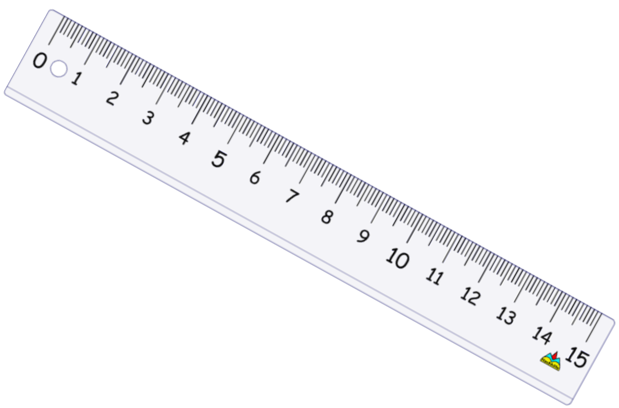
Geometrical Optics

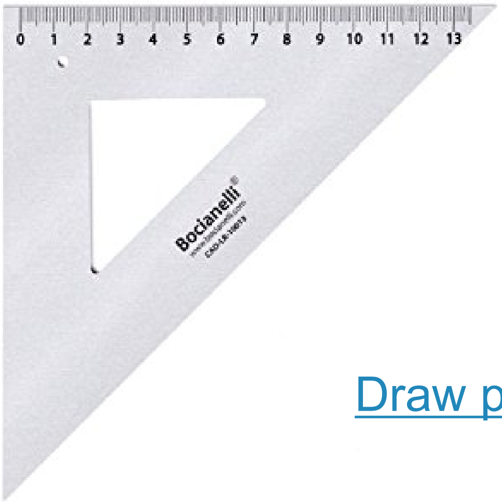
Geometrical optics is mostly **Geometry**

What is geometry?

Maths + Technical drawing

What do you need to have

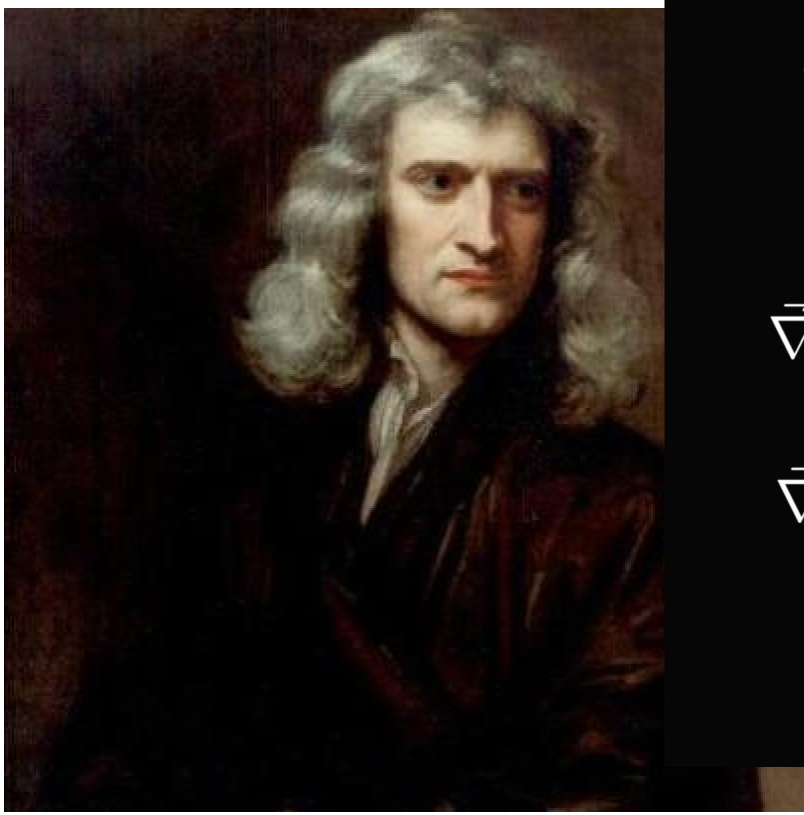




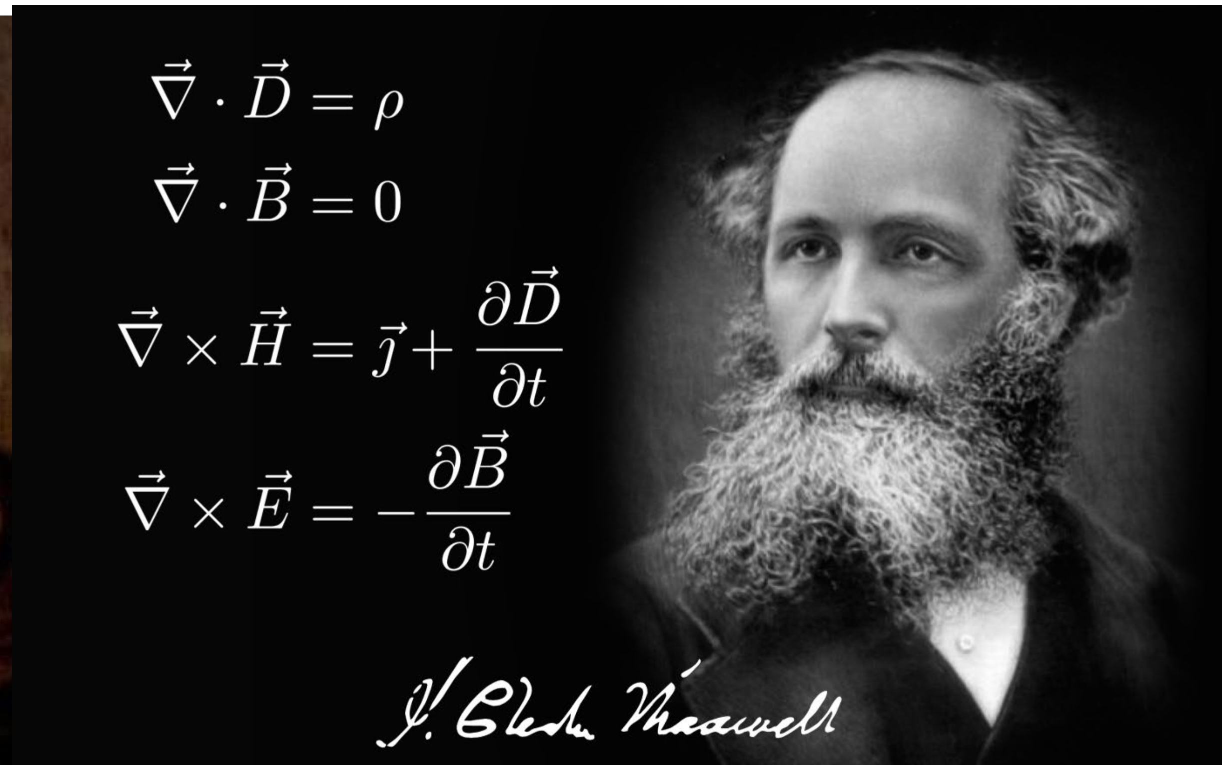
Draw parallel lines

≈350 years ago, in 1666 Newton made revolutionary inventions and discoveries in calculus, motion, optics and gravitation.

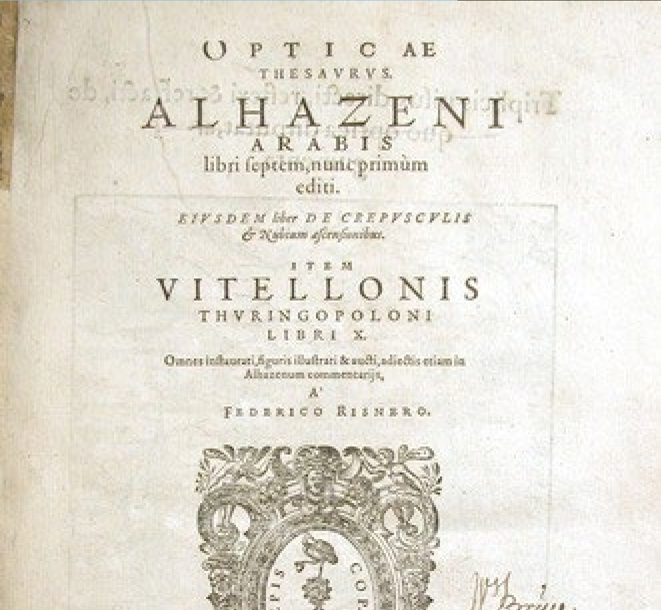
2015 was the International Year of Light.
≈150 years ago:
Maxwell's Equations 1861-1873



Sir Isaac Newton FRS
1643-1727



James Clerk Maxwell FRS FRSE
1831-1879



965-1040

In medieval Europe,
Ibn al-Haytham was honoured
as the "Second Ptolemy“.

