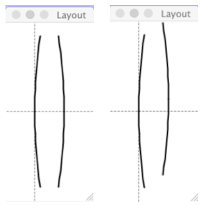
OPTEC LASEA GROUP

Lenses,- for beginners, but we can all learn!

The word 'lens' is C17th & comes from the Latin 'lentil' because of the similarity in shape.
In school we learn to draw one, usually something like this, we suppose with spherical surfaces because these are the ones that are by far the easiest to manufacture. An astute pupil might say a 'bad' lens would be one where the centres of curvature are not correctly 'aligned' as at right but of course there is always a line at some angle joining the centres of two adjacent spheres,- the optical axis,- so the question is more how the outer edge of the lens lies w.r.t. that axis,- very appropriately the operation to do that is appropriately termed 'edging'.

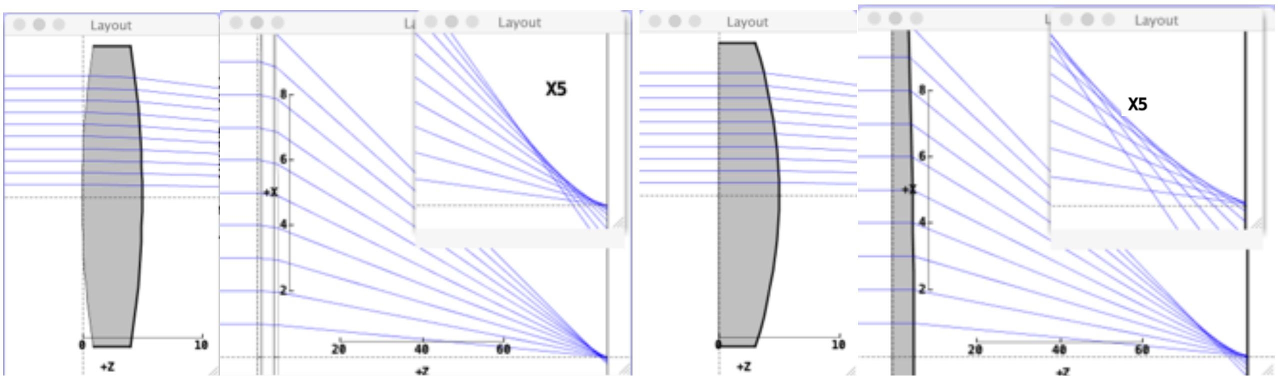


If the surfaces are not truly spherical then we possibly have the bottom of a beer bottle or a 'bullseye' crown glass window pane, and most likely a really bad & useless lens, but of course there is always ***some*** departure from a perfect sphere however small, In general one can define/specify regularity,- how close that is to being a true spherical surface, and conformity how close it is to being the radius of curvature ROC that we want. Both are traditionally measured in fringes, i.e. Newton's interference rings between the lens surface and a test glass of opposing curvature with a surface known to be spherical to at least a higher degree than the lens we are trying to test,- all is relative!

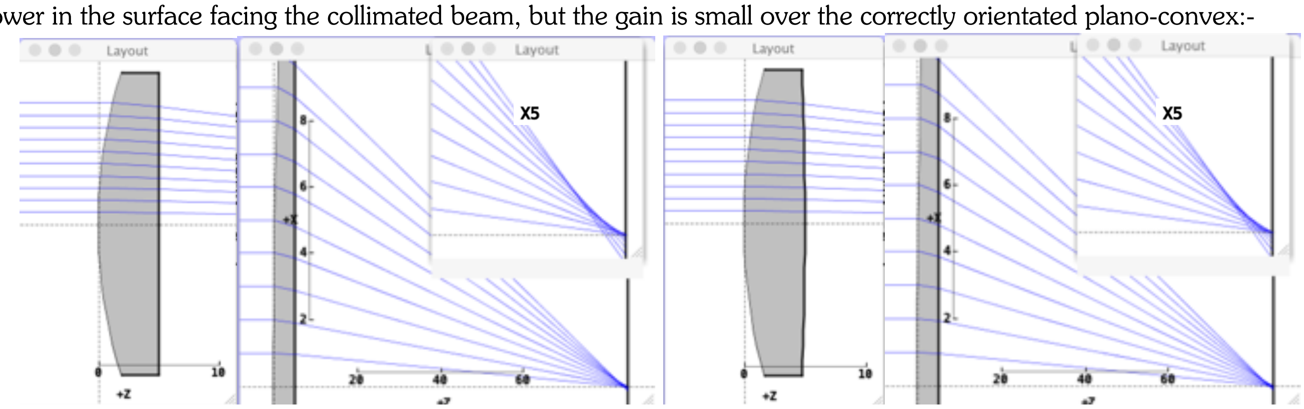
Assuming all these things to be under control, does that mean that this lens is good? Good for what? Let's start with a simple task of focusing a collimated beam of light, as for e.g. from a laser.

