Apertures and stops-objectives

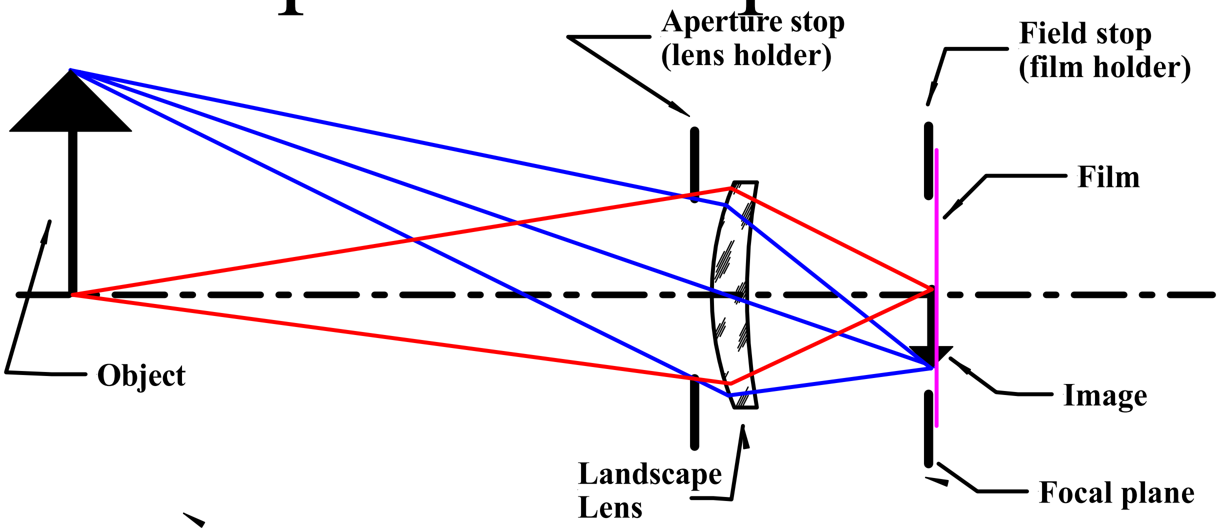
- Name three different types of stops in an optical system
  - aperture stop
  - field stop
  - glare stops and baffles
- Name four effects of the aperture stop
  - determines brightness of image
  - determines depth of focus
  - modifies aberrations
  - determines diffraction-limited spot size
- Define terms
  - entrance and exit pupils
  - entrance and exit windows
  - f/number and numerical aperture
  - field of view, vignetting

What is a stop?

- Every optical system has some limit to the set of rays that can get through it
  - Example, a simple single lens only passes rays that are within its diameter
- Ray tracing up till now has ignored this
  - Note that the three rays of the parallel ray method can be done no matter whether the chosen rays actually get through the lens or not

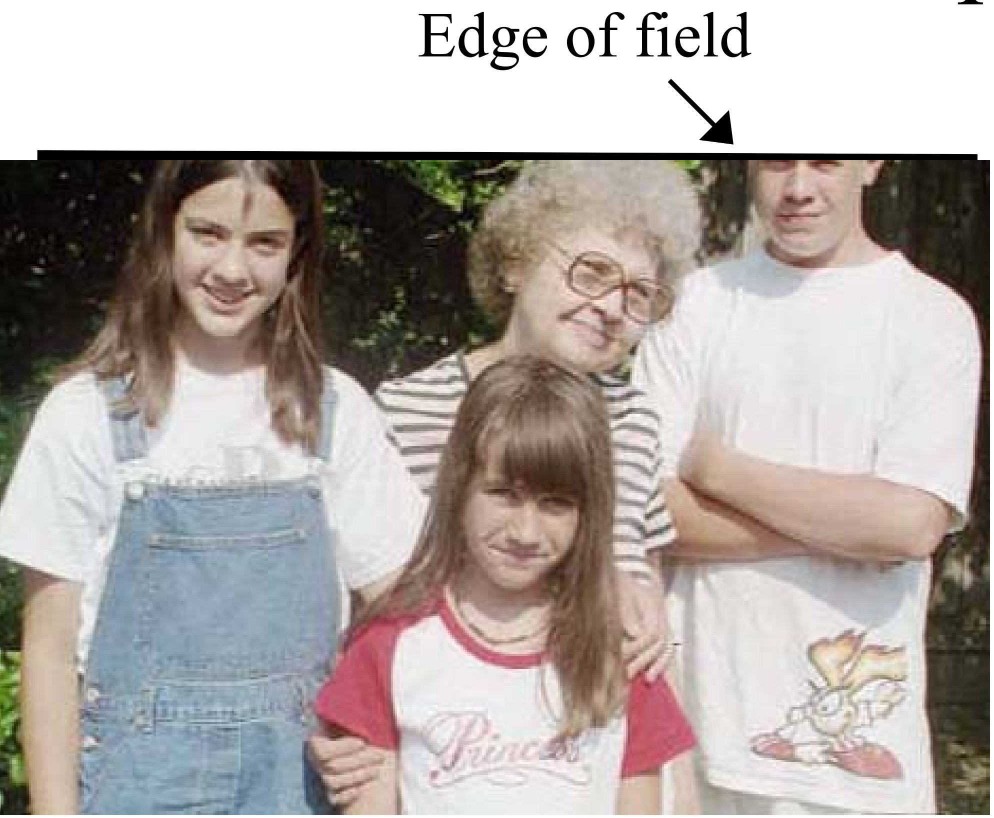
> A stop is anything that limits which light rays can get through an optical system

