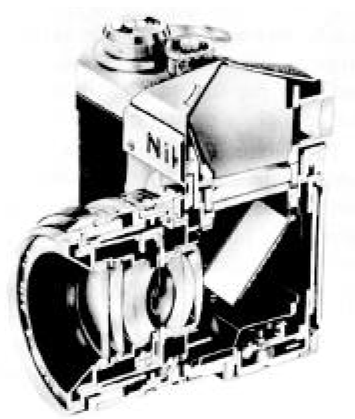
Camera Simulation



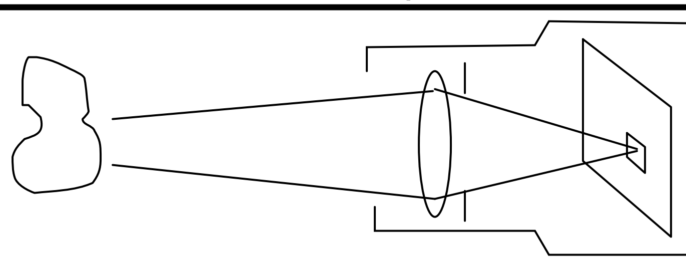
Effect	Cause
Field of view	Field stop and focal length of lenses
Depth of field	Aperture stop and focal length
Motion blur	Shutter
Exposure	Film, aperture, shutter

References

Photography, B. London and J. Upton

Optics in Photography, R. Kingslake

The Measurement Equation



$$R = \iint\iint L(T(x,w,l),t,l)\,P(x,l')\,S(x,w,t)\,d\vec{A}\bullet d\vec{w}\,dt\,dl$$

Scene radiance	$L(x,w,t,l)$
Imaging optics	$(x',w') = T(x,w,l)$
Sensor/Pixel response	$P(x,l)$
Shutter	$S(x,w,t)$

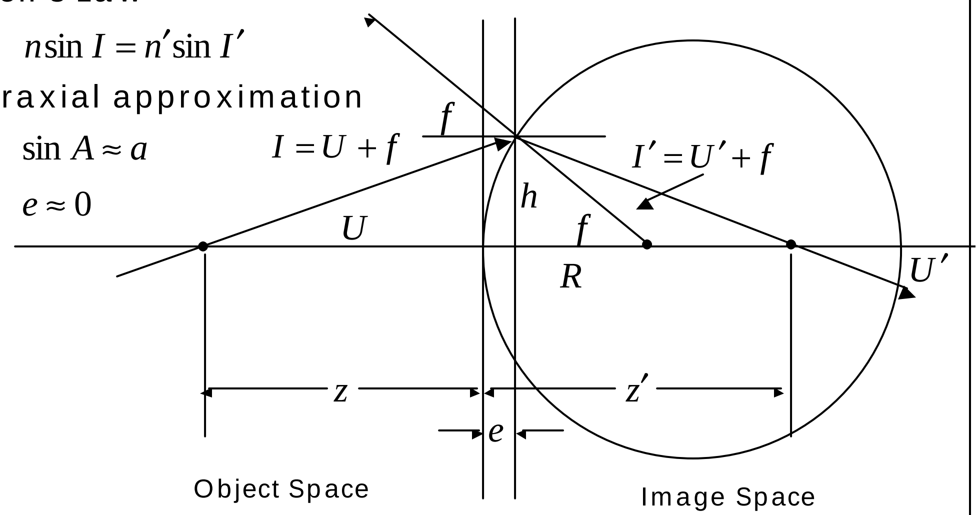
Paraxial Refraction

Snell's Law

$$n \sin I = n' \sin I'$$

Paraxial approximation

1. $\sin A \approx a$
2. $e \approx 0$



Derivation

$$n \sin I = n' \sin I'$$

$$ni = ni'$$

$$n(u + f) = n'(u' + f)$$

$$n\left(\frac{h}{z} - \frac{h}{R}\right) = -n'\left(\frac{h}{z'} + \frac{h}{R}\right)$$

$$\frac{n}{z} + \frac{n'}{z'} = \frac{(n - n')}{R}$$

Note sign conventions

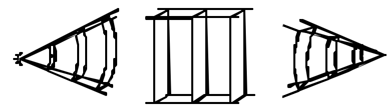
$$\sin U \approx u \approx \tan U = \frac{h}{z}$$

$$\sin U' \approx u' \approx \tan U' = -\frac{h}{z'}$$

$$f = -\frac{h}{R}$$

Thin lense equation

Vergence $V = \frac{n}{r}$ $V' = V + P$



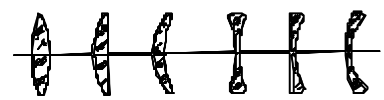
Negative = Diverging

Positive = Converging

Surface Power $P = \frac{n'-n}{R} = \frac{1}{f}$

Lensmakers formula $P = (n'-n)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{f}$

Thin lens equation $\frac{1}{z'} = \frac{1}{z} + \frac{1}{f}$



Note different sign convention!

