Lecture 27

Fundamentals of Physics

Phys 120, Fall 2015

Optics

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Overview

- Vision
- Light
- Lenses
- Optical theory

Vision

We perceive the world through our 5 senses: vison, hearing, smell, taste and touch. But for humans the most important sense arguably is vision. It allows us to detect objects in our sourrounding from a distance, we can detect shapes and colors.

But how does this work?

A key element in vision is light. Without light, we cannot see.

Genesis 1 – Light

written in the 5th century BC, likely at the court of Solomon:

In the beginning God created the heavens and the earth.

Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters.

And God said, "Let there be light," and there was light.

God saw that the light was good, and he separated the light from the darkness.

God called the light "day," and the darkness he called "night." And there was evening, and there was morning–the first day.

Lenses

The earliest known lenses were made from polished crystal, often quartz, and have been dated as early as 750 BCE for Assyrian lenses such as the Nimrud / Layard lens. There are many similar lenses from ancient Egypt, Greece and Babylon. The ancient Romans and Greeks filled glass spheres with water to make lenses. However, glass lenses were not thought of until the Middle Ages.

Some lenses fixed in ancient Egyptian statues are much older than those mentioned above. There is some doubt as to whether or not they qualify as lenses, but they are undoubtedly glass and served at least ornamental purposes. The statues appear to be anatomically correct schematic eyes.

Euclid

In his Optics Greek mathematician Euclid observed that "things seen under a greater angle appear greater, and those under a lesser angle less, while those under equal angles appear equal". In the 36 propositions that follow, Euclid relates the apparent size of an object to its distance from the eye and investigates the apparent shapes of cylinders and cones when viewed from different angles. Pappus believed these results to be important in astronomy and included Euclid's Optics, along with his Phaenomena, in the Little Astronomy, a compendium of smaller works to be studied before the Syntaxis (Almagest) of Ptolemy.

Euclid: introduction of Geometrical Optics

The early writers discussed here treated vision more as a geometrical than as a physical, physiological, or psychological problem. The first known author of a treatise on geometrical optics was the geometer Euclid (c. 325 BC265 BC). Euclid began his study of optics as he began his study of geometry, with a set of self-evident axioms.

1. Lines (or visual rays) can be drawn in a straight line to the object.
2. Those lines falling upon an object form a cone.
3. Those things upon which the lines fall are seen.
4. Those things seen under a larger angle appear larger.
5. Those things seen by a higher ray, appear higher.
6. Right and left rays appear right and left.
7. Things seen within several angles appear clearer.

Euclid did not define the physical nature of these visual rays but, using the principles of geometry, he discussed the effects of perspective and the rounding of things seen at a distance.

Democritus

Democritus (460 - 370 BCE) is known only by the surviving fragments of his works; he is said to have been a wealthy citizen of Thrace (modern Bulgaria, for the most part). His place in the history of Physics rests upon his conceptions of the Void and of eternal, indivisible, infinitesimal atoms. He made the first attempt to explain perception and color; his theory was that sensation was caused by the size and shape of atoms, and that color was due to such properties as the roughness of the constituent atoms.

Aristotle

Aristotle (384 -322 BCE) was a son of the Macedonian court physician. He was sent to Athens to study, later founded a school of philosophy there, and for a while was tutor to Alexander the Great. When his works were translated into Latin during the 12th and 13th centuries, they exerted a profound influence on European thought. Aristotle was concerned by questions of perception, and rejected the Euclidian theory that vision was solely due to rays emanating from the eyes and "touching" the object.

Aristotle on perception

He begins his discussion of perception in II.5 by saying that perception:

1. occurs in being moved and affected.
2. seems to be a type of alteration.
3. is a process in which like is affected by like.

Much of his subsequent discussion is on the physics and physiology of perception:

1. Each sense has a sense-organ.
2. Each sense has a medium (e.g., air, water).
3. Each sense has its own proper objects (of sight, color; of hearing, sound).
4. The proper object of a sense is a qualification of an external object. E.g., the color (red) we perceive is a quality of some individual body (a tomato).
5. Perception is (or involves) a causal process leading from the external object through the medium to the sense-organ, and ultimately to the primary sense-organ in the heart.
6. This process is one in which the sensible quality of the external object (e.g., its color) is transferred to the sense-organ of the perceiver. (For details on this process, see the II.7 discussion of sight as the transmission of color from the object of perception through the intervening mediumwater or airto the eye.)

