Geometrical Optics
Apertures: Pupils and Windows

Introduction to Optical Engineering

L04

Prof. Joshua Brake

Overview of Unit 1: Geometrical Optics

- Radiometry Key Concepts
- Fundamental Principles & Laws
  - Refraction
  - Reflection
  - Snell's Law
  - Huygens Principle
  - Fermat's Principle
- Focusing and Imaging
- **Apertures: Stops, Pupils, and Windows**
- ABCD Matrices
- Aberrations
- Later: Wave Optics

Topics for Today

- Introduction to apertures
    - Pupils
    - Windows
- Practice
    - Front stop
    - Back stop
    - Multiple-lens system

Learning Outcomes

By the end of this lecture you should be able to…

- Explain why we need to incorporate apertures within our optical system.
- Describe how apertures serve as pupils or windows.
- Calculate the location and size of the entrance and exit pupils and windows in an optical system.

A reminder about the ray tracing diagram

- Light travels in straight lines until hitting a surface. Then we either refract or reflect
- Sign conventions for lenses
  - Object distance (s) positive to *left* of lens
  - Image distance (s') positive to *right* of lens
  - Focal length positive for convex, negative for concave.
  - Magnification is ratio of image height to object height where the height is positive if above the optical axis.

TABLE 1 SUMMARY OF GAUSSIAN MIRROR AND LENS FORMULAS

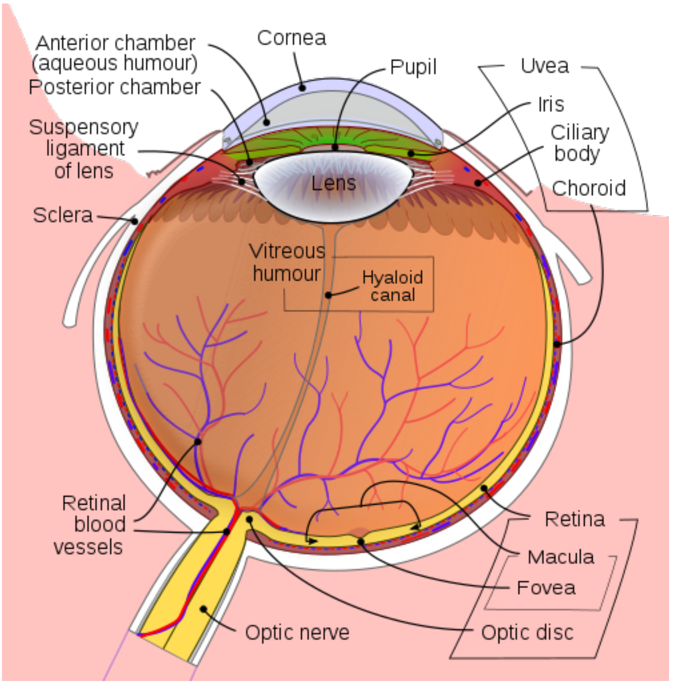
	Spherical surface	Plane surface
Reflection	$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}, f = -\frac{R}{2}$ $m = -\frac{s'}{s}$ Concave: $f > 0, R < 0$ Convex : $f < 0, R > 0$	$s' = -s$ $m = +1$
Refraction Single surface	$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$ $m = -\frac{n_1 s'}{n_2 s}$ Concave: $R < 0$ Convex : $R > 0$	$s' = -\frac{n_2}{n_1}s$ $m = +1$
Refraction Thin lens	$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ $\frac{1}{f} = \frac{n_2 - n_1}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ $m = -\frac{s'}{s}$ Concave: $f < 0$ Convex : $f > 0$	

Pedrotti *et al.*, *Introduction to Optics 3rd Ed.* Table 2.1

Stops: Pupils, and Windows

- Apertures in an optical system have two main purposes:
  - Limit the field of view – **field stop**
  - Control the image brightness - **pupil**

