History of Optics

Based on:
"*A short history of Optics*" by B. Vihnsen,
Physica Sciptra, vol. T109, pp. 75-79 (2004) &
Various articles available from the ***Internet***

Optical Engineering

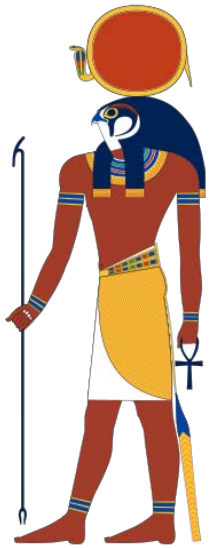
Prof. Elias N. Glytsis

School of Electrical & Computer Engineering
National Technical University of Athens

Chronological Periods

- Ancient Optics
- Geometric Optics, Euclid and Ptolemy
- Islamic Era
- The Middle Ages and Early Renaissance
- Early Modern Period: Kepler's Optics
- Newton's Ray Optics and Corpuscular Hypothesis
- 19th Century Optics: Wave Theory of Optics
- Modern Developments and Quantum Optics

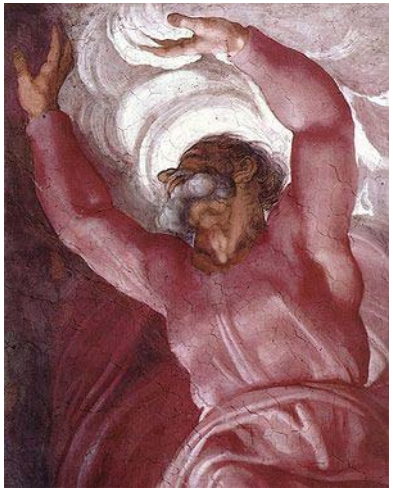
Light in Ancient Years



---------- **Ancient Optics** ----------

Ra: Egyptian God of the Sun (~5000BC)

Bible:
"**Let there be Light**" (day) (~1500-1060BC)

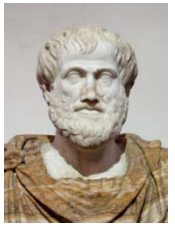


Ancient Greeks: **Pythagoras**' (569-475BC) Followers,
Democritus' (460-370BC) Followers,
Empedocles' (494-434BC) Followers

~ **400 B.C.** *Democritus:* developed the concept of atoms; attempted to explain perception and color.

Democritus (460BC-370BC)

~ **350 B.C.** *Aristotle:* questions of perception; rejected the Euclidian theory that vision was solely due to rays emanating from the eyes and "touching" the object.



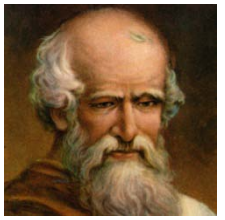
Aristotle (384BC-322BC)

---------- Geometric Optics, Euclid and Ptolemy ----------

~ **300 B.C.** *Euclid:* In his ***Optica*** he noted that light travels in straight lines and described law of reflection. He believed that vision involves rays going from the eyes to the object seen.

Euclid (325BC-265BC)

~ **250 B.C.** *Archimedes:* setup of optical weapons/defense machines for the king of Syracuse (Sicily) to defend the city against the Romans; very much involved in *Catoptrics* (reflection on surfaces).



Archimedes (287BC-212BC)

~ **30 A.D.** *Seneca:* wrote about magnifying effect of liquids in transparent vessels.

Seneca (4BC-65AD)

~ **60** *Hero of Alexandria:* Light follows the shortest path, law of reflection.

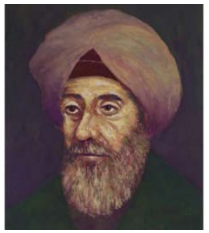
Hero (10-70)

~**120** *Ptolemy:* wrote a five volume textbook on optics; observed the small angle approximation of Snell's law (i.e. the ratio of the angle of incidence vs. angle of refracted light is constant).

Ptolemy (90-168)

---------- Islamic Era ----------

~**1000** *Alhazan (Abu Ali Hasan Ibn al-Haitham):*
investigated reflections from spherical & parabolic mirrors, disproved Ptolemy's refraction law; disagreed with Euclidian theory of vision; discussed atmospheric refraction; explained the increase in apparent size of the sun and moon near the horizon; attempted to measure the height of the atmosphere.



