Ray Tracing for Convex and Concave Lens

A simple convex lens is shown in Figure-9a and a concaved lens in Figure-9b.

In the figures, the Object is the item being viewed while the Image is the replication of that item formed by the lens.

The focal point F is the point at which all parallel light rays entering the lens (Ray-1 in the figures) converge (for a real image) or appear to converge (for a virtual image) after passing through the lens. Virtual, or apparent, rays are shown as dashed lines in the figures. The image in Figure-9a is a real image since the light from the object actually passes through the location of the image. The image in Figure-9b is virtual since the light from the object only appears to pass through the image location (dashed lines).

The focal length f is the distance along the optical axis from the focal point F to the center of the lens. d_o is the distance along the optical axis from the Object to the center of the lens while d_i is the distance of the Image from the lens. d_o is positive. d_i is positive for a real image and negative for a virtual image. C is the radius of curvature for the lens.

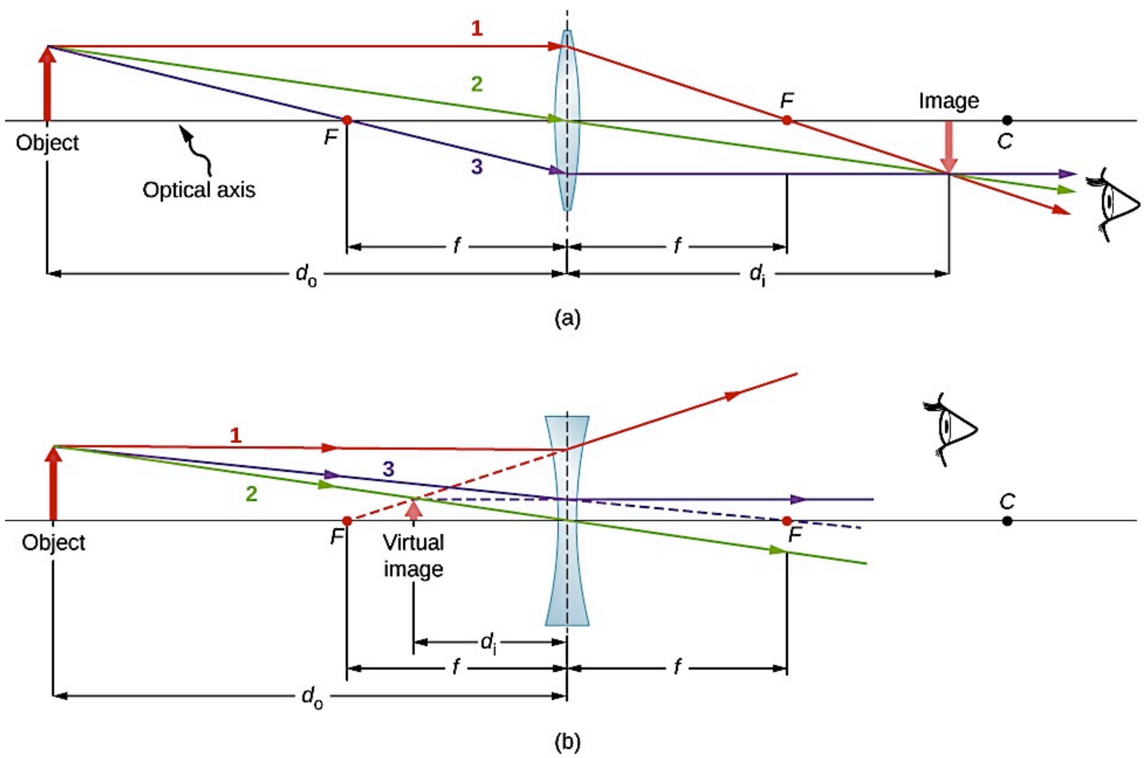

Figure 9 Convex Lens (a) and Concaved Lens (b)

The relation between $f,\ d_o,\ and\ d_i$ is

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

The magnification m of the lens is given by the equation

$$m = -\frac{d_i}{d_o}$$

The minus sign is required so that m will be negative for an inverted image, as in Figure-9a.

