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The eye stays in the picture: The emergence of virtual images in early modern optics

Outline of my talk:

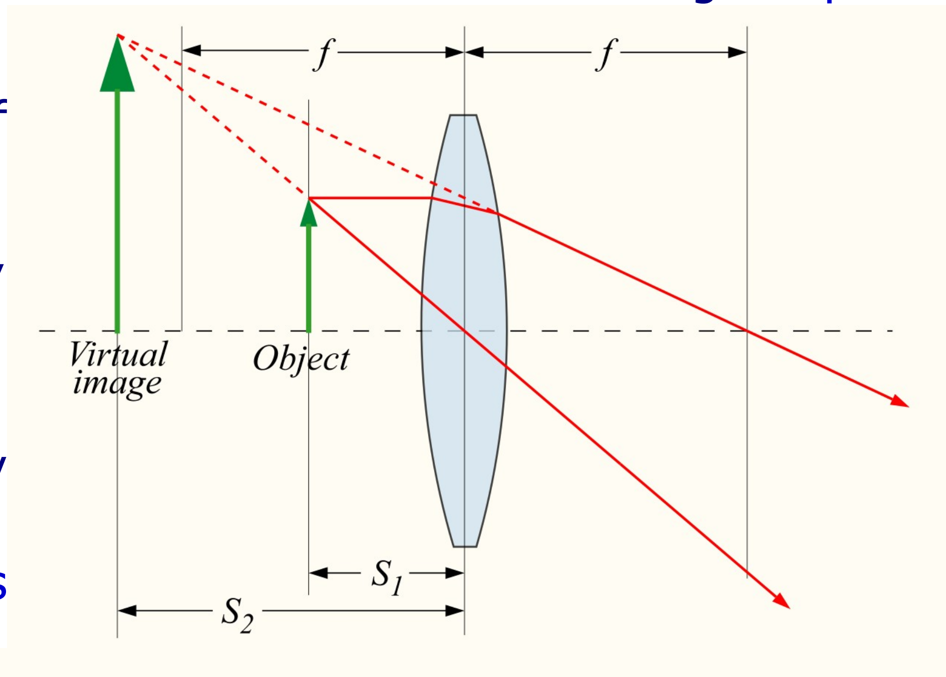
- initial remaks: real and virtual images - not a simple notion!
- the changing relationship between optical diagrams and the emerging notions of real and virtual image
    - pre-modern times: the cathetus rule and the eye in the picture
    - the long seventeenth century (ca. 1590-1715): the emergence of a purely geometric notion of image: getting the eye out of the picture
    - a quick look at the nineteenth century: is the eye really out of the picture?

Thesis: Real and virtual images may seem simple - but they are not!

- they are abstract constructs inextricably linked to optical diagrams
- they have a complex relatioship to experience
- they cannot be fully distinguished from each other in the general case

[like real/virtual particles?]

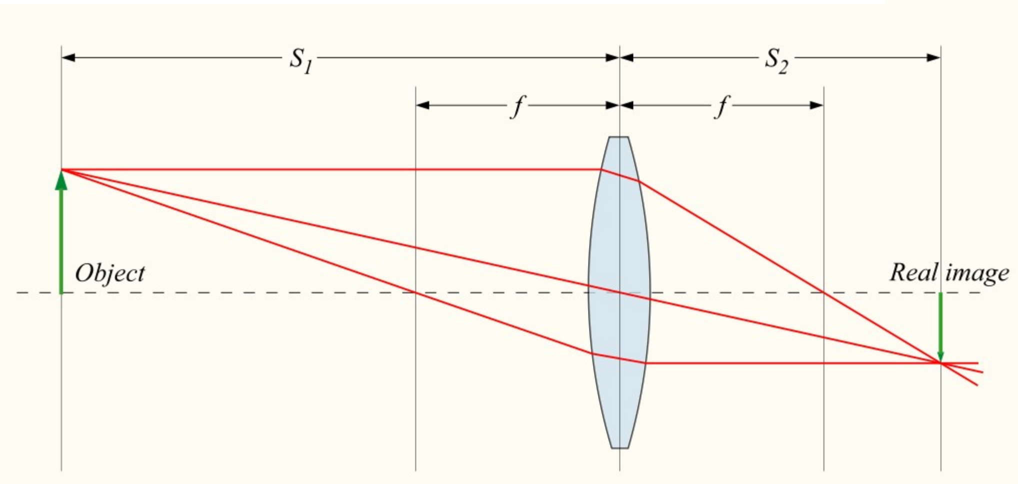
Today's real and virtual images in convex lenses as defined through optical diagrams



virtual image: intersection of prologation of refracted rays, upright

real image: intersection of rays, inverted

The notions appear immediately linked to visual experience...
....but both real and virtual images



are seen where drawn only thanks to binocular vision!

