STOPS (5.3)

Aperture Stop

As $\theta$ increases the ray will eventually hit the edges of one of the components of the system.

Rays that will not be collected by the optical system.

Rays that will not be collected by the optical system.

diaphragm
Aperture Stop: It is the opening in an optical system that limits the amount of light that can be collected. This aperture could be:

- The rim of a particular lens in the optical system, as in figure A and B
- A purposely placed diaphragm, as in figure C

In rank: Image location
- Aperture stop
- Entrance pupil
- Exit pupil

Terminology

[Diagram of light path through an optical system with labels for object space and image space]
**Entrance Pupil:** It is the image of the aperture stop seen from the object space.

**Exit Pupil:** It is the image of the aperture stop as seen from the image space.
Significance of the Entrance Pupil

First, let's find the image of the aperture stop.

Now, let's image an object.
Having determined the image $M'N'$, let's draw ray (3), which trace $N$ to $N'$, passing by $Q$. Point $Q$ is on the rim of the AS.

Let's trace the ray $QP$. 

[Diagram of a lens with rays passing through it, labeled M, F, N, P, Q, and N', showing the tracing of ray (3) and the entry of light at the pupil.]
Due to the principle of reversibility, we realize that ray $\overrightarrow{QP}$ should be traced down to $N$.

Also, since $Q'$ is the image of $Q$ (when seen from the object space) we must conclude that ray $\overrightarrow{PN}$ is traced back to $Q'$. 

![Diagram of光学系统及其光路追踪](image-url)
From these diagrams we conclude that the image of the aperture stop, when seen from the object space, determine the cone of rays (from the object point $N$) that will make it to the image point $N'$.

Thus, the aperture stop can be replaced by a hole located at the entrance pupil.
**Example**

Lenses (1) and (2) are biconvex. Determine graphically the **entrance pupil**.

Notice the direction of the ray tracing to determine the image of the aperture stop AS.

Notice: lens (2) does not play a role in determining the **entrance pupil**.
Example. Lenses (1) and (2) are biconvex. Determine graphically the Exit pupil.

Notice the direction of the ray tracing to determine the image of the aperture stop AS.
Object MN is imaged through the optical system composed by 2 lenses and an aperture stop.

Notice: the cone of rays from N is determined by the entrance pupil.
the cone of rays from N" is determined by the exit pupil.
Chief Rays  Rays that pass through the center of the aperture stop.

A chief ray can be traced in both directions:

- In object space, any chief ray appears to come from the centre $\text{Enp}$ of the entrance pupil.

\[ \Delta \]

Since the entrance pupil is the image of the aperture stop, $\text{Enp}$ is the image of $A$. 

\[ F_{o1} \quad A \quad \text{Enp} \]

$A$: Center of the aperture stop

$\text{Enp}$: Centre of the entrance pupil

\[ \text{Dens} \quad \text{AS} \]
In Image space, any chief ray appears to come from the center of the Exit Pupil.

\[ \text{Exit Pupil} \]

\[ \text{Exp} \]

\[ \text{A} \]

\[ \text{AS} \]

\[ \text{a chief ray} \]

\[ \text{lens} \]

\[ \text{D} \]

\[ \text{Exp : center of the Exit Pupil} \]

\[ \text{A: center of the Aperture Stop} \]
In the figure below, an object MN is imaged through the optical system composed by 2 lenses. The final image is M"N".

Notice: Out of the many chief rays (all of them passing through A) one of them can be traced to N and to N".

The chief ray, associated with a conical bundle of rays from a point N on the object, effectively behaves as the central ray of the bundle and is representative of it.

(See also Fig 5.36, page 173)
We can increase the slope of the chief ray until we encounter a limitation by some edge in the optical system. Such limitation can occur either:

1. at the Object space (lens-1 for example in the figure above)
2. at the Image space (film)

The opening that limits the maximum slope of the chief rays is the Field Stop.
Example where the size of the frame holding the film is the factor that limits the maximum slope (around the center A of the aperture stop) of the chief ray. Therefore, the size of the film becomes the aperture size of the field stop.
Example where the front lens limits the maximum slope of a chief ray (around the center $A$ of the aperture stop)

In short: the borders of the field stop aperture are touched by the chief rays of maximum slope.
Similar to what we did in imaging the aperture stop from Object-Space and Image-Space, we'll do the same thing with the Field Stop.