2015 – 1000 years of his
Book of Optics (7 books).

Robert Grosseteste, bishop of Lincoln

1220 to 1235 he wrote:

De sphera. A text on astronomy.

De luce. On the "metaphysics of light."

De lineis, angulis et figuris.
Mathematical reasoning
in the natural sciences.

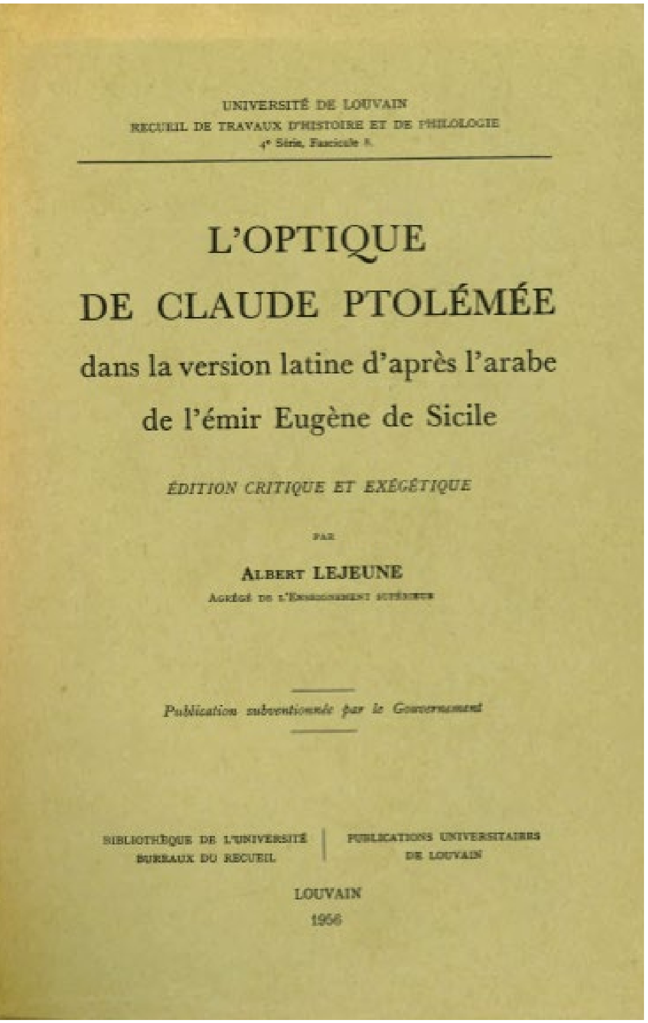
De iride. On the rainbow.

De Colore.

Robert Grosseteste, bishop of Lincoln

Colour is light incorporated in a transparent medium.
But, in fact, there are two different media: there are pure transparent media separated from earth materials or impure media mixed with them.
The light, however, is four-fold differentiated: there is the bright and the obscure light, and the intense or the tenuous light.

Ptolemy, 100-170, Alexandria



UNIVERSITÉ DE LOUVAIN
RECUEIL DE TRAVAUX D'HISTOIRE ET DE PHILOLOGIE
4e Série, Fascicule 8.

L'OPTIQUE
DE CLAUDE PTOLÉMÉE
dans la version latine d'après l'arabe
de l'émir Eugène de Sicile

ÉDITION CRITIQUE ET EXÉGÉTIQUE

PAR

ALBERT LEJEUNE

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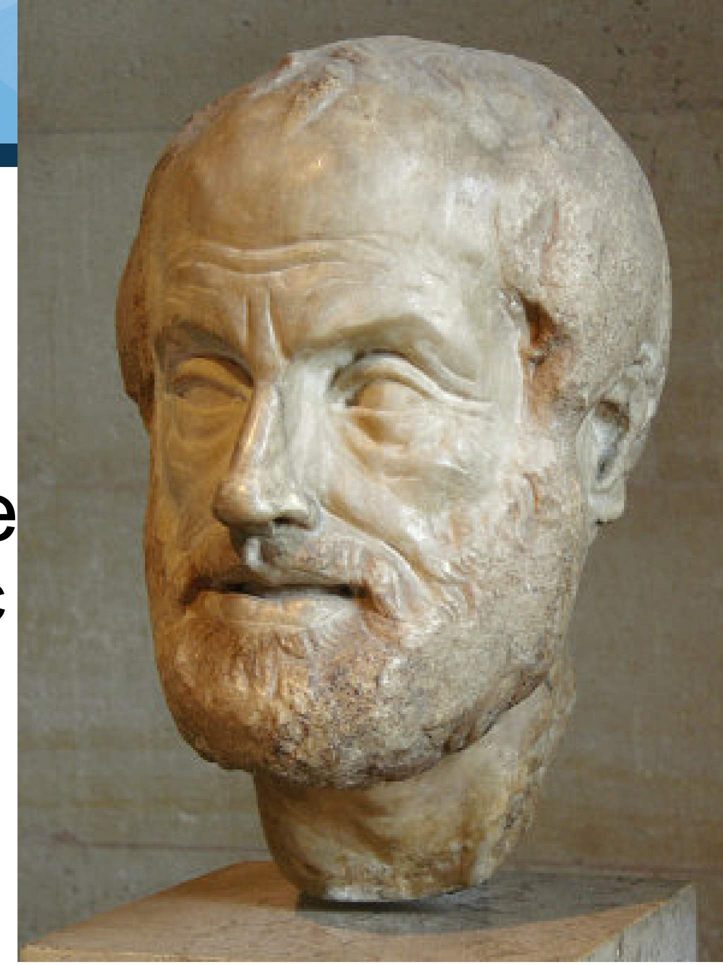
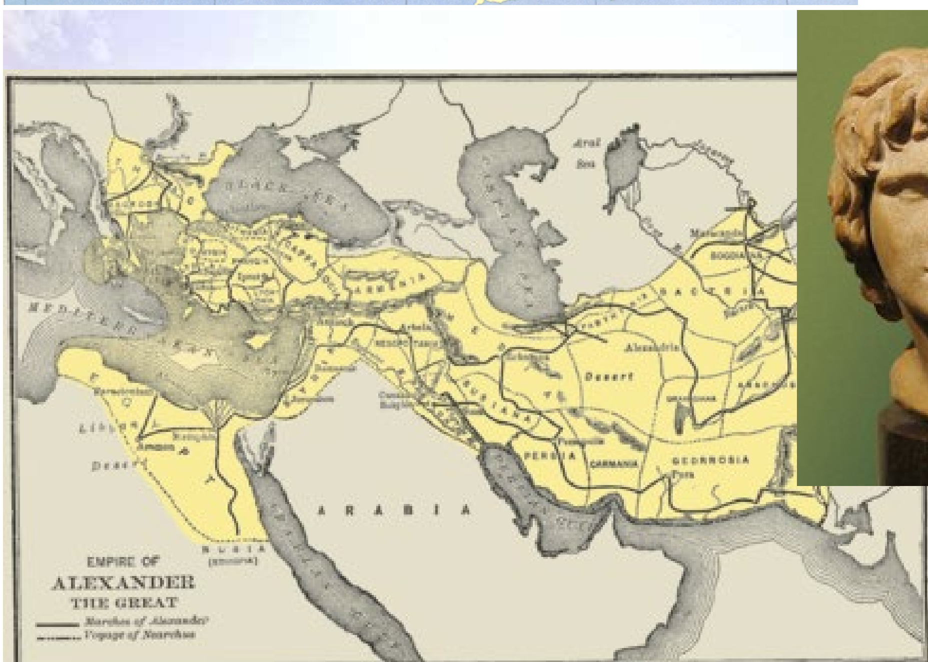
1956

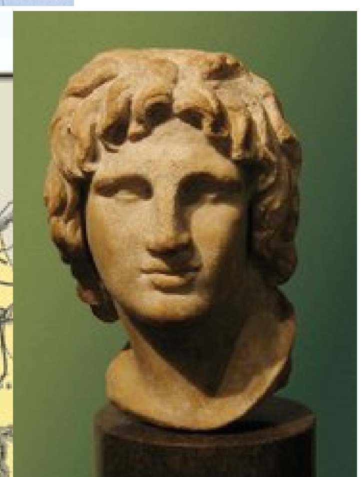
His *Optics* survives only in a poor Arabic translation and in about twenty manuscripts of a Latin version of the Arabic, which was translated by *c*. 1154. In it Ptolemy writes about properties of light, including reflection, refraction, and colour.