The position of the Image relative to the Object is determined by ray tracing according to the following rules:

1. A ray parallel to the axis (Ray-1 in the figures) passes through the lens and then directly [or when extended (dashed lines)] through the focal point F_2. Focal point F_2 is the focal point closest to the image.

2. A ray passing through the center of the lens continues on undeflected (Ray-2).

3. A ray passing through the lens after traveling directly [or when extended (dashed lines)] through the focal point F_1 will emerge from the lens parallel to the axis (Ray-3).

1.4.3 Ray Tracing for Convex and Concave Mirrors

Similar parameters apply to mirrors.

A concave mirror is shown in Figure-10a and a convex mirror in Figure-10b . The image of a convex mirror (Figure-10b) is always virtual. For a concave mirror, the image is virtual if the Object is located inside the focal point F (between the focal point and the mirror) and real if it is located beyond the focal point. In Figure-10a the Object is located beyond the focal point so the image is real.

The relation between $f,\ d_o,\ and\ d_i$ for mirrors is the same as for lenses, specifically

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

The magnification m of a mirror is also given by the same equation

$$m = -\frac{d_i}{d_o}$$

The concave and convex mirror ray tracing rules for determining the position of the Image are:

1. A ray that strikes the mirror parallel to its axis (Ray-1 in the figures) passes directly [or when extended (dashed lines)] through the focal point F. Note with mirrors there is only one focal point.

2. A ray that strikes the mirror after passing directly [or when extended] through the focal point F will emerge parallel to the axis (Ray-2).

3. A ray that strikes the mirror after passing directly [or when extended] through the center of curvature C returns along itself (Ray-3)

4. A ray that strikes the mirror at its center will be reflected such that the angle of reflection equals the angle of incidence (Ray-4).

