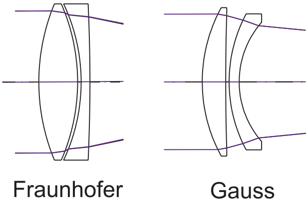
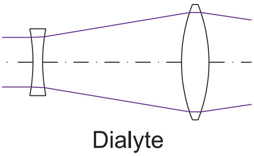
Airspaced Doublets

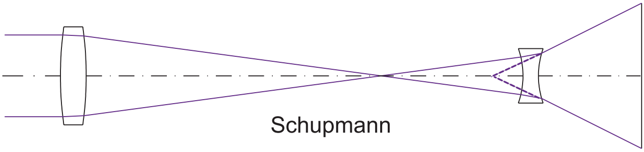


The speed of a **Fraunhofer doublet** can be increased to ~$f/2.5$ by separating the cemented surface to create an **airspaced doublet**. The extra curvature and airspace are used to control higher-order spherical aberration and spherochromatism. However, the ray angles of incidence in the airspace between the two elements can become very large, making the alignment tolerances of the two elements very tight. A second type of airspaced doublet is a **Gauss doublet**, which has much steeper curves and significantly larger higher-order aberrations. As a result, Gauss doublets are not as fast as Fraunhofer doublets and are often found in stop-symmetric anastigmatic lenses.



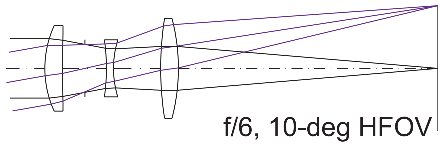
Two separated positive and negative elements (or groups of elements) with a relatively large air gap between them is known as a **dialyte**. Although the performance of a simple two-element dialyte is usually insufficient (primarily due to its inability to correct lateral color), it is the basis for more-complex **telephoto** (positive/negative) and **reverse telephoto** (negative/positive) multi-element designs.

A **Schupmann lens** is a special airspaced doublet that is corrected for primary color but uses the same material in both elements. Because the lens has a virtual image, it is seldom used alone but rather is often part of more-complex lens systems.



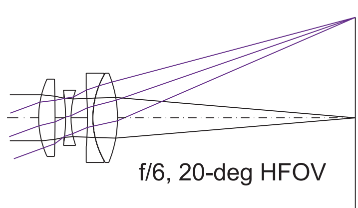
Cooke Triplet

The **Cooke triplet** is the simplest design form with enough degrees of freedom to correct all first- and third-order aberrations and hold first-order imaging constraints such as EFL and BFL. The outer two elements are positive crowns, and the middle element is a negative flint with the aperture stop located on either side of the middle element. The symmetry of the design helps control coma, distortion, and lateral color. Because it is only corrected to third order, the Cooke triplet is limited by higher-order aberrations and is thus capable of relatively slow apertures (~$f/6$) and moderate fields (10–15 deg). Up to 50% vignetting may be needed in systems with larger fields.

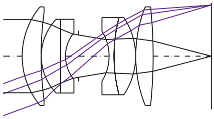


The Cooke triplet is the most basic form of an **anastigmat lens**. Strictly speaking, the term anastigmat means "free of astigmatism;" however, it is also used to describe optical systems with reduced astigmatism and relatively flat fields. In these designs, the field is flattened by separating positive and negative power along the optical axis (between surfaces, elements, or even multi-element groups of components). **PLAN microscope objectives** use this principal to flatten the field curvature.

Many **photographic objective** design forms are derived from the Cooke triplet by **splitting**, **compounding**, or otherwise modifying elements of the basic triplet. For example, in the **Tessar** lens, the last element of a Cooke triplet is compounded into a doublet. This design allows for speeds up to $f/4$ and/or larger fields of view than the basic triplet with reduced vignetting.



Double Gauss

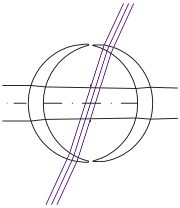


f/2, 20-deg HFOV

The **double Gauss** (or **Biotar** or **Planar**) is a powerful anastigmat design form used in a wide range of applications, including fixed-focus camera objectives, projection lenses, and high-resolution microscope objectives. The classic six-element design is nearly symmetric about the stop (reducing coma, distortion, and lateral color), with outer positive singlets and inner cemented thick-meniscus doublets (to minimize Petzval). Astigmatism is controlled by adjusting the distance of the elements from the stop, as this separation has little effect on the other aberrations. Design improvements to the basic form have been studied extensively in the literature; allowing the system to depart from symmetry and/or adding elements (by splitting or compounding) allows one to achieve speeds up to $f/1$ or FFOVs larger than 50 deg.

> Fast anastigmats with small fields tend to have relatively short vertex lengths, whereas slow-speed wide-angle lenses tend to have longer vertex lengths. In Cooke triplets the vertex length can be controlled by glass choice (particularly the difference in V between positive and negative elements).

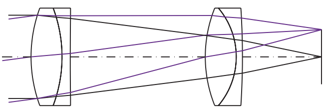
Many other lens forms use stop symmetry and power separation to achieve wide fields of view. The simplest is the **Hypergon**; two identical meniscus elements symmetric about the stop achieving an impressive 135-deg FFOV. Petzval is reduced by the separation of positive and negative power in the elements themselves where each element has a positive and a negative surface with radii differing by less than 7%. However, Hypergons are slow (~$f/20$) as there is no remaining degree of freedom to correct the spherical aberration. More-complex designs (e.g., **Topogon**, **Hologon**, and **Biogon**) add elements to increase their speed.



f/20, 65-deg HFOV

Petzval Lens

The **Petzval** or **Petzval portrait lens** is a design form useful for high-speed applications that require high-quality imaging over relatively small fields (e.g., aerial reconnaissance). Originally designed for indoor photography, Petzval lenses are an order of magnitude faster than landscape lenses. The Petzval lens is the basis of many microscope objectives where aplanatic elements are added to the short conjugate for increased NA.

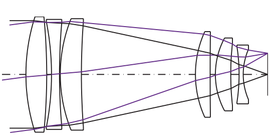

f/2.5, 7.5-deg HFOV

Unlike many of the other basic design forms, the Petzval lens has very little symmetry. The basic layout uses two separated, positively powered achromats with the stop at or near the front lens. Negative astigmatism from the first doublet is balanced with positive astigmatism from the second doublet. Because there are no lens groups with net negative power, the design form is fundamentally limited by Petzval, restricting its field size. Decreasing the airspace between the two doublets can help reduce the Petzval at the expense of increased astigmatism.

Given the focal length f of a Petzval lens, the first-order thin lens layout can be calculated as follows:

- Front element focal length: $2f$
- Rear element focal length: f
- Element separation: f
- Back focal length: $f/2$

Improvements to the basic Petzval lens include adding a strong negative **field lens** near the image plane to correct Petzval and increase its field (although this significantly decreases the working distance). The Petzval lens is also the base design form of many extremely fast (~$f/1$) lenses, including very high-speed, 6–8-element **Petzval projection lenses**.


f/1.5, 7.5-deg HFOV