Moreover, not all images are easily classified and it does not cover many optical experience (e.g. images in a glass sphere)

In short:

- neither the "real" not the "virtual" images are clearly defined in terms of observational procedures: they are theoretical constructs

- if you wish to make contact to experience, then the eye has to come into the picture

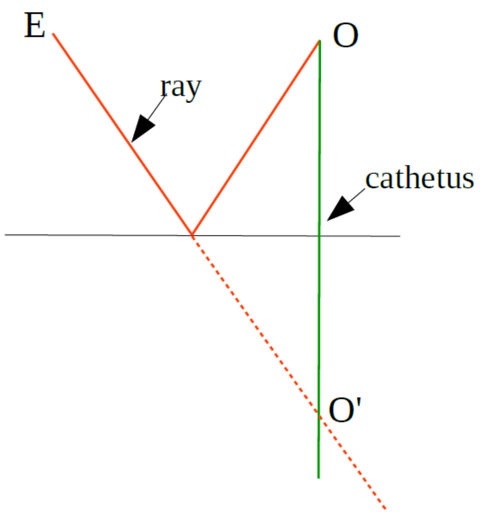
Let us see how this construct emerged, and how the eye was (only apparently) drawn out of the picture....

Ancient and medieval times: the “cathetus rule” for image construction

the image O' of an object O is seen by the eye E at the intersection of two lines:

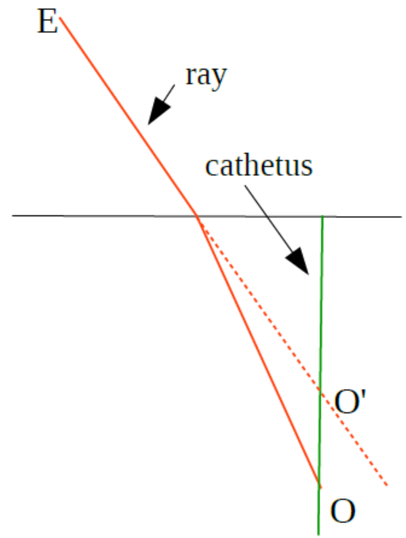
a) the (prolongation of the) reflected or refracted ray that reaches the eye E

b) the cathetus=perpendicular through O to the reflecting/refracting surface



reflection

refraction



The cathetus rule gives an empirically fitting constructio procedure for plane reflection and refraction – but what is the "cathetus", physically? Unclear!

N.B. the cathetus rule needs the eye for image construction

Renaissance/early modern period:

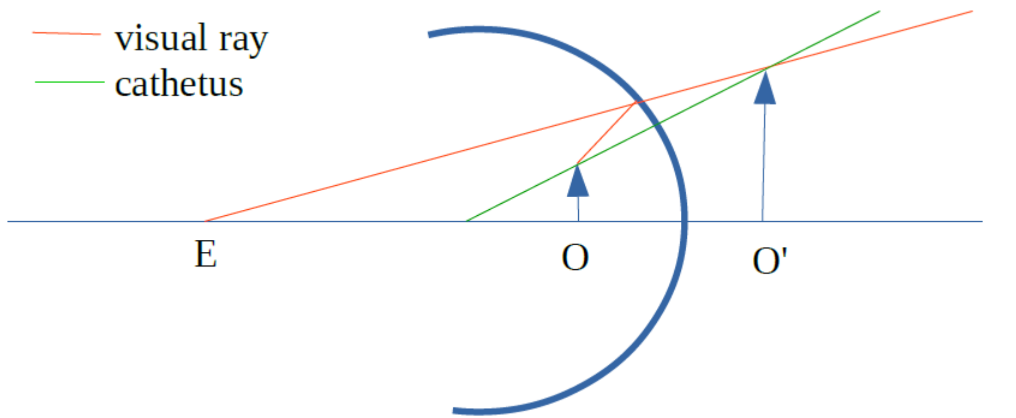
new "crystal glass" (transparent, homogeneus), new ways of polishing it