Archimedes

Archimedes (290? - 212? BC), the outstanding mathematician and inventor of the ancient world, was born and spent most of his life in Syracuse, the great city/state of Sicily. He was on close terms with the king, and participated actively in the defense of the city against the Romans, inventing and building war machines. He was killed when the city was finally taken and sacked. Archimedes was very much involved in catoptrics (reflections from surfaces) and in refraction, but his writings in this field are lost, and his mathematics papers were not translated into Latin until the 16th and 17th centuries when their appearance had a significant effect upon the development of mathematics.

Mirrors

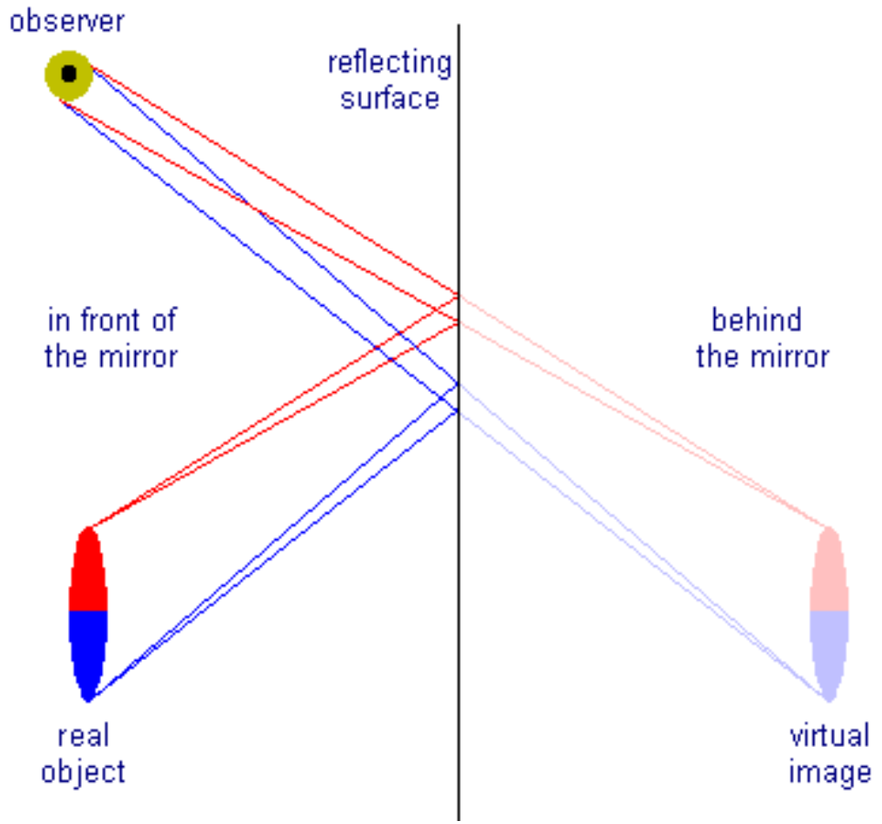
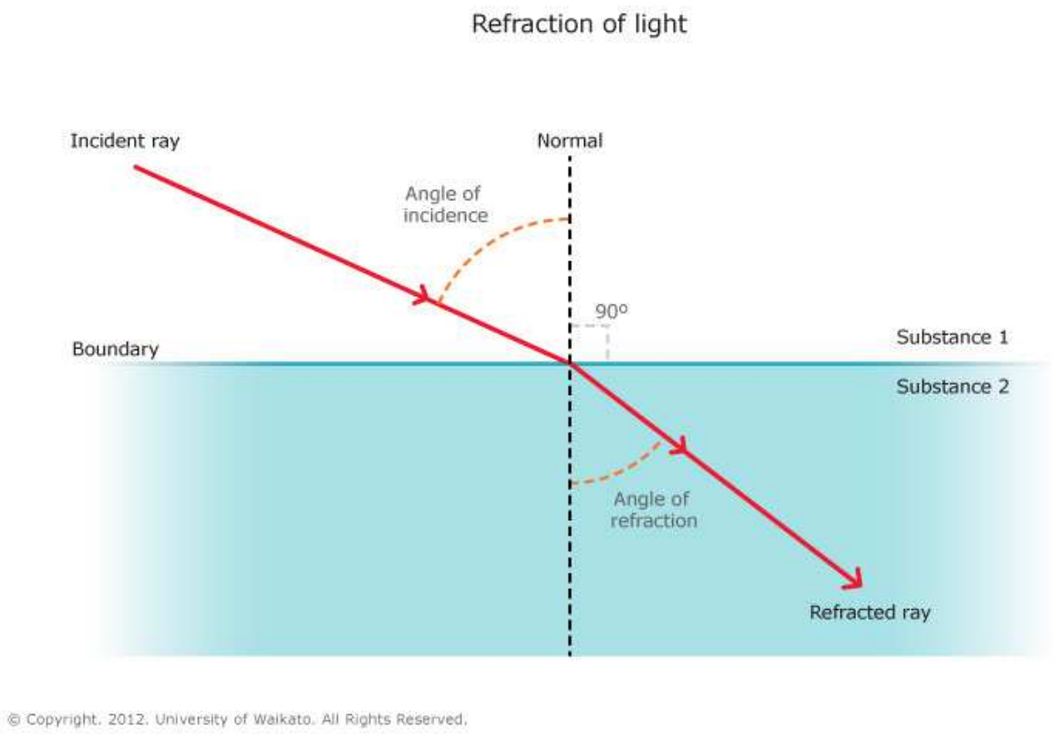