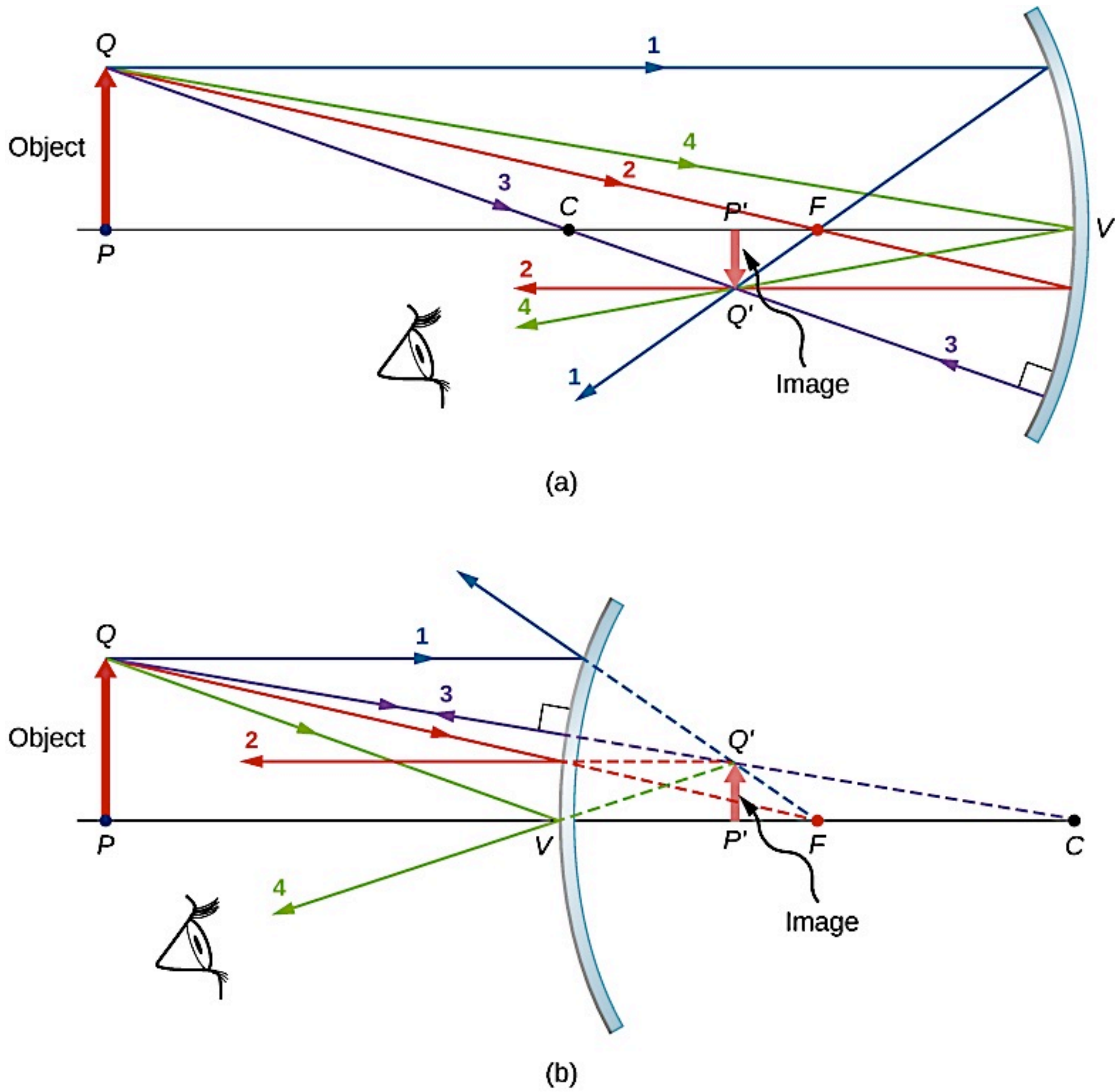

Figure 10 Concave (a) and Convex (b) Mirrors

1.4.4 Ray Tracing for Flat Mirrors

A flat mirror is shown in Figure 11. For a flat mirror the image is always virtual. In addition, $d_o = d_i$ and the magnification equals 1. However, the image in a flat mirror is reversed, that is, the right side of the Object (P) appears as the left side of the Image (Q).

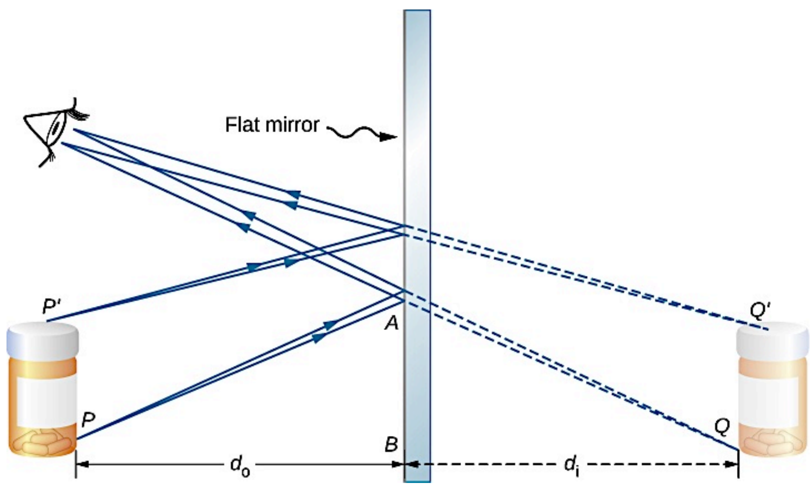

Figure 11 A Flat Mirror (source: Physics LibreTexts)

1.5 Telescopes, and Microscopes

The development of convex lenses for eye glasses lead to the invention of the telescope and microscope.

1.5.1 Telescopes

Hans Lippershey invented the refracting telescope in 1608. The following year Galileo improved on Lippershey's design. Galileo's telescope utilized a relatively large convex object lens at the front of the telescope (Figure 12) to focus parallel light coming from distance objects into an image within the telescope. A 3 inch object lens captures about 100 times more light than the human eye, permitting the telescope to view dim objects (the moon, planets, stars, etc.). The eye piece, another convex lens, magnifies the image. Galileo's initial telescope achieved a magnification of about 4X using lenses available to him. He built a telescope with a magnification of 8X after learning how to grind and polish his own lenses. One of the problems with refracting telescopes is chromatic aberration. Chromatic aberration causes colored fringes to appear around the edges of objects being viewed. It is caused by the failure of a lens to focus all the colors in white light at the same point.