Stops in a simple camera

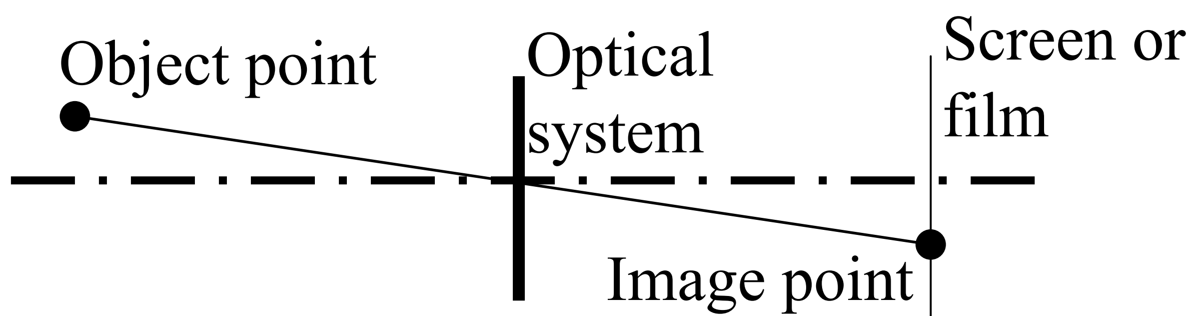


- Paraxial optics tells where bundles of light focus
  - Can be traced even for rays that don't get through system
- Aperture stop limits rays from a given point on object
  - A cone of rays gets through
  - If there is more than one limit, than one will give the smallest cone
  - Since rays carry light energy, the larger the cone, the brighter the image
- Field stop limits which points on object can produce an image
  - In camera example, no image is recorded on the film if it falls outside of the film holder

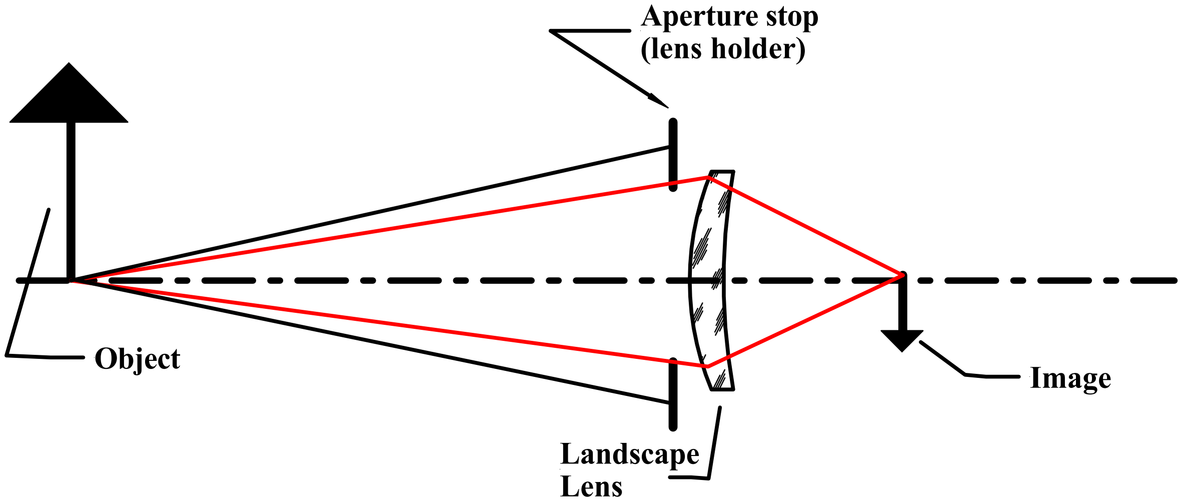
Field stop



- Each object point focuses to conjugate image point
- Field stop limits object points which appear at detector
- Like frame of a window
- Points in object space which image inside field stop are said to be in the field of view

