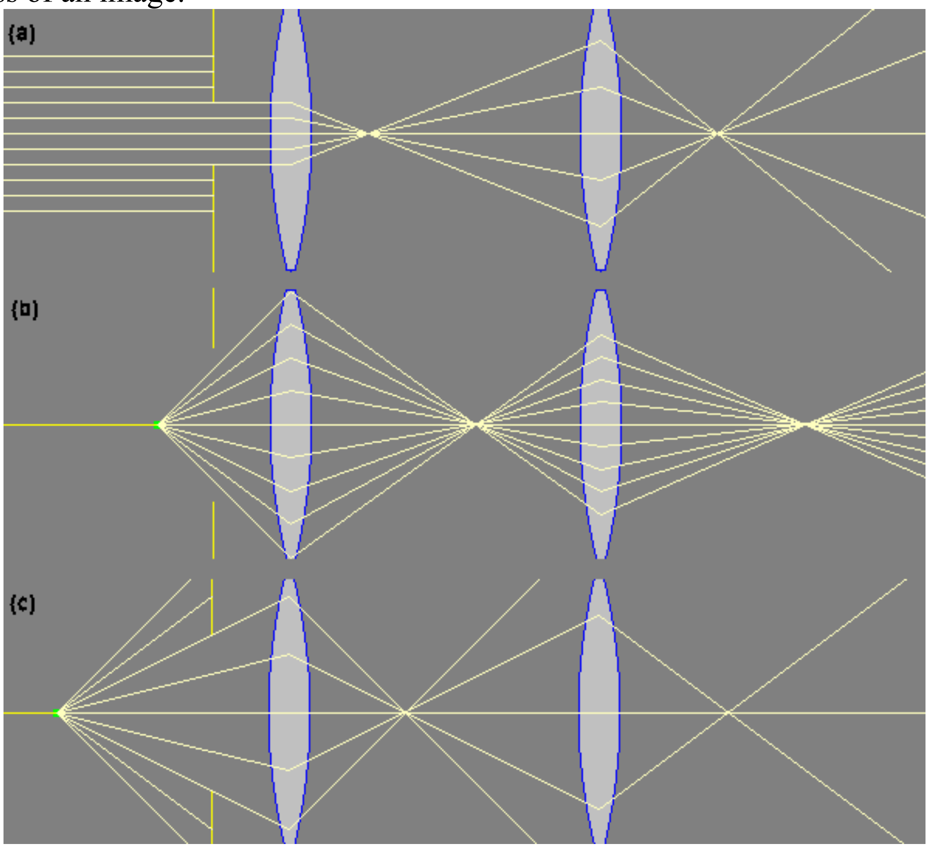
Stops and Apertures [Reading Pedrotti^3 Chapter 3]

(adapted from http://electron9.phys.utk.edu/optics421/modules/m3/Stops.htm)

Two important aspects of any imaging system are the amount of radiation passed by the system and the extent of an object that is seen by the system. Stops and apertures limit the brightness of an image and the field of view of an optical system.

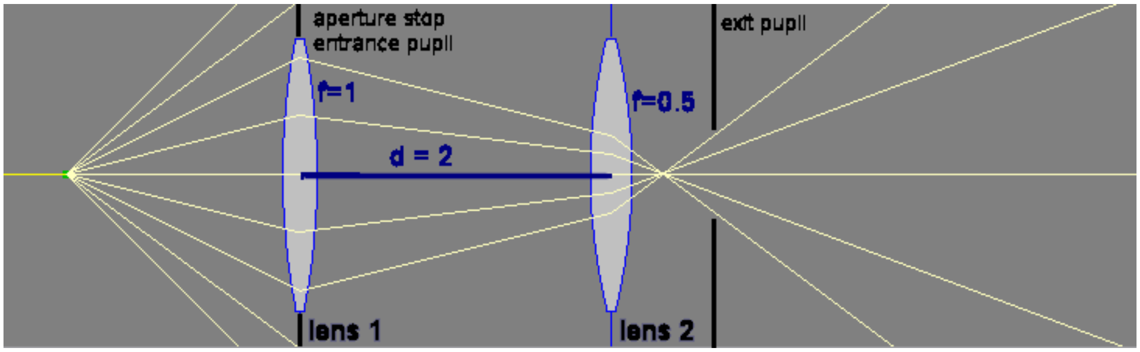
The **aperture stop** (AS) is defined to be the stop or lens ring, which physically limits the solid angle of rays passing through the system from an **on-axis** object point. The aperture stop limits the brightness of an image.



For system (a) in the figure above the aperture is the aperture stop, for system (b) the first lens is the aperture stop and for system (c) the second aperture is the aperture stop.