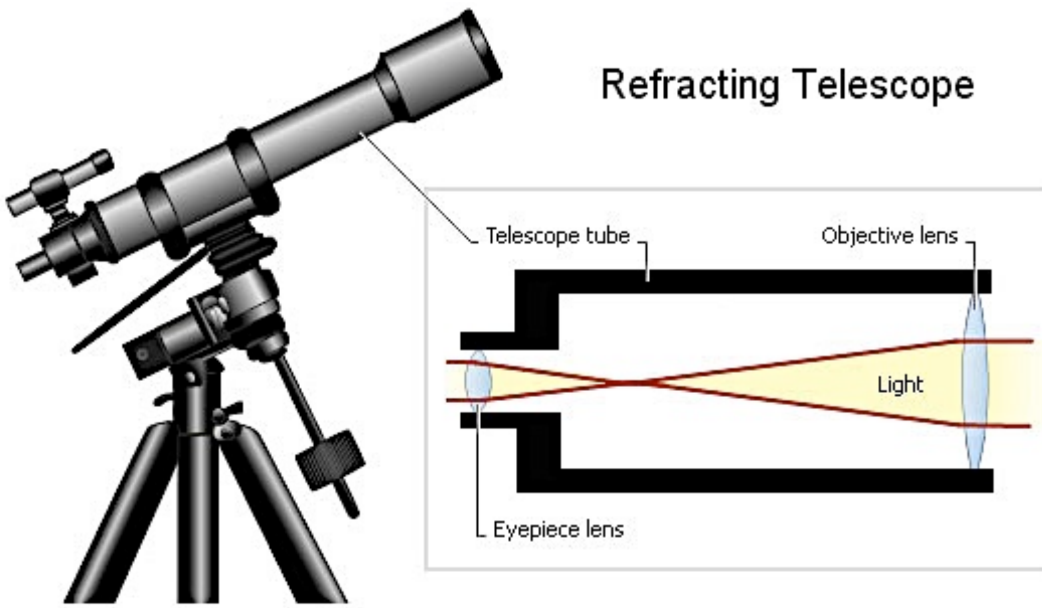

Figure 12 Refracting Telescope (source: Encarta Encyclopedia 2004)

1.5.2 Early Microscopes

The earliest microscopes were single lens magnifying glasses developed in the 13th century as the use of eyeglasses became widespread. These early magnifying glasses had a magnifying power of about 6X – 10X. Figure 13 illustrates the use of a magnifying glass.

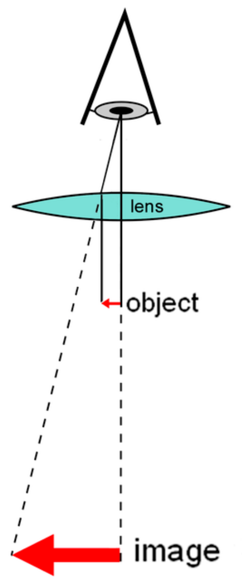

Figure 13 A Simple Microscope or Magnifying Glass (source: Wikipedia)

The Dutch Janssen brothers are credited with developing the first compound microscope around 1600. A simple compound microscope consisted of two convex lenses aligned in series inside a tube similar to that illustrated in Figure 14. One convex lens served as the object lens while the other was the eyepiece.

Figure 14 Simple Compound Microscope (source: Olympusamerica.com)

The object lens was placed closest to the item or specimen being observed. The eyepiece was, of course, placed next to the observer's eye. The compound microscope achieved two stages of magnification. The object lens projected a magnified image of the specimen in the body of the microscope tube. The eyepiece further magnified the image, as shown in Figure 15.

The first microscopes had a magnification of about 9X and the images were somewhat blurry. Consequently, these microscopes were more of a novelty than a scientific tool.