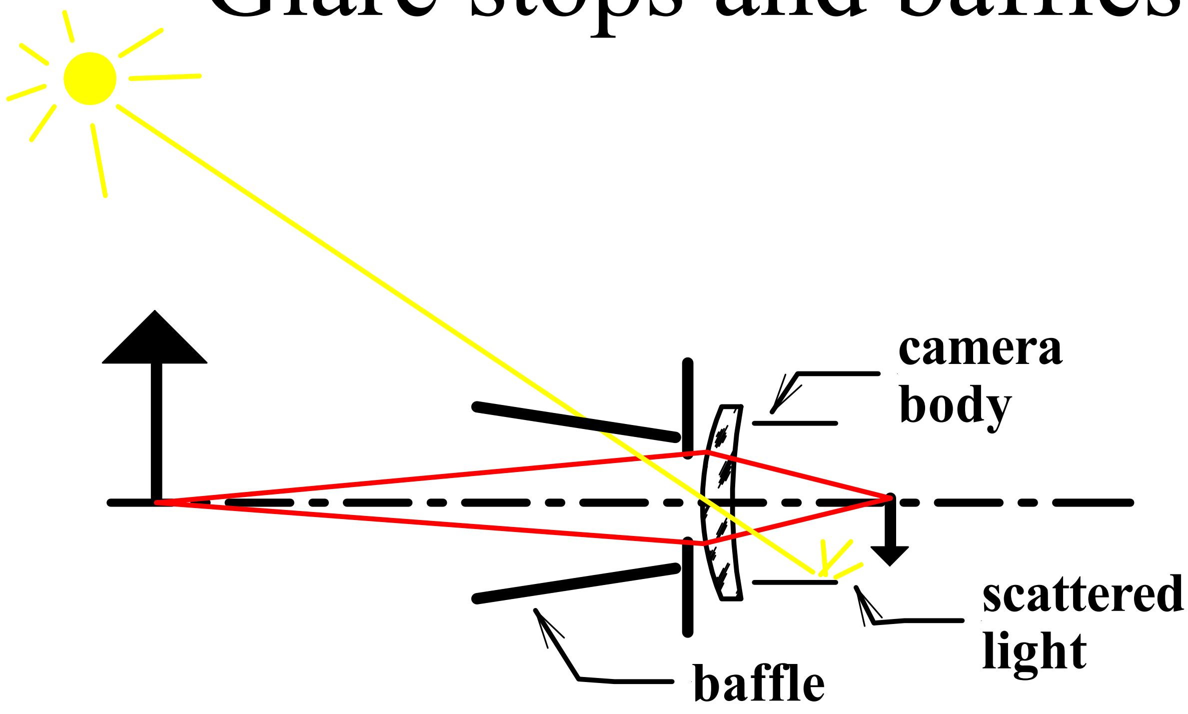


Aperture stop-light gathering power



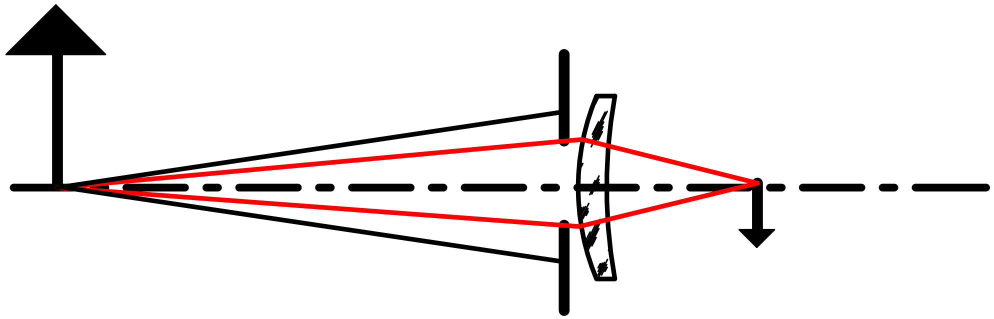
- Of all rays emitted by a point on the object only a certain bundle can pass through the system to the image
- The object that limits the bundle is called the aperture stop
- The size of the aperture stop determines how much of the light from the object point gets to the image, this determines the irradiance at the image
- Irradiance at image increases with square of aperture diameter $(1/f/\#)^2$

Glare stops and baffles

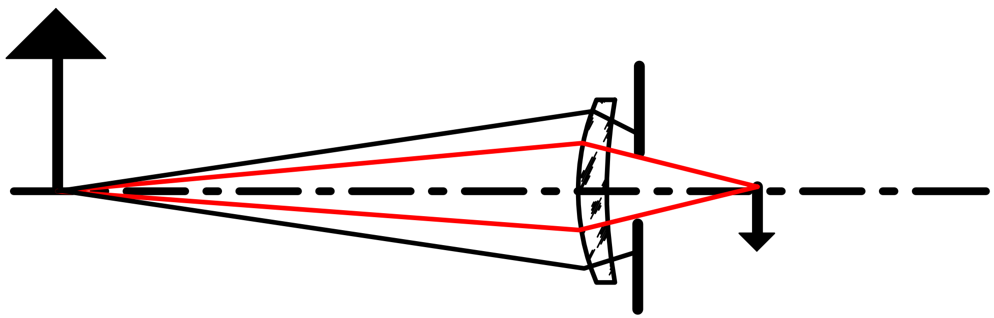


- Scattered light from very bright sources can interfere with image
- Baffles and glare stops control scattered light
- Control of scattered light is an important (and often neglected) area of optical design

