Photographic Technology

PhotoTechEDU series

Lecture 1: January 17, 2007

Overview: optical image formation, ideal camera, exposure settings, DOF, etc.

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Photography:
Writing with Light

- Light is the magical substance that makes it work.
- Human vision is the ultimate judge of whether it works.
- Technologies to form images, sense light and color, represent and reproduce images, etc., are under our control if we can understand them sufficiently well.

No Magic

- Just *technology*
- Respect physics
- Please your eye
- Play some tricks
- Have fun

- Photo by Steve Chong

(Lyon's) Three Laws of Photodynamics

1. Even an ideal camera needs enough light to make a good photo.
2. There's no such thing as an ideal camera.
3. The closer you can come to the ideal camera, the better.

Learn to compute how much light is needed under what circumstances, and why, and what non-idealities make matters worse, and how to mitigate them.

Rays: Kepler's 1604 explanation of the longstanding pinhole imaging anomalies

The problem of pinhole images was well-known in perspectiva. It was known since Antiquity that the image of the sun, projected by a square aperture, can still be round. This seemed to contradict the basic principle of optics: the rectilinearity of light rays. The solutions given by perspectivist writers did not satisfy Kepler. Each had in the end sacrificed the principle of rectilinearity – the foundation of geometrical optics.[60] Kepler had to resolve the problem by himself. His solution consisted of a new theory of the way rays form images of objects. This theory, in its turn, would be the foundation of his dioptrics as well as of seventeenth-century geometrical optics in general.

Kepler approached the problem anew and did so by uncompromisingly applying the principle of rectilinearity. In *Paralipomena*, he describes how he replaced a ray of light by a thread. He took a book, attached a thread to one of its corner and guided it along the edges of a many-cornered aperture, thus tracing out the figure of the aperture. Repeating this for the other corners of the book, and many more points, he ended up with a multitude of overlapping figures that formed an image of

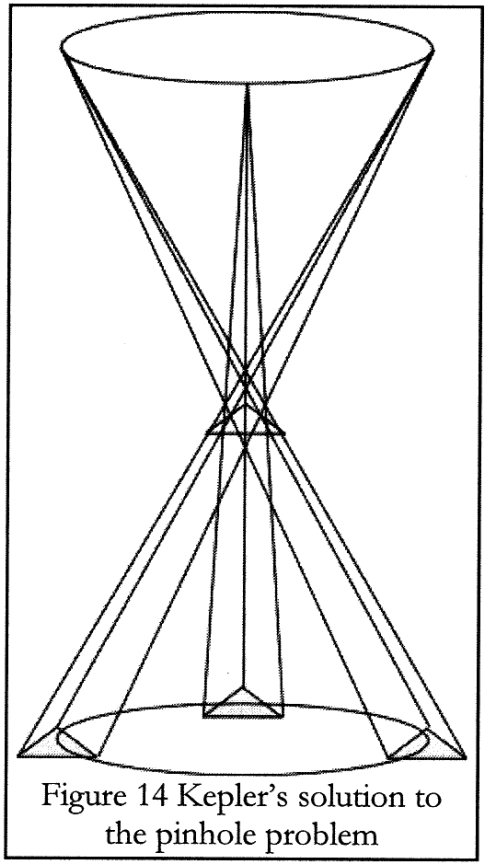
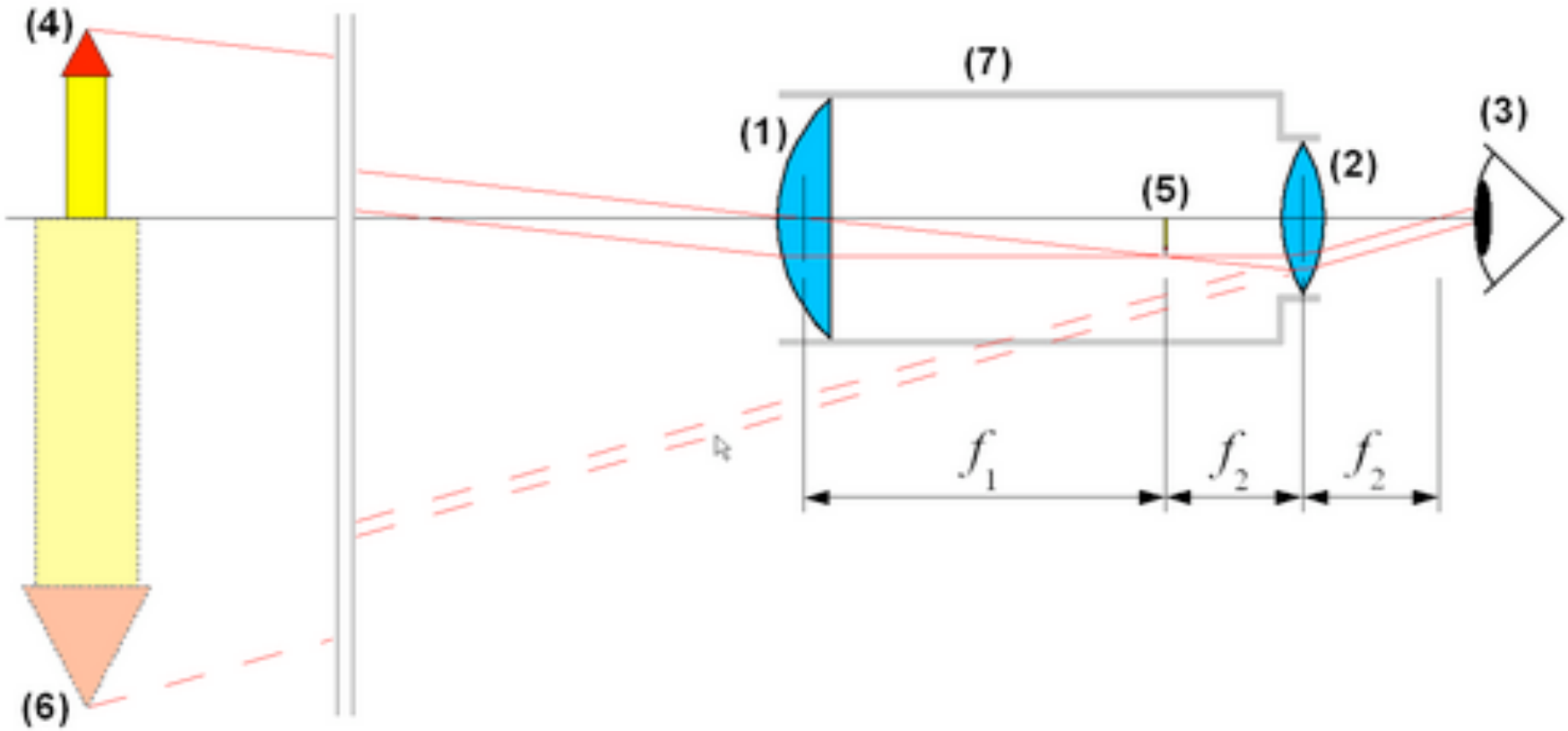
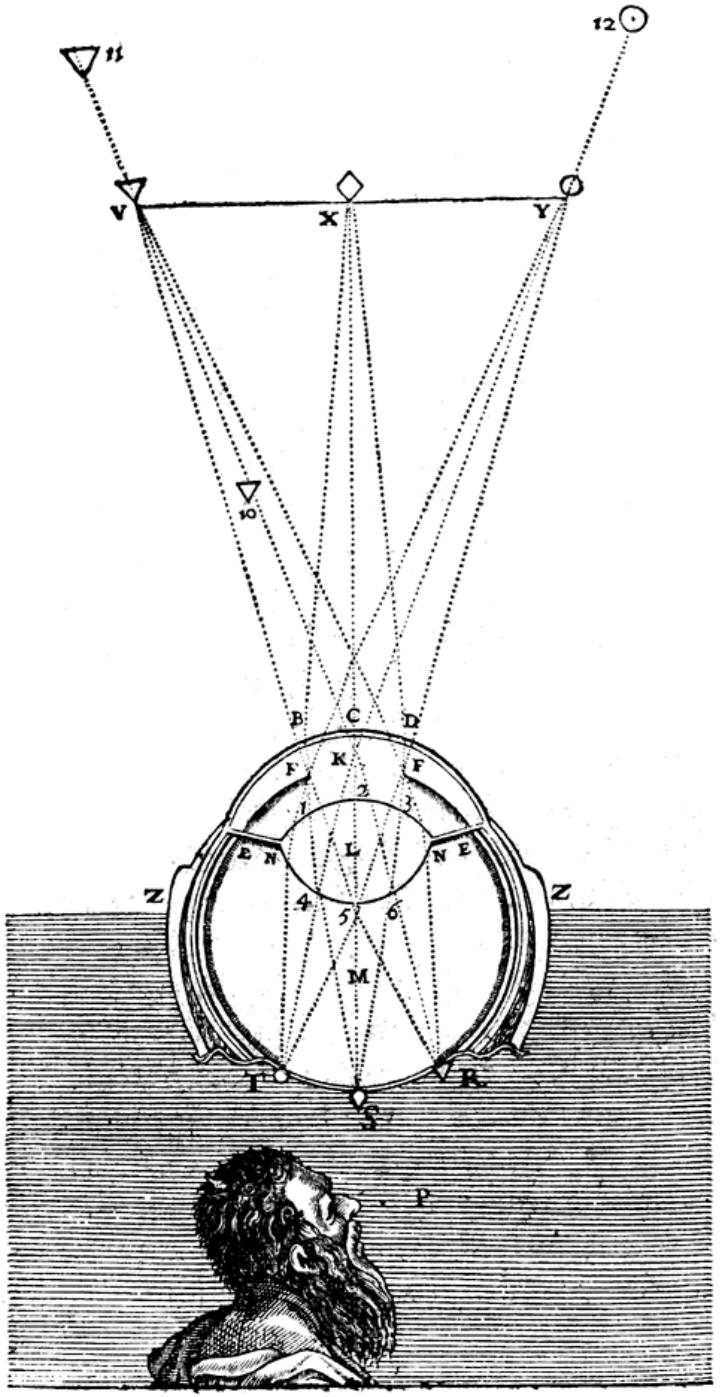


Figure 14 Kepler's solution to the pinhole problem

F. J Dijksterhuis, *Lenses and Waves: Christiaan Huygens and the Mathematical Science of Optics in the Seventeenth Century,* Kluwer, 2004

Kepler's *Dioptrice*: geometric optics driven by telescopes, before Snell's law of refraction was known





The Eye, Rays, and Waves of Light

- Inverted image formation by refraction in the eye: Descartes' *La Dioptrique*
- Descartes' or Snell's *Law of Sines* follows from Fermat's *principle of least time*
- Wave explanation by Huygens' *Dioptrics* and *Treatise on Light* (1689)
- Waves and diffraction are *ideal* effects, in that they are based on fundamental physics of light

Light as Particles: Planck and Einstein

- The ideal sensor makes a 2D histogram: counts of *photons* received at every location in a plane
- *Locations* finely divided, compared to the diffraction-limited ideal lens response
- *Shot noise* comes from the ideal statistical distribution of counts of independent photon absorption events: *Poisson distribution*

ZEHNTES KAPITEL.