Aristotle

384 -322 BC





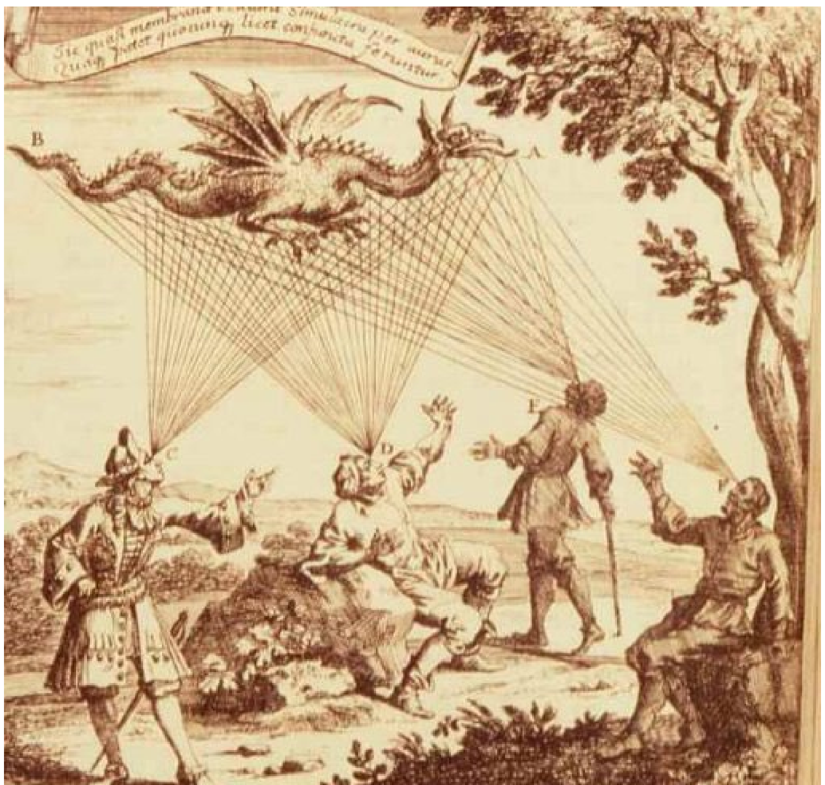


"In general, it is unreasonable to suppose that seeing occurs by something issuing from the eye."

Euclid's *Optics*

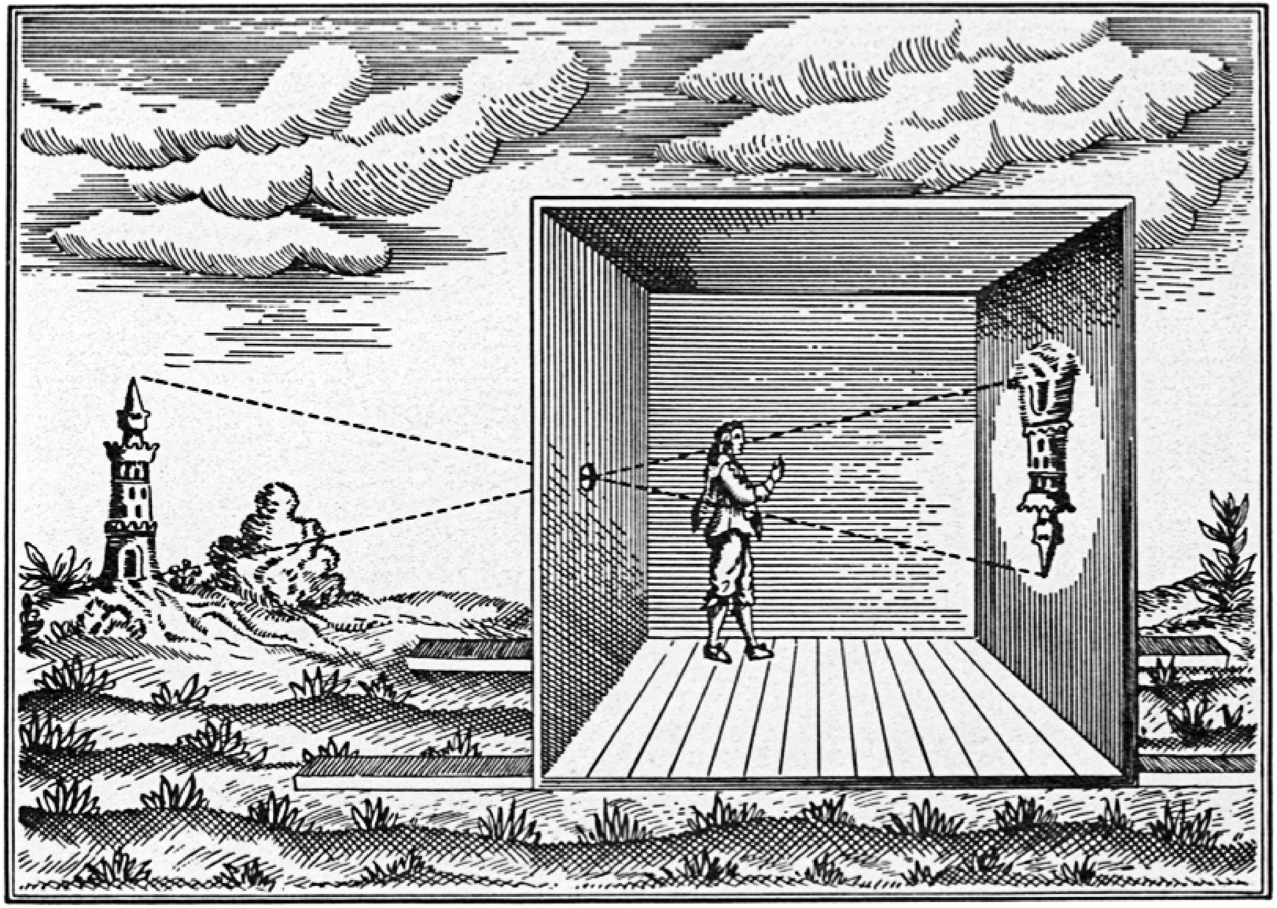
Visual rays proceed **from** the eyes onto objects.

Earliest surviving manuscript on *Optics.*



ca 4-3 century BCE
Alexandria
“father of geometry”

Camera obscura



First records 5-4 c BCE, China. Mentioned by Aristotle. Studies by Ibn Al-Haytham.

First clear description- L. da Vinci, 1502

Light and Optics

There are two historical models for the nature of light.

Newton was the chief architect of the particle theory of light.

- He believed the particles left the object and stimulated the sense of sight upon entering the eyes.

Christian Huygens argued that light might be some sort of a wave motion.

Dual Nature of Light

Light exhibits the characteristics of a wave in some situations and the characteristics of a particle in other situations.

Christian Huygens

1629 – 1695

Best known for contributions to fields of optics and dynamics

He thought light was a type of vibratory motion.

It spread out and produced the sensation of light when it hit the eye.

He deduced the laws of reflection and refraction.

He explained double refraction.

Measurements of the Speed of Light

Since light travels at a very high speed, early attempts to measure its speed were unsuccessful.

- Remember $c = 3.00 \times 10^8$ m/s

Galileo tried by using two observers separated by about 10 km.

- The reaction time of the observers was more than the transit time of the light.