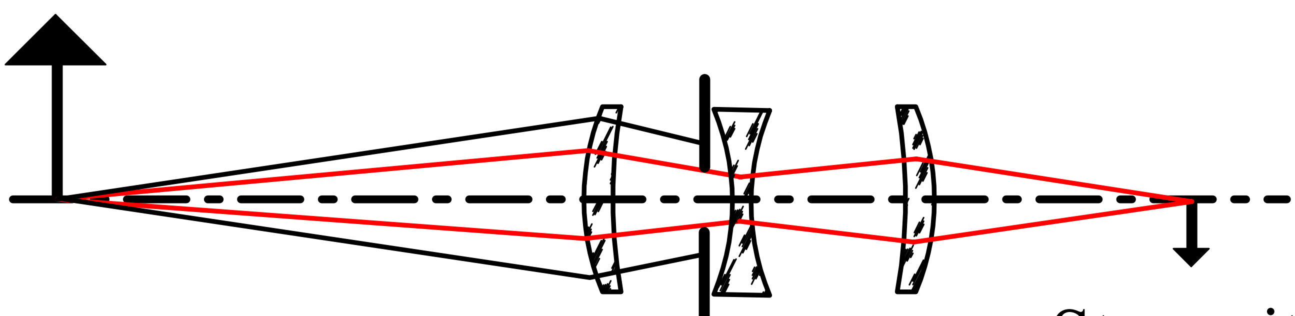
Location of aperture stop



- Stop in front of lens



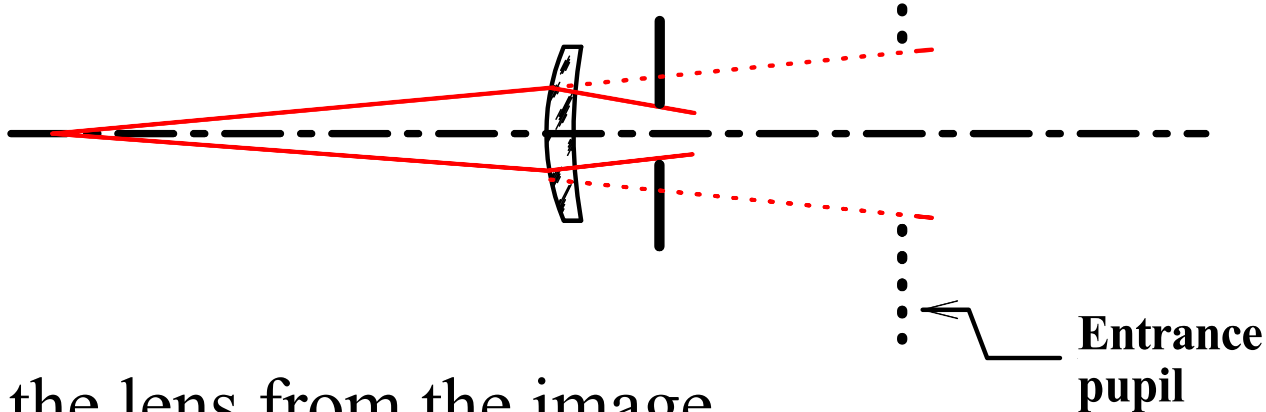
- Stop behind lens



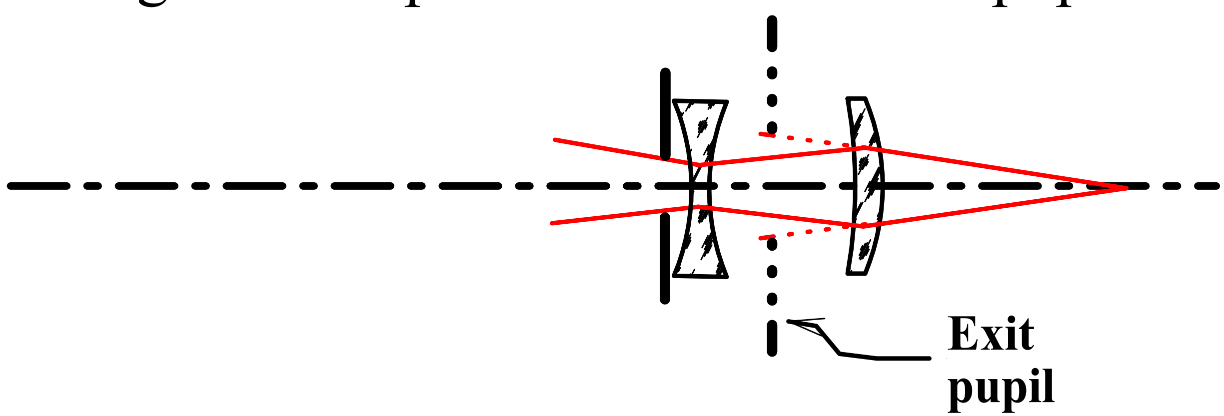
- Stop within lens

Entrance pupil, exit pupil

- View the lens from the object
  - You don't see aperture stop directly, but its image in the optics in front of it, that is the entrance pupil



- View the lens from the image
  - The image of the aperture is now the exit pupil



Size of aperture and f/number

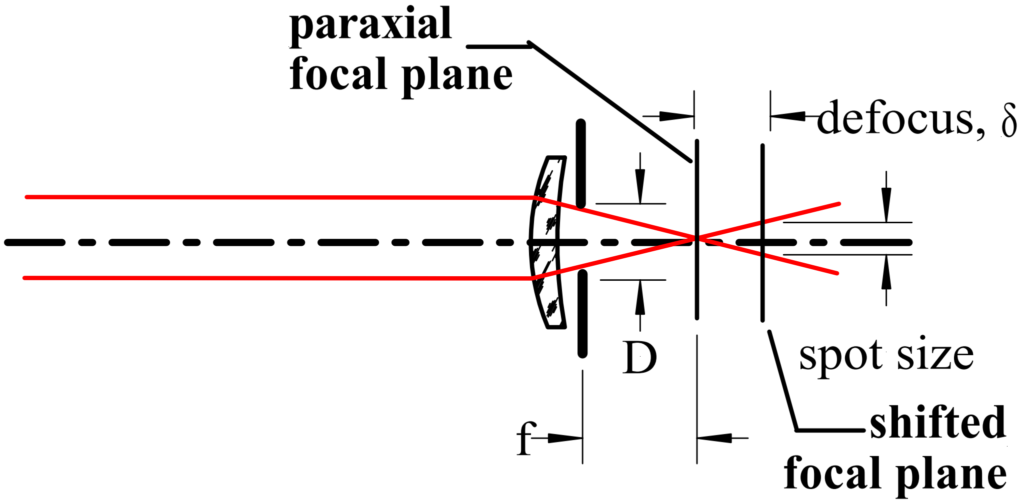
- Aperture size is a very important parameter of the lens
  - how do we determine if the aperture is large or small
  - is a 1mm aperture large, what about a 2 m aperture?
- The important thing is the aperture size compared to the focal length (for object at infinity)
  - Definition

$$f/\# \equiv \frac{\text{focal length}}{\text{diameter of aperture}} = \frac{\text{distance from exit pupil to image}}{\text{diameter of exit pupil}}$$

  - Also called focal ratio or speed(why?)

> A slightly more advanced concept
>
> For imaging of objects not at infinity use image distance instead of focal length, then it is called <u>Working f/#</u>, original definition sometimes called f/# for infinite conjugates

Aperture stop and depth of focus



$$\text{spot size} = \frac{\delta D}{f} = \frac{\delta}{\text{f/\#}}$$

- If the focal plane is not at the paraxial focal plane location then a point object is not sharply focused but produces a blur spot
  - size proportional to aperture stop (exit pupil) diameter
  - some blur spot size is acceptably small
- Defocus for which spot size is acceptably small is the depth of focus
  - depth of focus shorter for larger aperture size