--> new optical devices (glass mirrors, spheres, lenses)

--> new visual experiences: images inverted, or "hanging in the air"

by ca. 1550: cathetus rule extended to spherical mirror
cathetus = radius of the spherical surface (always perpendicular to it)

it works! and who cares
what the cathetus is.....



Giovanni Battista Della Porta

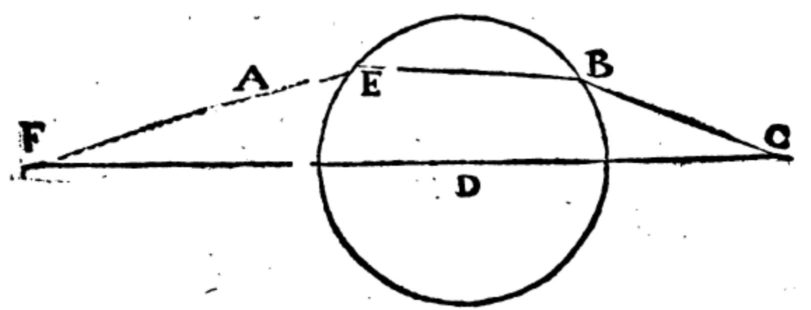
"De refractione" (1593)

Della Porta adaptats cathetus rule to the glass sphere (in analogy to the spherical mirror)

Della Porta describes various cases, among them one where

an image is seen "hanging in the air"

(here in F, where A is the eye,
and C the object)



Despite many efforts, Della Porta never manages to adapt the cathetus rule to biconvex or -concave lenses --> *how can one locate the image without cathetus?*

Johannes Kepler - Dioptrice (1611)

- Kepler rejects the cathetus rule, uses only reflected and refracted rays
- he draws many "qualitative" diagrams, which do not follow any precise optical-geometrical rule
- he introduces a distinction later be presented as the one between real and virtual image:

"pictura" = where rays converge, you can capture it on a piece of paper

"imago" = only the prolongations of rays converge

Kepler (qualitatively) locates the "imago" using (something like) binocular vision, while "pictura" is located on the surface where it is projected