Alhazan (965-1040)

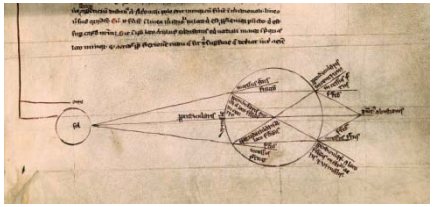
---------- Middle Ages and Early Renaissance----------

R. Grosseteste (1175 -1253)

~ **1220** *Robert Grosseteste:* University of Oxford: Theory should be combined with experimental observations as basic scientific method; He believed colors are related to light intensity. Share view with earlier Greeks that vision involves emanations from the eye.

R. Bacon (1214-1294)

~ **1250** *Roger Bacon:* insisted on experimental observations as basic scientific method; carried out experiments with lenses and mirrors; described principles of reflection and refraction. Finite speed of light. He attributed rainbow to sunlight reflection by raindrops.



Optical diagram showing light being refracted by a spherical glass container full of water (from Roger Bacon, *De multiplicatione specierum*). https://en.wikipedia.org/wiki/History_of_optics

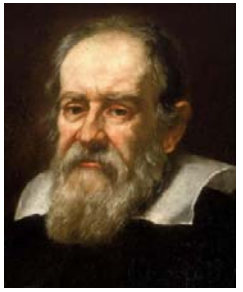
Witelo of Silesia (1230 -1275)

~ **1270** *Witelo (or Vitelo) of Silesia:*
completed ***Perspectiva*** which was a standard text on optics for several centuries. Parabolic mirrors construction, refraction (angle of refraction non proportional to angle of incidence).

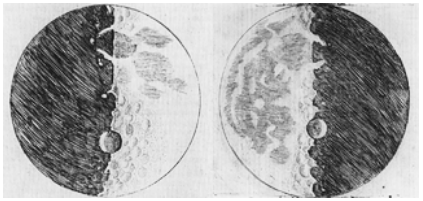
Page from a manuscript of *De Perspectiva*, with miniature of its author Witelo

https://en.wikipedia.org/wiki/Vitello

~ **1600** *Galileo Galilei:* learned in 1609 of the invention of the telescope (by a Dutch eye glass manufacturer - Hans Lippershey); build his own devices with magnification up to 30 times, i.e. the most powerful instruments of his time; thus enabled the discoveries that established the Copernican system.



G. Galilei (1564-1642)



https://www.atnf.csiro.au/outreach/education/senior/astrophysics/galileo.html

---------- Early Modern Period: Kepler's Optics ----------

~ **1600** *Johannes Kepler:* was among the few to accept the Copernican heliocentric astronomy; discovered the laws of planetary motion; provided correct explanation of vision and functions of the pupil, cornea and retina; gave first correct explanation of how eyeglasses work; changed the setup of Galileo's telescope by concave lenses (telephoto lens).

J. Kepler(1571-1630)

~ **1621** *Willebrord van Royen Snell:* found experimentally the law of refraction; *Rene Descartes:* described Snell's law for the first time involving sinus terms (i.e. the form we are used to).

W. van R. Snell (1580-1626)

R. Descartes (1596-1650)

~ **1657** *Pierre de Fermat:* postulated the principle of shortest propagation times; deduction of the refraction law from *Fermat's principle.*

~ **1665** *Francesco Maria Grimaldi:* described diffraction of light.

~ **1665** *Robert Hooke:* investigated interference effects at thin films; his ideas triggered the wave theory of light. Wrote *Micrographia* (used microscopes) – Contributions to Astronomy

P. Fermat (1601-1665)

F. M. Grimaldi (1618-1663)

R. Hooke (1635-1703)

---------- Newton's Ray Optics and Corpuscular Hypothesis ----------

~ **1666** *Isaac Newton:* (*among many other achievements)* investigated dispersion (e.g. at prisms) and the spectrum of white light; developed the particle theory of light; worked on the correction of lens errors (but did not believe in the possibility of achromats); developed mirror telescopes.

I. Newton (1642-1727)

Newton's own copy of his *Principia*, with hand-written corrections for the second edition, in the Wren Library at Trinity College, Cambridge.