Rays are that most convenient fiction tracking the perpendiculars to the wavefront through space, all a lens does is bend that wavefront according the Snell's law, i.e. redirect the rays at each surface bounded by different media. Pretty much the first thing we learn is that a lens brings initially parallel rays to a focus, i.e. at the same point. It would be nice,- though not in itself sufficient!,- if it did at least that, but let's have a closer look more closely….

In the paraxial situation,- OK, but the further rays are from the axis,- uh uh things start to go wrong & rays fall short; what we have here is axial spherical aberration. We can do worse, with a plano convex lens…,



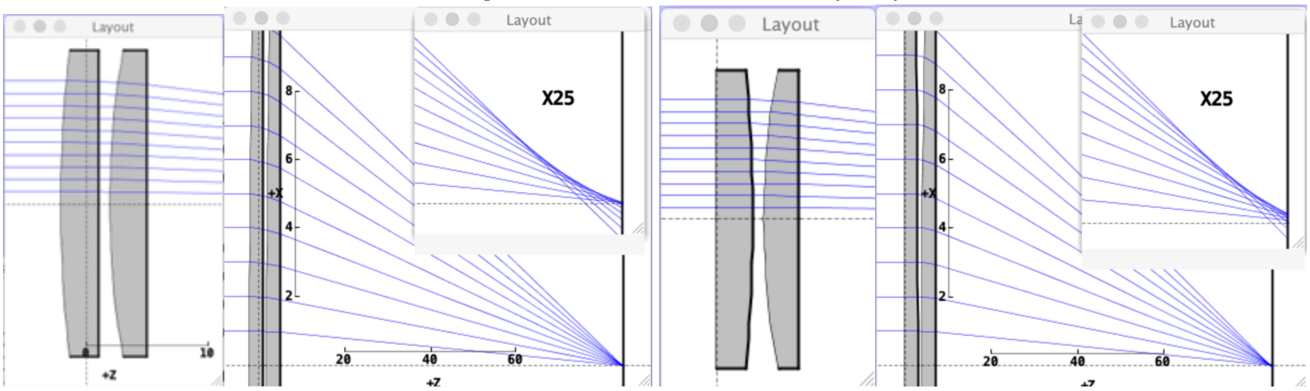
…or better, with the same lens the other way round! First lesson then; the most highly curved surface has always to be towards the most distant conjugate, in this case infinity. Slightly better again is a 'best form' lens with about 85% of the power in the surface facing the collimated beam, but the gain is small over the correctly orientated plano-convex:-



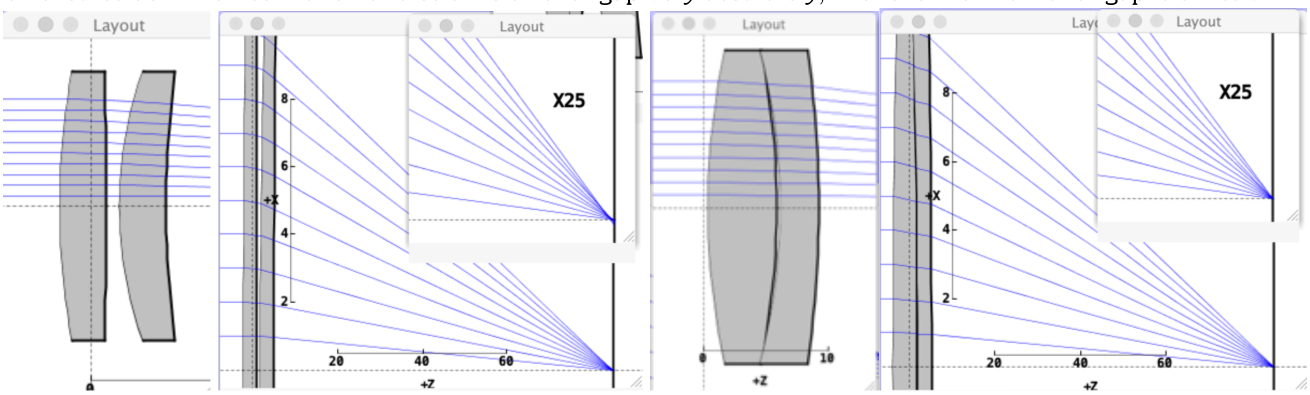
Spherical aberration is so-called because it results from the lens surface being spherical!; if it is allowed to be that of a prolate ellipsoid (sharp end of a rugby ball) then this aberration by itself can be reduced to very low levels, but aspheres are difficult to make, even more difficult to measure/characterize easily, and spherical aberration is only ONE of the things that can go wrong with a lens; in the more general case for rays away from the axis we also have to think about coma, astigmatism, field curvature, distortion, as well as chromatic aberrations, AND the waves which these rays track have to arrive in phase, or nearly so. This happens when the ray optical path differences OPD are minimal (has to take account of the refractive indices of the media through which the rays pass). More usually OPD can be expressed as departures from the average for a ray group, and plotted as a wavefront error WFE.