KoeppiK, Lenses with different apertures, CC BY-SA 4.0



Rhcastilhos. And Jmarchn., Schematic diagram of the human eye en, CC BY-SA 3.0

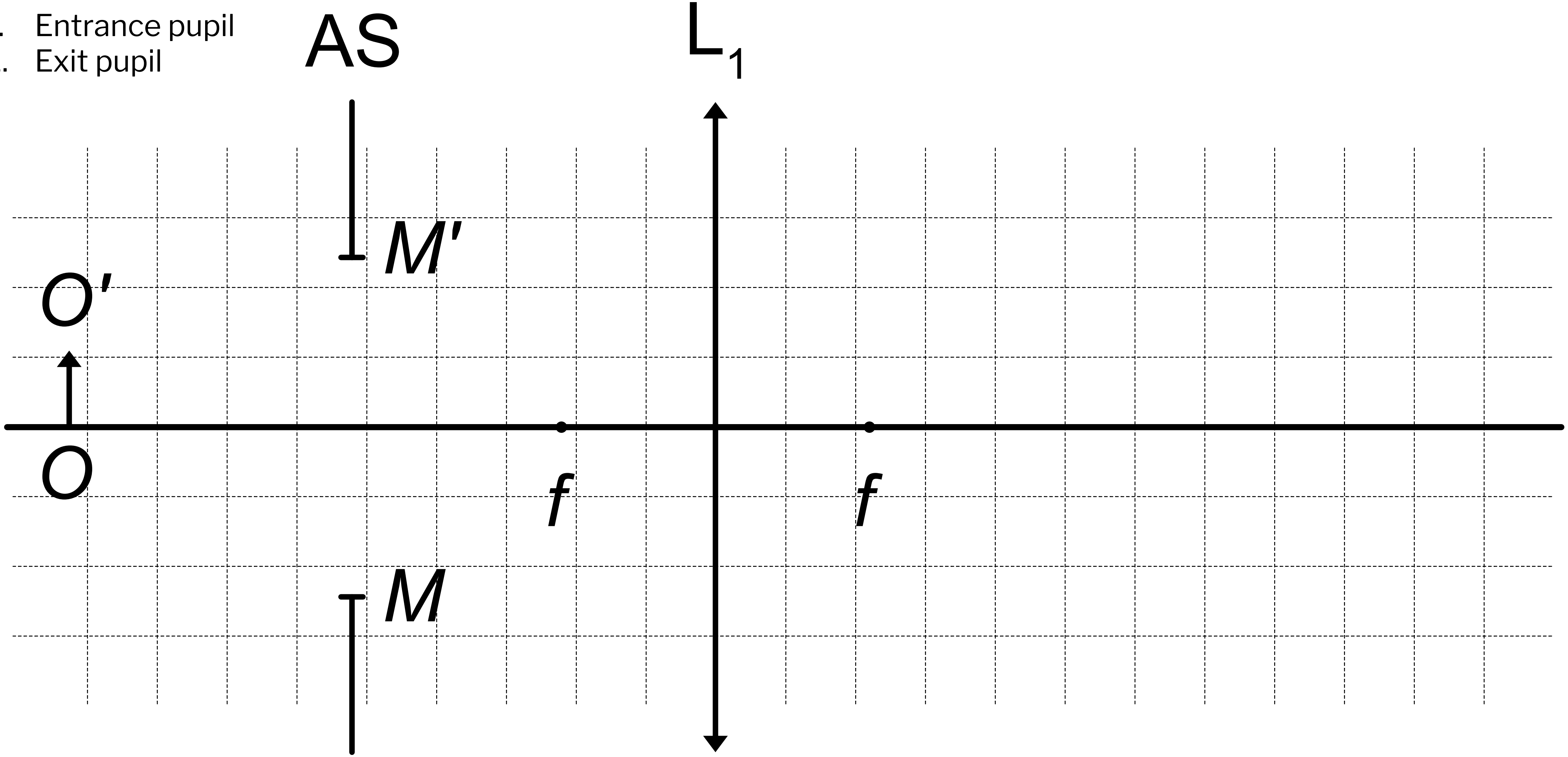
Image Brightness: Aperture Stops and Pupils