Die photograph-optischen Apparate.

Construction der Camera-obscura. — Fernrohrbilder. — Die Laterna magica. — Der Vergrösserungsapparat. — Das Stereoskop.

Wir haben eben gezeigt, dass eine Linse im Stande ist, vergrösserte und verkleinerte Bilder von Gegenständen zu erzeugen, je nach der Entfernung derselben.

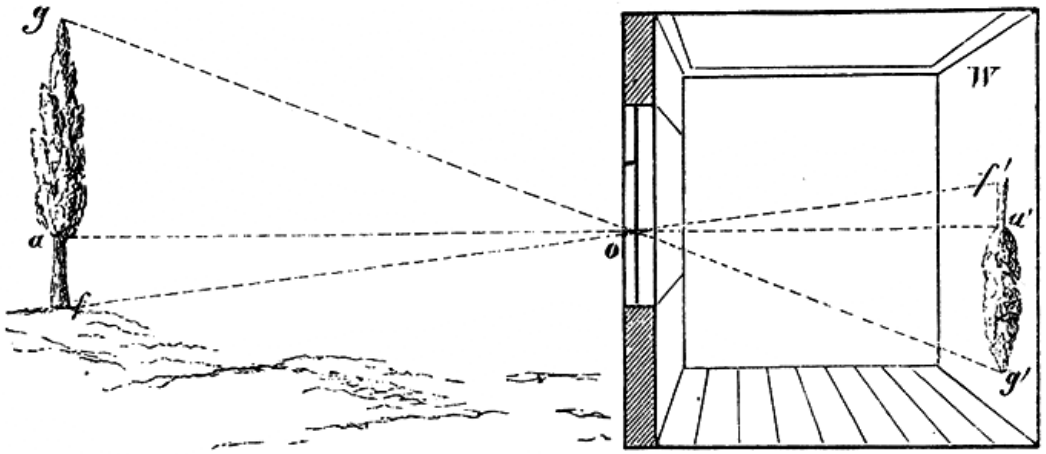


Fig. 36.

Darauf beruht die Wirkung der Camera-obscura, des wichtigsten photographischen Apparats, der dazu dient, von körperlichen Gegenständen in der Natur ebene Bilder zu entwerfen. Die einfachste Form desselben haben wir früher geschildert (s. S 7). Es ist ein dunkles Zimmer, in dessen Fensterladen ein kleines Loch angebracht ist. Solche Einrichtung liefert

Image formation in pinhole camera obscura:

too little light, too much diffraction blur

grenzt. Die Verbindungslinie, welche durch die Mittelpunkt der beiden Kugelflächen geht, nennt man die Achse der Linse, den Punkt E (Fig. 33), in welchem die parallel auffallenden Strahlen vereinigt werden, den Brennpunkt oder Focus, die Entfernung desselben von der Linse die Brennweite. Aber nicht nur die parallel auffallenden Strahlen werden durch die Brechung in einer solchen Linse in einen Punkt vereinigt, sondern überhaupt alle Strahlen, welche von einem einzigen Punkte ausgehen. Man nennt ihren Vereinigungspunkt den Bildpunkt.

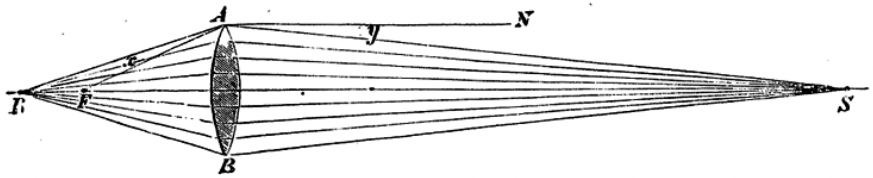


Fig. 34.

Ein leuchtender Punkt S z. B. sendet einen Kegel von Strahlen auf die Linse. Diese werden nach der Brechung in R vereinigt. Rückt S der Linse näher, so rückt R weiter ab, rückt S so nahe, dass es um

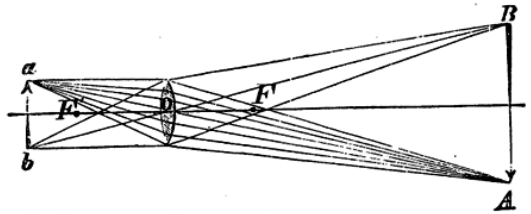


Fig. 35.

die doppelte Brennweite von der Linse entfernt ist, so ist der Vereinigungspunkt R derselben ebenso weit von der Linse entfernt.

Steht statt des leuchtenden Punktes ein Gegenstand, z. B. ein Pfeil AB, vor der Linse, so sendet jeder einzelne Punkt desselben einen Strahlenkegel auf die Linse, und alle Strahlen eines und desselben Kegels

Capturing more rays: Linse Focus und Bildpunkt

Hermann W. Vogel,
Photographie, 1874.

Limits to sharpness/detail/resolution

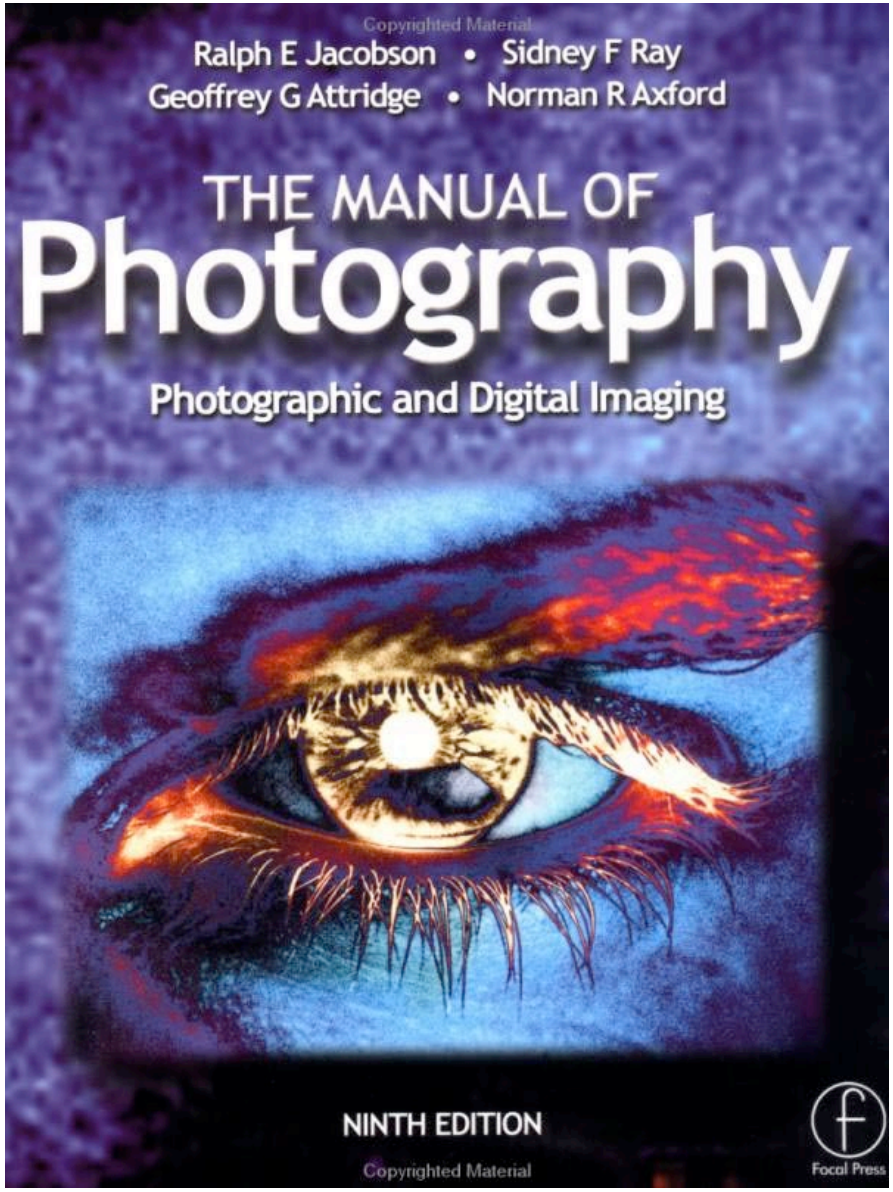
- Ideal Camera
  - Depth-of-field
  - Motion blur
  - Diffraction blur
  - Shot noise
- Non-idealities
  - Sensor resolution or film grain
  - Aberrations
  - Flare, glare, ghosting
  - Other noise sources

- More light always helps with the tradeoff of aperture area, exposure time, and shot noise; but not diffraction

Front-end things to study: lenses and sensors

- Image formation by lenses: distinguishing ideal effects of diffraction, limited depth of field, and motion blur from non-ideal effects such as aberrations, flare, distortion, etc.
- Light sensing by silver halide and by silicon: distinguishing ideal effects of shot-noise limit from non-ideal noises, leakage, reciprocity failure, resolution limits, aliasing, nonlinearity, etc.
- Color sensing methods and their problems.
- Data conversion, capture, processing, …