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Focal Points and Focal Lengths

To focus: move lens relative to backplane

Power and focal length

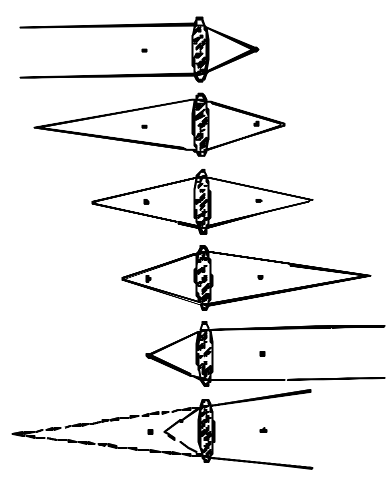
$$P = \frac{n'-n}{R} = \frac{1}{f}$$

Perspective transform

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f} \Rightarrow z' = \frac{fz}{z+f}$$

$$\Rightarrow x' = \frac{fx}{z+f}$$

Model as a 4x4 matrix



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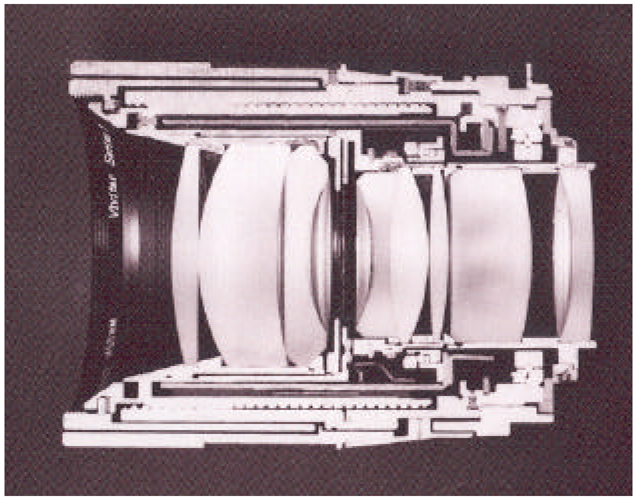
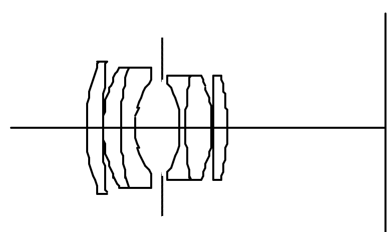
Real Lens



Cutaway section of a Vivitar Series 1 90mm f/2.5 lens
Cover photo, Kingslake, *Optics in Photography*

Double Gauss

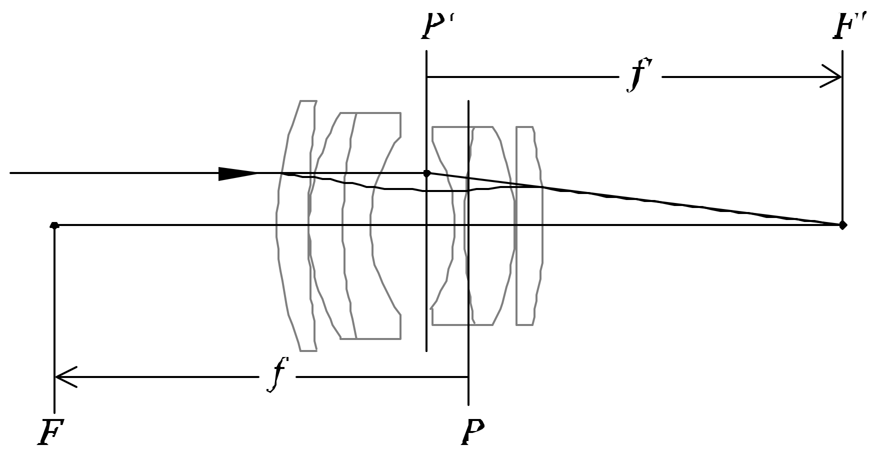
Radius (mm)	Thick (mm)	n_d	V-no	aperture
58.950	7.520	1.670	47.1	50.4
169.660	0.240			50.4
38.550	8.050	1.670	47.1	46.0
81.540	6.550	1.699	30.1	46.0
25.500	11.410			36.0
	9.000			34.2
-28.990	2.360	1.603	38.0	34.0
81.540	12.130	1.658	57.3	40.0
-40.770	0.380			40.0
874.130	6.440	1.717	48.0	40.0
-79.460	72.228			40.0



