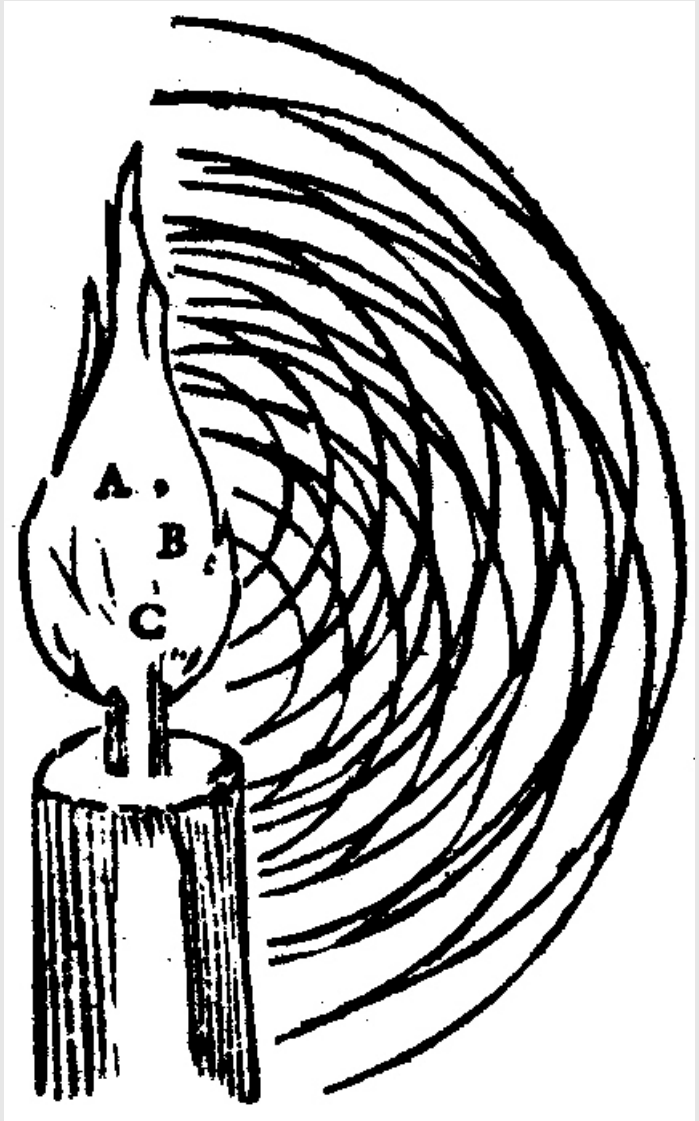
Wave Particle Duality: From Newton to Einstein

Alan E. Shapiro

Huygens. Light Waves



Christiaan Huygens, c. 1671

TRAITE
DE LA LVMIERE.

Où ſont expliquées

Les cauſes de ce qui luy arrive

Dans la REFLEXION, & dans la REFRACTION.

Et particulierement

Dans l'etrange REFRACTION

DV CRISTAL D'ISLANDE.

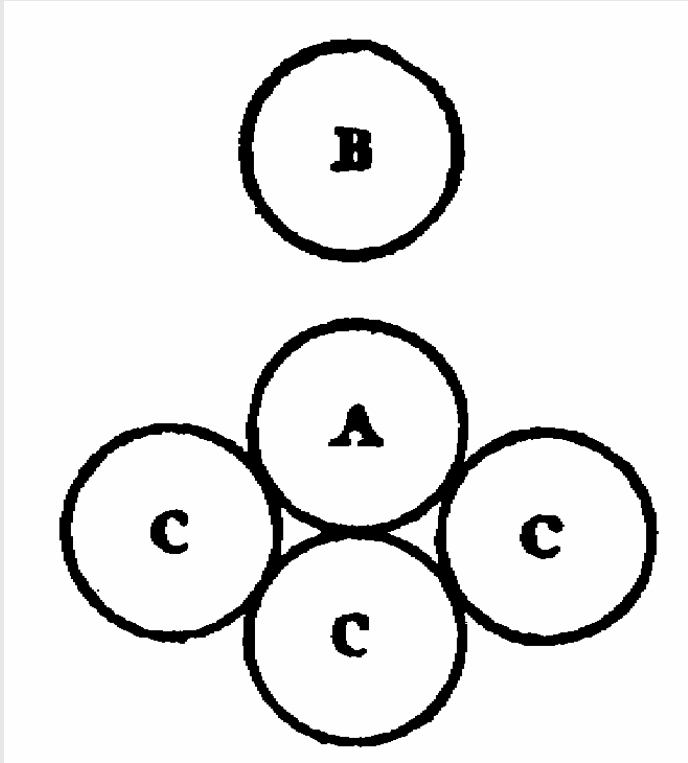
Par Monſieur CHRISTIAN HUYGENS, Seigneur de Zeelhem.

Avec un Diſcours de la Cauſe

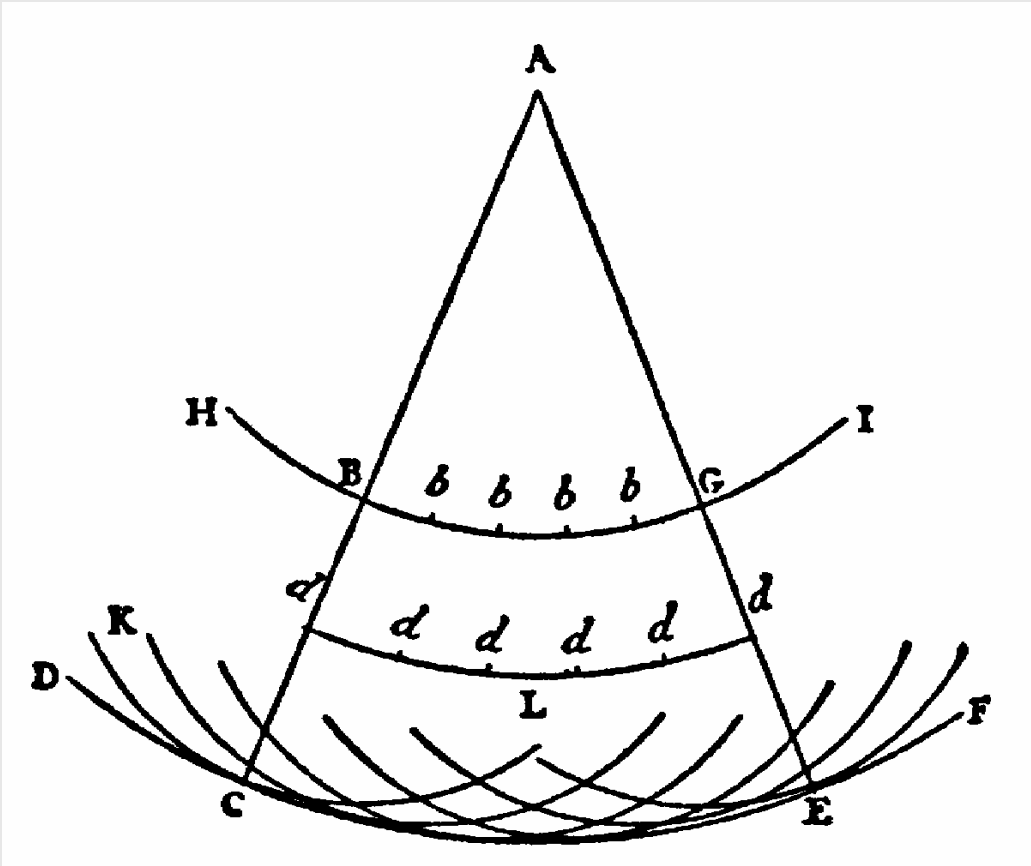
DE LA PESANTEVR.