Good books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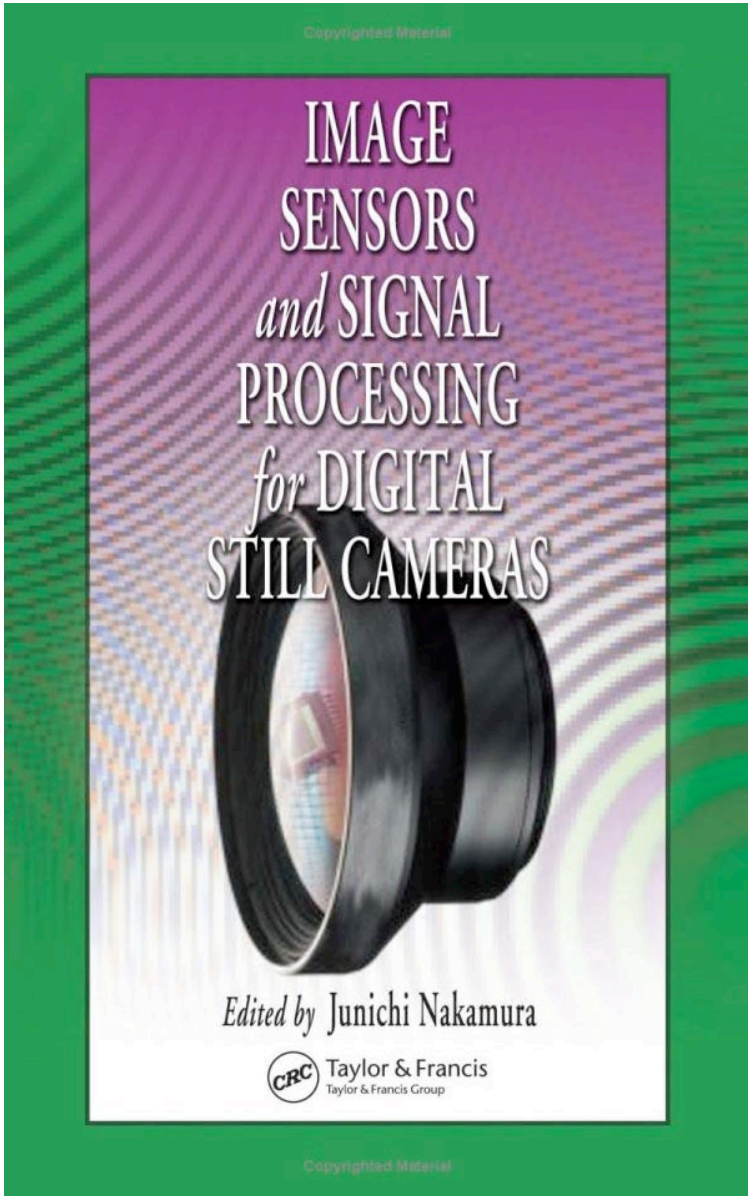
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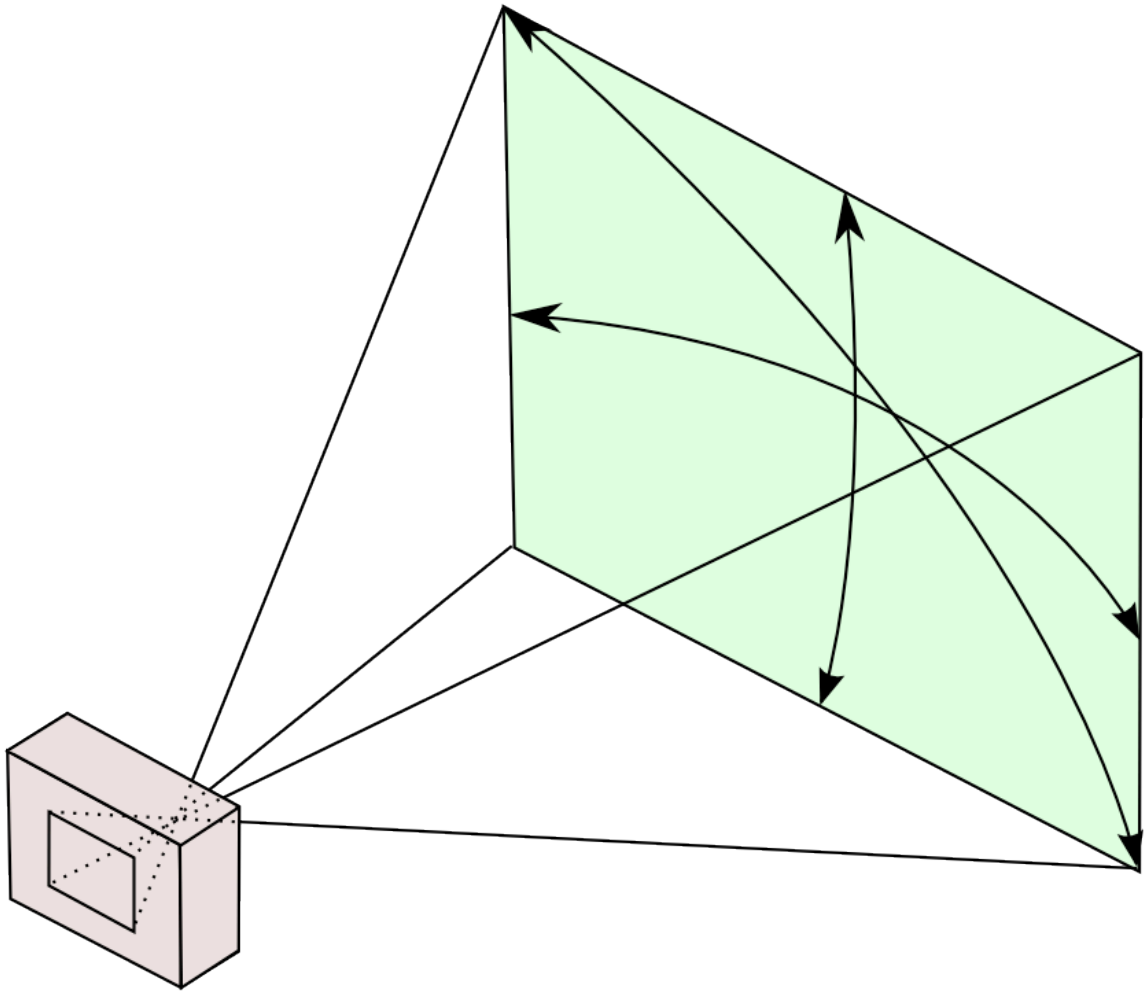
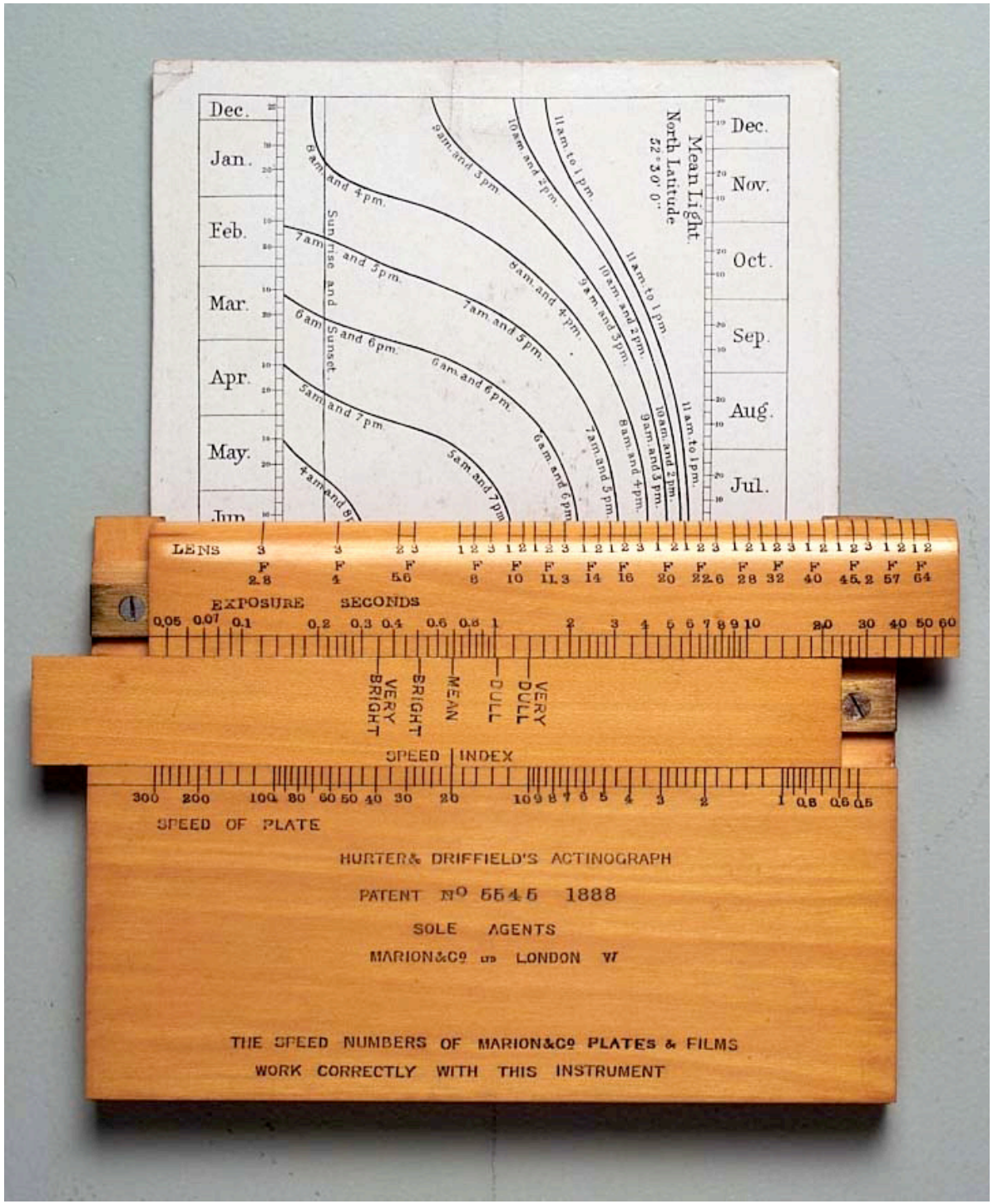
The camera: a box with a lens — angle of view, determined by focal length and format (and distortion)