The **exit pupil** is the image of the aperture stop formed by the light rays after they have passed through the optical system, i.e. it is the image of the aperture stop as seen through all the optics beyond the aperture stop. It can be a real or virtual image, depending on the location of the aperture stop.

The **entrance pupil** is the opening an observer would identify as the limitation on the solid angle of rays diverging from an on-axis object point, i.e. it is the image of the aperture stop in as seen through all the optics before the aperture stop. Again, it can be a real or virtual image, depending on the location of the aperture stop.



The following is simply a recipe for finding the aperture stop, entrance pupil, and exit pupil, given a lens system.

- Image all optical elements in the system into object space.
- Find the angle subtended by each element image at the on-axis position of the object.
- The element image with the smallest angle is the entrance pupil.
- The physical object corresponding to this image is the aperture stop.
- The image of the aperture stop in image space is the exit pupil.

The diagrams above shows two thin lenses with focal lengths f = 1 unit and f = 0.5 units, respectively, placed two units apart. The on-axis object is located 1.5 units in front of the first lens. Lens 1 is the aperture stop for the shown position of the object. It is also the entrance pupil, since there are no optical elements located in front of it. The (real) image of lens 1, as seen through lens 2, is the exit pupil. All the light from the object gathered by the optical system passes through the exit pupil.

In an optical system designed for visual observations, it is desirable to have the exit pupil approximately coincide with the pupil of the observer's eye, since all the light from the object gathered by the optical system then enters the eye. This is the origin of the term "pupil".

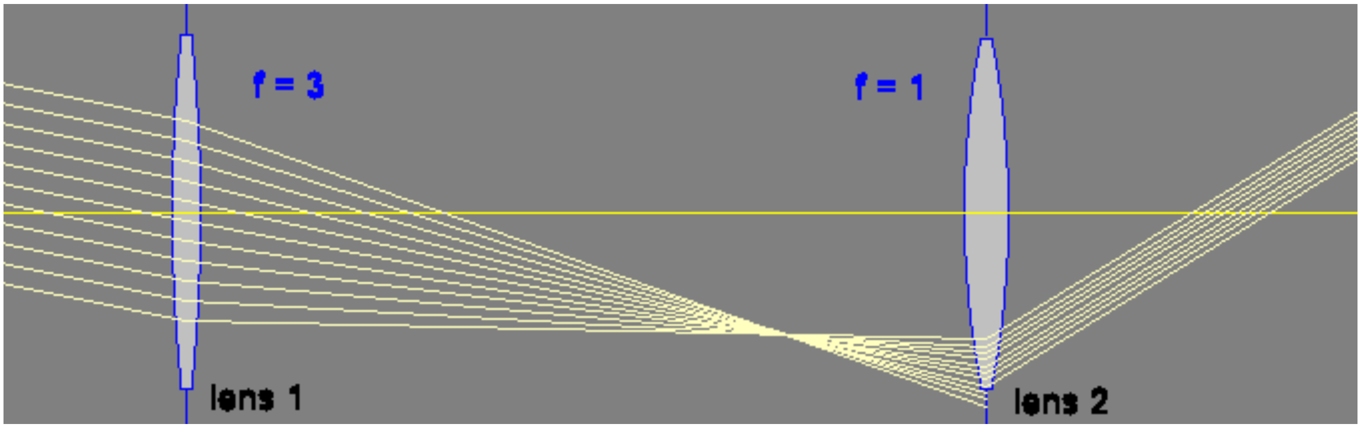
Aperture stop vs. Field stop

For an off-axis object, the chief ray (CR) is the ray that passes through the center of the aperture stop. Rays that pass through the edge of the aperture stop are marginal rays (MR).

The aperture stop determines the solid angle of the transmitted light cone for an on-axis object. It limits the brightness of an image. The **field stop** determines the solid angle formed by chief rays from **off-axis** objects. It limits the field of view of an optical instrument.

The image of the field stop as seen through all the optics before the field stop is called the **entrance window**.

The image as seen through all the optics after the field stop is called the **exit window**.



For the telescopic system shown above, the second lens (eyepiece) is the field stop for very distant objects.

The following is simply a recipe for finding the field stop, entrance window, and exit window, given a lens system.

- Image all optical elements in the system into object space.
- Find the angle subtended by each image at the on-axis position of the entrance pupil.
- The element image with the smallest angle is the entrance window
- The physical object corresponding to this image is the field stop.
- The image of the field stop in image space is the exit window.

A cone of light rays from an off-axis object to the entrance pupil will not necessarily be transmitted in its entirety. It can be partially cut off by field stops or lens rims in the system. This is called vignetting.