A LEIDE,
Chez PIERRE VANDER AA, Marchand Libraire.
MDCXC.

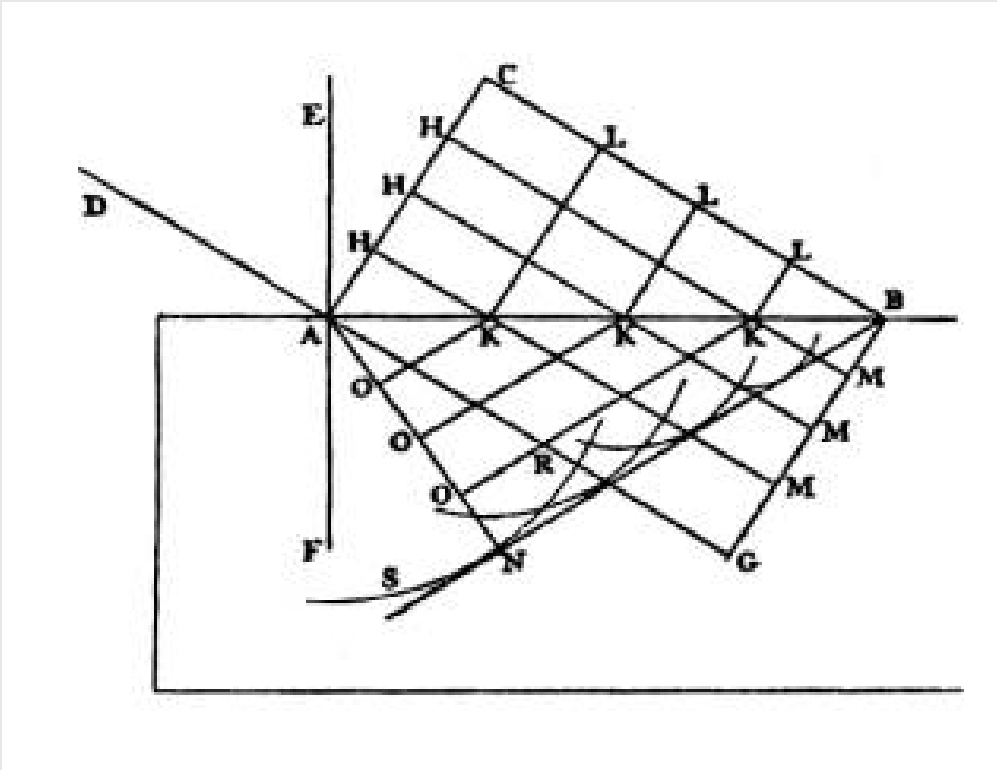
The Little Balls of the Aether



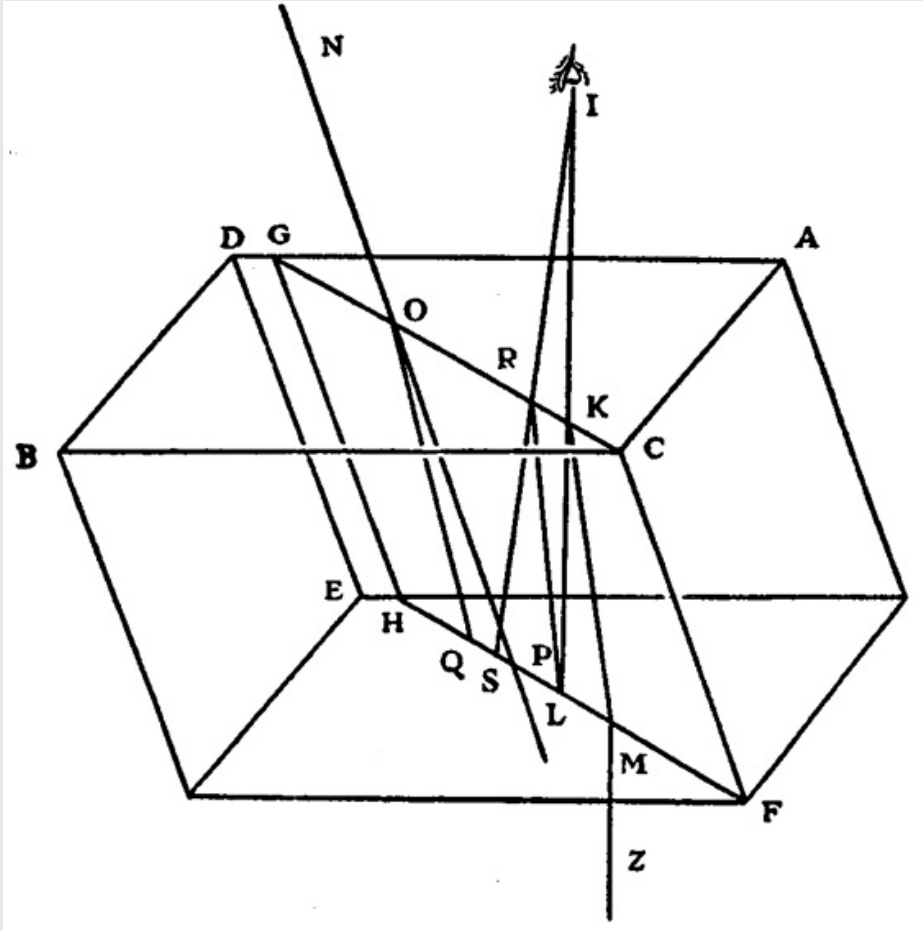
Huygens' Principle



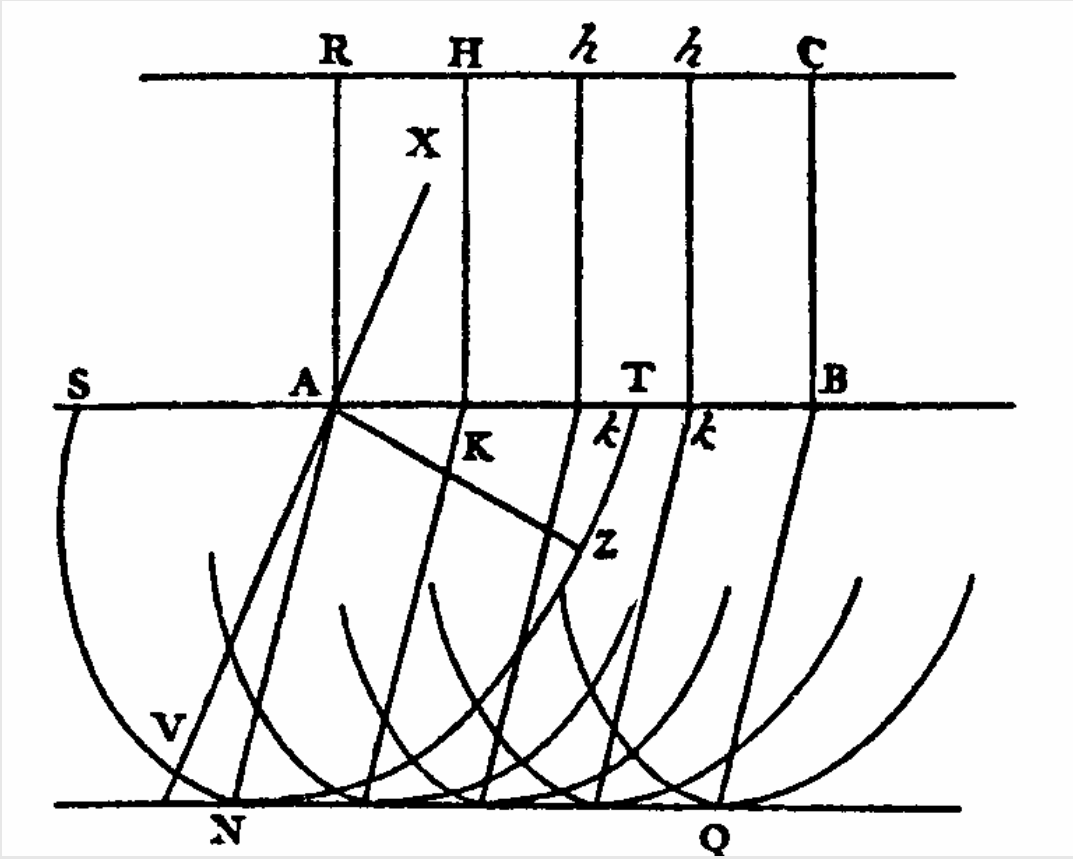
Refraction of a Plane Wave



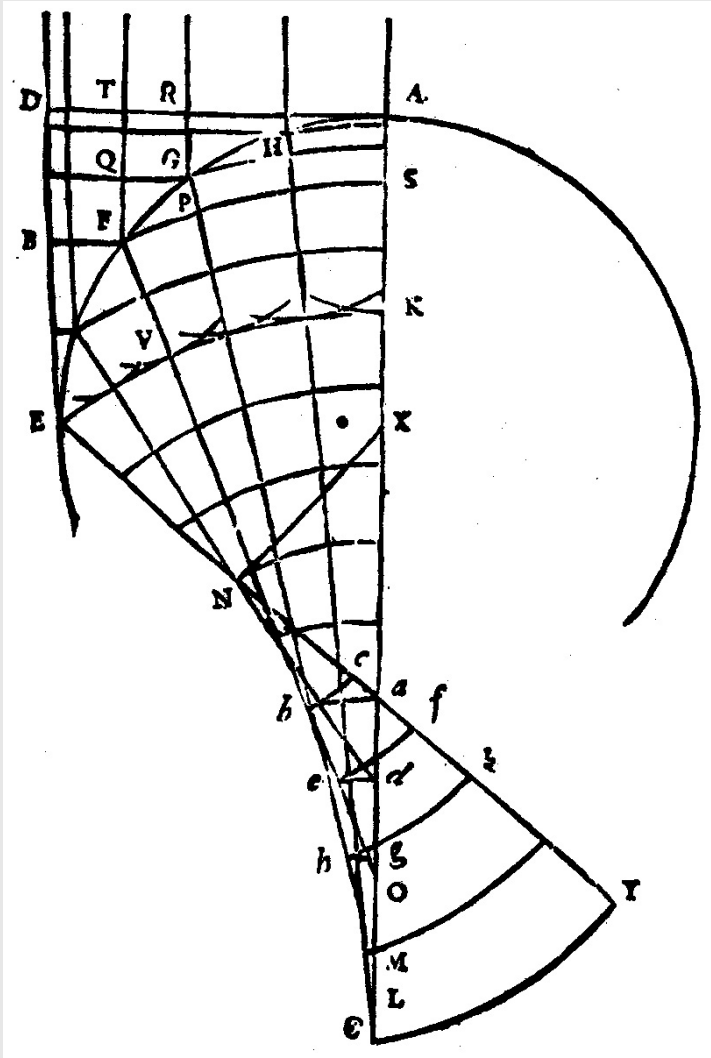
Double Refraction in Iceland Crystal



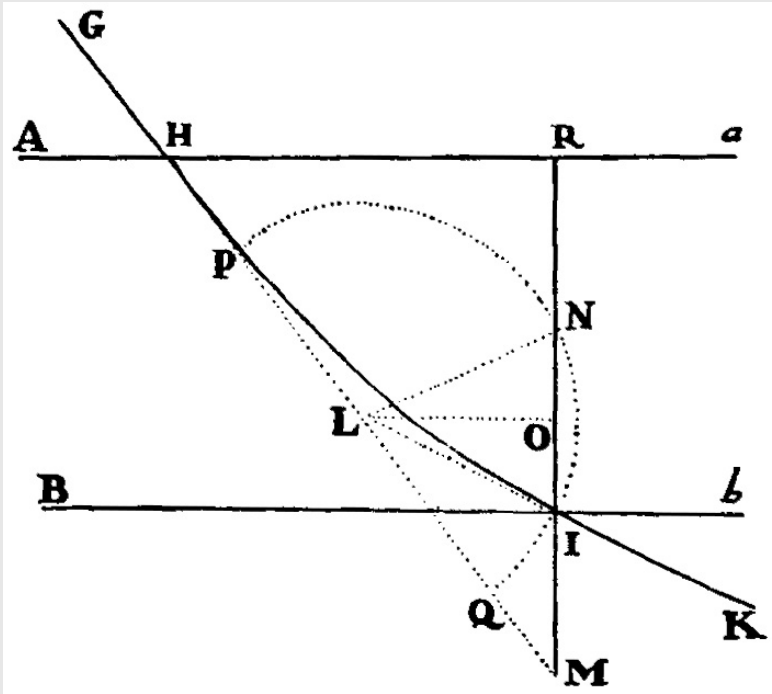
Ellipsoidal Waves in Iceland Crystal



Caustic Curve



Short-Range Force Acts on Light Corpuscles



***Principia*, Bk. I, Prop. 94**

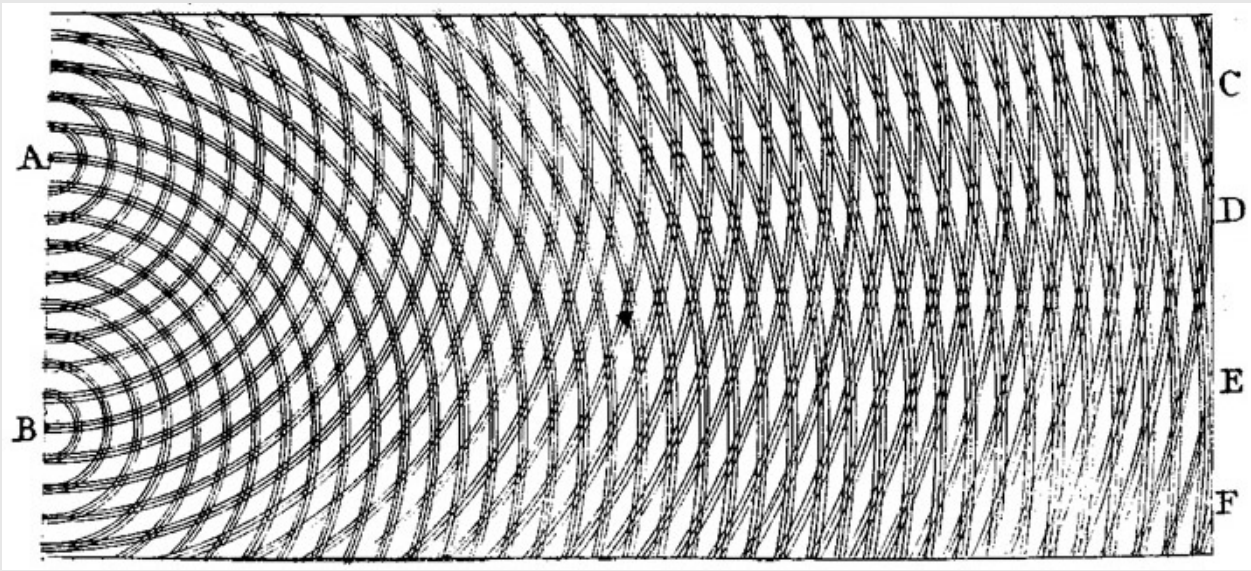
Gravitational Optics

John Michell, 1772-1784

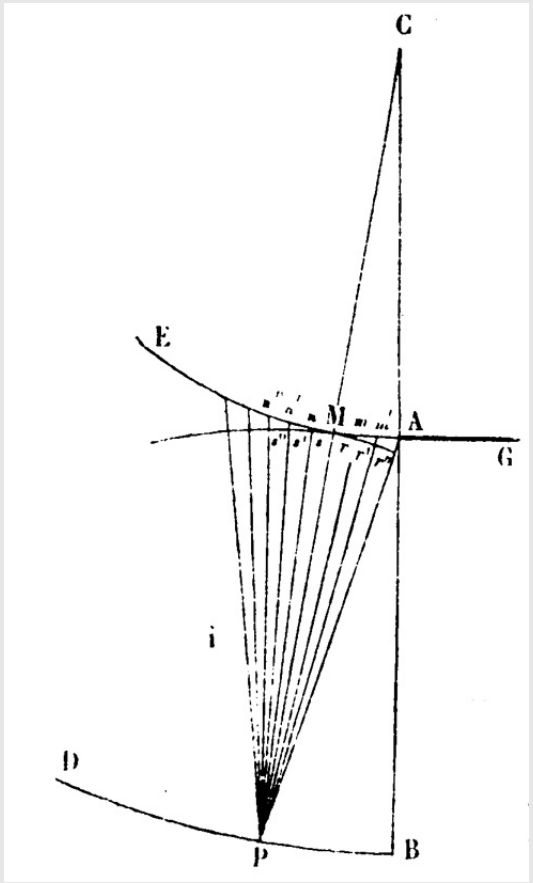
Pierre-Simon Laplace, 1795

Johann Georg von Soldner, 1801