Camera Settings (ideal)

- Shutter speed
- Aperture
- Focus



Estimating exposure: Hurter & Driffield's *Actinograph*

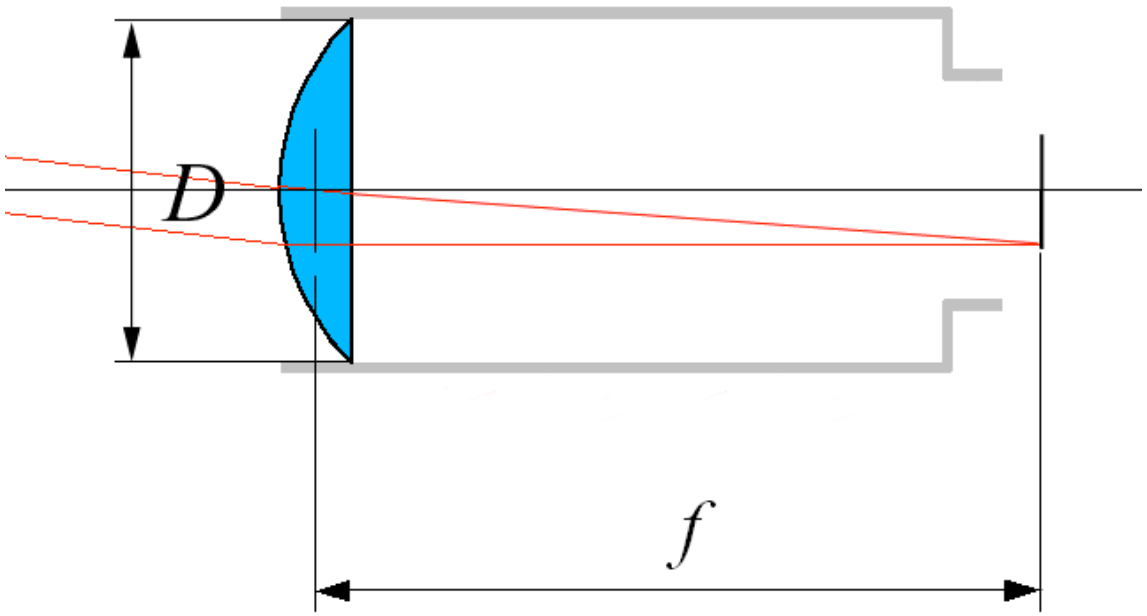
A more modern Nikkor lens

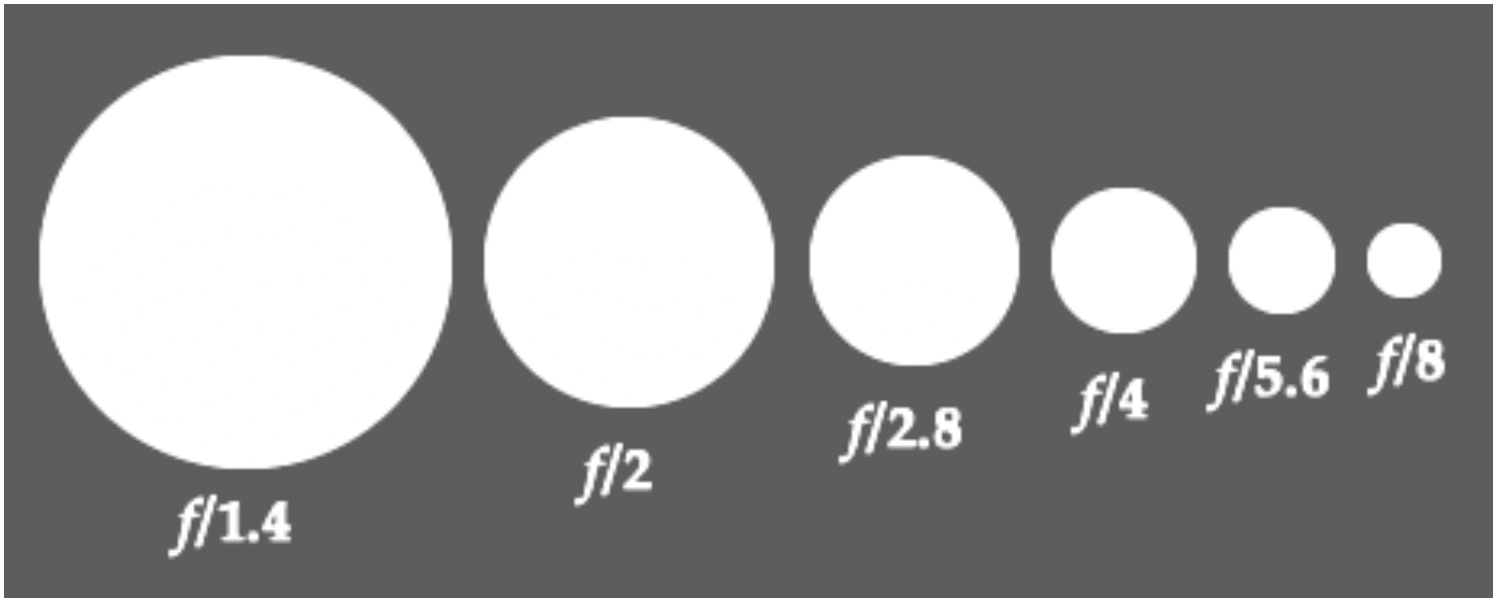
with markings for focal length, max aperture, f-numbers, focus distance, and depth of field (but shutter is in the camera body)

f-number N:
Relative
Aperture

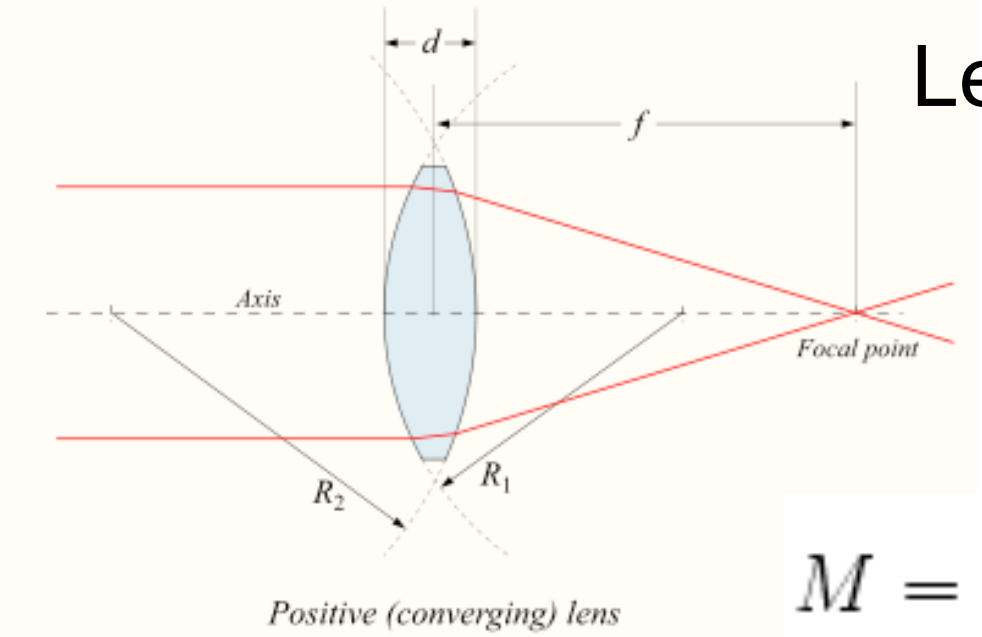
$$N = f/D$$

$$D = f/N$$





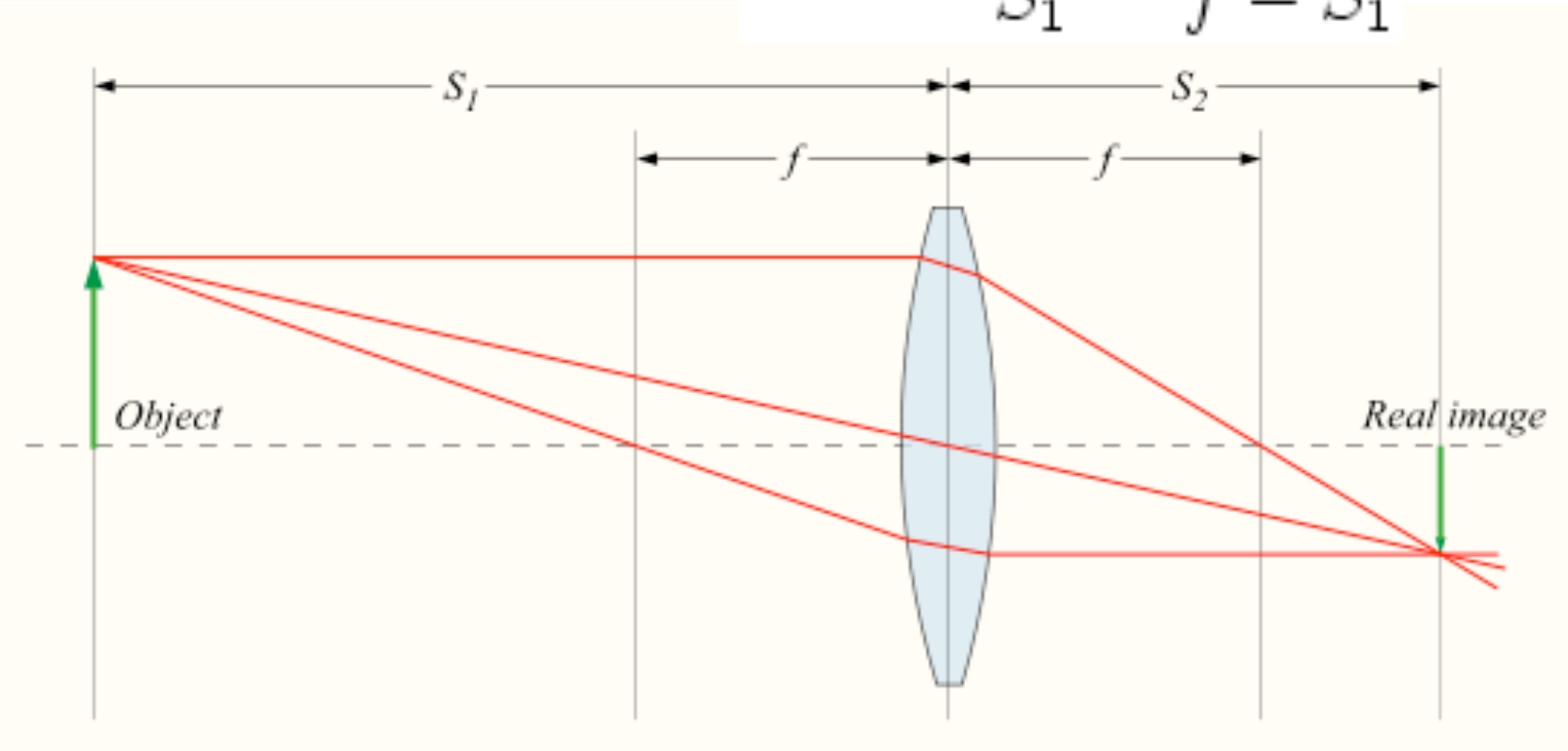
Lens equation, curvature, magnification, etc.