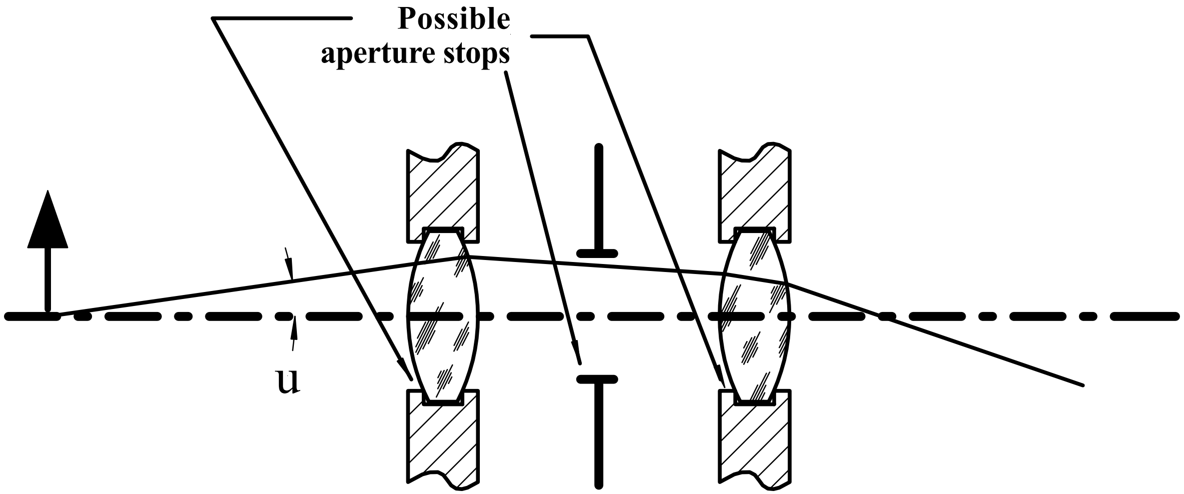
Aperture stops and aberrations

- As the aperture size decreases:
  - rays strike closer to the axis on all optics
  - rays with higher angles of incidence on optics get stopped
- This tends to reduce deviations from paraxial imaging (aberrations)
- All aberrations except distortion and field curvature decrease with smaller aperture size (distortion changes with location of the aperture stop)
- Example: In good light, your pupil (aperture stop of your eye) gets smaller and it is therefore easier to see small details because aberrations are reduced

Aperture stops and diffraction

- No lens forms a perfect image even if aberrations are perfectly small
- Diffraction (more later in semester) makes a point in the object focus to a blurred spot
- The smallest possible (diffraction limited) spot size is approximately
  - diameter of diffraction limited spot $\approx 2\ \lambda\ f/\#$

Finding the aperture stop of an optical system

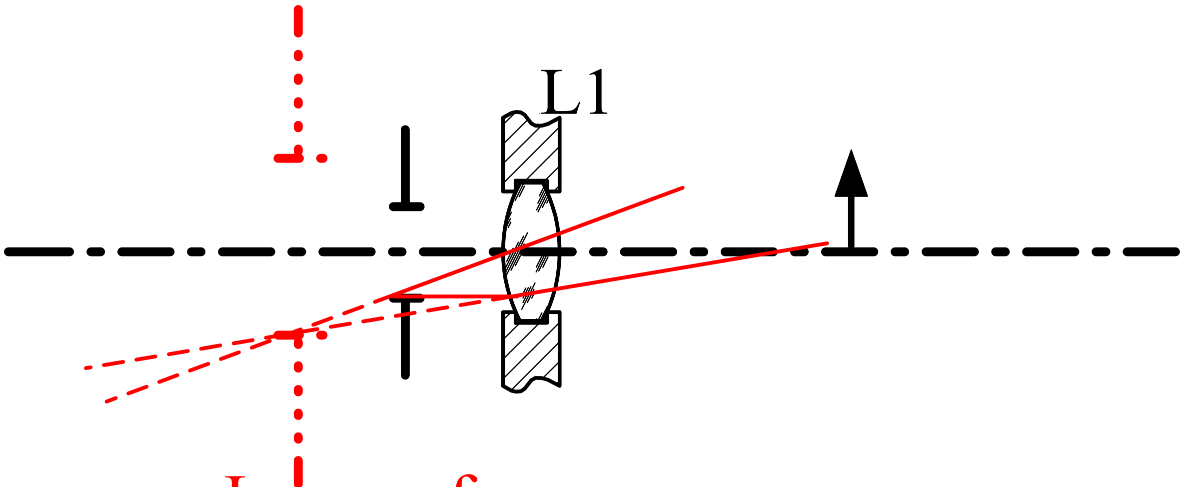


- Every limiting aperture in a lens can potentially be an aperture stop
- As the angle u increases, which edge will the ray first encounter?
- Easiest procedure is to project all the stops into object space