- **Aperture Stop (AS):** the physical aperture that limits the size of the maximum cone of rays from an axial object point to a conjugate image point.
- **Entrance Pupil (E_nP):** The limiting aperture that the light rays ”see” looking into the optical system from the object.
- **Exit Pupil (E_xP):** The image of the controlling aperture stop formed by the imaging elements following it (i.e., to the right)

Example: Front Stop

Find

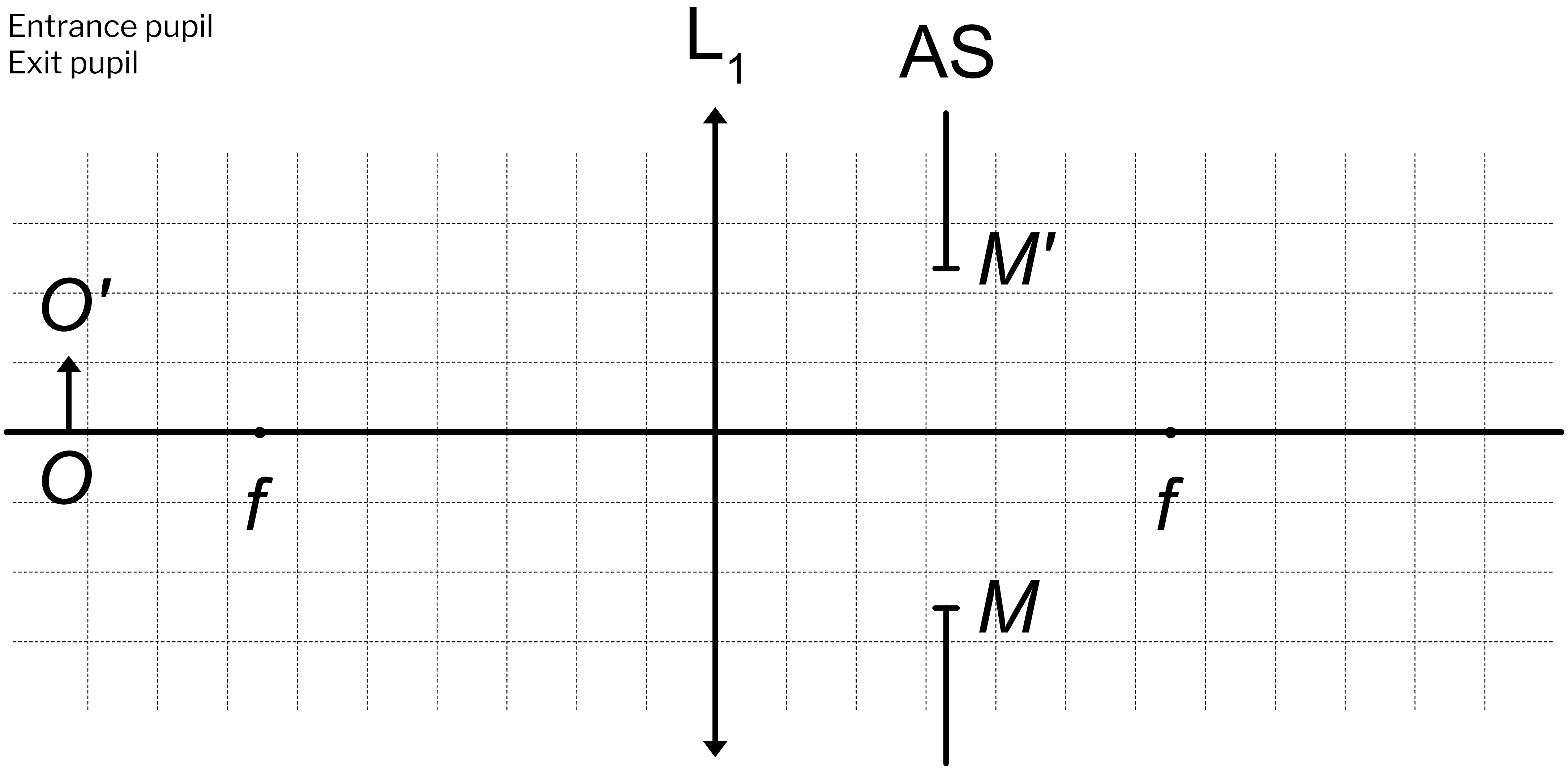
1. Entrance pupil
2. Exit pupil



Example: Back Stop

Find

1. Entrance pupil
2. Exit pupil



A few important terms

- **Chief Ray** – a ray from an object point which passes through the center of the pupil (and any conjugate planes such as the entrance and exit pupil).
- **Marginal Ray** – a ray from an object point which just barely passes through the edge of the aperture (i.e., it is “on the margin”)