---> Kepler underscores a distinction already known

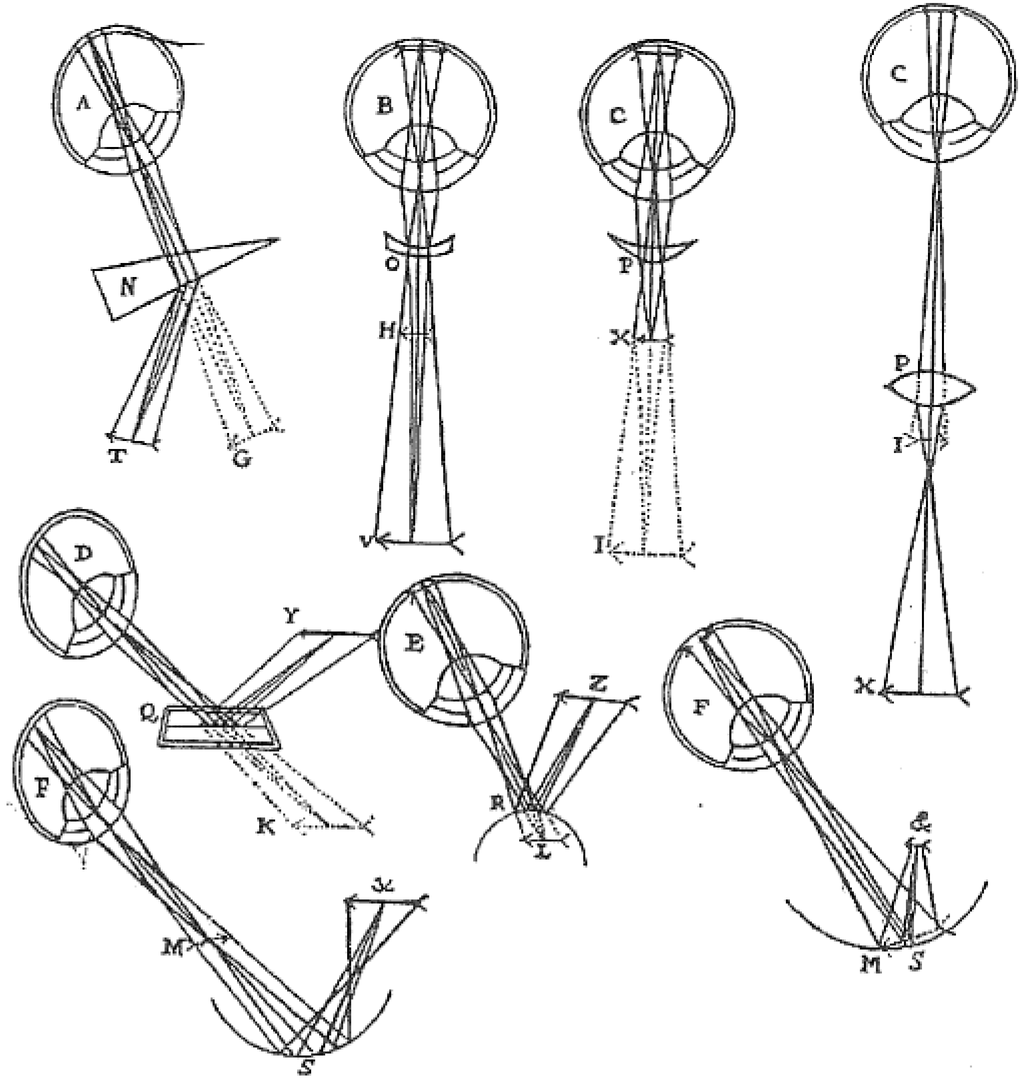
---> *Kepler rejects the cathetus, but does not provide any alternative geometrical rule for locating the image*

René Descartes: *La Dioptrique* (1637)

Descartes formulates the
sinus rule of refraction

He includes diagrams on
refraction and the eye (see
figure)....

... but states no rules for
image construction!



Late 17th and early 18th century:

- further study of the geometrical properties of lenses
- determination of the location of the focus of lenses of various kind
- special interest: construction of telescopes, microscopes etc.

I will discuss just a few authors particularly interesting for our theme - no general treatment of the evolution of geometrical optics intended!

Those interested in more, see:

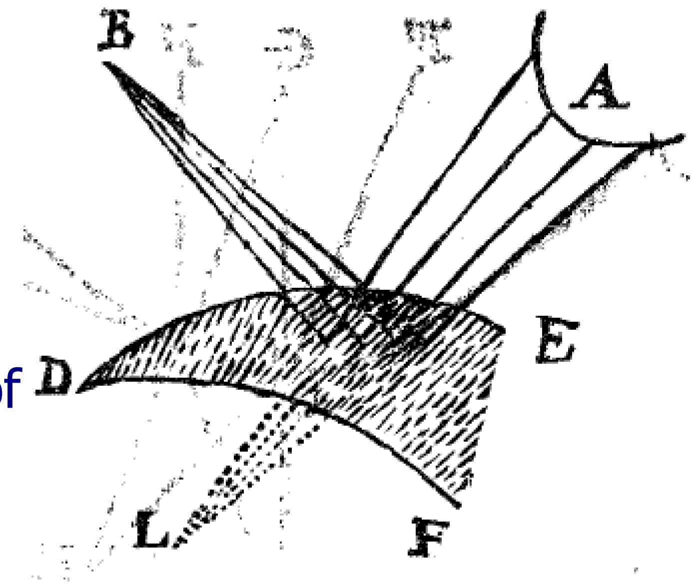
A. E. Shapiro, "Images: Real and Virtual, Projected and Perceived, from Kepler to Dechales" *Early Science and Medicine* 13 (2008): 270–312

O. Darrigol, *A History of Optics from Greek Antiquity to the Nineteenth Century* (2012)

James Gregory, *Optica promota* (1663)