Important points in finding aperture stop

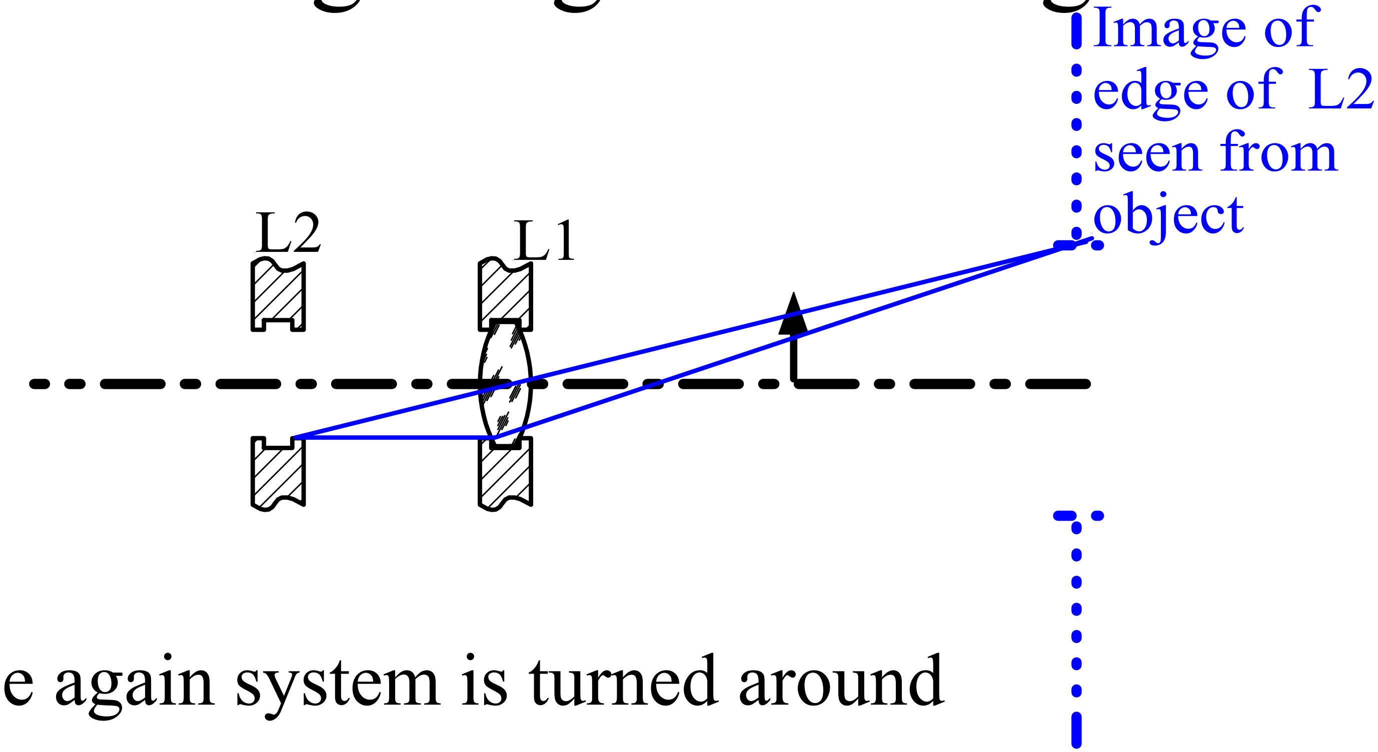
- Every surface must be imaged by all lenses in front of it
  - This means to the left if the optical system is drawn in the standard way with the object on the left
  - For purposes of finding the aperture stop or entrance pupil, it is the lens edge or iris or other surface which must be considered an object; thus light will be traveling from right to left
  - The most foolproof way of dealing with this is to draw a separate diagram showing the lens edge or iris on the left and then tracing the rays in the ordinary way
  - The location of the entrance pupil (or possible entrance pupil) is then found in the original system by turning the diagram back around to the standard orientation
- The entrance pupil can potentially be behind the object
  - Remember rays can be extended whenever needed

Finding image of iris



- System has been turned around so object (iris) is on the left
- Lens 2 is not part of this calculation
- Two rays are traced in the ordinary way to determine the image of the iris, image is virtual

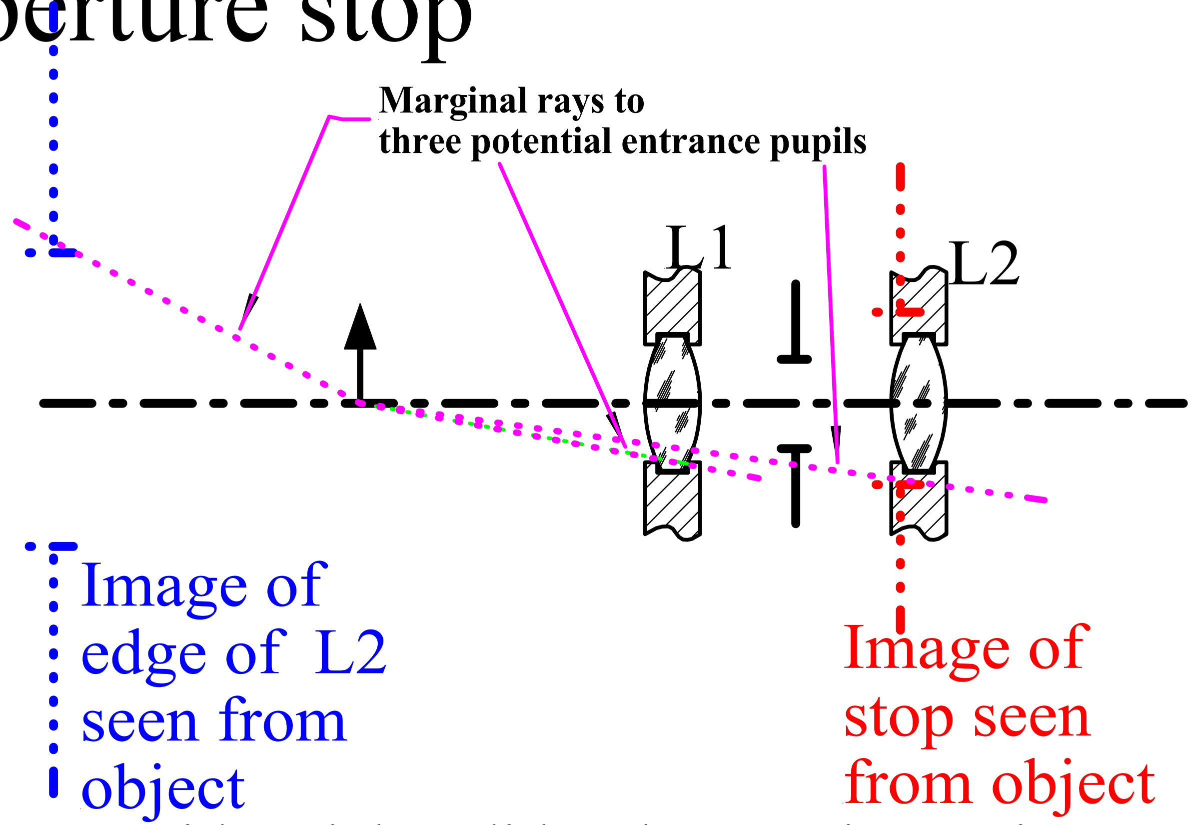
Finding image of L2 edge



- Once again system is turned around
- Lens 2 again is not part of the problem
  - Only the edge which is a potential aperture stop is important
- This time we get a real image because L2 is more than one focal length from L1