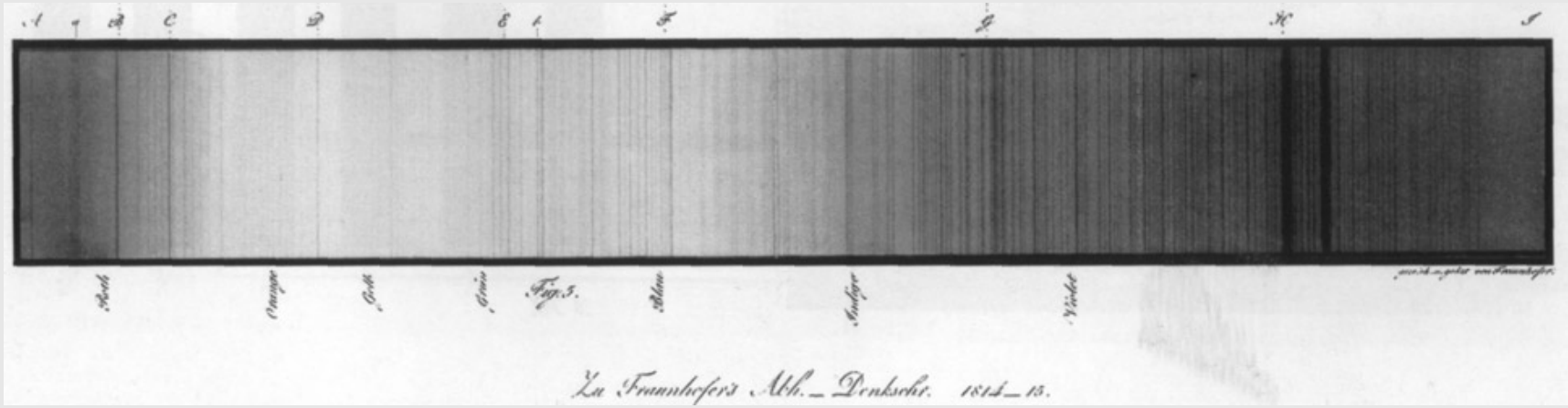
Thomas Young

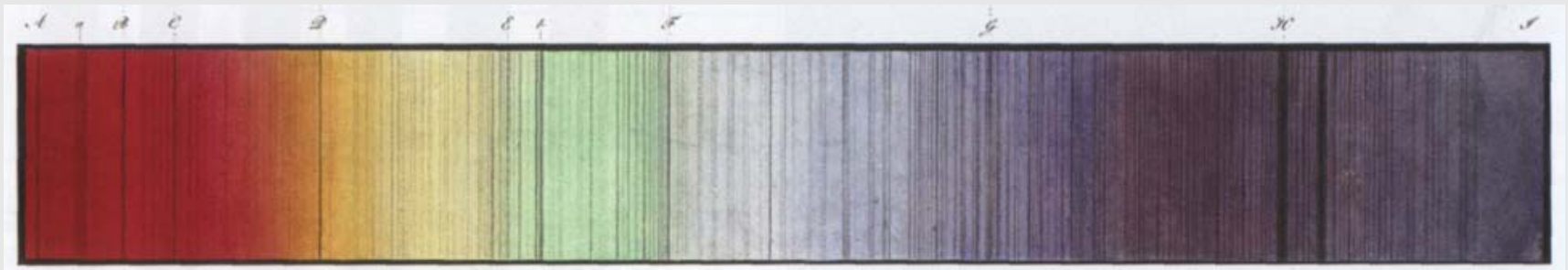


Augustin Fresnel



Fraunhoffer's Spectra





Newton on Emission & Absorption of Light

Quest. 30. Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter their Composition? …
The changing of Bodies into Light, and Light into Bodies, is very conformable to the Course of Nature, which seems delighted with Transmutations.

It seems that the rays of light of different Colours have the greatest share in Natural effects. that for example while the green rays alone are reflected from most plants the rest of the rays are bussy within, and while the blue rays (or otherwise coloured) rays are alone reflected from the flower the rest are busy within.

“On the development of our views concerning the nature and constitution of radiation,” 1909

It is undeniable that there is an extensive group of data concerning radiation which show that light has certain fundamental properties that can be understood much more readily from the standpoint of the Newtonian emission theory than from the standpoint of the wave theory. It is my opinion, therefore, that the next phase of the development of theoretical physics will bring us a theory of light that can be interpreted as *a kind of fusion of the wave and emission theories. … a profound change in our views of the nature and constitution of light is indispensable*.