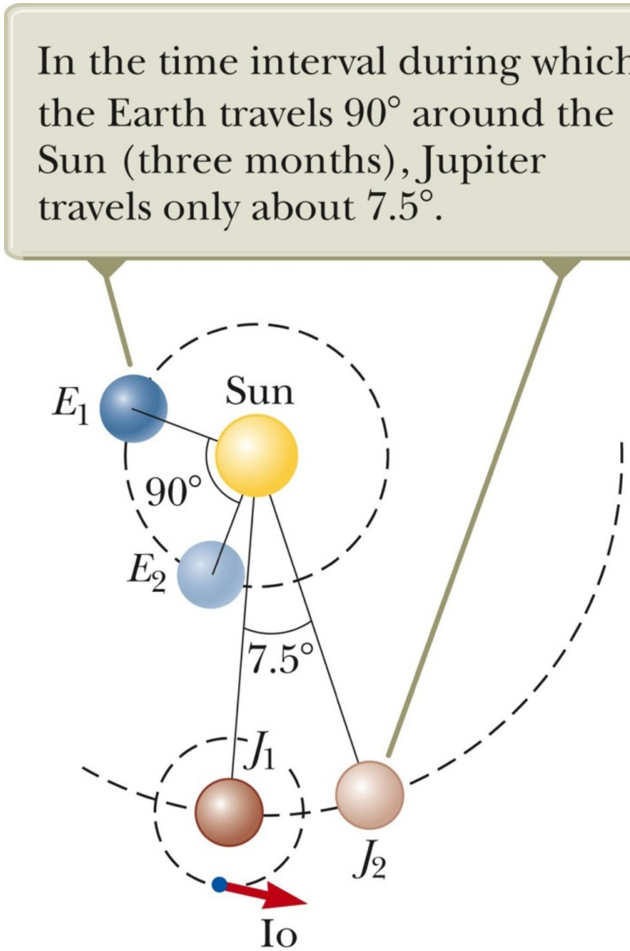
Measurement of the Speed of Light – Roemer's Method

In 1675 Ole Roemer used astronomical observations to estimate the speed of light.

He used the period of revolution of Io, a moon of Jupiter, as Jupiter revolved around the sun.

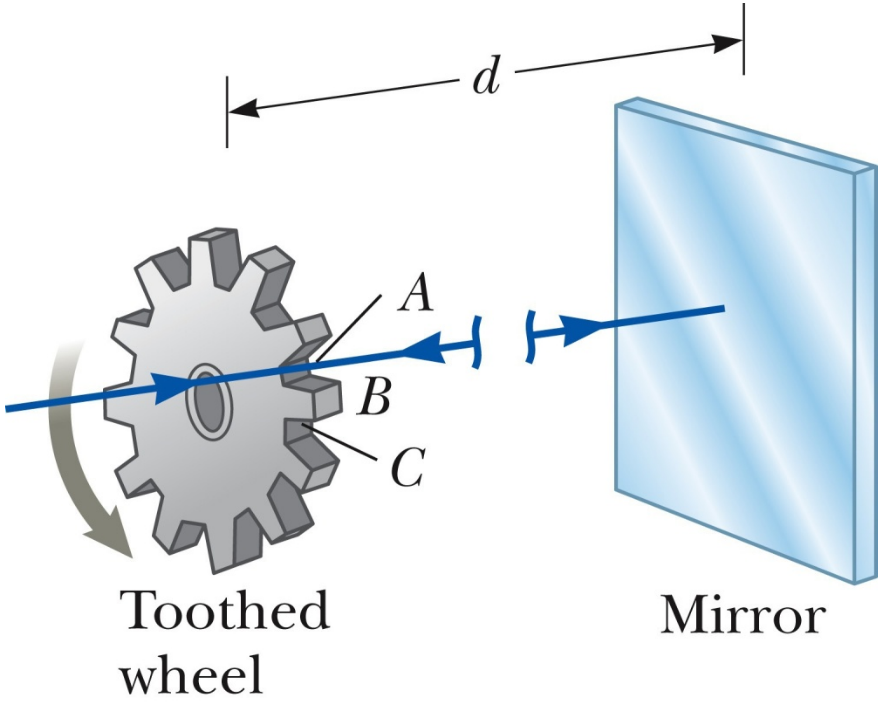
The angle through which Jupiter moves during a 90° movement of the Earth was calculated.

Using Roemer's data, Huygens estimated the lower limit of the speed of light to be 2.3 x 10^8 m/s.



Measurements of the Speed of Light – Fizeau's Method

This was the first successful method for measuring the speed of light by means of a purely terrestrial technique. It was developed in 1849 by Armand Fizeau.



d is the distance between the wheel and the mirror.

Δt is the time for one round trip.

Then $c = 2d / \Delta t$

Fizeau found a value of

$c = 3.1 \times 10^8$ m/s.

The Ray Approximation in Ray Optics

Ray optics (sometimes called *geometric* optics) involves the study of the propagation of light.

It uses the assumption that light travels in a straight-line path in a uniform medium and changes its direction when it meets the surface of a different medium or if the optical properties of the medium are nonuniform.

The ray approximation is used to represent beams of light.

Reflection of Light

A ray of light, the *incident ray*, travels in a medium.

When it encounters a boundary with a second medium, part of the incident ray is reflected back into the first medium.

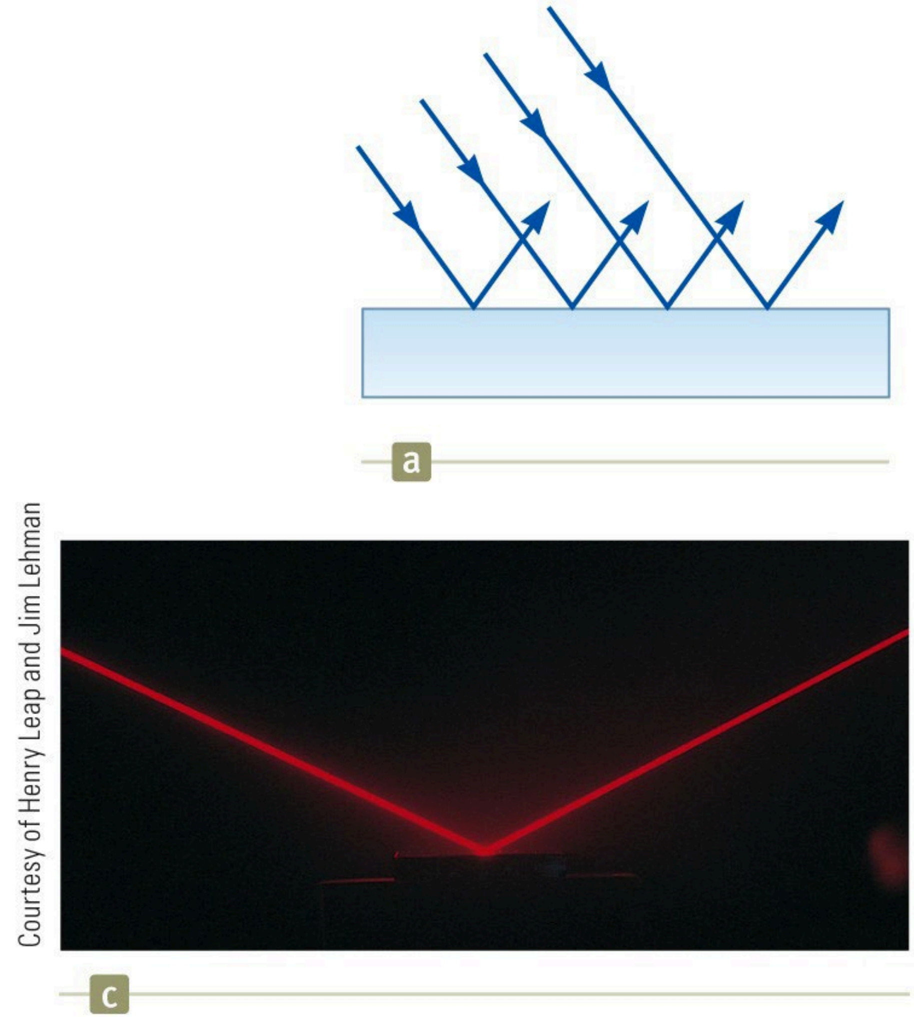
- This means it is directed backward into the first medium.

Specular Reflection

Specular reflection is reflection from a smooth surface.

The reflected rays are parallel to each other.

All reflection in this text is assumed to be specular.