What about more than one lens element. A catalogue cemented achromat doublet of Flint & Crown glasses, though as the name implies designed to correct chromatic aberration, also makes a good job of correcting spherical aberration. However, we are concerned here with lasers, and in the case of excimer lasers deep UV, ruling out almost all ‘optical glasses’ & cemented doublets, so for the moment we look only at what can be done with separate fused silica elements.

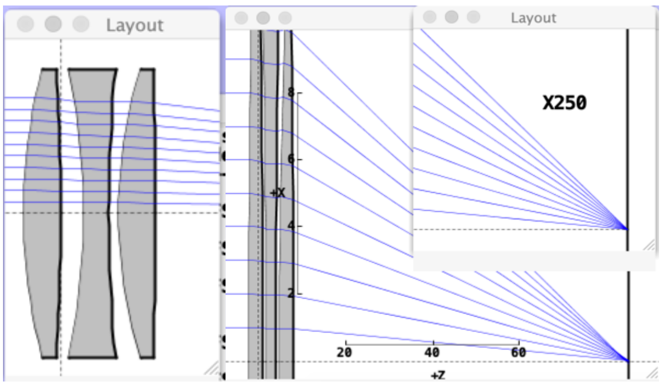
Sharing the power between two plano-convex catalogue elements helps quite a lot; in this configuration the 2^{nd} element ideally needs to have about 60% of the power. Now we have two elements, turning one of them round also works, and can be useful since an assembled doublet has plane outer faces which are very easy to clean:-

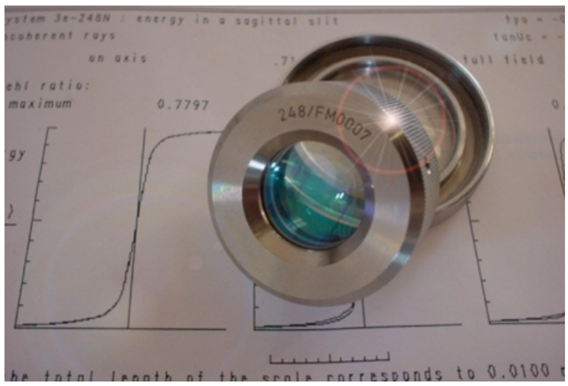


If lenses can be other than plano-convex then dramatic improvements can be made. The design at left was reached in <5s by allowing my PC to adapt surface ROC freely in order to reduce the spherical aberration to a local minimum. However there are many local minima, & different solutions; the design at the right (a litte bit more diffilcult to find) is particularly interesting because the convex element is symmetrical (easier to make & eliminates mounting error in getting a close-to-symmetrical element the wrong way round!) Then there is an edge contact between the 2^{nd} & 3^{rd} surfaces, which ensures both their centration and sets the axial airgap very accurately; in a lens like this that airgap is critical.



If we allow 3 elements, the world is pretty much our oyster. Such a Cooke triplet can correct all five 3^{rd} order Siedel aberrations, as well as colour if more than one material is used, for e.g. for UV wavelengths UVFS & CaF2 .





Once aberrations are reduced beyond a certain point, they are no longer relevant & the lens becomes ‘diffraction limited’, with performance determined by the wave nature of light; see Technote RA/E/05. Giant tomes have been written on lens design, nowadays made relatively easy by computers. However the most important step in any lens design remains to cleary define the objectives, which then might suggest one ‘family’ of lens types over another.

Most Optec machines feature high performance proprietary ‘designed-for-purpose’ lenses of the last two designs here.

Anyone still wants to be amazed by the miracles of light & vision? With no apologies I suggest the one & only late Richard Feynmann at his best:- https://youtu.be/FjHJ7FmV0M4