- Gregory derives sine formula of refraction (independently from Descartes) and the position of the focus of various lenses - he describes the "Gregorian telescope"

- images are constructed as points of convergence or divergence of reflected/refracted rays [or their continuation] - no distinction is made whether an image can or cannot be projected on paper



how does the eye estimate the posittion of a reflected image? through the different rays reaching the eye A!

the image presents a very problematic construction, where the extended surface of the eye is used to argue that the image is seen at the convergence of the rays' prolongations

Francesco Eschinardi, *Centuria problematum opticorum* (1666-1668)

- Eschinardi discusses lenses, mirrors, telescope and microscope
- he (a Jesuit) uses the cathetus line for explaining image position in plane reflection, but admits it's problematic for more complex systems
- he uses the term to indicate any point of convergence of rays or their prolongation (not only what we call focus!)

  "real focus": intersection of rays, image can be projected on paper

  "fictive or imaginary focus": intersection of prolongation of rays

  "basis": as focus, but more extended, also real or fictive/imaginary

- he provides quantitative rules for computting the releative positions of "focus", object and lense - makes no attempt expaining image location

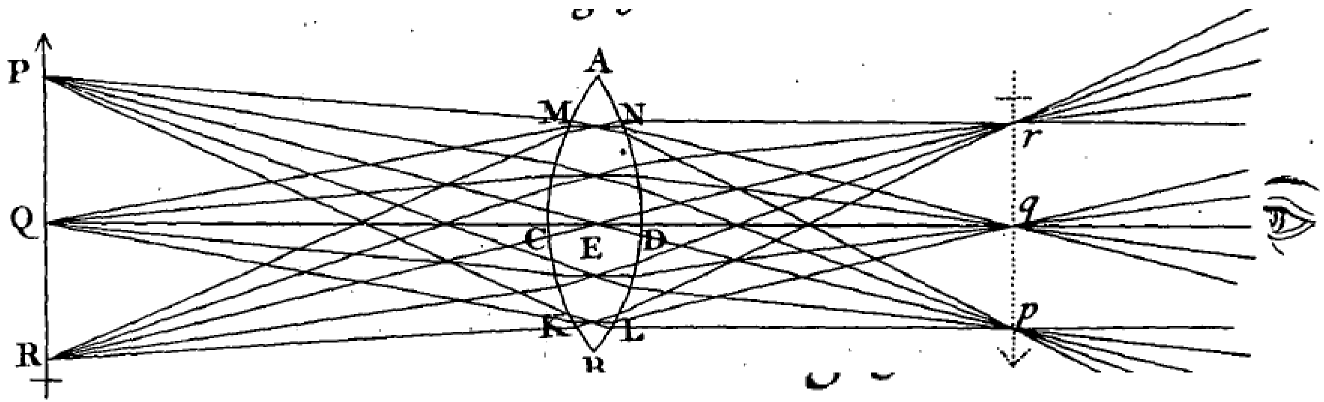
--> Eschinardy uses a distinction similar to real/virtual image, but is aware that it does not explain image location like the cathetus rule!

Claude Deschales *Cursus seu mundus mathematics* (1674)