Figure 4

Refraction



Seneca

Lucius Annaeus Seneca (4 BCE - 65 CE) managed to survive 69 years in the midst of the intrigue and murder at the center of Roman imperial power. Nearly killed by Caligula, exiled for adultery by Claudius, tutor and favorite of Nero, he was finally ordered to commit suicide after being implicated in a plot against his former student. His writings include a number of philosophical works (he was a Stoic) and a series of revenge tragedies. His place here is due to the fact that he noted and wrote about the magnifying effects of liquids in transparent vessels.

Hero of Alexandria

In his Catoptrica, Hero of Alexandria (ca 10-70 CE) showed by a geometrical method that the actual path taken by a ray of light reflected from a plane mirror is shorter than any other reflected path that might be drawn between the source and point of observation.

Much of Hero's original writings and designs have been lost, but some of his works were preserved in Arabic manuscripts.

Nero

Nero (Nero Claudius Caesar Augustus Germanicus) (37 - 68 CE) became Emporer of Rome at the age of 17 as the result of successful series of poisonings by his mother, Agrippina. His subsequent megalomaniac artistic pretensions, extravagances and misrule led to his eventual overthrow, death, and traditional infamous reputation. His place in a history of optics is due to the circumstance that he used an emerald (the first monocle) while watching combats in the arena.

Ptolomy

Ptolemy (Claudius Ptolemaeus) (85 - 165 CE) propounded the geocentric system which prevailed for the next 1400 years. Nothing is known about his life and he has no biography. Only one of the five volumes he wrote on optics has survived. He dealt with refraction and obtained the small angle approximation to Snells law, concluding that the ratio of the angles of incident and refracted light were constant.. He also discussed the refraction of starlight by the atmosphere but held to the theory that vision is due to rays emitted from the eye touching the object .

Al-Kindi

Al-Kindi (c. 801–873 CE) was one of the earliest important optical writers in the Islamic world. In a work known in the west as De radiis stellarum, al-Kindi developed a theory "that everything in the world ... emits rays in every direction, which fill the whole world." This theory of the active power of rays had an influence on later scholars such as Ibn al-Haytham, Robert Grosseteste and Roger Bacon.

Ibn Sahl

Ibn Sahl (c. 940–1000 CE) was a Persian mathematician associated with the court of Baghdad. About 984 he wrote a treatise On Burning Mirrors and Lenses in which he set out his understanding of how curved mirrors and lenses bend and focus light. In his work he discovered a law of refraction mathematically equivalent to Snell's law.[9] He used his law of refraction to compute the shapes of lenses and mirrors that focus light at a single point on the axis.