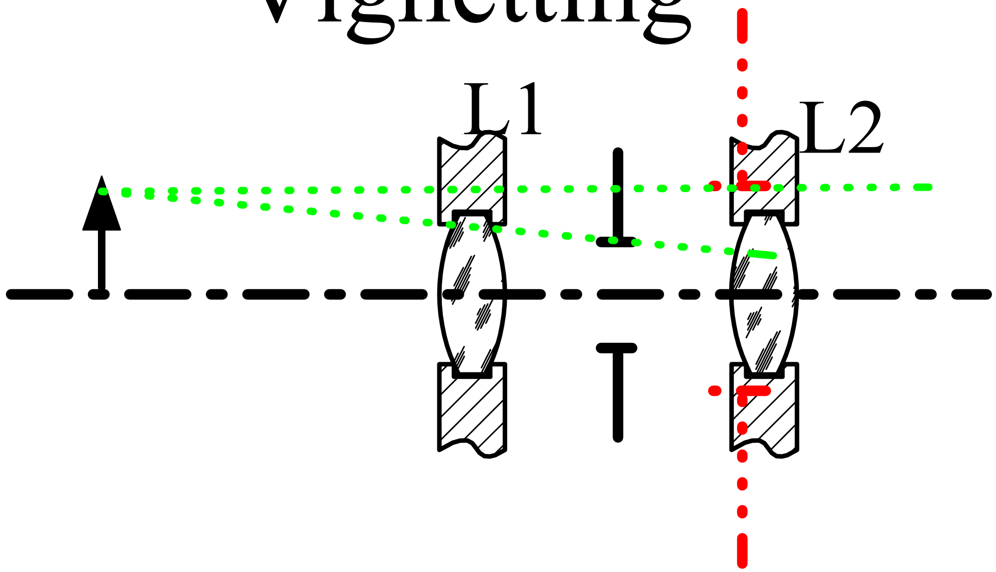
Location of aperture stop

- Rays from base of object are extended to edge of each potential aperture stop
  - Rays don't bend at lens, refraction at lens already taken into account
  - The edge of L1 is also considered, but didn't have to image it, its already in object space



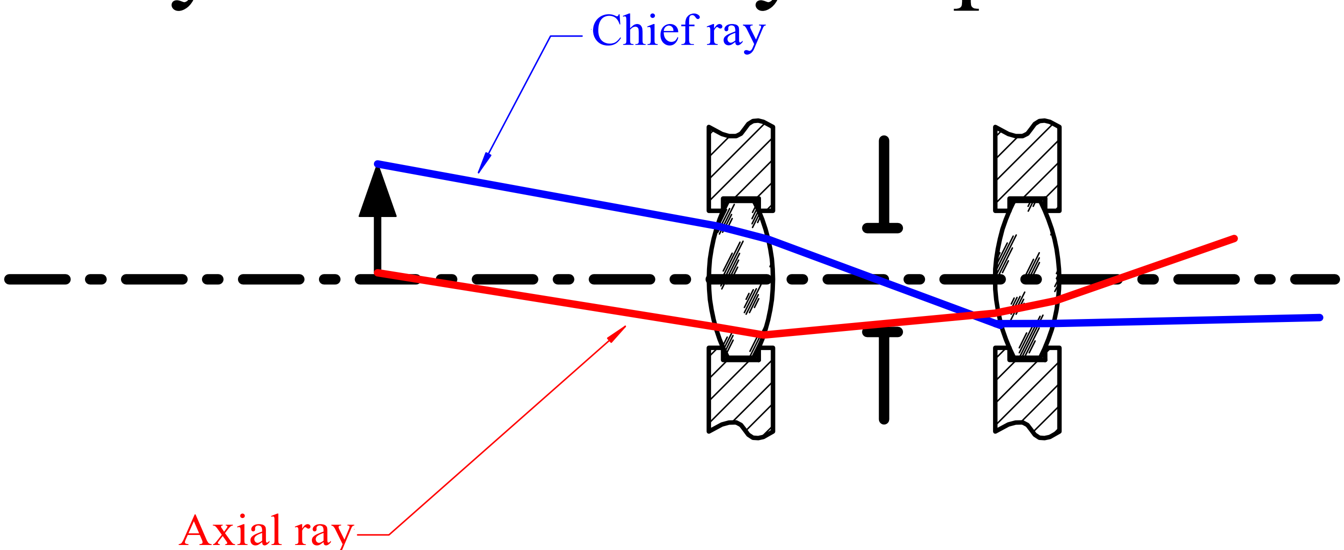
- Look for smallest limiting angle
  - No difference if image is behind object, just extend rays as needed
  - Aperture stop is iris in this case, but could change if iris size increased or object position moved

Vignetting



- Rays from the tip of the object are limited by the lens holder of L1 at the top and the aperture stop at the bottom
- Since a smaller bundle of rays from the tip than from the base gets through the system, the image irradiance from the tip is smaller than that of the base