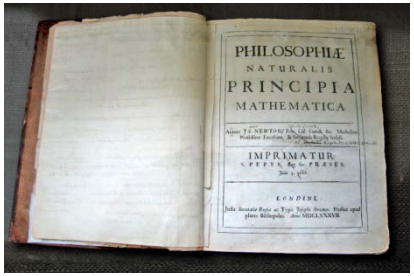
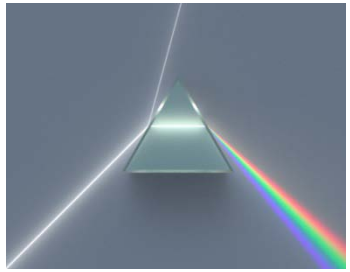


Illustration of a dispersive prism separating white light into the colours of the spectrum, as discovered by Newton



https://en.wikipedia.org/wiki/Isaac_Newton

~ **1676** *Ole Christensen Römer*, proposed an experiment (by astronomic observation of a total eclipse of the sun, and of Jupiter satellite Io eclipses) to prove and determine the finite speed of light

O. C. Romer(1644-1710)

A redrawn version of the illustration from the 1676 news report. Rømer compared the apparent duration of Io's orbits as Earth moved towards Jupiter (F to G) and as Earth moved away from Jupiter (L to K).

https://en.wikipedia.org/wiki/R%C3%B8mer%27s_determination_of_the_speed_of_light

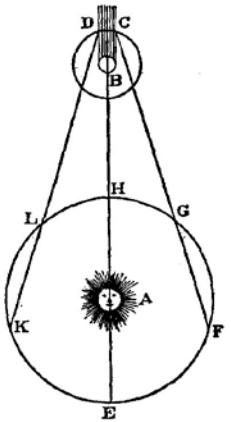
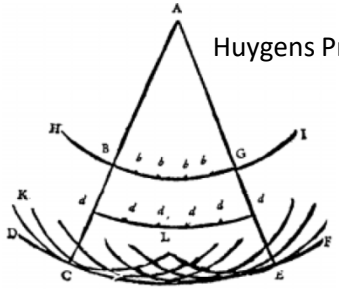


Fig. 70.

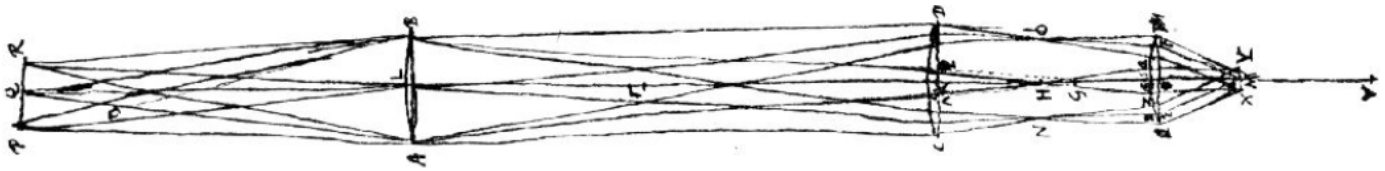
~ **1678** *Christiaan Huygens:* developed the wave theory of light; introduced the concept of elementary waves; applied the theory to explain the lower speed of light in a dense medium, refraction and birefringence; he also observed polarization in birefringent crystals.

C. Huygens (1629-1695)

Huygens Principle.



Huygens Eyepiece

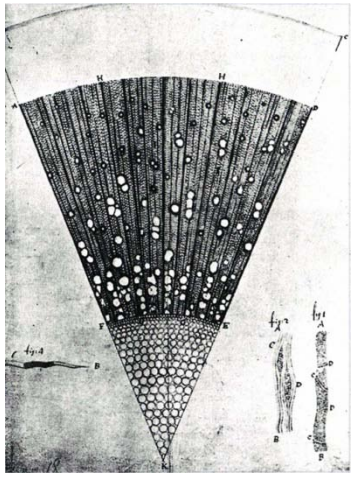


F. J. Dijksterhuis, "Lenses and Waves: C. Huygens and the Mathematical Science of 17th century," Kluwer Academics, 2004.

~ **1670** after the invention of the microscope in 1595 (by *Zacharias Janssen*), *Antonie van Leeuwenhoek* improved the concepts and developed powerful devices (magnification up to 300 times)