Alhazan

Ibn al-Haytham (known in as Alhacen or Alhazen in Western Europe) (965–1040 CE) produced a comprehensive and systematic analysis of Greek optical theories. Ibn al-Haytham's key achievement was twofold: first, to insist that vision occurred because of rays entering the eye; the second was to define the physical nature of the rays discussed by earlier geometrical optical writers, considering them as the forms of light and color. He then analyzed these physical rays according to the principles of geometrical optics. He wrote many books on optics, most significantly the Book of Optics (Kitab al Manazir in Arabic), translated into Latin as the De aspectibus or Perspectiva, which disseminated his ideas to Western Europe and had great influence on the later developments of optics.

Grosseteste

The English bishop, Robert Grosseteste (c. 1175–1253), wrote on a wide range of scientific topics at the time of the origin of the medieval university and the recovery of the works of Aristotle. Grosseteste reflected a period of transition between the Platonism of early medieval learning and the new Aristotelianism, hence he tended to apply mathematics and the Platonic metaphor of light in many of his writings. He has been credited with discussing light from four different perspectives: an epistemology of light, a metaphysics or cosmogony of light, an etiology or physics of light, and a theology of light.

Setting aside the issues of epistemology and theology, Grosseteste's cosmogony of light describes the origin of the universe in what may loosely be described as a medieval "big bang" theory. Both his biblical commentary, the Hexaemeron (1230 x 35), and his scientific On Light (1235 x 40), took their inspiration from Genesis 1:3, "God said, let there be light", and described the subsequent process of creation as a natural physical process arising from the generative power of an expanding (and contracting) sphere of light.

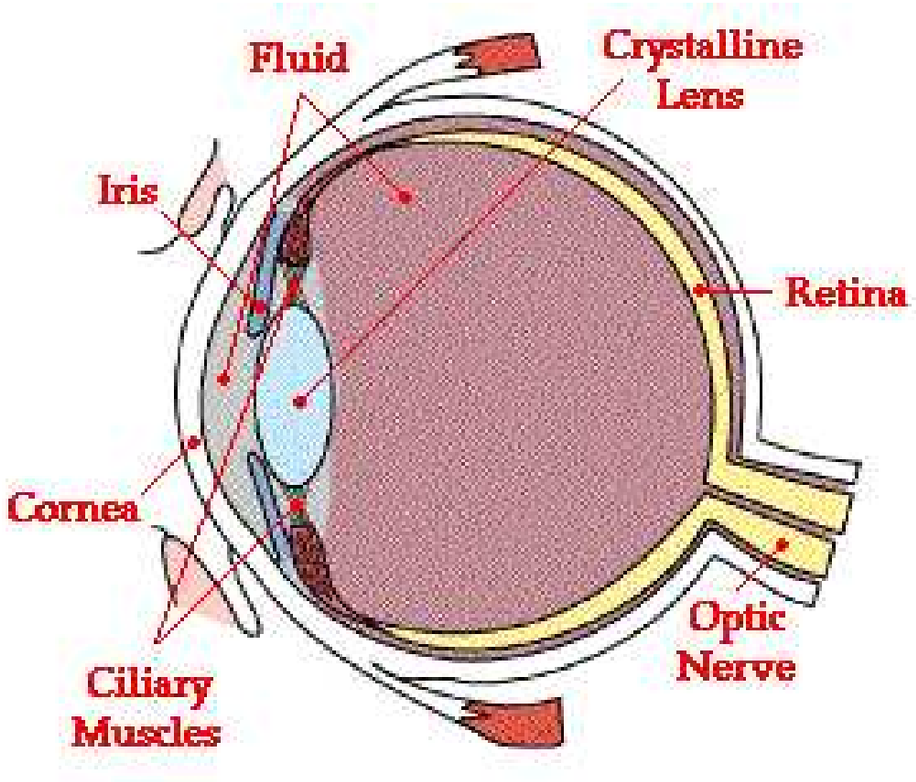
Bacon

Roger Bacon (1220 - 1292) was a young lecturer at Oxford who became preoccupied with the idea of experimental studies. He carried out some experiments with lenses and mirrors and described the principles of reflection and refraction, but his great contribution was his insistence on systematic observation and experiments and he is regarded as a forerunner of modern science. He joined the Franciscan order at age 33. About 1266 he applied for papal permission to write a book about the positive effects of experimental methods; he was enjoined to send the book secretly. Without the knowledge of his superiors he completed the work, but the popes death in 1268 ended his hope of putting experimental science into the curricula of the universities. Bacon was imprisoned for two years (1277 - 1279), it is believed, by the Franciscan order for "novelties" in his teaching but continued to write aggressively until his death