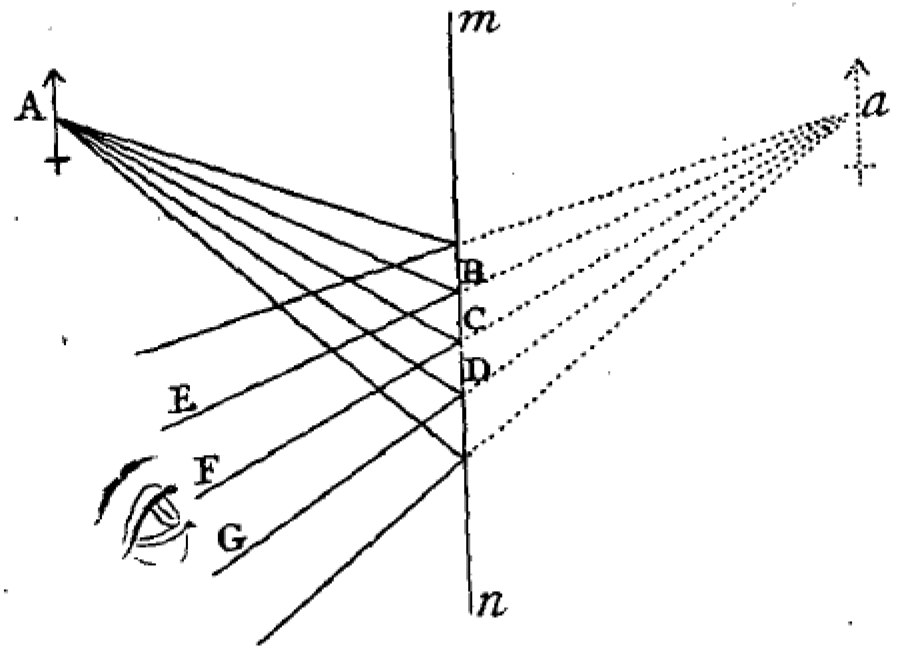
- Deschales probably builds upon Eschinardi, but does not quote him
- he is relevant for us because he introduces the term "virtual" for the focus and the image
- convex lenses: real, true focus/image - rays converge, image can be captured on paper
- concave lenses: virtual focus/image: rays diverge, seems to come from one point
- he does not discuss image location, but only the geometrical constructions

Isaac Newton, *Optics* (1. ed. 1704, 4th ed. 1730)

axiom VII: rays converging in a point form a "picture" which can be projected on a white object - and can be seen by the eye



axiom VIII:
"*An object seen by reflection or refraction appears in that place from whence the rays after their last reflection or refraction diverge in falling on the spectator's eye*"



A figure similar to Gregory's?

In the 18th and 19th century, geometrical optics became increasingly important for the construction of optical instruments, but the term "virtual" did not appear often, it at all (work in progress!)

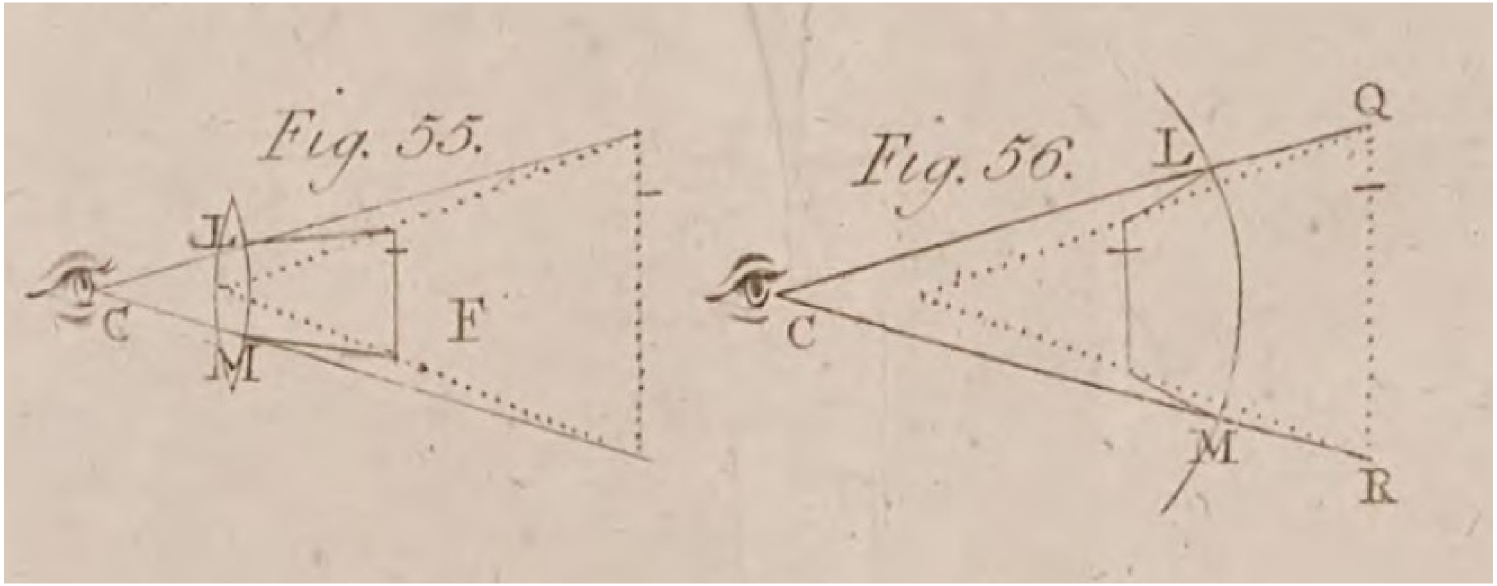
in general, the distinction virtual/real was rarely underscored - possibly because not relevant for the practical purposes on instruments-makers, and perhaps problematic because of the problem of image location

Although at this point work is still very much in progress, I would like to finish with a quick jump forward in time....