Particles	Waves
Periodicity	
Aethereal Vibrations. Newton 1670	None. Huygens
Fits. Newton, 1692	Euler, 1746
Polarization	
Sides: Newton, 1706	
Mobile Polarization. Biot, 1812	Transverse Waves: Fresnel, 1821
Interference	
Fits. Newton 1704	Young & Fresnel, *c* 1800-20
Absorption	
Newton: fundamental operation	
Affinities, force:18th century	Post Fresnel

Particles

Waves

Dynamics

Force

Force, Newton, *Principia*, 1687

Gravitational force. Michell, Laplace, Soldner, 1772-1801

Aether

Fluid: Descartes

Elastic Solid: Fresnel, 1821

Electromagnetic: Maxwell, 1873

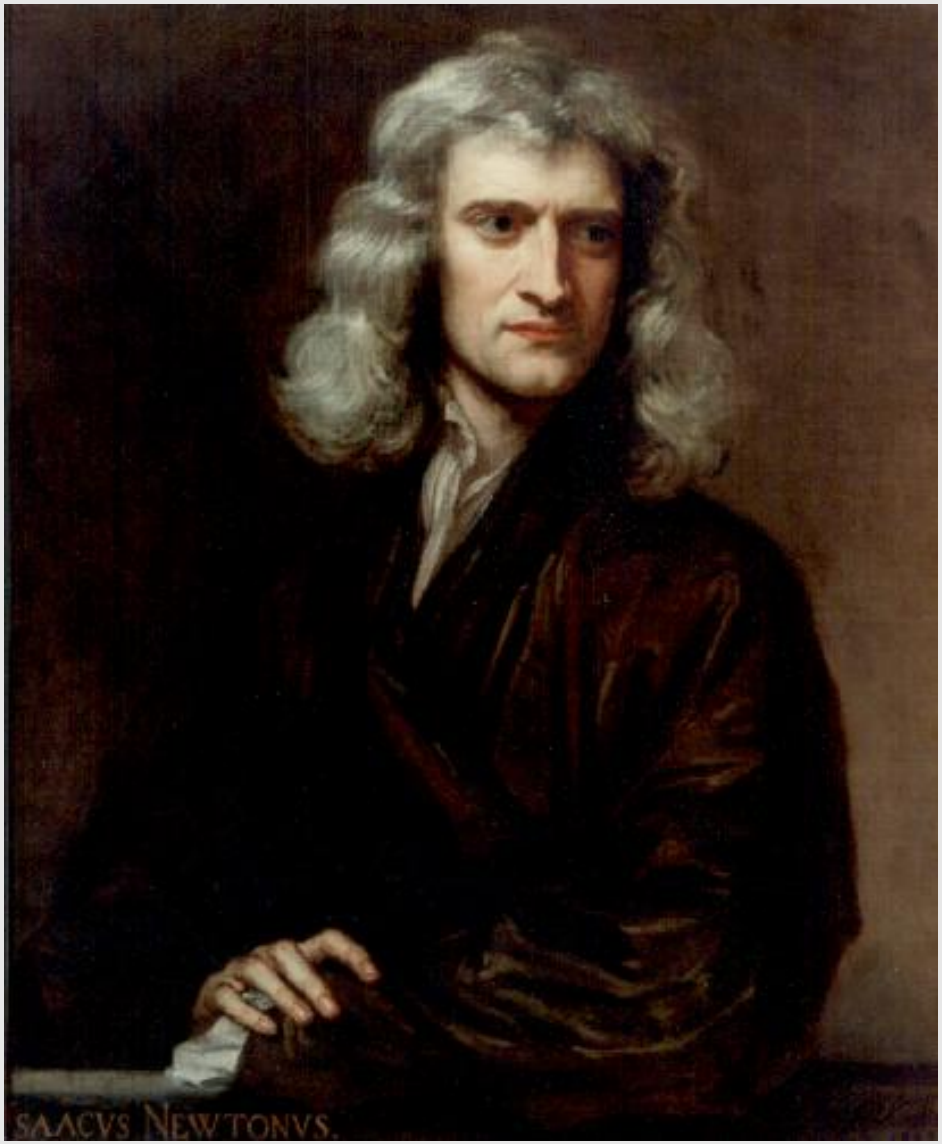
Early Quantum Theory

Photoelectric effect. Einstein, 1905

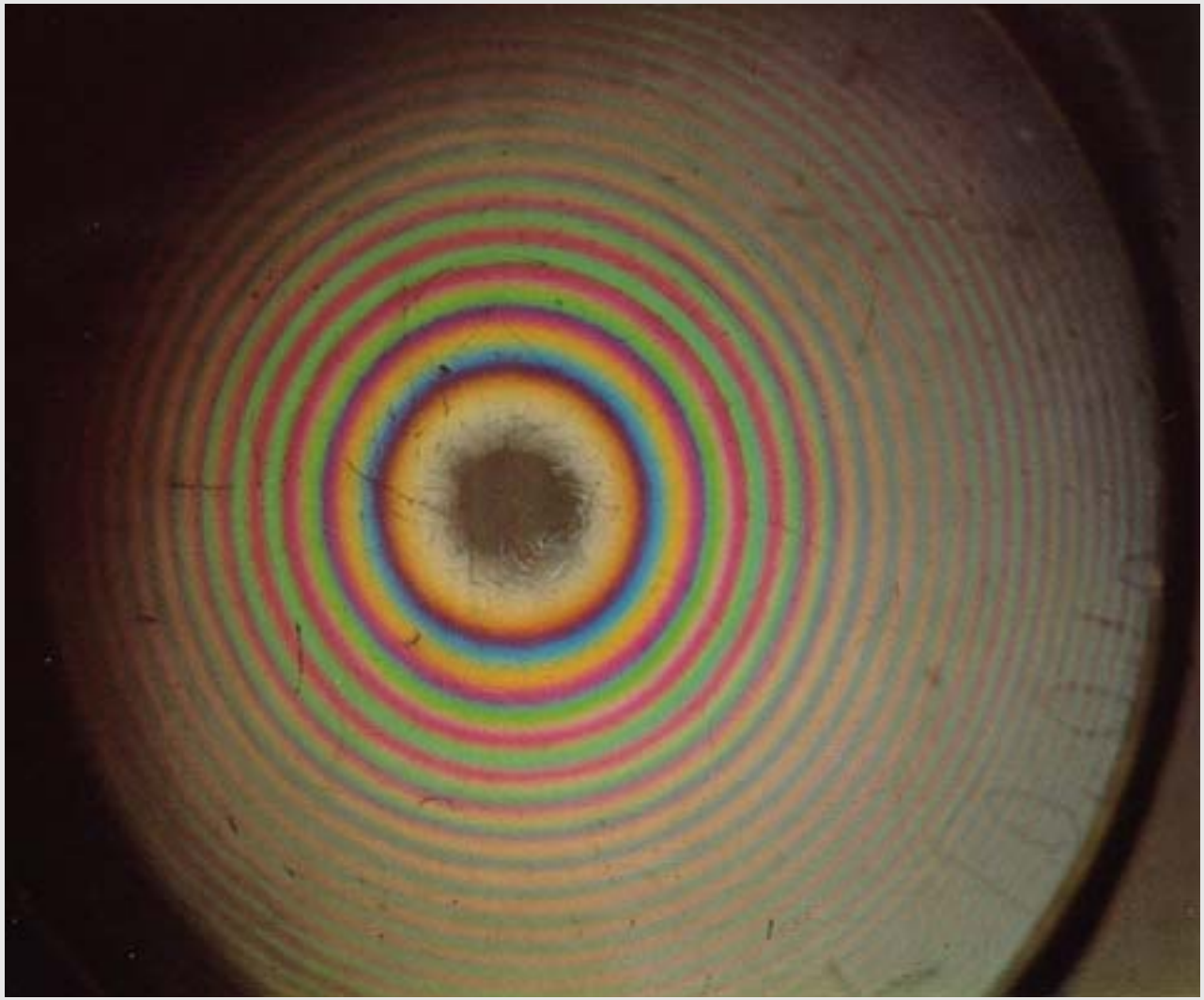
Blackbody radiation. Einstein, 1905

• • •

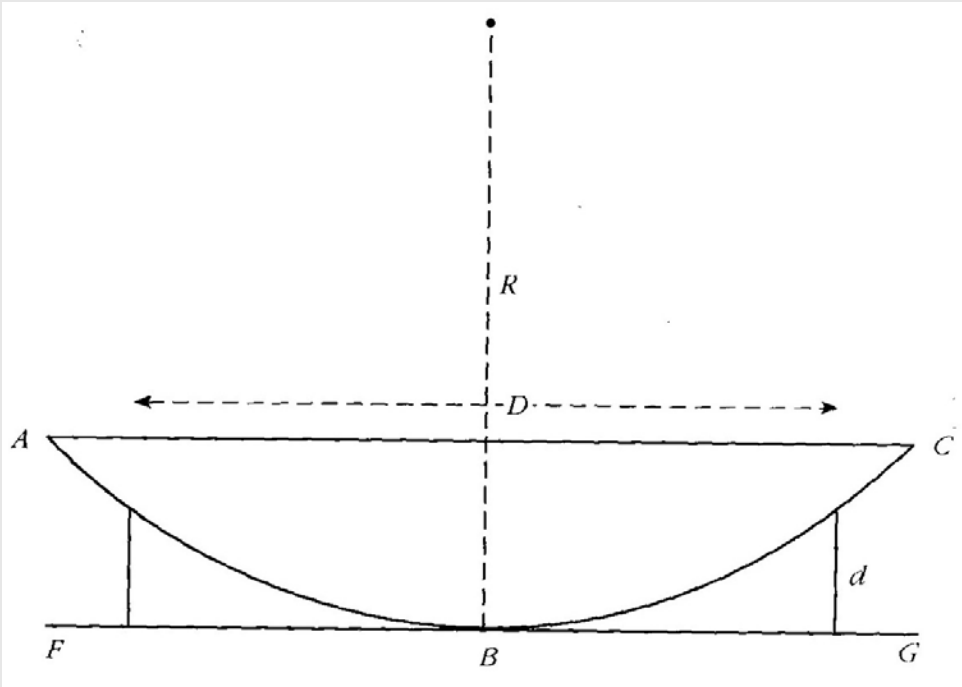
Sir Godfrey Kneller, Newton at 46. 1689



Newton’s Rings, White Light



Newton's Rings



$$d = \frac{D^2}{8R} = \frac{ml}{2}$$

“Of Colours,” 1666

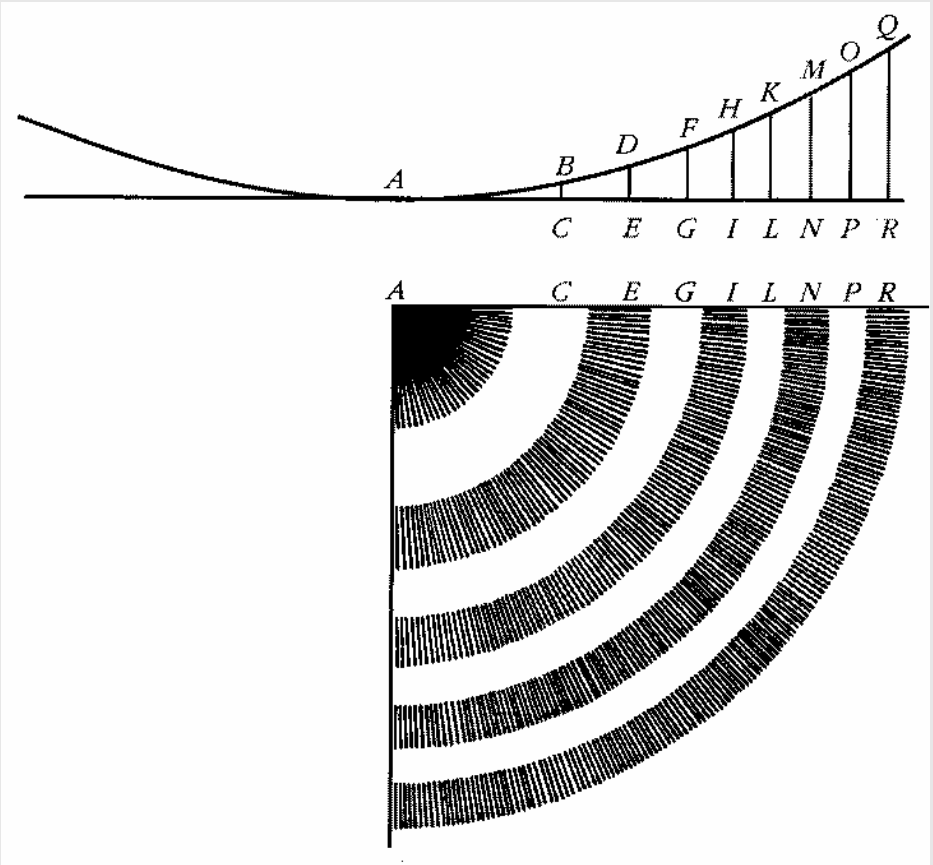
y^{e} thicknesse of y^{e} aire for one circle was 1/64000^{inch} or 0,000015625. [w^{ch} is y^{e} space of a pulse of y^{e} vibrating medium.]

“An hypothesis explaining the properties of light discoursed of in my several papers,” 1675

that no man may confound this with my other discourses, or measure the certainty of one by the other

I suppose Light is neither this Aether nor its vibrating motion.

The Formation of ‘Newton’s Rings,’ 1675



“Of ye Coloured Circles,” *c* 1671

Prop 2. That they [i.e., the coloured circles] swell by y^{e} obliquity of the eye: soe y^{t} the diameter of y^{e} same circle is as y^{e} [co]secants of y^{e} rays obliquity in y^{e} interjected filme of aire, or reciprocally as y^{e} sines of its obliquity; that is, reciprocally as y^{t} part of the motion of y^{e} ray in y^{e} said filme of aire w^{ch} is perpendicular to it, or reciprocally as y^{e} force it strikes y^{e} refracting surface wthall.

Prop 3. And hence y^{e} spaces w^{ch} y^{e} rays passe through twixt y^{e} circles in one position to the said spaces in another position are as y^{e} squares of y^{e} said [co]secants or reciprocally as y^{e} [s]quares of y^{e} sines, motion, or percussion

OPTICKS:

OR, A

TREATISE

OF THE

REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS

OF

LIGHT.