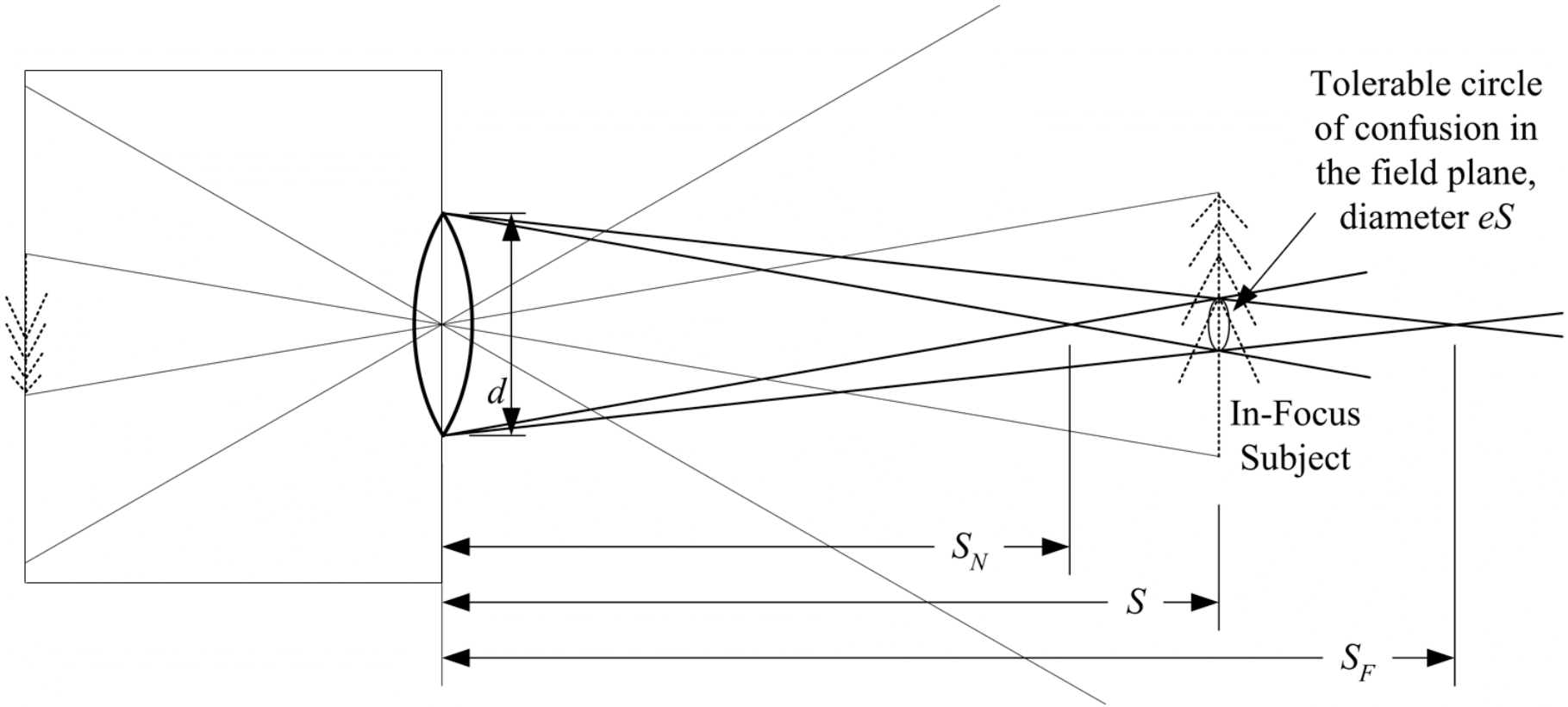
Positive (converging) lens

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

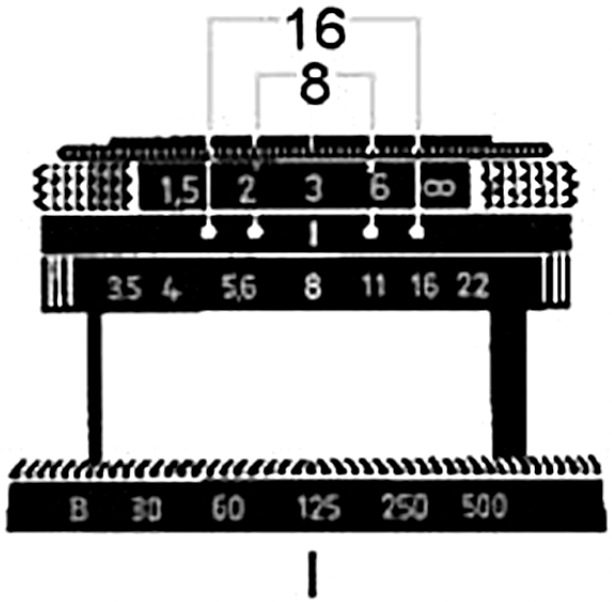
$$M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$$

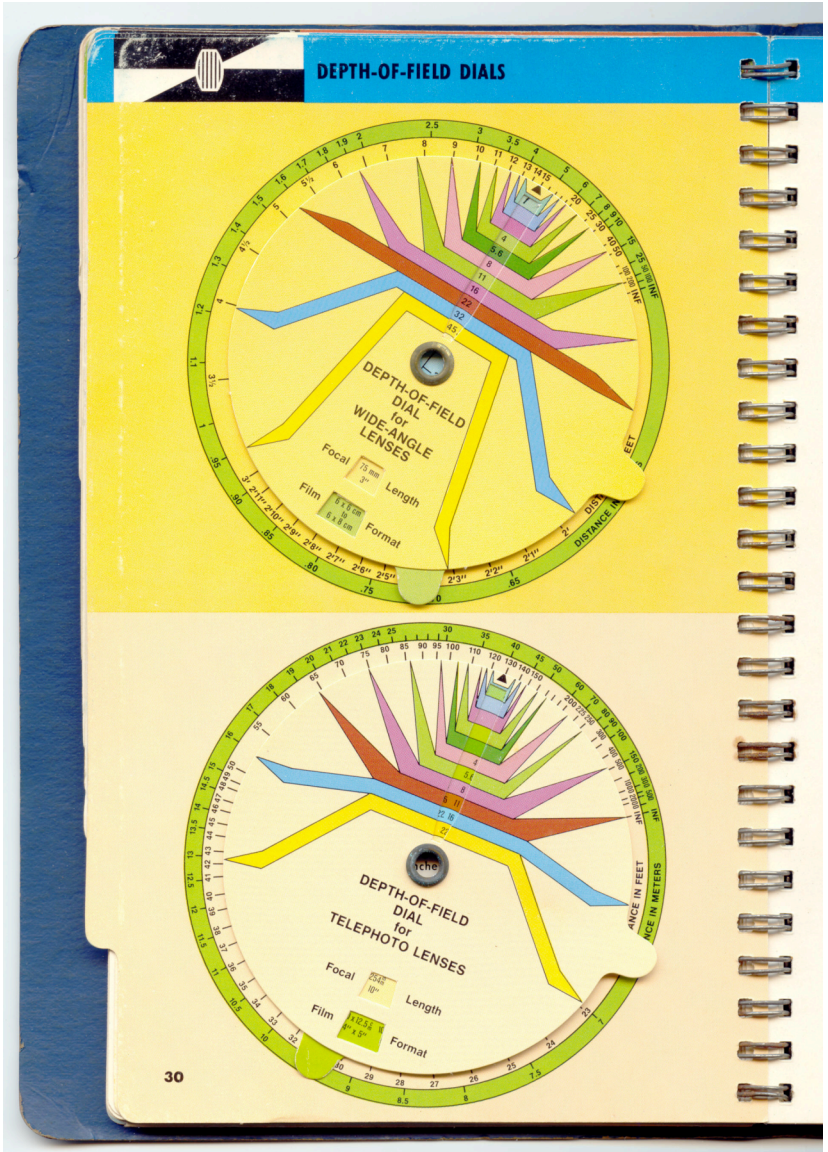


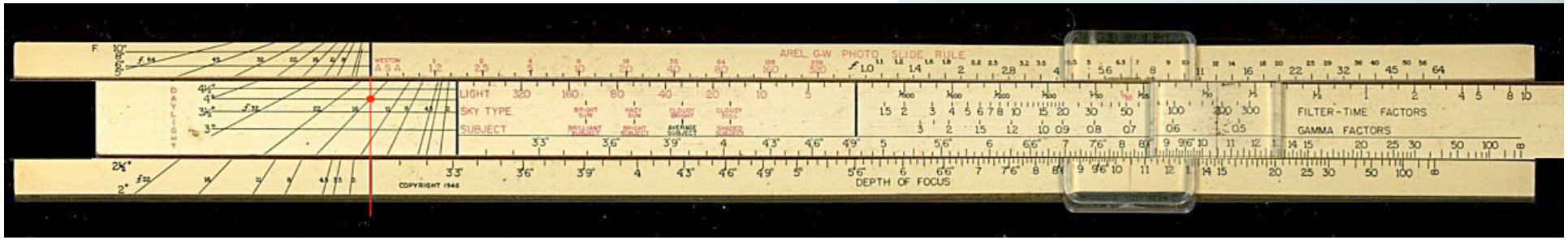
Depth of field by Moritz von Rohr's method ("outside the box")