A. Val Leeuwenhoek (1632-1723)

Z. Janssen (1580-1638)



A microscopic section of a one-year-old ash tree (*Fraxinus*) wood, drawing made by van Leeuwenhoek

https://en.wikipedia.org/wiki/Antonie_van_Leeuwenhoek

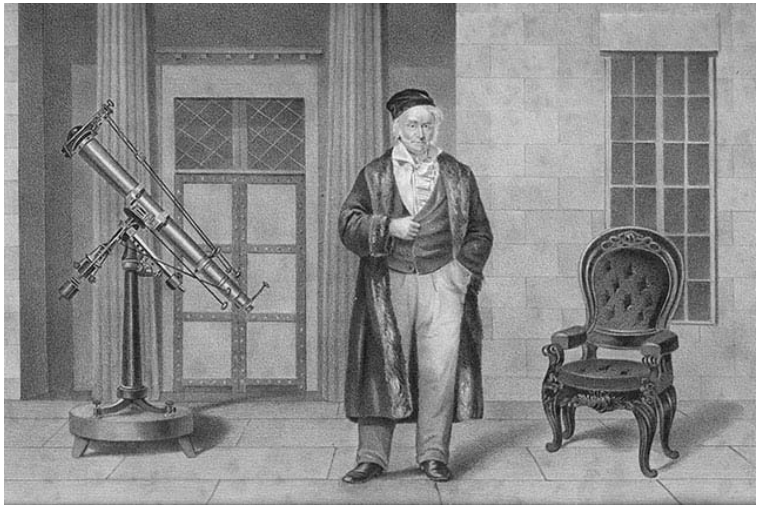
~ **1730** *Chester Moore Hall*, developed an achromatic lens by trying different combinations of flint and crown glass; *John Dollond* copied and patented Hall's concept to start commercial production

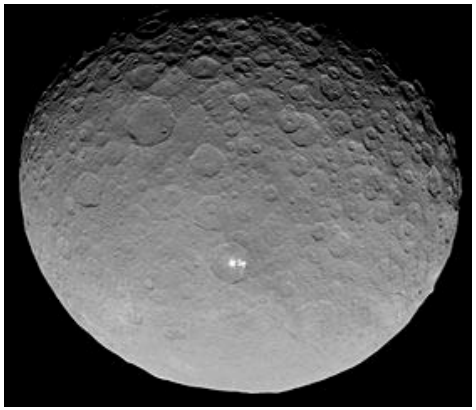
C. M. Hall (1703-1771)

J. Dollond (1706-1761)

~ **1800** *Carl Friedrich Gauss:* (*among many other achievements)* directed an astronomical observatory, developed a mathematical description of lenses ("Gaussian optics"), i.e. provided the mathematical basis for optical imaging theory; made contributions to the theory of electromagnetism

C. F. Gauss (1777-1855)





Another Gauss's achievement is the rediscovery of the first known asteroid Ceres. It had been found in 1800 by the Italian astronomer Giuseppe Piazzi,

Eduard Ritmüller's portrait of Gauss on the terrace of Göttingen observatory //Carl Friedrich Gauss: Titan of Science by G. Waldo Dunnington, Jeremy Gray, Fritz-Egbert Dohse

http://serious-science.org/carl-friedrich-gauss-7078

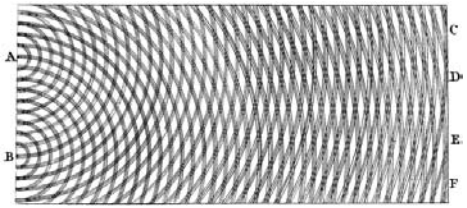
---------- 19th Century Optics: Wave Theory of Optics ----------

~ **1802** *Thomas Young:* supported the wave theory of light and postulated the interference principle, i.e. two light fields show constructive or destructive interference when coherently superimposed; introduced the idea of light as a *transversal wave (so far understood as longitudinal, e.g. as sound waves)*

T. Young (1773-1829)

Thomas Young's sketch of two-slit diffraction, which he presented to the Royal Society in 1803

https://en.wikipedia.org/wiki/History_of_optics



~ **1815** *Augustine Jean Fresnel:*
supported the wave theory of light; explained the straight propagation of light in homogeneous, isotropic media; calculated diffraction patterns at apertures; deduced eqns. for the amplitudes of reflection and refraction (Fresnel eqns.)