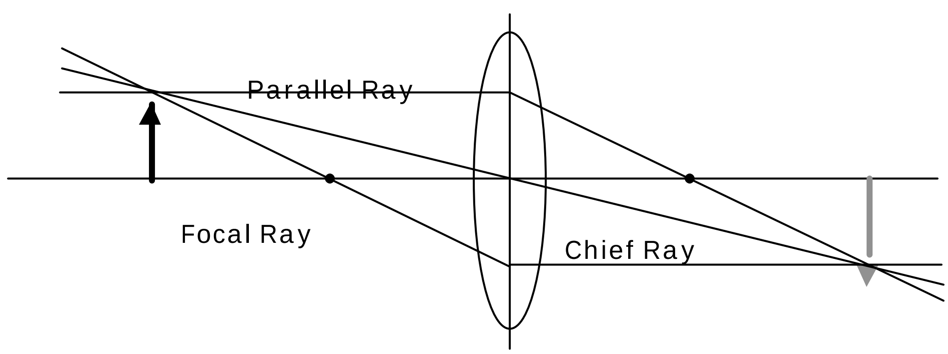
Data from W. Smith, Modern Lens Design, p 312

Positive radii, convex; negative radii, concave

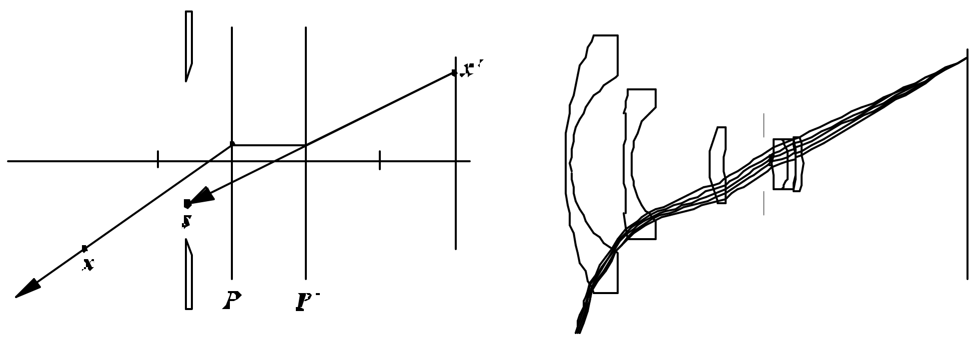
Thick Lenses



Gauss' Ray Tracing Construction



Camera Simulation



From Kolb, Mitchell and Hanrahan (1995)

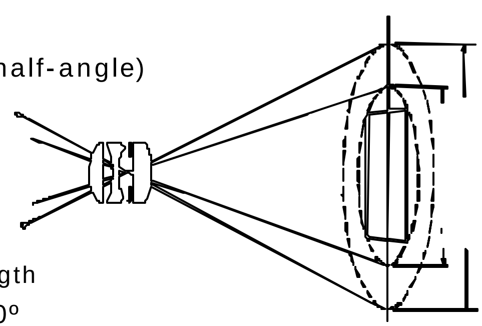
Field of View

Eye

- Concentrate 10º (half-angle)
- Resolve 26º
- Detect 60º

Lenses

- Normal 26º
  - Film diagonal = focal length
- Wide-angle 75-90º
- Narrow-angle 10º



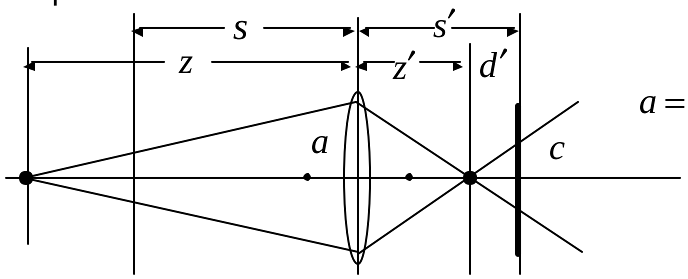
From Kingslake, *Optics in Photography*

Still vs. Motion

- Still designed for scanning, wider than eye
- Motion narrower (14º)
- Focal length of the projector greater than camera

Circle of Confusion

Image space view



$$a = f / N$$

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f} \Rightarrow z' = \frac{z+f}{zf}$$