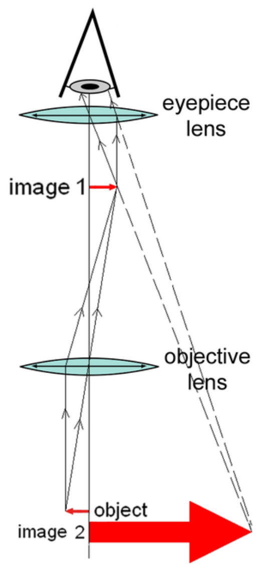

Figure 15 Compound Microscope Diagram (source: Wikipedia)

Dutch scientist Antony Van Leeuwenhoek (1632 – 1723) developed the first scientifically useful microscope in the late 17th century. His hand held microscope consisted of a single convex glass lens attached to a metal holder (Figure 16). Utilizing his own lenses, which were superior to others at the time, he was able to achieve magnification of 270 X. Other microscope of that era were lucky to achieve a magnification of 50 X. Leeuwenhoek's microscope was focused using screws.

Figure 16 Leeuwenhoek's Microscope (source: Olympusamerica.com)

1.6 References

J. J. O'Connor and E. F. Robertson; *Light through the ages: Ancient Greece to Maxwell*; MacTutor History of Mathematics, (University of St. Andrews, Scotland) 2002, http://www-history.mcs.st-andrews.ac.uk/HistTopics/Light_1.html

Abramowitz, Mortimer; Spring, Kenneth R.; Parry-Hill,Matthew; Flynn, Brian O.; Tchourioukanov, Kirill I. Fellers, Thomas J.; Davidson, Michael W.; *The Physics of Light and Color*; Olympus-Life Science, Olympus America Inc. https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/

Setterfield, Barry; *A Brief History of c*; 1987

Halliday, David; Resnick, Robert; *Physics For Students of Science and Engineering Part I*; 1962 John Wiley & Sons, Inc.

Halliday, David; Resnick, Robert; *Physics For Students of Science and Engineering Part II*; 1962 John Wiley & Sons, Inc.

Spring, Kenneth R.; Fellers, Thomas J.; Zuckerman, Lawrence D.; Davidson, Michael; *Speed of Light*; Olympus-Life Science, Olympus America Inc.

Fowler, Michael; UVA Physics Department, *The Speed of Light,* University of Virginia, http://galileoandeinstein.physics.virginia.edu/lectures/spedlite.html

Urone, Paul Perter; *Image Formation by Mirrors*; LibreTexts

Kovacs, Peter; *History of the reading stones*; Light Microscopes

UVA Physics Department; *Newton's Particles Theory of Light-Galileo;* University of Virginia; http://galileo.phys.virginia.edu/classes/609.ral5q.fall04/Lecture:PDF/L20LIGHTII.pdf

Ling, Samuel J.; Sanny, Jeff; Moefs, William; *University Physics Volume 3*; 2018 Openstax Rice University

Plonsey, Robert; Collin, Robert E.; Principles and Applications of Electromagnetic Fields; McGraw-Hill Book Company, Inc., 1961

Davies, Kenneth; Ionospheric Radio; Peter Peregrinus Ltd.,1990

McNamara, Leo F.; The Ionosphere: Communications, Surveillance, and Direction Finding; Krieger Publishing Companay,1991

Hunsucker, R. D. and Hargreaves, J. K.; The High-Latitude Ionosphere and its Effects on Radio Progration; Cambridge University Press, 2003

Levis, Curt A.; Johnson, Joel T.; Teixeira, Fernando L.; Radiowave Propagation Physics and Applications; John Wiley & Sons Inc., 2010

Yeang, Chen-Pang; Probing the Sky with Radio Waves; The University of Chicago Press, 2013

Goodman, John M.; Space Weather & Telecommunications; Springer, 2005

Zavrel, Robert J. Jr.; Antenna Physics: An Introduction; The American Radio Relay League, Inc. 2016

Nichols, Eric P.; Propagation and Radio Science; The American Radio Relay League, Inc., 2015

White, Ian; The VHF/UHF DX Book; DIG Publishing LTD, 1995

Dampier, W. C.; *A History of Science*; 1961 Cambridge University Press

Cajori, Florian; *A History of Physics in its Elementary Branches*; 1917, The Macmillan Company

Williams, Henry Smith; *A History of Science Part 1*; 1904 Kessinger Publishing

Williams, Henry Smith; *A History of Science Part 2*; 1904 Kessinger Publishing

Wikipedia; *History of optics*

Wikipedia: *History of glass*

Wikipedia; *Glasses*

Wikipedia; *Mirror*

Wikipedia; *al Haytham's Book of Optics*

Carroll, Bradley W.; Ostlie, Dale A.; *An Introduction to Modern Astrophysics*; 1996, Addison-Wesley Publishing Company Inc.