A. J. Fresnel(1788-1827)

~**1814** *Joseph von Fraunhofer:* developed telescopes, invented the spectroscope, investigated diffraction at optical gratings (Fraunhofer diffraction), and detected absorption lines in the solar spectrum (Fraunhofer lines)

J. van Fraunhofer (1787-1826)

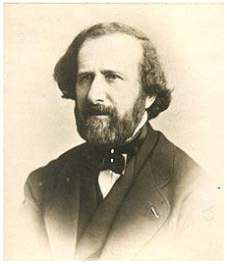
~ **1845** *Gustav Kirchhoff:* (*among other achievements)* developed the (Kirchhoff) radiation law, and contributed to spectroscopy (e.g. investigation of *Fraunhofer* lines).

G. Kirchhoff (1824-1887)

~ **1849** *Michael Faraday:*
(*among other achievements*) demonstrated the rotation of the polarization of light in a medium, manipulated by a magnetic field (Faraday effect).

M. Faraday (1791-1867)

~ **1849** *Hippolyte Fizeau & Leon Foucault:*
measured the speed of light, for the first time in a earth-bound experiment (also proposed by F. Arago).



H. Fizeau (1819-1896)

L. Foucault (1819-1868)

~ **1864** *James Clerk Maxwell:*
(*among other achievements*) developed the electromagnetic (classical wave) theory of light; deduced the transversal characterof light and the speed of light.

J. C. Maxwell (1831-1879)

~ **1881** *Albert Abraham Michelson:*
determined experimentally the speed of light with large accuracy; invented the Michelson interferometer; disproved the existence of an ether (i.e. a medium, which was supposed to work as a carrier for light) light travels through vacuum without the need for a carrier medium.

A. A. Michelson (1852-1931)

~ **1887** *Ernst Abbe:* developed the theory of optical images in a microscope, design and production of optical instruments based on scientific theory rather than try-and-error; investigated lens errors.

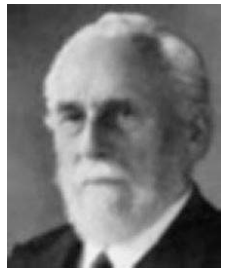
E. Abbe (1840-1905)

~ **1888** *Heinrich Hertz:* designed a detector and an oscillator (Hertz dipole) for EM waves, to demonstrate reflection and refraction in the laboratory; EM wave properties are the same as those of light; light is an EM wave; Hertz also discovered the photo-electric effect.

H. Hertz (1857-1894)

~ 1891/1892 *Ludwig Mach and Ludwig Zehnder:*
described (separately) what is known as a *Mach-Zehnder* interferometer (find changes in refractive index – density changes is gas flows).


L. Mach (1868-1951)


L. Zehnder (1854-1949)

~ 1896 *Wilhelm Wien :*
described how the spectral distribution of radiation of a blackbody varies with temperature.


W. Wien (1864-1928)

~ 1899 *Lord Rayleigh (John William Strutt):*
Explained blue color of the sky and red sunsets due to preferential scattering in the earth's atmosphere.


Lord Rayleigh (1848-1919)

~ 1899 *Marie P A C Fabry and Jean B G G A Perot:*
Described the *Fabry-Perot* interferometer which enabled high resolution observation of spectral features.

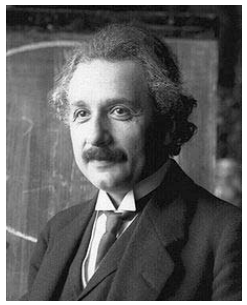

M. Fabry (1867-1945)


J. Perot (1863-1928)

~ **1900** *Max Planck:*
quantum theory of light (beginning of quantum optics); Planck's black-body radiation law; deduction of the values for Planck's constant *h*.


M. Planck (1858-1947)

~ **1905** *Albert Einstein*: (*among other achievements*) explained the photo-electric effect; introduced the concept of light quanta (later called "photons"); postulated a constant speed of light (special theory of relativity); contributed to the quantum theory of light (and matter).


A. Einstein (1879-1955)

~ **1912** *Max von Laue:* discovered the diffraction of X-rays at crystals; conducted optical experiments to support Einstein's special theory of relativity.


M. von Laue (1892-1987)

~ **1924** *Louis de Broglie*, postulated the existence of matter waves (i.e. defining the beginning of matter wave optics); the wave character of matter was demonstrated by *Clinton Davisson* and *Lester Germer* (**1926**), observing the interference of an electron beam on a Nickel crystal; *Claus Jönnson* demonstrated the interference of an electron beam in a double-slit experiment (**1961**).