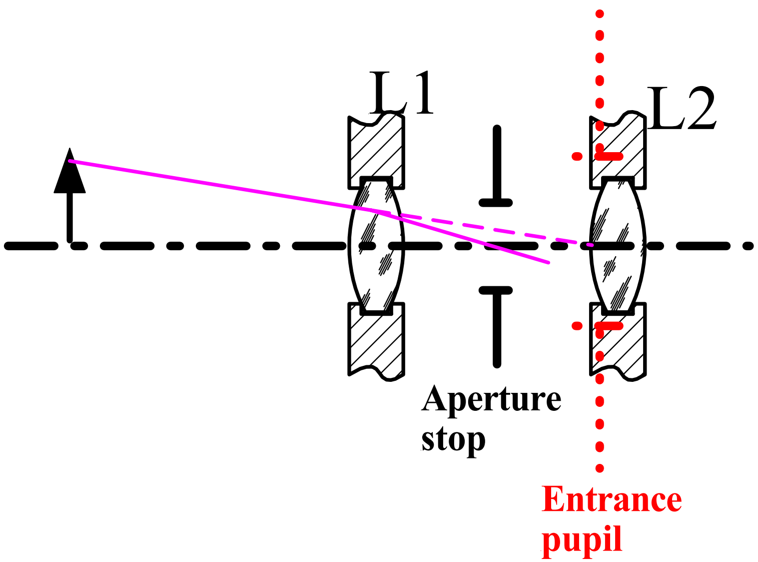
Axial ray and chief ray-improved definition



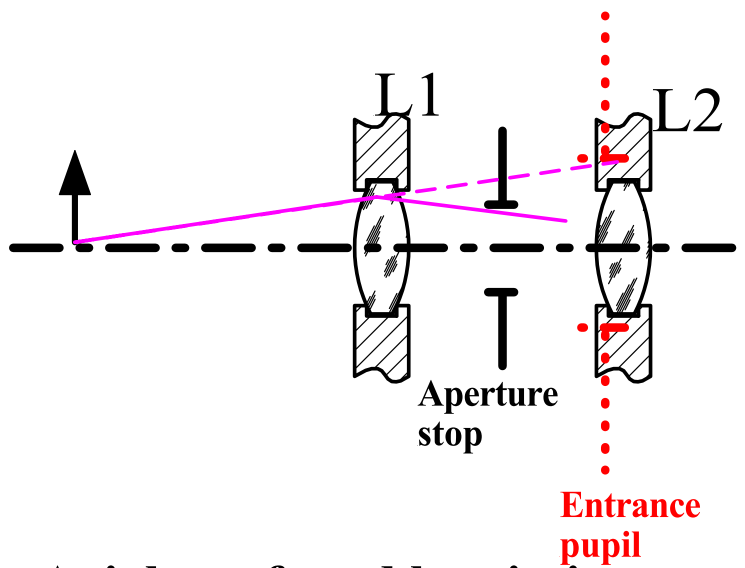
- Previous definition of axial ray and chief ray must be made more general for complex optical systems
  – previous definition only for single lens with stop at lens
- Axial ray is the ray from the base of the object through the edge of the aperture stop
- Chief ray is the ray from the tip of the object through the center of the aperture stop
  – sometimes called the principal ray

Locating the chief ray, axial rays and marginal rays

- Once the entrance pupil is found locating the chief ray and axial rays is easy
  - Aiming rays at the entrance pupil guarantees that the rays after refracting through the lens go through the aperture stop
  - Marginal rays can be done the same way if no vignetting



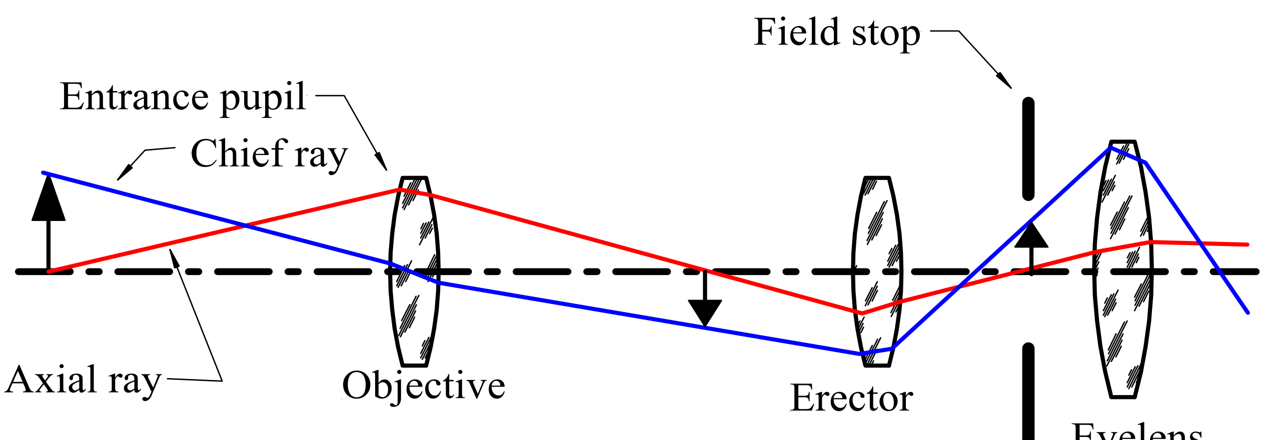
Chief ray found by aiming towards center of entrance pupil



Axial ray found by aiming towards edge of entrance pupil

Field stop

- Field stop is found by increasing size of object until chief ray is limited at some surface
- As with aperture stop another procedure can be used
  - image all stops into object space
  - from the point of view of the entrance pupil find which aperture subtends the smallest angle, this is the field stop
- Field stop not necessarily at an image plane



A simple terestrial telescope

Entrance window, exit window

- The image of the field stop through all elements in front of it is called the entrance window
- The image of the field stop through all elements behind is is called the exit window
- The angular size of the entrance window when viewed from the entrance pupil is the angular field of view
  – sometimes the field of view is the half angle (from axis to chief ray) sometimes it is the full angle (from chief ray to the chief ray on the other side of the axis)