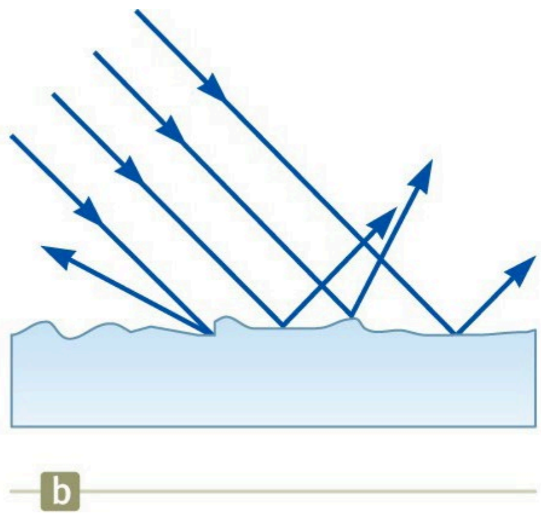


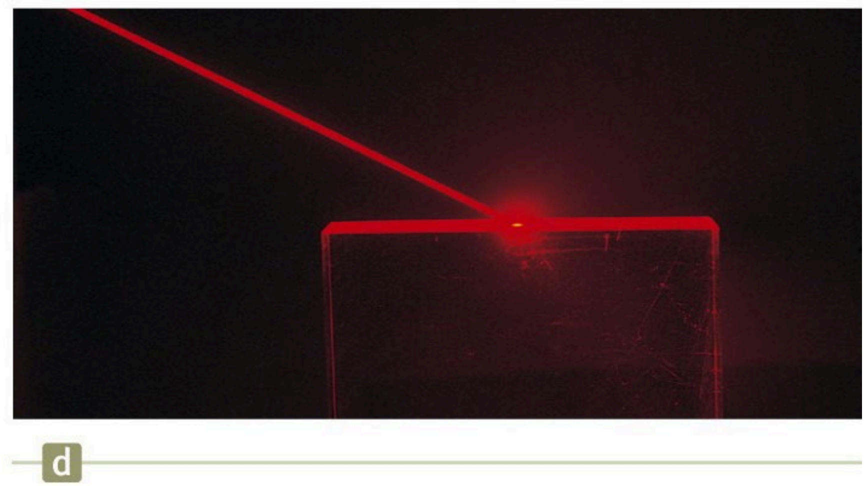
Diffuse Reflection

Diffuse reflection is reflection from a rough surface.

The reflected rays travel in a variety of directions.

A surface behaves as a smooth surface as long as the surface variations are much smaller than the wavelength of the light.





Courtesy of Henry Leap and Jim Lehman

Law of Reflection

The *normal* is a line perpendicular to the surface.

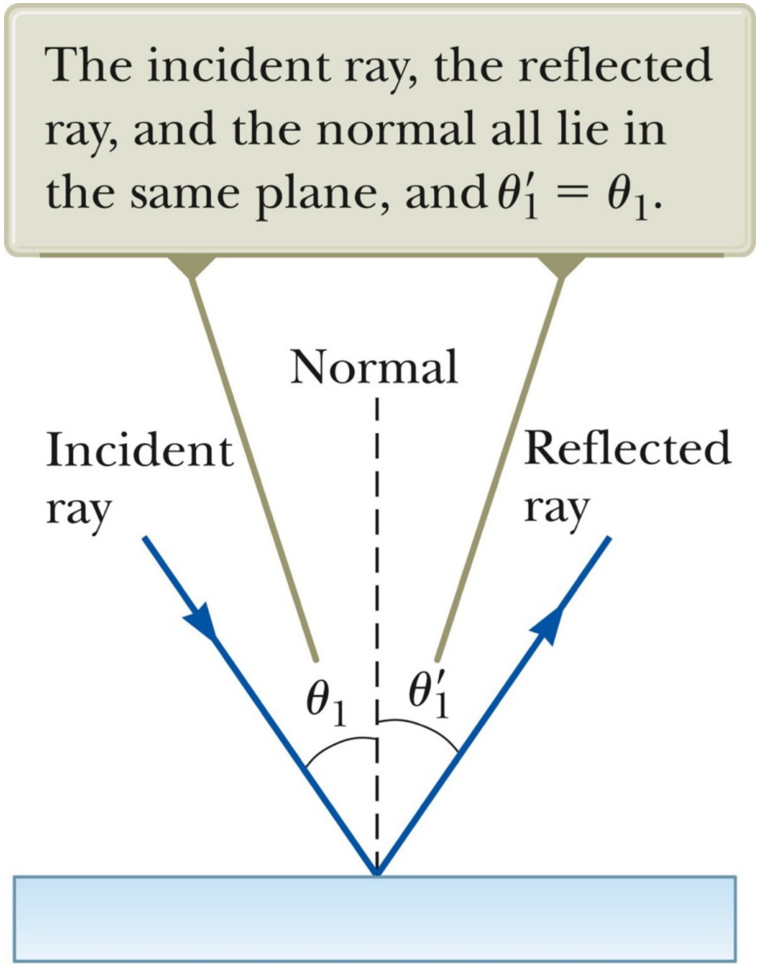
- It is at the point where the incident ray strikes the surface.

The incident ray makes an angle of θ_1 with the normal.

The reflected ray makes an angle of θ_1' with the normal.

$\theta_1' = \theta_1$ - Law of Reflection.

- The subscript 1 refers to parameters for the light in the first medium.
- If light travels in another medium, the subscript 2 will be associated with the new medium.



Refraction of Light

When a ray of light traveling through a transparent medium encounters a boundary leading into another transparent medium, part of the energy is reflected and part enters the second medium.

The ray that enters the second medium changes its direction of propagation at the boundary.

- This bending of the ray is called *refraction.*

Following the Reflected and Refracted Rays

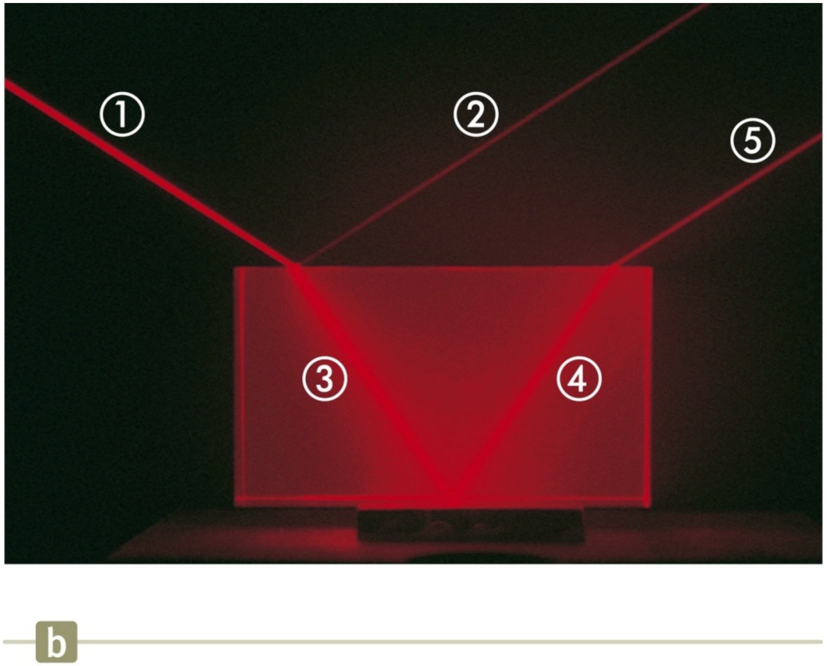
Ray ① is the incident ray.

Ray ② is the reflected ray.

Ray ③ is refracted into the lucite.

Ray ④ is internally reflected in the lucite.

Ray ⑤ is refracted as it enters the air from the lucite.



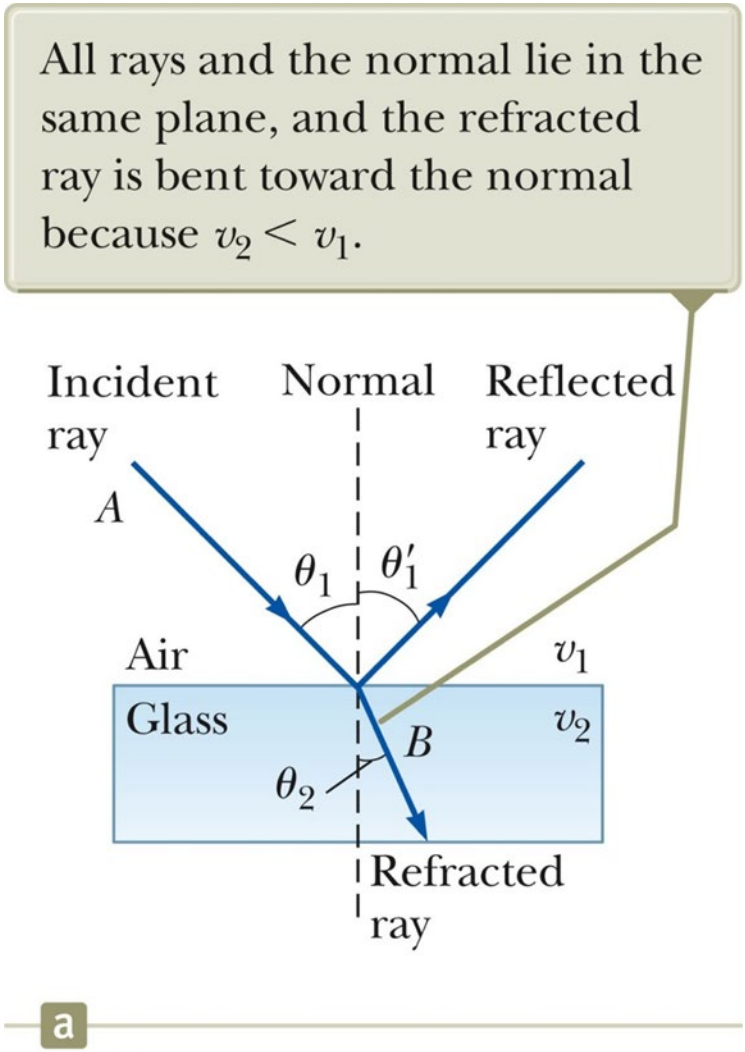
Refraction, cont.