V. L. de Broglie (1892-1987)


C. Davisson (1881-1958)
L. Germer (1896-1971)


C. Jonsson (1930-)

~ **1923** *Arthur H. Compton*
Scattering of a photon by a particle and the subsequent increase in wavelength of the scattered photon. (Nobel prize **1927**)


A. H. Compton (1892-1962)

~ **1931** *Ernst Ruska* and *Max Knoll*
build the first (transmission) electron microscope, based on the concepts of matter waves and electron optics (e.g. implemented with electro-static and magnetic lenses).


E. Ruska (1906-1988)


M. Knoll (1897-1969)

~ **1957** *Gordon Gould* patented the optically pumped-laser, based on the concepts of light amplification (laser physics), developed by *Charles Hard Townes*, *Nicolai Basov*, *Alexander Mikhaylovich Prokhorov* (**1954**, Nobel prize **1964**).

G. Gould (1920-2005)

C. H. Townes (1915-2015)

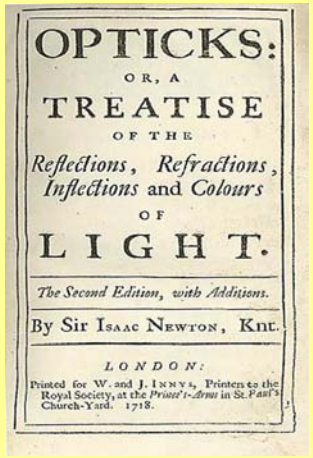
N. Basov (1922-2001)

A. M. Prokhorov (1916-2002)

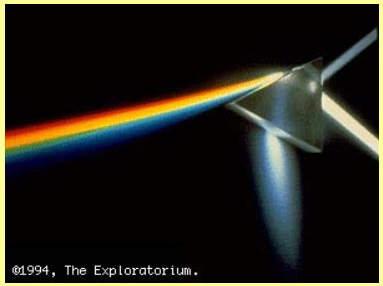
~ **1957** till today :
the invention of the laser pushed a huge amount of research and developments in modern applied optics & optical technologies.

Wave-Particle Duality of Light

Particles

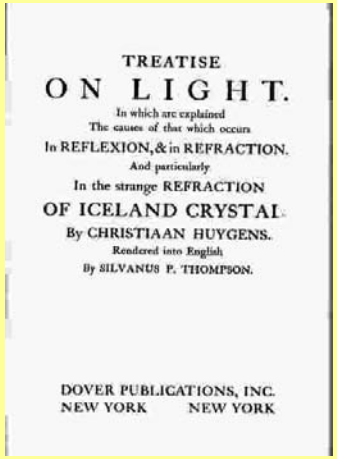

OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and *Colours*
OF
LIGHT.
The Second Edition, with Additions.
By Sir Isaac Newton, Knt.
LONDON:
Printed for W. and J. Innys, Printers to the Royal Society, at the *Prince's-Arms* in St. Paul's Church-Yard. 1718.

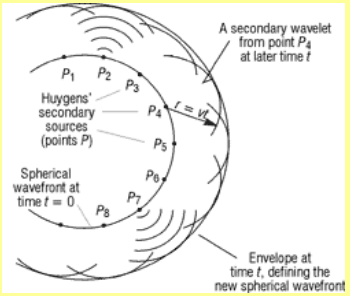

Sir Isaac Newton
(1642-1727)

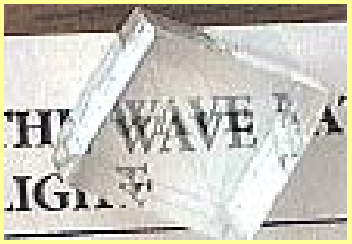


Waves


Christaan Huygens
(1629-1695)


TREATISE
ON LIGHT.
In which are explained
The causes of that which occurs
In REFLEXION, & in REFRACTION.
And particularly
In the strange REFRACTION
OF ICELAND CRYSTAL.
By CHRISTIAAN HUYGENS.
Rendered into English
By SILVANUS P. THOMPSON.
DOVER PUBLICATIONS, INC.
NEW YORK NEW YORK





De Broglie (**1924**): $\lambda = h / p$,
$h = 6.626 \times 10^{-34}$ J sec, p = momentum