Kepler

Johannes Kepler (1571 - 1630) born in a small German town, was the son of a mercenary soldier. His mother was the daughter of an innkeeper. He received a university scholarship, became an astronomer and rose to the position of imperial mathematician in the court of the Holy Roman emperor. Kepler was among the few to accept the Copernican heliocentric astronomy and he discovered the laws of planetary motion which set the path for Newtons theory of gravitation. In the course of his astronomical investigations he provided a correct explanation of vision and the functions of the pupil, cornea and retina and after more than three centuries gave the first correct explanation of how eyeglasses work. Kepler lived during the ravages and horrors of the Thirty Years War (1618-1648). At one point he had to rush home to save his mother from death at the stake after she had been accused of witchcraft; his gravesight was lost in the turmoil of the war.

The eye



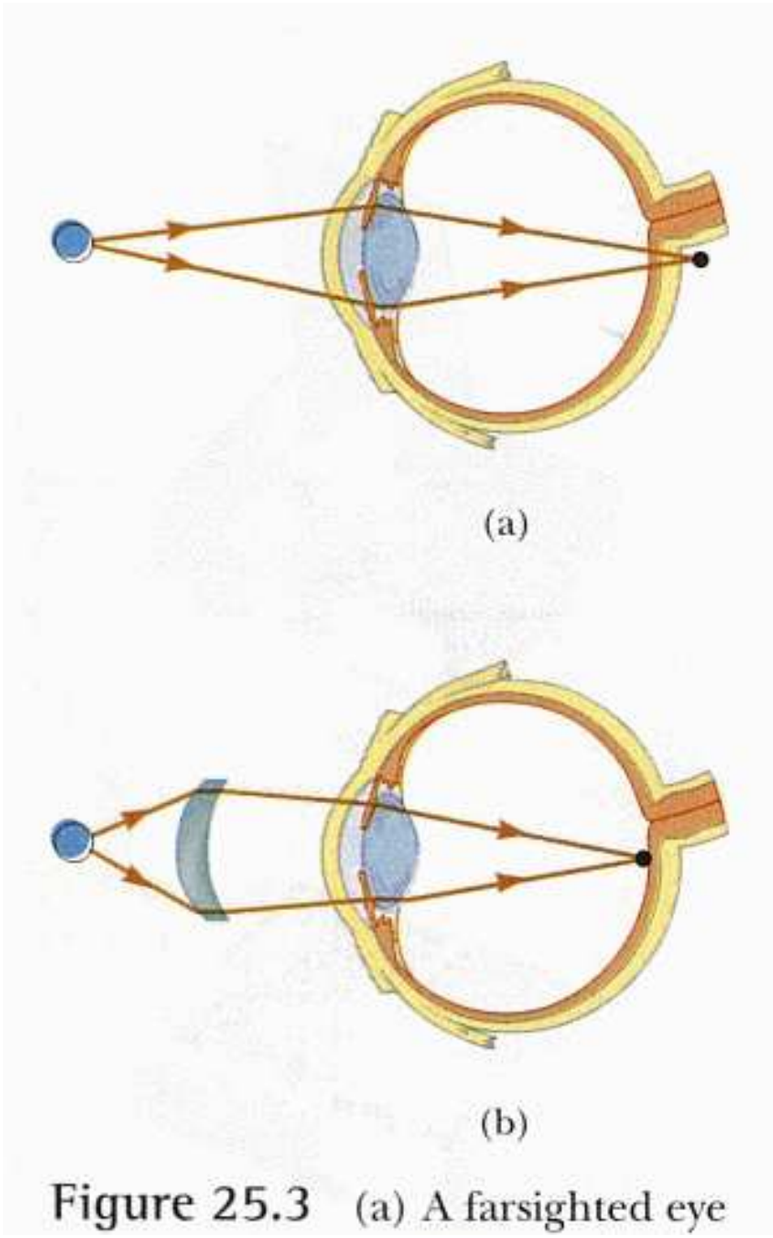
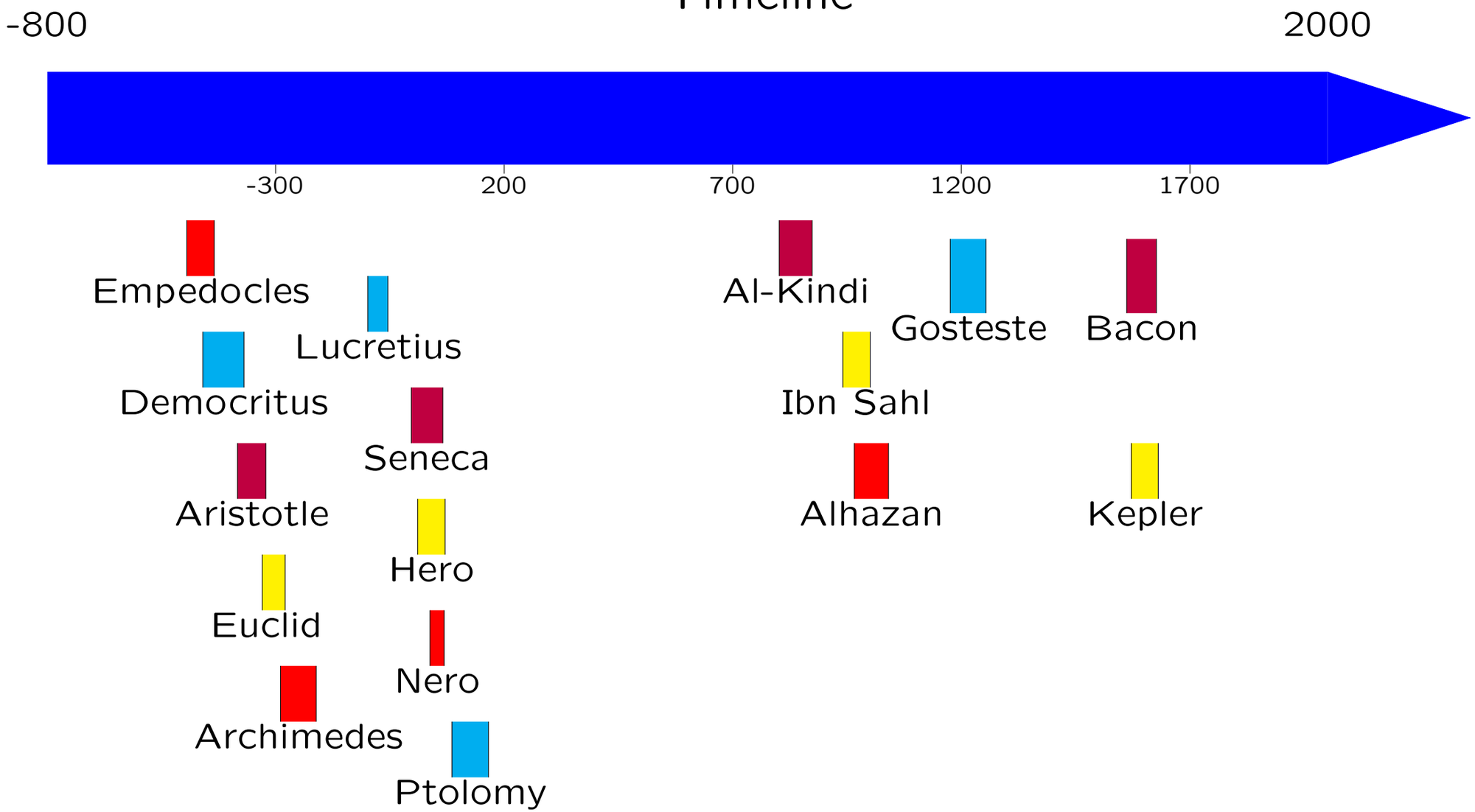


Figure 25.3 (a) A farsighted eye

Timeline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2000
-300
200
700
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Empedocles
Lucretius
Democritus
Seneca
Aristotle
Hero
Euclid
Nero
Archimedes
Ptolomy
Al-Kindi
Gosteste
Bacon
Ibn Sahl
Alhazan
Kepler

Summary

- History of Optics
- Geometrical Optics
- Reflection
- Refraction and lenses
- The Eye