Field of view

The angular field of view is the angle formed by the edges of the entrance window at the on-axis position of the entrance pupil. We find the location of the entrance window by finding the location of the image of lens 2 formed by lens 1. ($1/4 + 1/x_i = 1/3$, $x_i = 12$,) The entrance window is located 12 units to the left of lens 1. Since the magnification is M = -3, the diameter of the entrance window is three times the diameter of lens 2. The entrance pupil is lens 1 itself. The half angle q for the field of view is given by tanq = 3*(radius of lens 2)/12.

In a system with vignetting, the angular field of view may also be defined as the largest angle of an input chief ray with the optical axis.

Example Problem:

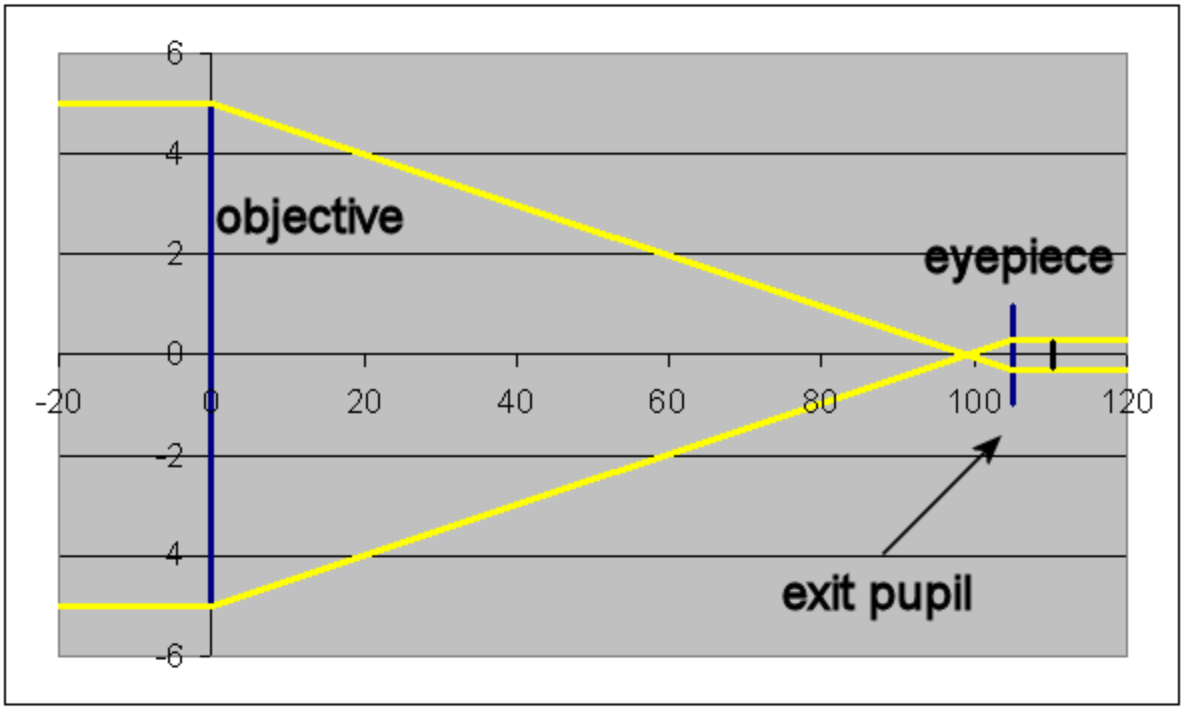
A telescope has the following parameters:

	Focal length (cm):	Diameter (cm):
Objective:	100	10
Eyepiece:	5	2

If the two lenses are separated by a distance of 105 cm, show that the objective serves as the entrance pupil and its image is the exit pupil. Find the position and size of the exit pupil.

Solution

A telescope is used for viewing distant objects. Rays from on-axis distant objects enter the optical system parallel to the optical axis. Assume we have thin lenses. A ray diagram shows that the objective is the aperture stop for distant objects.



Every ray entering the system through the objective passes through the eyepiece. The image of the aperture stop seen through all the optical elements to the left of the aperture stop is the aperture stop itself, since there are no optical elements to the left of it.

The objective serves as the entrance pupil. Its image when viewed through all the optical elements to the right of it is the exit pupil. The exit pupil therefore is the image of the objective formed by the eyepiece.
Its location is found from $1/s' + 1/s = 1/f$, $1/s' = 1/5 - 1/105 = 20/105$. $s' = 5.25$.

The position of the exit pupil is 5.25 cm to the right of the eyepiece.
Its diameter is $d' = M\ (10\ \text{cm}) = s'/s\ (10\ \text{cm}) = 5$ mm.