Depth-of-field computers







"Tone"

This negative is printed on paper. To make the process clear, the printing is shown to be done by means of a lens. The time of exposure of the paper is given as t_y. The print is developed, fixed, and

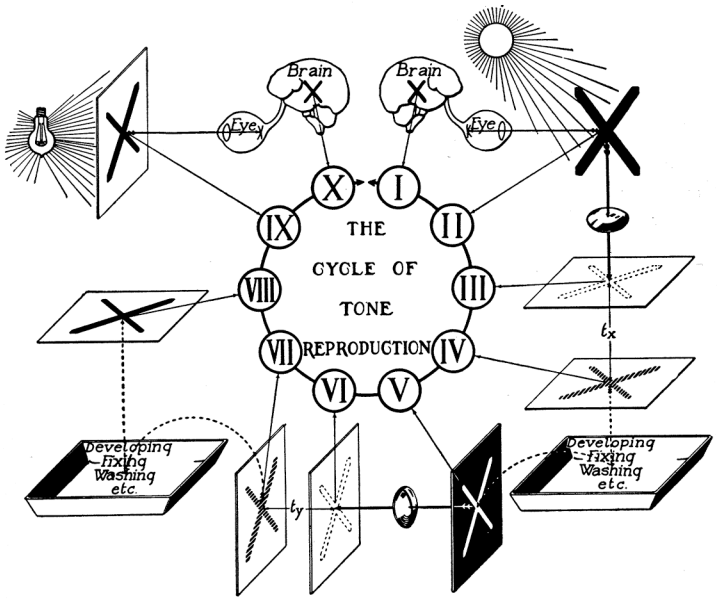
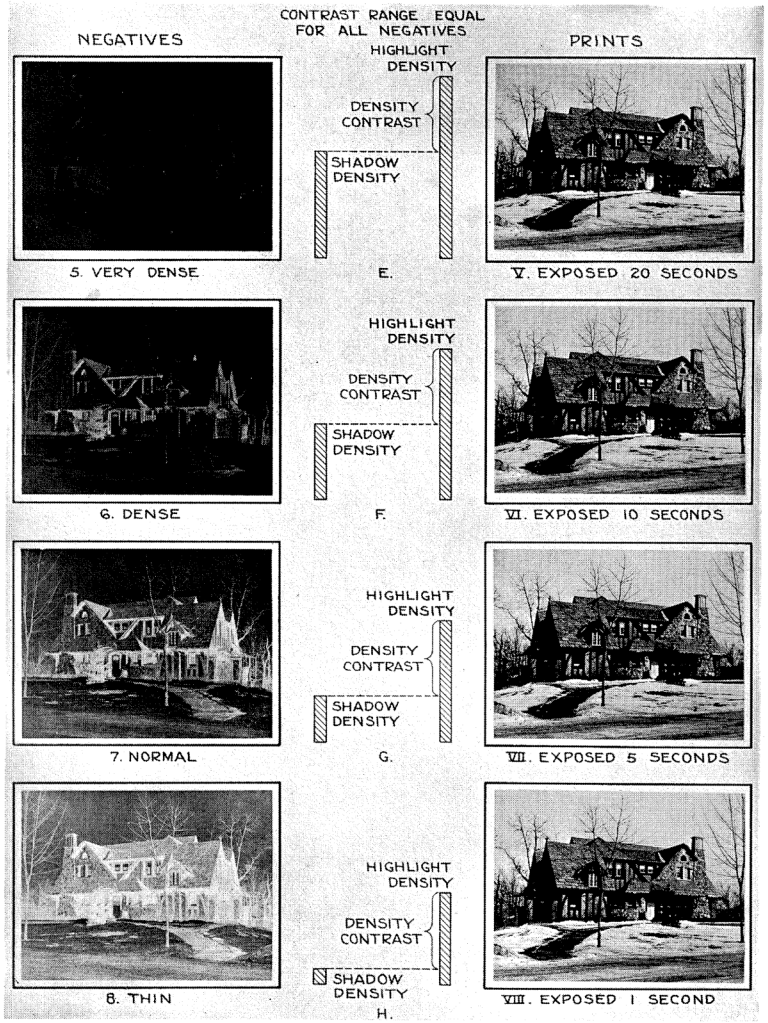


Fig. 27. A diagram of the cycle of operations in tone reproduction.

washed, and the finished photograph shown at the top, left, is obtained.

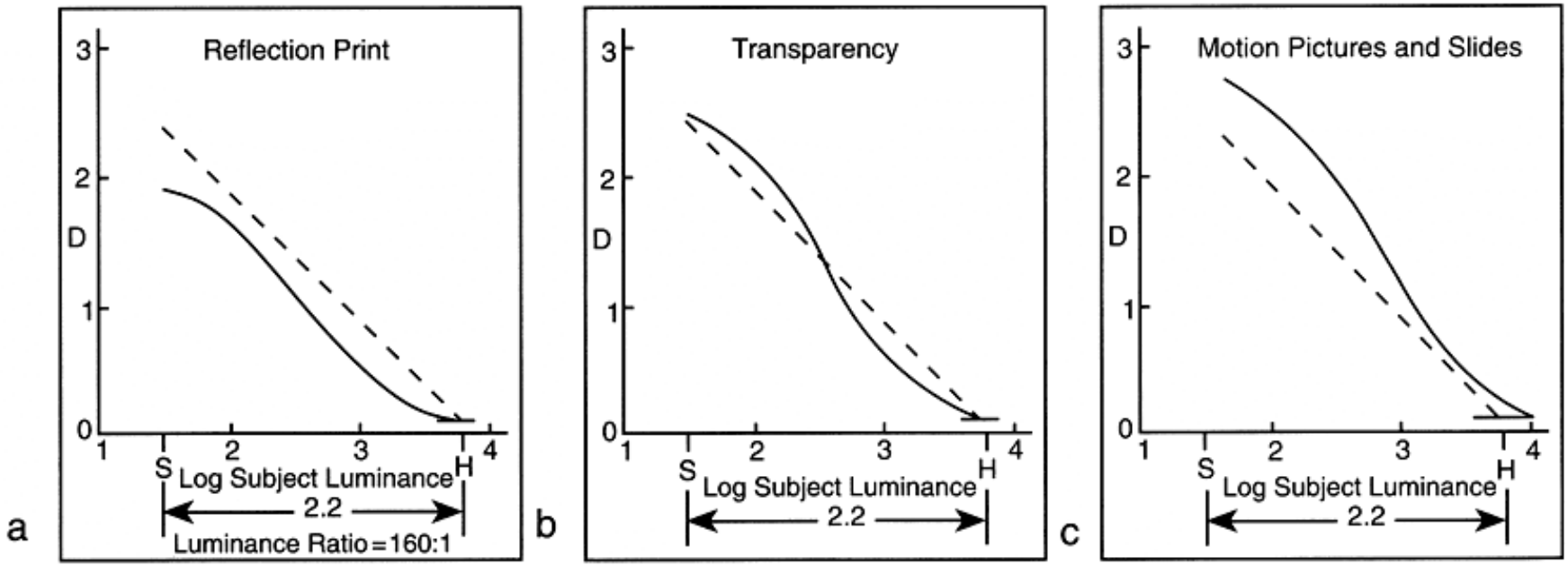
The original subject was illuminated by the sun, but the finished photograph is illuminated by an electric lamp. There may, therefore, be a change in the subjective impression produced in the brain. If the



The effect of density of a negative on the exposure required for printing. (*p.* 104)

Vision is non-trivial and nonlinear

- Preferred tone reproduction is subjective:



Preferred tone-reproduction curve. (a) Objective tone-reproduction curve for a preferred reflection print of an average outdoor scene. (b) Objective tone-reproduction curve for a transparency of preferred quality, viewed on a bright illuminator under average room light. (c) Objective tone-reproduction curve for motion pictures and slides of preferred quality, projected on a screen in a darkened room.

Since, in the correct representation of the light and shade of the subject photographed, the opacity of the negative should be proportional to the quantity of light coming from the subject, it

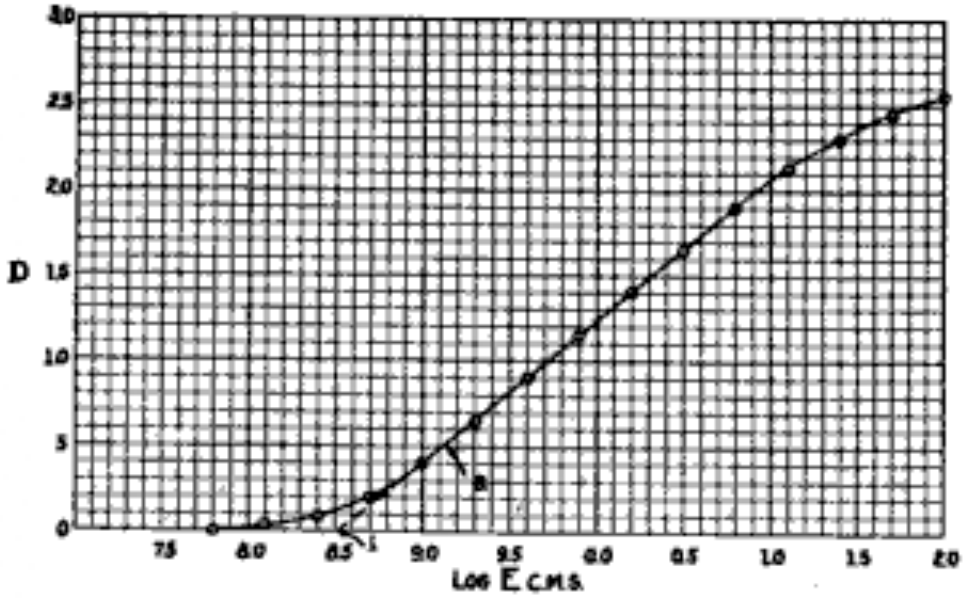


FIG. 6—*Density-exposure curve showing toe, straightline, and shoulder*

follows that the time of exposure should be such as to give densities on the plate which lie on the straight-line portion of the density-exposure curve. It is found that if the exposure is too short, there is no detail in the shadows, although there may be a slight deposit of silver all over the plate, or if the development has been such that detail does show, the representation of light and dark in the picture does not correspond to the light and dark of the subject.