The incident ray, the reflected ray, the refracted ray, and the normal all lie on the same plane.

The angle of refraction depends upon the material and the angle of incidence.

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

- v_1 is the speed of the light in the first medium and v_2 is its speed in the second.



The Index of Refraction

The speed of light in any material is less than its speed in vacuum.

The **index of refraction**, n, of a medium can be defined as

$$n \equiv \frac{\text{speed of light in a vacuum}}{\text{speed of light in a medium}} \equiv \frac{c}{v}$$

For a vacuum, n = 1

- We assume n = 1 for air also

For other media, n > 1

n is a dimensionless number greater than unity.

- n is not necessarily an integer.

Some Indices of Refraction

Table 35.1 Indices of Refraction

Substance	Index of Refraction	Substance	Index of Refraction
Solids at 20°C		*Liquids at 20°C*	
Cubic zirconia	2.20	Benzene	1.501
Diamond (C)	2.419	Carbon disulfide	1.628
Fluorite (CaF_2)	1.434	Carbon tetrachloride	1.461
Fused quartz (SiO_2)	1.458	Ethyl alcohol	1.361
Gallium phosphide	3.50	Glycerin	1.473
Glass, crown	1.52	Water	1.333
Glass, flint	1.66		
Ice (H_2O)	1.309	*Gases at 0°C, 1 atm*	
Polystyrene	1.49	Air	1.000 293
Sodium chloride (NaCl)	1.544	Carbon dioxide	1.000 45

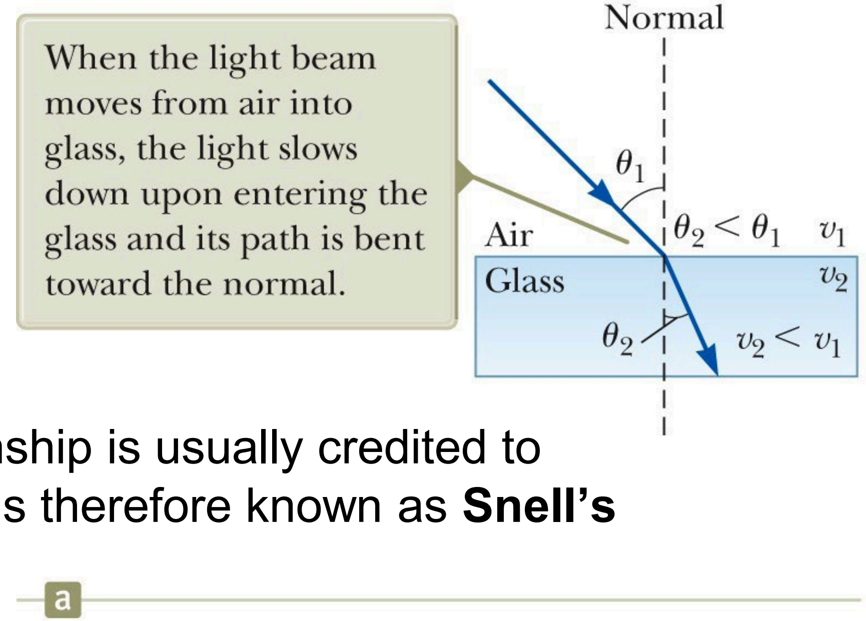
Note: All values are for light having a wavelength of 589 nm in vacuum.

Snell's Law of Refraction

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

- θ_1 is the angle of incidence
- θ_2 is the angle of refraction

The experimental discovery of this relationship is usually credited to Willebrord Snellius, ca 1621, Leiden, and is therefore known as **Snell's law of refraction.**



It was already formulated in 984 by Ibn Sahl in Baghdad.

Light may refract into a material where its speed is lower.

The angle of refraction is less than the angle of incidence.

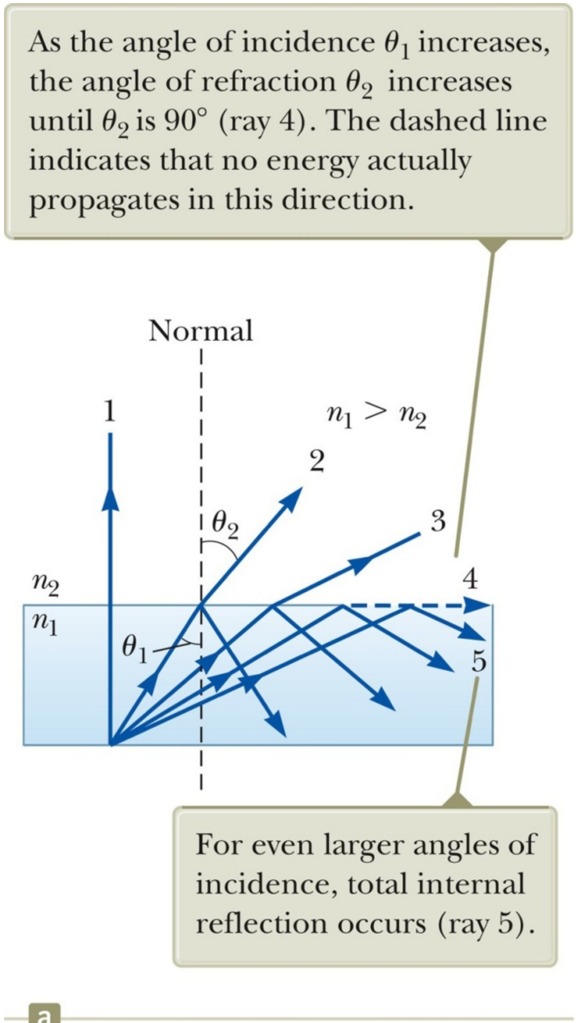
- The ray bends *toward* the normal.

Total Internal Reflection

A phenomenon called **total internal reflection** can occur when light is directed from a medium having a given index of refraction toward one having a lower index of refraction.

Possible directions of the beam are indicated by rays numbered 1 through 5.

The refracted rays are bent away from the normal since $n_1 > n_2$.



Critical Angle

There is a particular angle of incidence that will result in an angle of refraction of 90° .

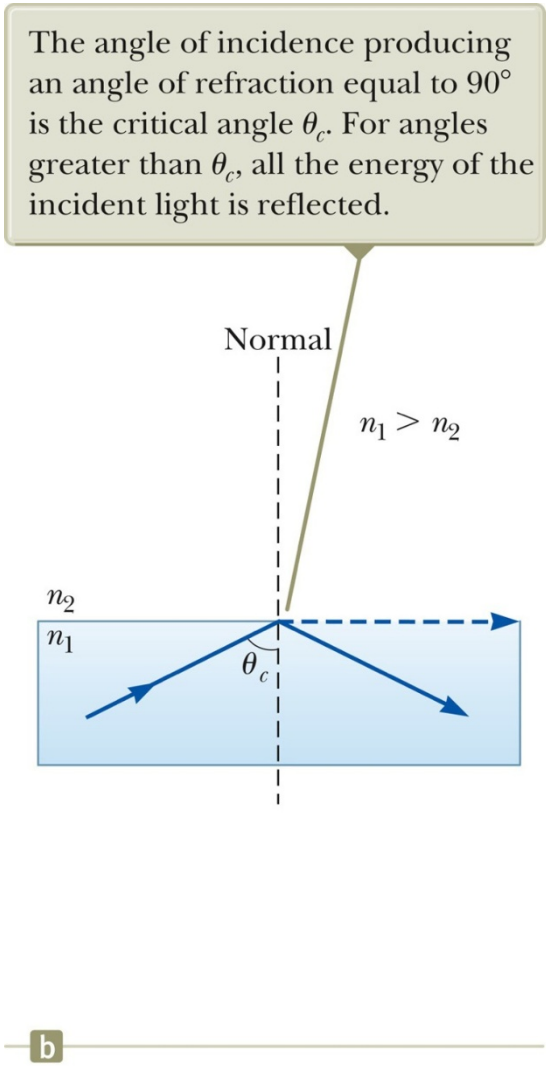
- This angle of incidence is called the *critical angle*, θ_C.

$$\sin \theta_C = \frac{n_2}{n_1} \quad (\text{for } n_1 > n_2)$$

For angles of incidence *greater* than the critical angle, the beam is entirely reflected at the boundary.

