Lanthanum Glass.

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1. Introduction.

The use of Lanthanum, or Rare Earth glasses is a key part of modern optical technology. They enable lenses to be made of exceptional performance. The reasons for this take us to the very depths of chemistry and physics, and it is my intention to attempt to go over the various parts that make up this part of lens science.

2. Glass.

Glass is an interesting material. Our optical glass is only part of a much larger group of compositions referred to as glasses. What then are the properties of glasses? First of all, they have no hard-and-fast chemical composition, as does salt, diamond or rust. They are not crystalline, meaning that there is no regular pattern to the positions of atoms in the material. More it is as though the maker had said: "Well, we'll put a bit of this in and some of that, and they will sort-of fit, but not exactly."

This, seemingly random, arrangement of the components also serves to make the glass isotropic, which means that when the properties of the glass are measured, they are not dependant on the direction from which they are measured. Crystals decidedly do *not* have this property. It would be tricky, but not impossible, to make a lens from a crystalline material. Diamond (a crystalline form of the element carbon), would be a very intriguing lensing material, when we learn to make it synthetically.

Optical glasses can then have a vast range of components in continuously changeable concentrations. They are made by putting measured amounts of raw materials in a crucible, and heating to beyond the melting point of the glass, hoping that sufficient mixing will occur so that on cooling the glass is uniform in composition. Cooling must be controlled lest strain be introduced into the glass that would again show up as optical inhomogeneities. The molten mass of glass can also be poured into moulds that may approximate the shape of the final lens.

Given that we have the technology to produce this vast range of glasses, what properties should we look for that would be important in making lenses. This I will cover in the next section.

3. The important properties of glass.

From the lens designer's point, the first property, so important that it is usually ignored, is that the glass transmits the radiation of interest. (Some infrared and UV optics do not transmit visible radiation at all well.) That being said, the next property of importance is the Refractive Index (RI). This property is a numerical measure of the degree to which a glass will alter the direction of a light ray. Figure 1 shows the property of a glass called Refractive Index, and also the property called Dispersion. (Of which, more, a little later.)

Figure 1.
The properties of glass.

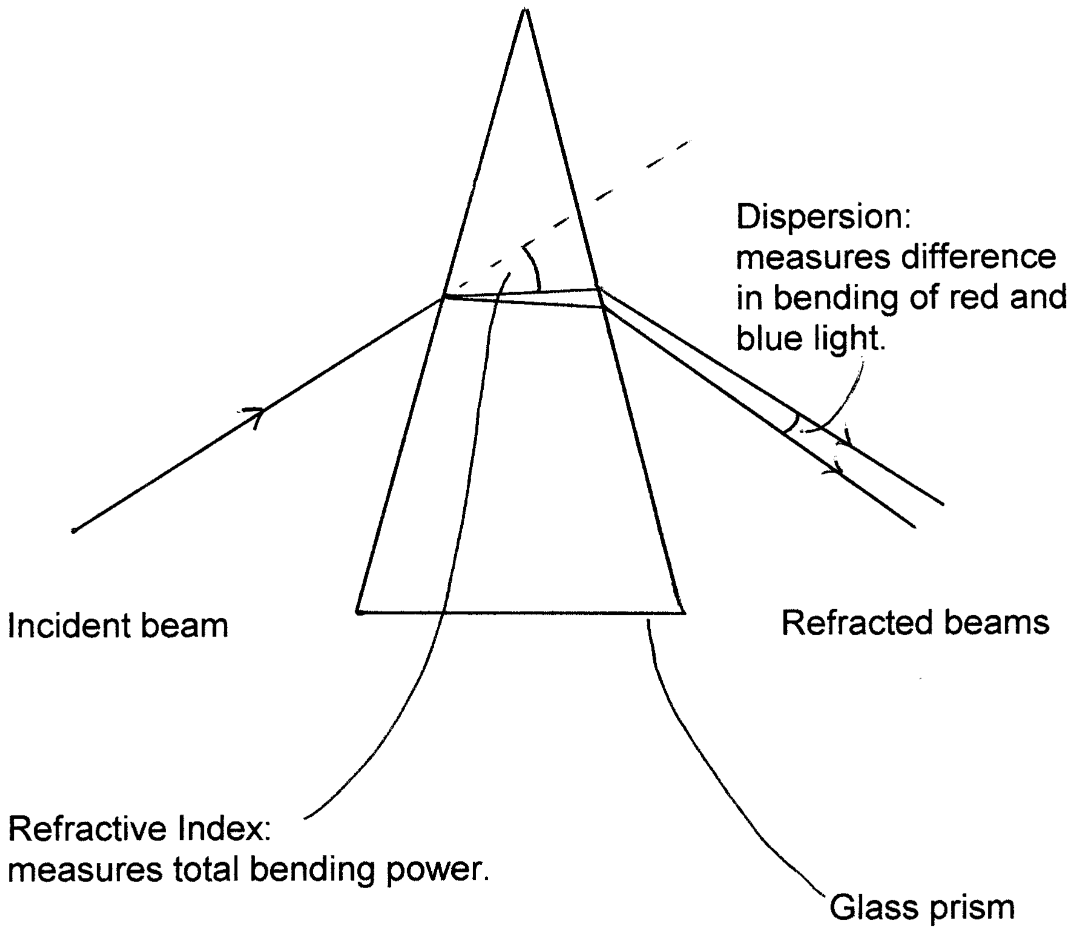

Table I gives the RI of a variety of materials.