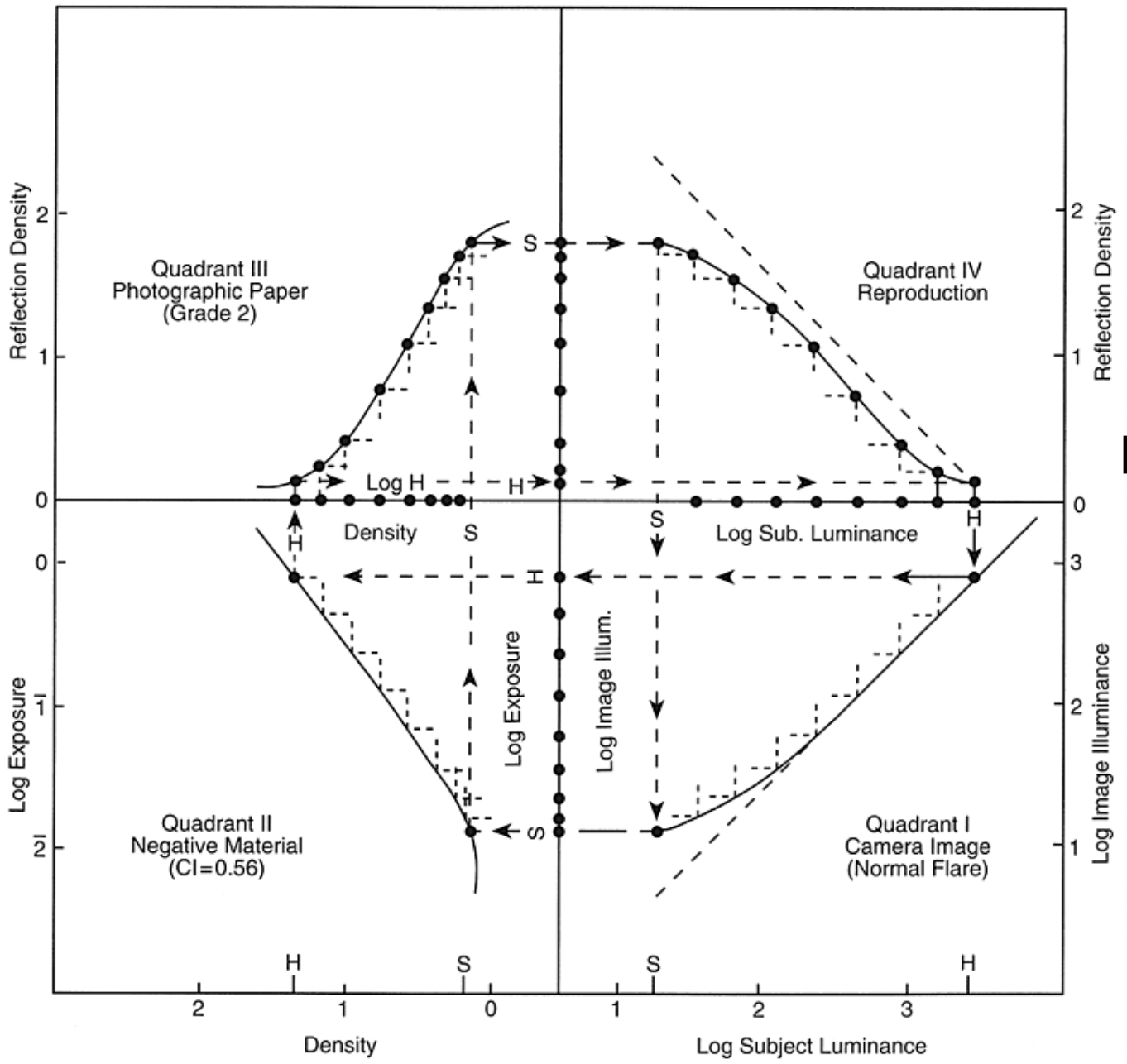
Film is nonlinear, too

H&D or D–logE curve

Enlarging to make a print (positive from a negative)

KODAK HOME ENLARGER

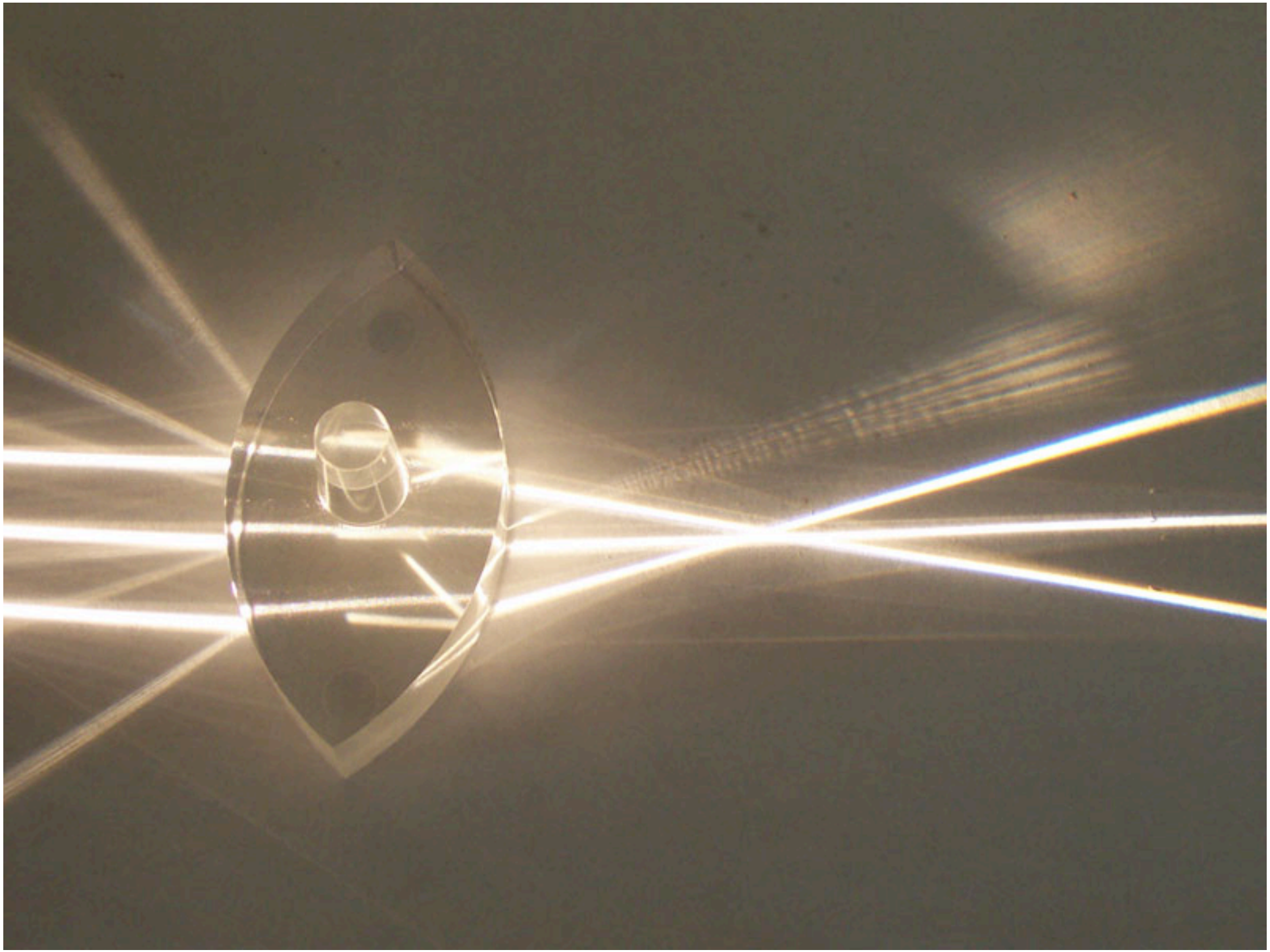
THIS is a simple enlarger offered for the picture taker's own use, and is particularly adapted to the beginner. It takes negatives from half-vest pocket size up to and including 3¼ x 4¼-inch and 9 x 12-centimeter. A 3¼ x 5½-inch negative will fit in the holder but only 4½ inches of its length can be enlarged. Enlargements up to 11 x 14 inches can be made; up to 5 x 7 from half-vest pocket negatives, and proportionate enlargements from larger-sized negatives. Exact-size prints by projection also can be made.