ALSO

Two TREATISES

OF THE

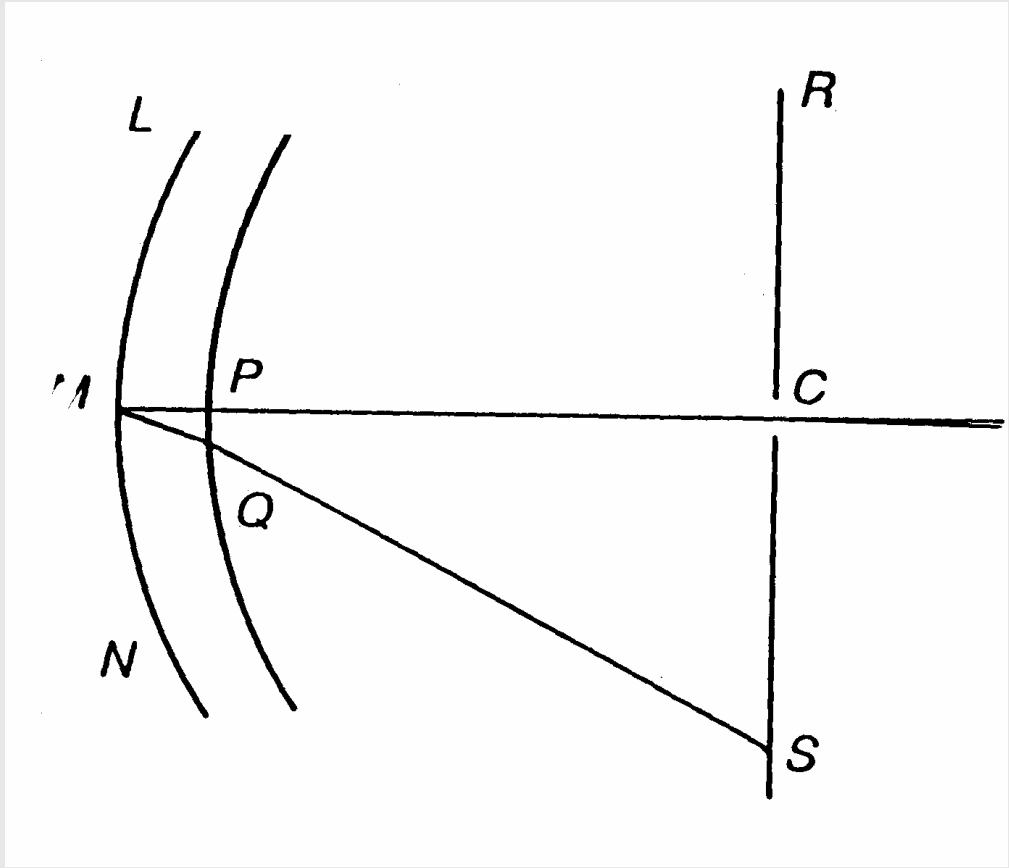
SPECIES and MAGNITUDE

OF

Curvilinear Figures.

LONDON,
Printed for SAM. SMITH, and BENJ. WALFORD,
Printers to the Royal Society, at the *Prince's Arms* in
St. *Paul's* Church-yard. MDCCIV.

Colors of Thick Plates



Definition of a Fit
Thomas Willis, *De febribus*, translated 1684

It hath certain remissions, or times of intermission; that every fit [*paroxysmus*] begins with cold or shaking, for the most part, and ends in sweat; that the accessions or coming of the fits, return at set Periods, and certain intervals of times, that a Clock is not more exact.

Fits, *Opticks*, 1704

PROP. XII.

Every ray of Light in its passage through any refracting surface is put into a certain transient constitution or state, which in the progress of the ray returns at equal intervals, and disposes the ray at every return to be easily transmitted through the next refracting surface, and between the returns to be easily reflected by it.

DEFINITION

The returns of the disposition of any ray to be reflected I will call its *Fits of easy reflexion*, and those of its disposition to be transmitted its *Fits of easy transmission*, and the space it passes between every return and the next return, the *Interval of its Fits*.

Fits, *Opticks*, 1704

PROP. XIII

The reason why the surfaces of all thick transparent bodies reflect part of the light incident on them & refract the rest is that some rays at their incidence are in Fits of easy reflexion & others in Fits of easy transmission.

…

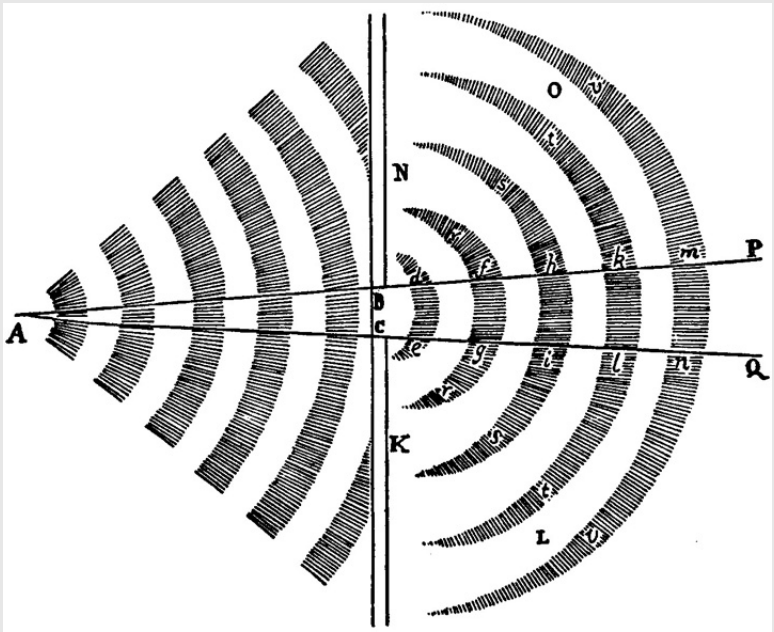
And hence light is in fits of easy reflexion & easy transmission before its incidence on transparent bodies. And probably it is put into such fits at its first emission from luminous bodies & continues in them during all its progress.

“What kind of action or disposition this is? Whether it consist in a circulating or a vibrating motion of the ray, or of the medium, or something else? I do not here enquire.”

For “those that are averse from assenting to any discoveries, but such as they can explain by an Hypothesis.”

Just like a stone thrown in water, light rays incident upon a body: “excite vibrations in the refracting or reflecting medium or substance... that the vibrations thus excited... move faster than the rays so as to overtake them; and that when any ray is in that part of the vibration which conspires with its motion, it easily breaks through a refracting surface, but when it is in the contrary part of the vibration which impedes its motion, it is easily reflected; and, by consequence, that every ray is successively disposed to be easily reflected, or easily transmitted, by every vibration which overtakes it.”