- This ray obeys the law of reflection at the boundary.

Total internal reflection occurs only when light is directed from a medium of a given index of refraction toward a medium of lower index of refraction.



Fiber Optics

An application of internal reflection

Plastic or glass rods are used to "pipe" light from one place to another.

Applications include:

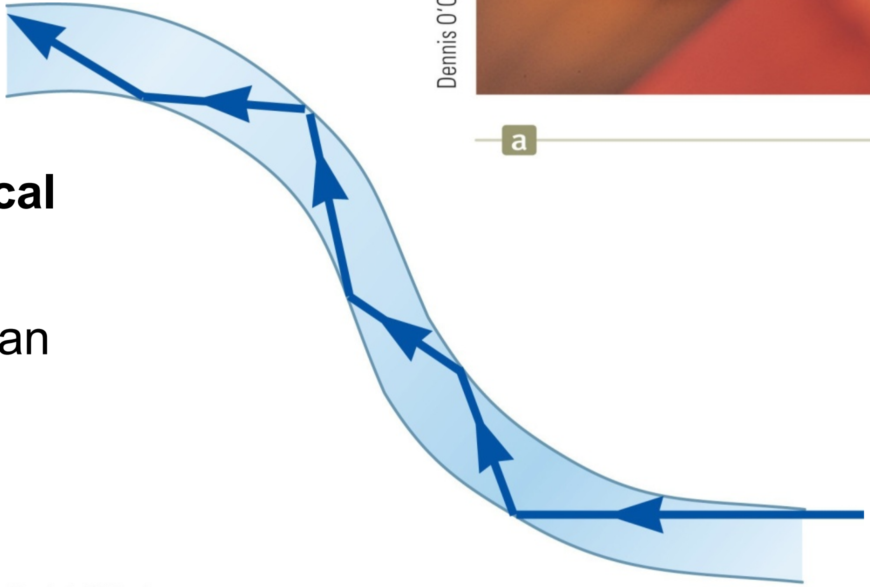
- Medical examination of internal organs
- Telecommunications

A flexible light pipe is called an **optical fiber.**

A bundle of parallel fibers (shown) can be used to construct an optical transmission line.

Dennis O'Clair/Getty Images

a



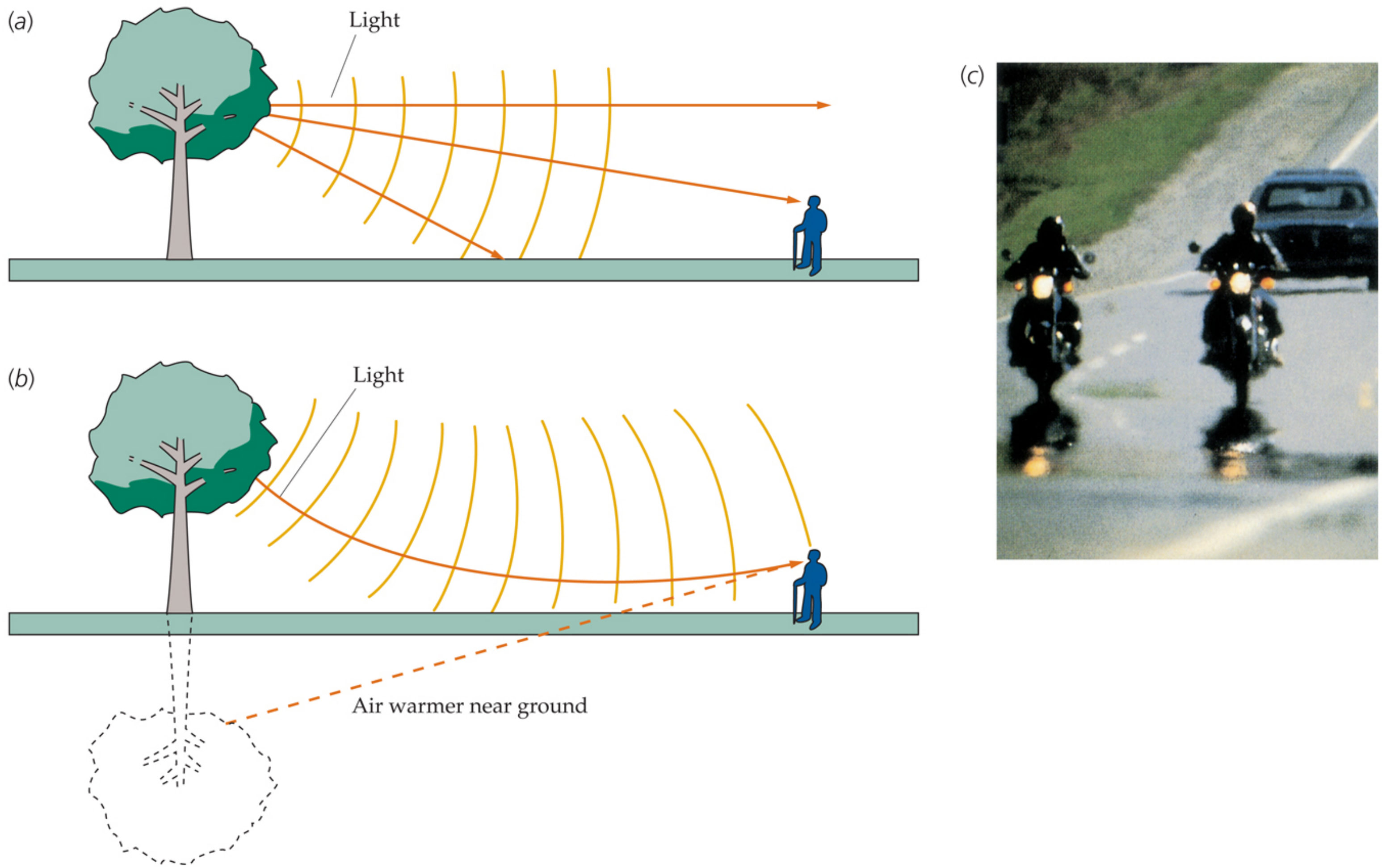
Fermat's principle, 1662

Early version Ibn Al-Haytham.

<u>Light travels along the path of least time.</u>

1607-1665

Best known for
Fermat's Last Theorem



Air of different temperature has different density and therefore different n.

Dispersion

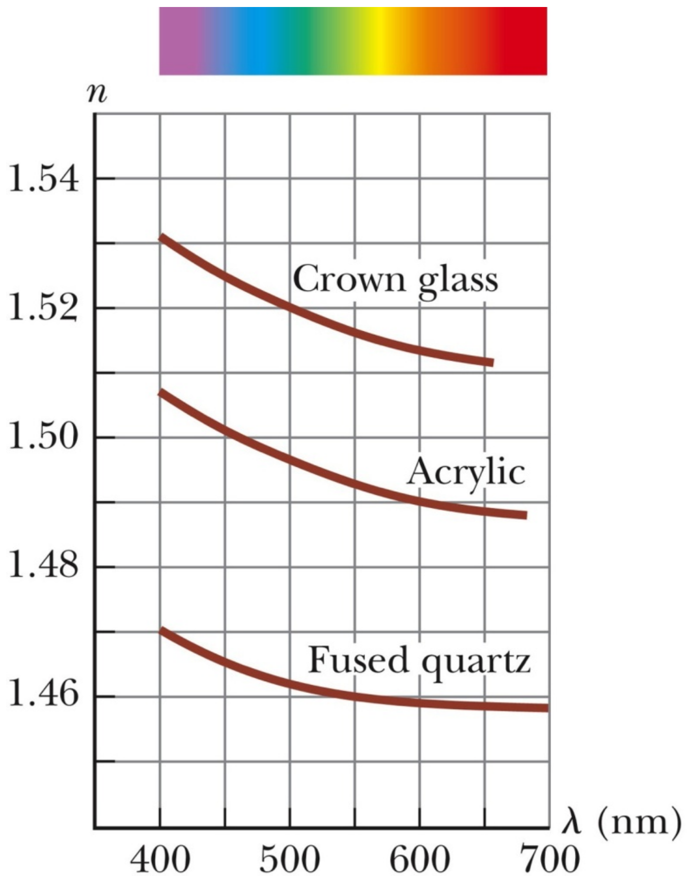
For a given material, the index of refraction varies with the wavelength of the light passing through the material.