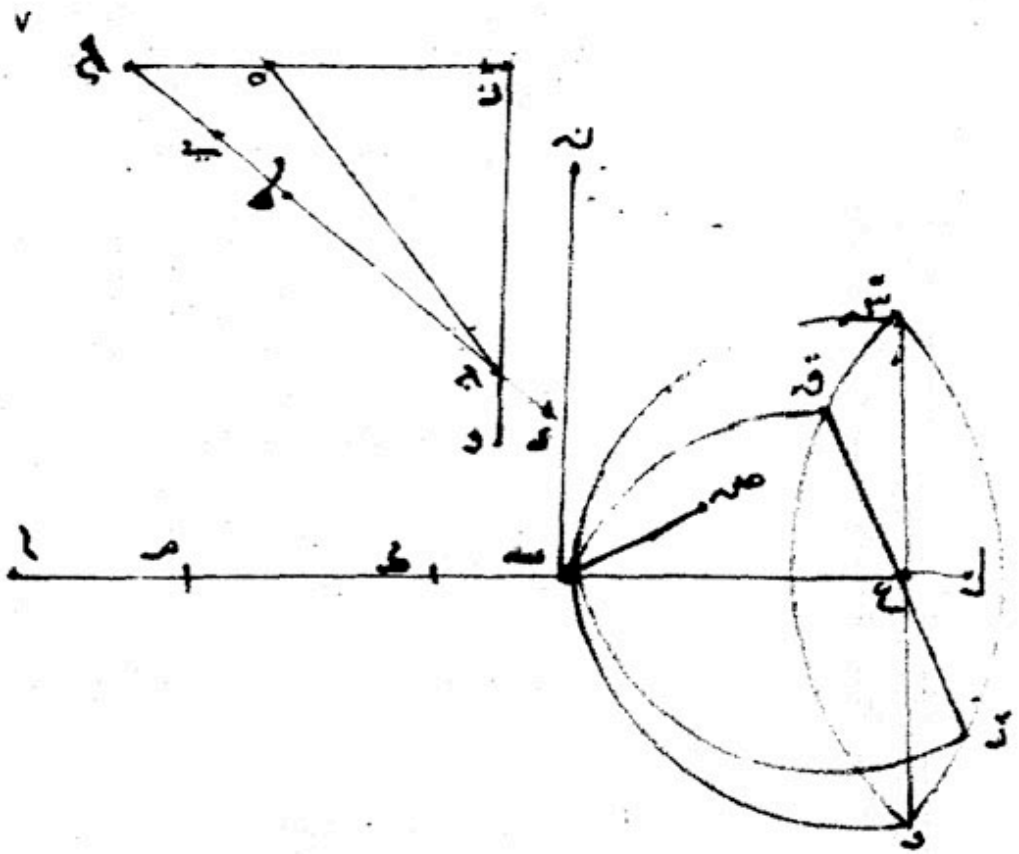


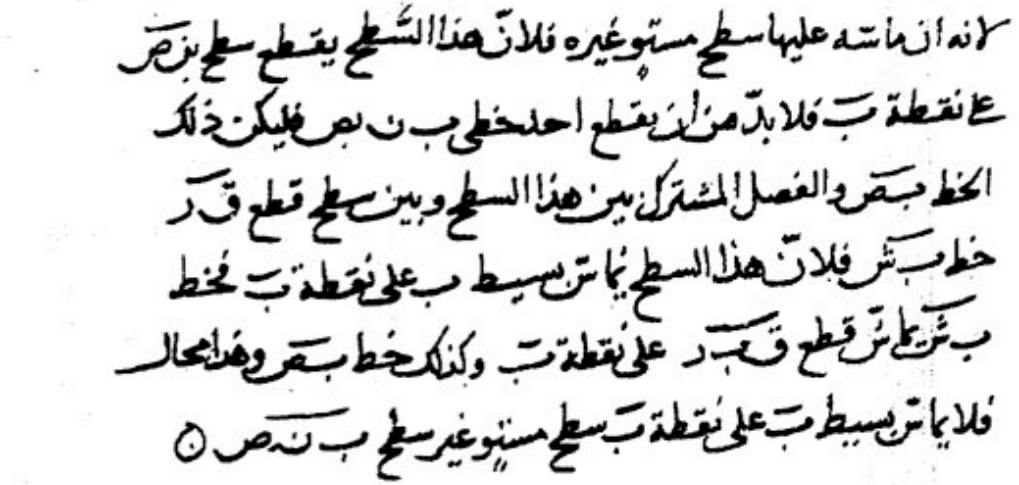
Complete objective tone-reproduction diagram for a pictorial system. The print characteristic is represented by the curve in Quadrant IV.

Nonlinearities dominate objective tone reproduction:

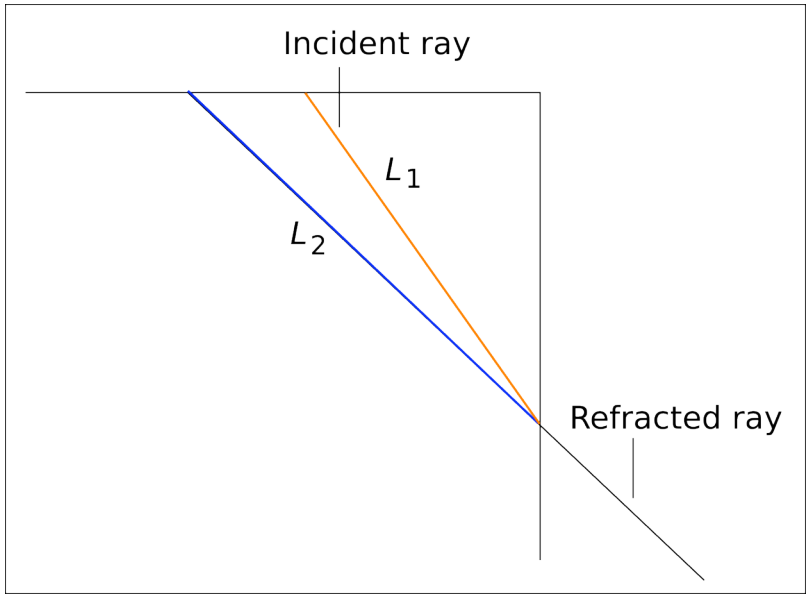
Lloyd A. Jones diagram







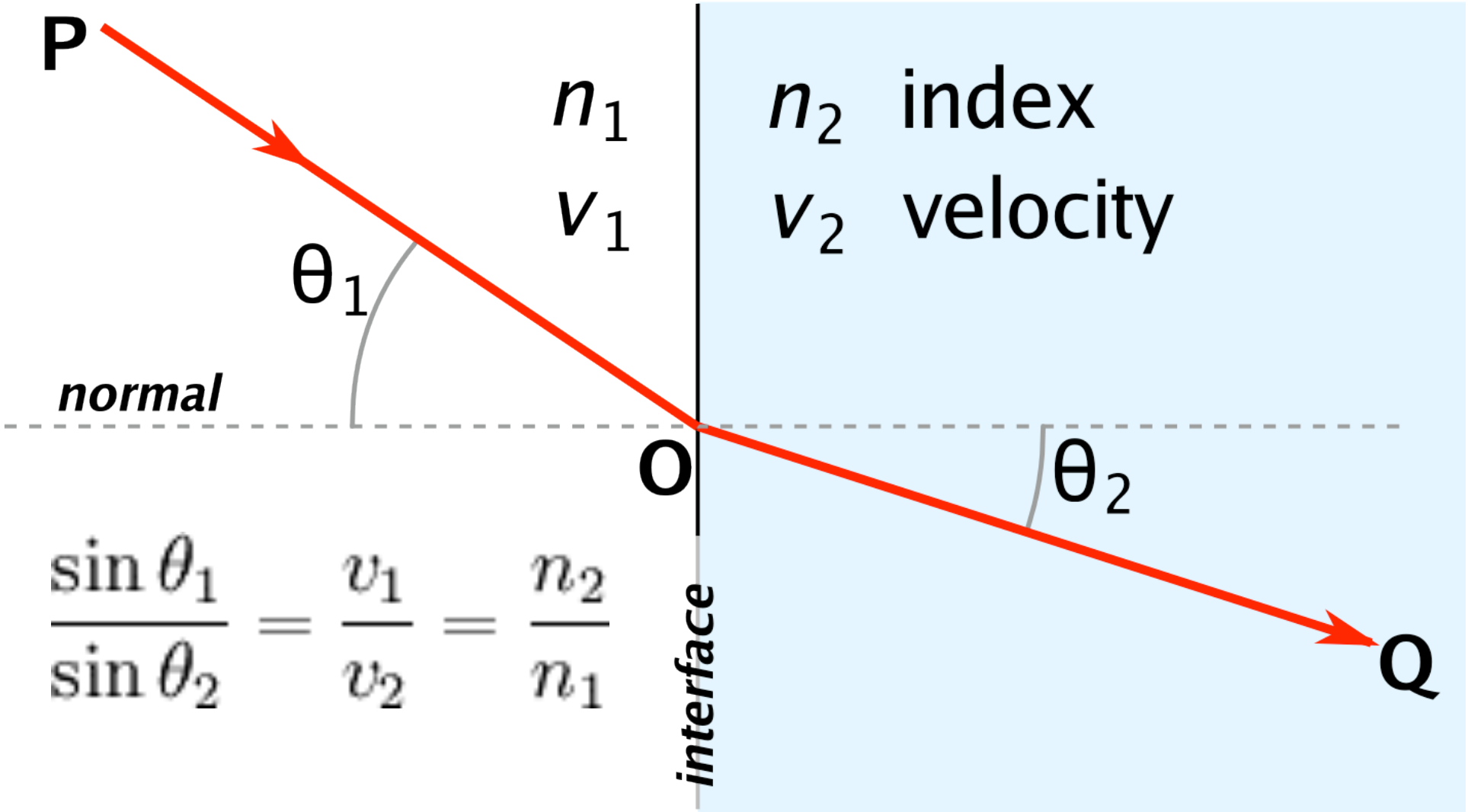
لانه ان ماسه عليها سطح مستوغيره فلان هذا السطح يقطع سطح بن ص
على نقطة ب فلا بد من ان يقطع احد خطى ب ن ب ص فليكن ذلك
الخط ب ص والفصل المشترك بين هذا السطح وبين سطح قطع ق ر
خط ب ش فلان هذا السطح يماس بسيط ب على نقطة ب لخط
ب ش على ش قطع ق ب ر على نقطة ب وكذلك خط ب ص وهذا محال
فلا يماس بسيط ب على نقطة ب سطح مستو غير سطح ب ن ص ○



Refraction law by Ibn Sahl (984 AD)

L_1:L_2 constant, depending on materials

Snell's law: ratio of sines is constant, equal to ratio of velocities, consistent with Fermat's *principle of least time*



Huygens (1689)