**Entrance Window:**
- It is the image of the Field Stop seen from the Object-Space

**Exit Window:**
- It is the image of the Field Stop seen from the Image-Space

**Notice:** Since the Field Stop aperture is touched by chief rays (the ones with maximum slope), which are rays that are traced through the optical system, therefore an image of the Field Stop will also be touched by the same set of chief rays (the ones with maximum slope).
Imaging the field stop from the object-space
Imaging the FIELD STOP from the Image-space.
Angular Field of View

In the object space, the angular field of view is the angle at the entrance pupil defined by chief rays that touch the edges of the field stop.
Finding the Aperture Stop

In a situation where it is not clear which element is the actual aperture stop, each component of the system must be imaged by the remaining element to its left.

The image that subtends the smallest angle at the axial object point is the ENTRANCE PUPIL.

The element whose image is the entrance pupil is then the aperture stop of the system for that object point.

(Please note: Problem 5.44)
In the previous optical system (a positive and a negative lens) it turns out that:

- lens (1) is the aperture stop
- lens (1) is also the entrance pupil (since there are not optical lenses at the left of lens (1))

From the center of the aperture stop we draw the chief rays. Notice that lens (2) is the only element that will limit the maximum slope of a chief ray. Therefore:

- lens (2) is the field stop.
- lens (2) is also the exit window (since there are not lenses at the right of lens (2))

Object

Exit Pupil
(image of AS from image space)
VIGNETTING

F F

AS

EXIT pupil

EXIT pupil
Notice the field stop causes a gradual fading out of the image at points near its periphery.

This reduction in the effective aperture stop of the system is called VIGNETTING.
Optical Instruments

Simple Magnifier

For $s_o < f$

The transverse magnification is given by

$$m = \frac{h_i}{h_o} = \frac{f}{f - s_o}$$

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

$$s_i = -\frac{f}{f - s_o} \cdot s_o$$
ANGULAR MAGNIFICATION

When viewing virtual images with optical instruments, the images may end up located at great distances ("at infinity"). In such cases the transverse magnification also approaches infinite which turns out to be not very useful. A more convenient term is the defined: the angular magnification

\[ \theta_0 = \frac{h_o}{25 \text{ cm}} \]

Angular size of the object

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Standard EYE near point

EYE fully accommodated

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object

\[ h_o \uparrow \]

25 cm

eye will not be able to image the object on the retina (object is too close, eye cannot accommodate more)
what a lens does is to increase the focal length power (i.e. decreases the overall focal length)
In order to focus on the retina, objects that are closer than 25 cm from the eye, we can use a lens.

\[ \theta_i = \frac{h_i}{25 \text{ cm}} \]

Notice, using a lens we gain angular magnification.

\[ \theta_o = \frac{h_o}{25 \text{ cm}} \]

* Didn't we say that a concave lens was needed to correct a myopic eye? Why are we using a convex lens now?

Answer: A myopic eye has, relatively speaking, in comparison to a normal eye, too much power. The objective of wearing glasses of negative focal length is to make it function as a normal eye. The objective is not for seeing things closer than...
Example: Given $f$, where should we place the object such that its image is formed at 2.5 cm from the eye?

What will be the angular magnification?

$$s_i = -25\text{cm} \Rightarrow \frac{1}{s_o} + \frac{1}{-25\text{cm}} = \frac{1}{f}$$

$$\Rightarrow s_o = \frac{f \cdot 25\text{cm}}{f + 25\text{cm}}$$

Angular size $\theta_i = \frac{h_i}{25\text{cm}}$

From the figure

$$\theta_i = \frac{h_i}{25\text{cm}} = \frac{h_o}{s_o} = \frac{f + 25\text{cm}}{f} \cdot h_o$$

Angular magnification

Since $\theta_o = \frac{h_o}{25\text{cm}}$, $\frac{\theta_i}{\theta_o} = \frac{f + 25\text{cm}}{f}$
\[
\frac{\theta_i}{\theta_o} = \frac{2.5\text{ cm}}{f} + 1
\]