Note: Circle of confusion proportional to the size of the aperture

$$\frac{c}{a} = \frac{d'}{z'}$$

$$= \frac{s'-z'}{z'} \quad behind\ focal-plane$$

$$= \frac{z'-s'}{z'} \quad before\ focal-plane$$

Depth of Field

Object space view

- Resolving power $\frac{c}{s} = \frac{1}{1000}$
- Depth of field series

$$\frac{c}{a} = \frac{d}{z}$$

$$= \frac{d_f}{s+d_f} \Rightarrow d_f = \frac{s^2}{1000\,a - s}$$

$$= \frac{d_n}{s-d_n} \Rightarrow d_n = \frac{s^2}{1000\,a + s}$$

- Hyperfocal distance

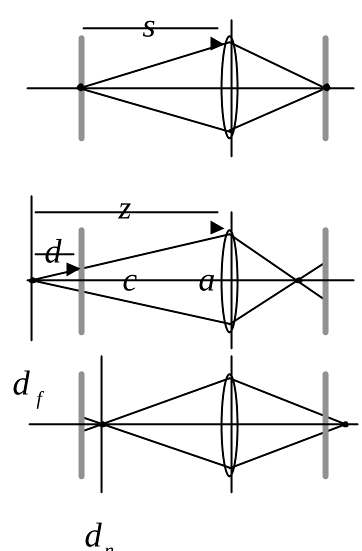
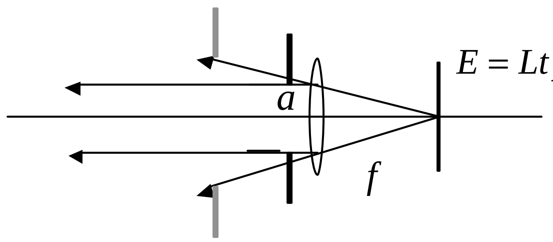


Image Irradiance

Assumes image plane at focal point



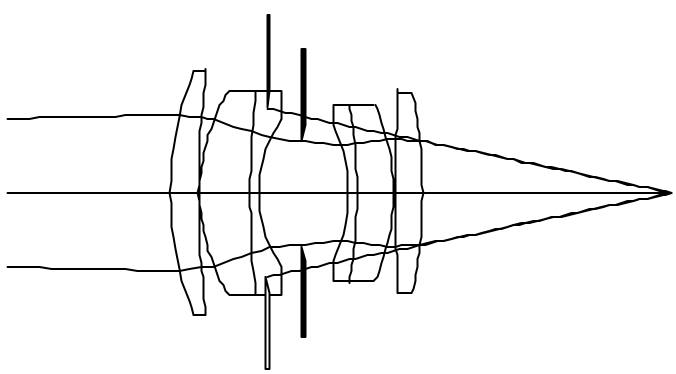
$$E = Lt p \sin^2 q = Lt \frac{p}{4}\left(\frac{a}{f}\right)^2$$
$$= Lt \frac{p}{4}\frac{1}{N^2}$$

F-Stop/F-Number: $f_N = \frac{1}{N} = \frac{a}{f}$

Fstops: 1.4 2 2.8 4.0 5.6 8 11 16 22 32 45 64

1 stop doubles exposure

Stops and Pupils



Stops - physical limits

Pupils - logical limits

Exit and Entry pupil

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Camera Exposure

H = E x T

- Reciprocity failure
- Automatic exposure

Exposure overdetermined

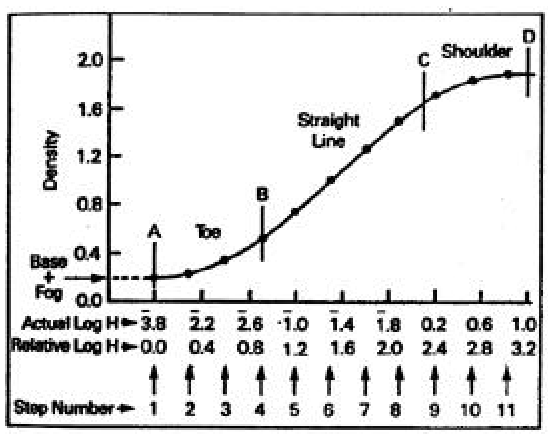
Aperture: f-stop - 1 stop doubles H

Interaction with depth of field

Shutter: Doubling the effective time doubles H

Interaction with motion blur

Photographic Exposure



Density vs. Transparency

$$D = \log \frac{1}{T}$$

Gamma

$$g = \frac{\Delta D}{\Delta \log H}$$

Film speed

$$Speed = \frac{1}{H} \Rightarrow ISO(ASA) = 0.8 \frac{1}{H_m}$$

High Dynamic Range

Sixteen photographs of the Stanford Memorial Church taken at 1-stop increments from 30s to 1/1000s.

From Debevec and Malik, High dynamic range photographs.

Method: Each stop has a useful range of radiances ...

Simulated Photograph

Adaptive histogram compression

Also with glare, contrast, blur