Foukal, Peter; *Solar Astrophysics*; 2013 Wiley-VCH Verlag GmbH & Co.

Tyson, Neil Degrasse; Strauss, Michael A.; Gott, J. Richard; Welcome to the Universe an Astrophysical Tour; Princeton University Press; 2016

Palen, Stacy; Kay Laura; Blumenthal; Understanding Our Universe; W. W. Norton & Company, Inc., 2018

Golub, Leon; Pasachoff, Jay M.; *The Nearest Star The Surprising Science of Our Sun*; 2014 Cambridge University Press

Khazanov, George V.; Space Weather Fundamentals; CRC Press, 2016

Cander, Ljiljana R.; Ionospheric Space Weather; Springer Geophysics, 2019

Moldwin, Mark; An Introduction to Space Weather; Cambridge University Press, 2008

Zettili, Nouredine; *Quantum Mechanics Concepts and Applications*; 2009 John Wiley & Sons, Ltd.

Masi, Marco; *Quantum Physics: an overview of a weird world*; 2018 Marco Masi

Klus, Dr. Helen; *How We Came to Know the Cosmos: Light & Matter*; 2017, The Star Garden, UK.

Friedman, Herbert; *The Astronomer's Universe Stars, Galaxies, and Cosmos*; 1990, The Commonwealth Fund Book Program

Hogan, Craig J.; *The Little Book of the Big Bang A Cosmic Primer*; 1998 Springer-Verlag New York Inc.

Sagan, Carl; *Cosmos*; 1980 Carl Sagan Productions

Piccioni, Robert L.; *Everyone's guide to Atoms Einstein and the Universe*; 2010 Robert L. Piccioni; Real Science Publishing

Starr, Chester G.; *A History of the Ancient World*; 1991, Oxford University Press

Davies, Norman; *Europe a History*; 1998, Harper Perennial

Pannekoek, A.; *A History of Astronomy*; 1961, George Allen and Unwin Ltd.

Merzbech, Uta C.; Boyer, Carl B.; *A History of Mathematics*: 2011, John Wiley & Sons, Inc.

El-Abbadi, Mostafa; *Library of Alexandria*; Encyclopedia Britannica

Williams, L. Pearce; *History of Science*; Encyclopedia Britannica

Rodrigue, Christine M; *The Geography of Mars: Lab Cassini, Richer, and Picard Experiment, 1672*; Department of Geography California State University, Long Beach, CA.; http://www.csulb.edu/~rodrigue/

Herivel, John; *Christiaan Huygens Dutch Scientist And Mathematician*; Feb 14, 2019; Encyclopedia Britannica

Rodriguez, Emily; *Robert Hooke British Scientist*; Feb 27, 2019; Encyclopedia Britannica

Westfall, Richard S; *Sir Isaac Newton English Physicist and Mathematician*; Feb 1, 2019; Encyclopedia Britannica

Crowley, Theodore; *Roger Bacon*; Encyclopedia Britannica

Jones, Alexander Raymond; *Ptolemy*; Encyclopedia Britannica

Meinwald, Constance C.; *Plato*; Encyclopedia Britannica

Amadio, Anselm H.; Kenny Anthony J. P.; *Aristotle*; Encyclopedia Britannica

Lorch, Richard;Ibn; *al-Haytham*; Encyclopedia Britannica

Van der Waerden, Bartel Leendert; Taisbak, Christian Marinus; *Euclid*; Encyclopedia Britannica

Editors of Encyclopedia Britannica; *Heron of Alexandria*; Encyclopedia Britannica

Westman, Robert S.; *Johannes Kepler*; Encyclopedia Britannica

Van Helden, Albert; *Galileo*; Encyclopedia Britannica