Field of View: Field Stops and Windows

- **Field Stop (FS):** the physical aperture that controls the field of view by limiting the solid angle formed by the chief rays. *As seen from the center of the entrance pupil, the field stop or its image subtends the smallest angle.*
- **Entrance Window (E_nW):** The image of the field stop formed by all optical elements *preceding* it.
- **Exit Window (E_xW):** The image of the field stop formed by all elements *following* it.

Why use stops?

- Filter out areas of the image where performance drops below a certain threshold.
- Enable the user to select the amount of light that passes through the optical system (this also has the tradeoff of limiting the depth of field).

Optical System Example

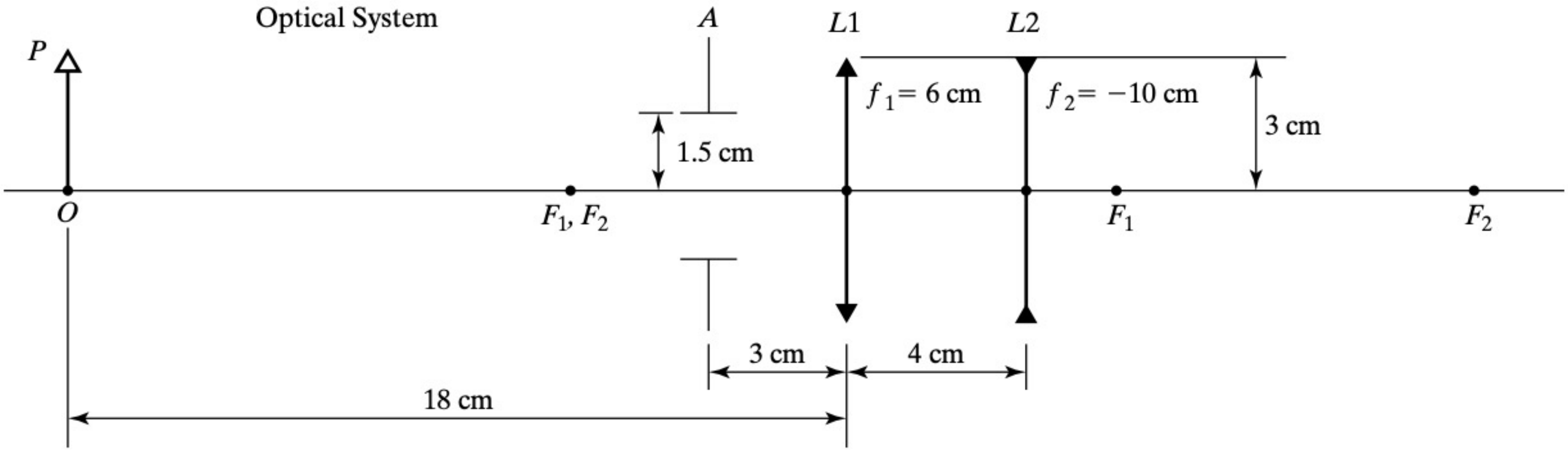
For the given optical system, find the following:

(a) Which element (A, L_1, or L_2) serves as the aperture stop?

(b) Determine the size and location of the entrance and exit pupils

(c) Determine the location and size of the intermediate image formed by L_1 and the final image formed by the system.

(d) Using a scale of your choice, draw a scale diagram of the optical system including the two pupils (entrance and exit), the intermediate image, and the final image.



Pedrotti *et al.*, *Introduction to Optics 3rd Ed.* Fig. 3.4

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