Newton's Objection to a Wave Theory of Light

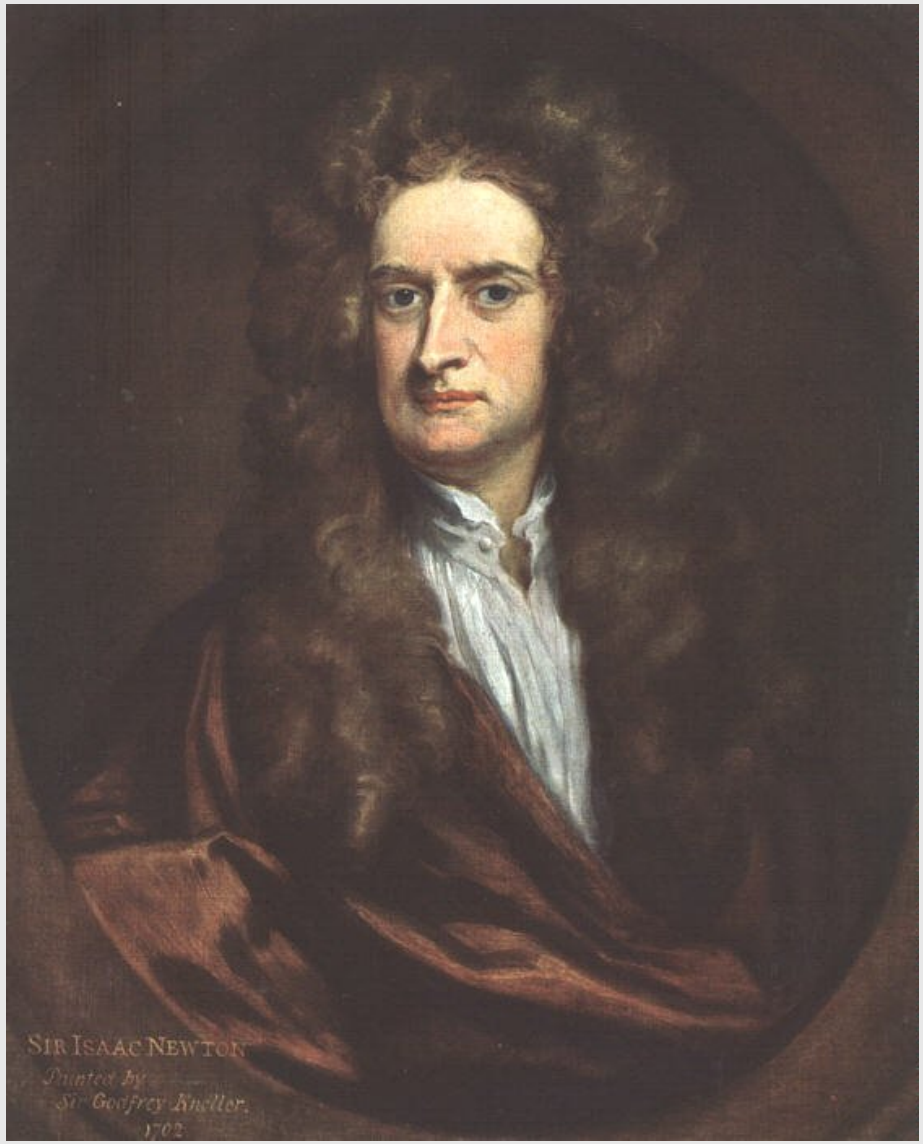


Principia, 1689, Bk. II, Prop. 41

to me the fundamentall supposition it selfe seemes impossible, namely that the waves or vibrations of any fluid can like the rays of Light be propagated in streight lines, without a continuall & very extravagant spreading & bending every way into y^{e} quiescent Medium where they are terminated by it. I am mistaken if there be not both *Experiment* & *Demonstration* to the contrary.

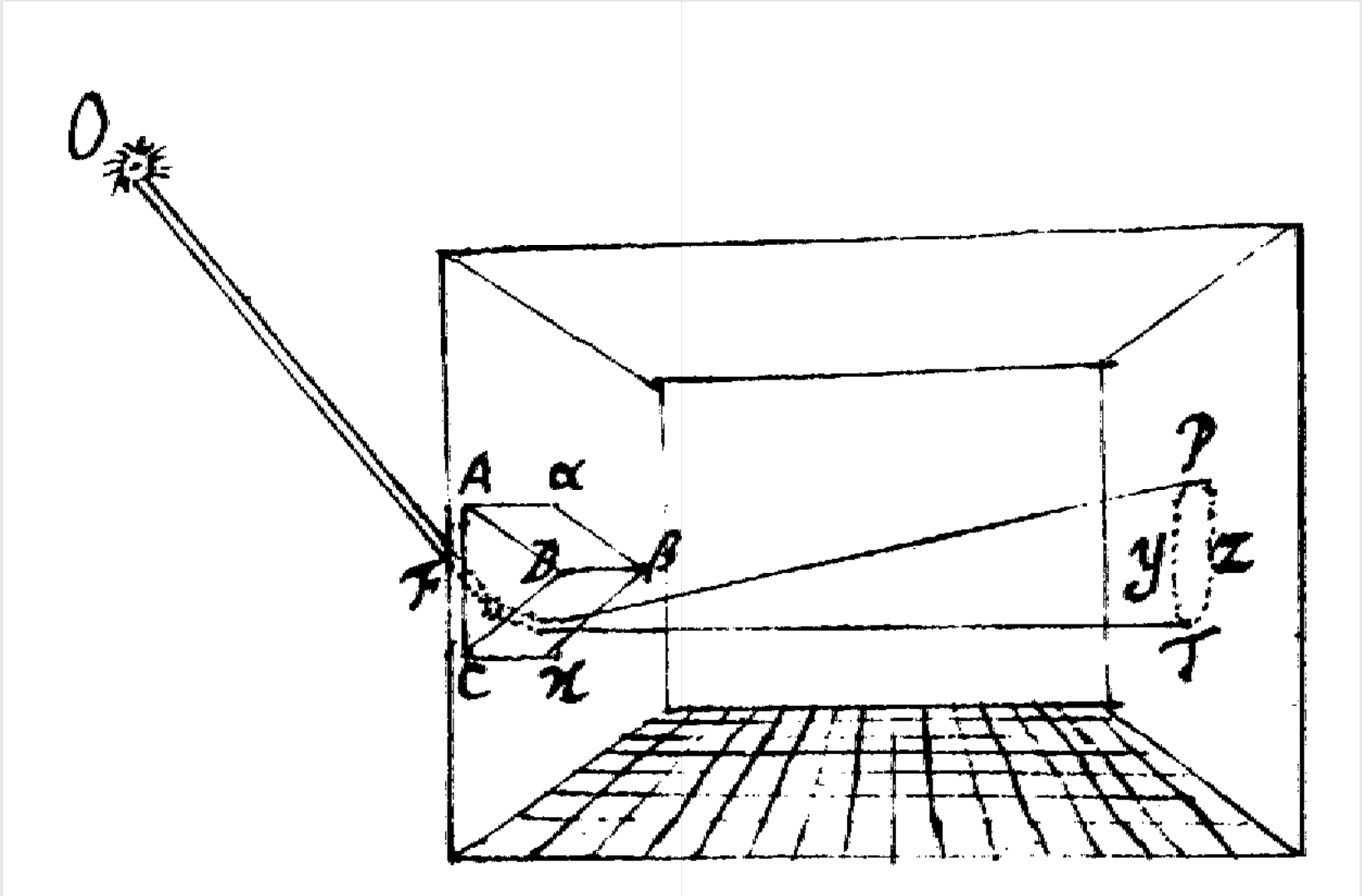
Newton to Hooke, June 11, 1672

Sir Godfrey Kneller Newton at 59, 1702



Newton's basic spectrum experiment

Optical Lectures



Einstein's Forward to *Opticks*, 1931

FORTUNATE Newton, happy childhood of science! … Nature to him was an open book, whose letters he could read without effort. The conceptions which he used to reduce the material of experience to order seemed to flow spontaneously from experience itself, from the beautiful experiments which he ranged in order like playthings and describes with an affectionate wealth of detail. … He stands before us strong, certain, and alone: his joy in creation and his minute precision are evident in every word and in every figure.