John Stack, *A short system of optics* (1783)

Stack discusses geometrical constructions, but the opposition virtual/real images is not used, under this or other name - at one point, though, he states that images formed by a concave lens are "only imaginary" because the rays do not really meet

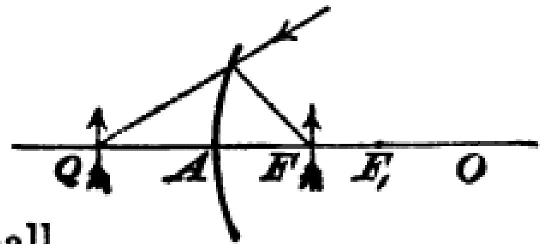
In the diagrams discussing magnification, the eye appears, but with a very different role than in Gregory or Newton: it indicates the angle of vision - there is no discussion of image location



Stephen Parkinson, *A treatise on optics* (1859, 3rd. ed. 1870)

Parkinson does not use the term "virtual"

He introduces geometrical optical constructions, but notes the difference between "geometrical image" and "visible image"



26. *Obs.* In the diagrams of the preceding Art. a small object has been placed in the position of *Q*, and its *geometrical image* in the position of *F*, as a guide to the student in tracing the form of such an image relatively to the object: understanding by *geometrical image*, the locus of the geometrical foci of pencils diverging from consecutive points of the object, and reflected at the surface.

This *geometrical image*, will rarely coincide with the *visible image* as seen by an eye in a given position. In a subsequent chapter we propose to give a method of determining the visible image in ordinary cases.

the abstract character of diagrammatic images is acknowledge

Osmond Airy, *Geometrical optics* (1870) - one of the earliest school-textbooks of geometrical optics

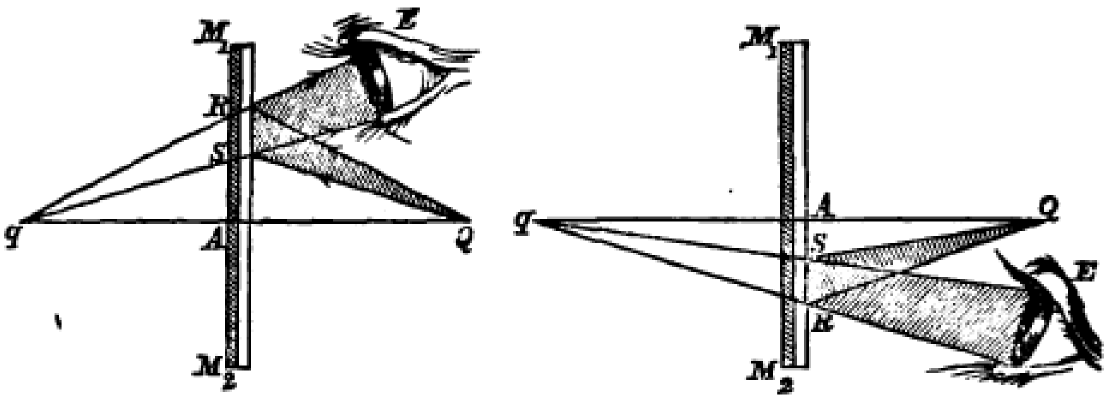
---> *here virtual and real images are prominent!*

"An image through which rays do not really pass is called virtual. An image through which rays pass is called real"

"A virtual image may be described as an image that does not exist until there is an eye to receive the rays. The eye calls the image, though not the rays, into existence."

But can you really see virtual images? Airy tries to connect them to the experience of seeing - with the same trick as Gregory and Newton!

Fig. 6.



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