This dependence of n on λ is called dispersion.

Snell's law indicates light of different wavelengths is bent at different angles when incident on a refracting material.

The index of refraction for a material generally decreases with increasing wavelength.

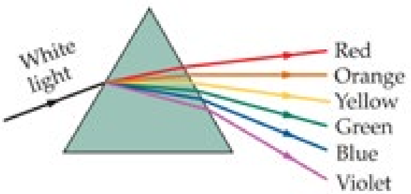
Violet light bends more than red light when passing into a refracting material.

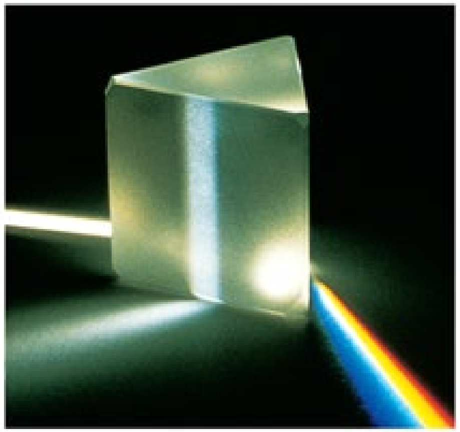


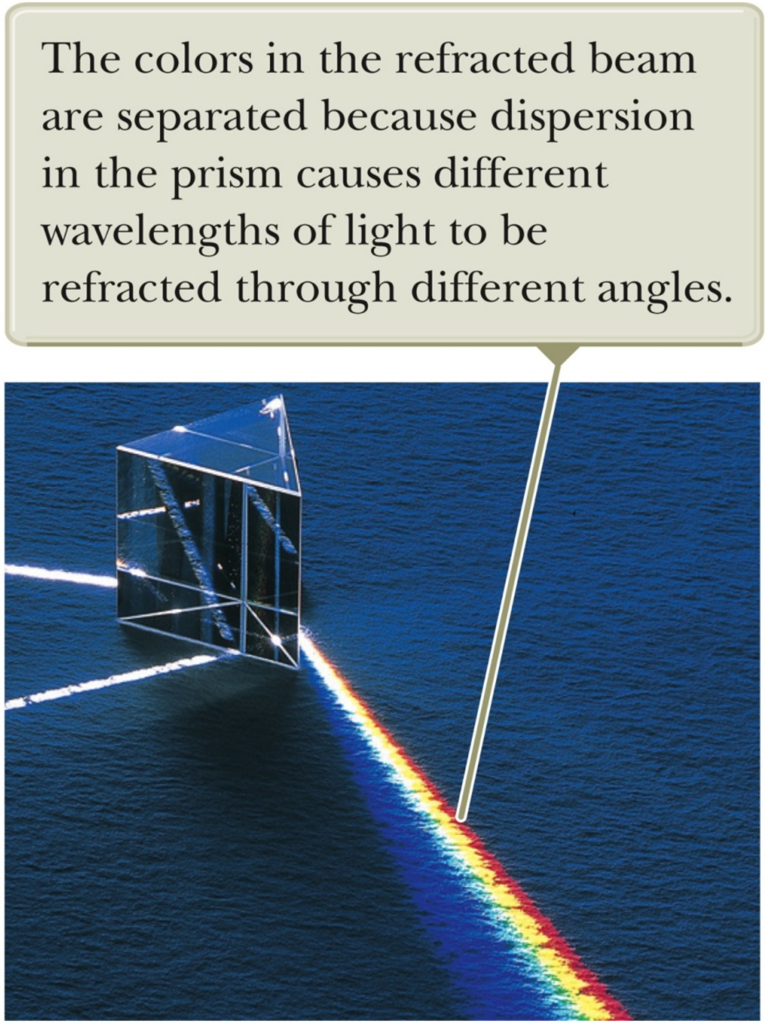
Refraction in a Prism

Since all the colors have different angles of deviation, white light will spread out into a *spectrum.*

- Violet deviates the most.
- Red deviates the least.
- The remaining colors are in between.







The Rainbow

A ray of light strikes a drop of water in the atmosphere.

It undergoes both reflection and refraction.

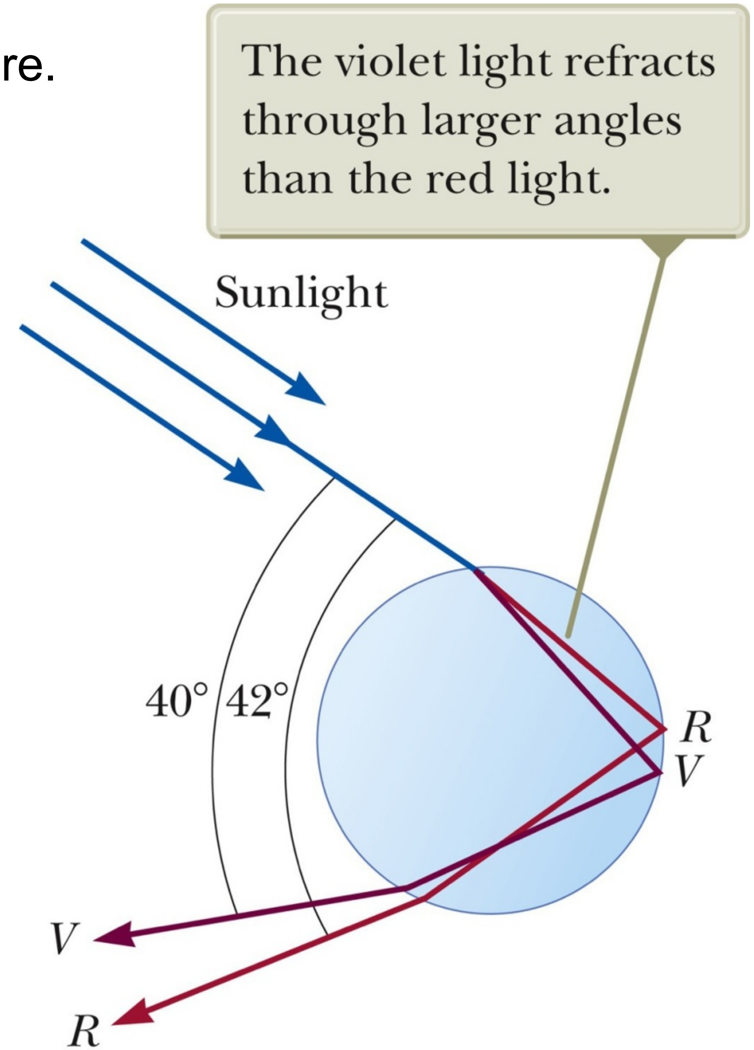
- First refraction at the front of the drop
  - Violet light will deviate the most.
  - Red light will deviate the least.

At the back surface the light is reflected.

It is refracted again as it returns to the front surface and moves into the air.

The rays leave the drop at various angles.

- The angle between the white light and the most intense violet ray is 40°.
- The angle between the white light and the most intense red ray is 42°.



Huygens's Principle

Huygens assumed that light is a form of wave motion rather than a stream of particles.

Huygens's Principle is a geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it.

All points on a given wave front are taken as point sources for the production of spherical secondary waves. These waves are called wavelets, they propagate outward through a medium with speeds characteristic of waves in that medium.

After some time has passed, the new position of the wave front is the surface tangent to the wavelets.

Huygens's Construction for Plane and Spherical Waves

- At $t = 0$, the wave front is indicated by the plane *AA*.'

The points are representative sources for the wavelets.

After the wavelets have moved a distance $c\Delta t$, a new plane *BB*' can be drawn tangent to the wavefronts.

- The inner arc represents part of the spherical wave.

The points are representative points where wavelets are propagated.

The new wavefront is tangent at each point to the wavelet.