Table 1.

Refractive Index of miscellaneous materials.

Water	1.33
Gelatin	1.54
Fused silica	1.46
Soft Crown glass	1.52
Barium Light Flint glass	1.60
Kodak Lanthanum glasses	1.68 - 1.88
Silver chloride	2.06
Diamond	2.42

RI is important, in that a lens with a high RI can bend the light further with less surface curvature, and this reduces Spherical Aberration.

However, the RI is not constant over all the spectrum. It is a different number for blue light than it is for red light, and the measure of this property is called the Dispersion. If glass behaved the same way for all wavelengths, we would not have chromatic aberrations in our lenses.
Dispersion is not constant over a range of glasses, for a given RI, Dispersion can vary considerably, and it is this property that enables us to correct for chromatic aberrations. (Think of a pair of lenses, one converging and one diverging. They have different RI, but similar Dispersions. The two focal lengths can be adjusted make the two Dispersion values equal and opposite. Because of the RI differences, the focal lengths are not the same and a useful lens results. It would be corrected for chromatic aberration at two wavelengths, or colors, of light.)
In the early 1930's, G.W. Morey of the Geophysical Laboratory of Washington, developed some new glasses, and in 1934 came up with a glass with unusual properties. Eastman Kodak undertook to commercialize this discovery. (For more details of this see Rudolf Kingslake's "A History of the Photographic Lens", p77.) The glasses were referred to as the Lanthanum Crowns. The properties of these glasses are best illustrated by reproducing Kingslake's diagram. (My figure 2.)

Figure 2.

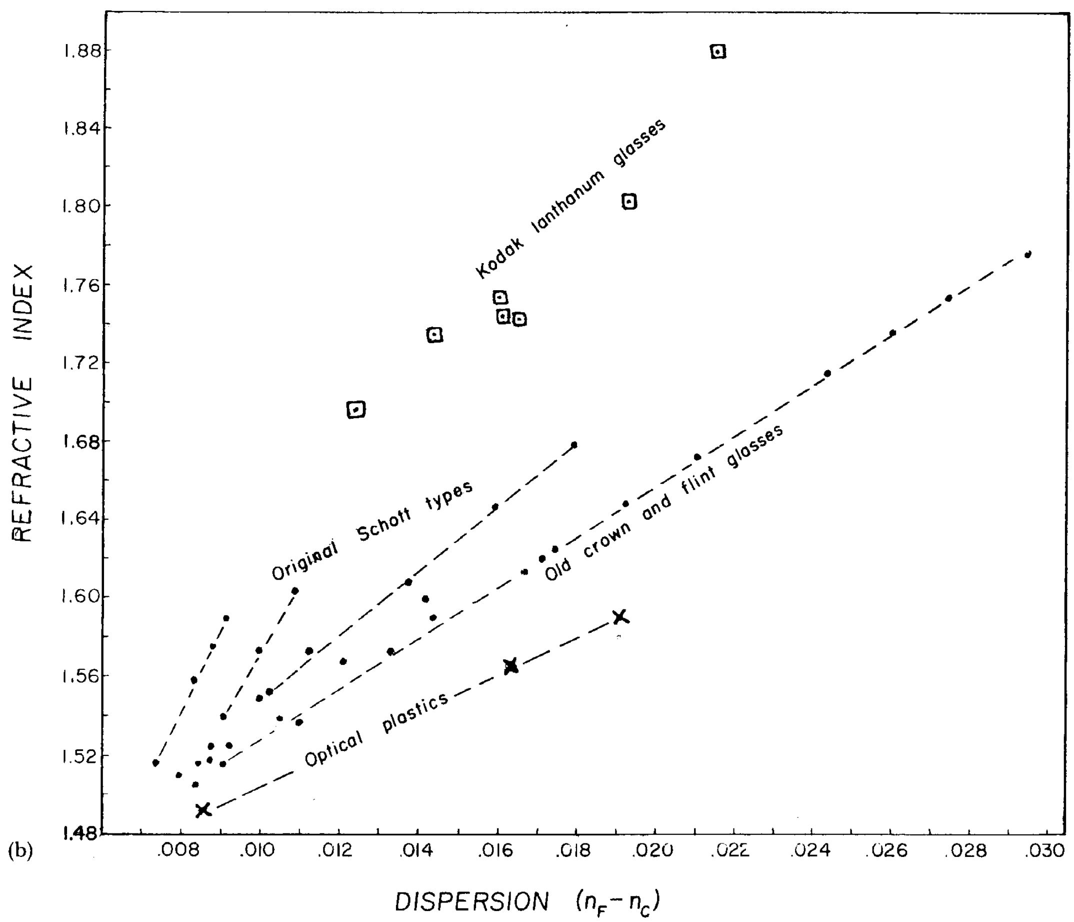

Figure 5.1. (b) The same as Figure 5.1(a) with the addition of early lanthanum glasses and plastic materials.

The highest number of Protons in any atom found in Nature is in Uranium with 92. Any atom with a higher number tends to be unstable, and decays Radioactively. We can make them, but we can't keep them.
Now chemical properties are very much determined by the outermost orbit Electrons, and their number, so by the time we are starting to fill up the "Mars" orbit, the Electrons in the "Mercury" and "Venus" are not having any influence on the chemical properties of the element we are studying.
Now something interesting happens. At a certain point in the Periodic Table (the list of elements), the extra electrons being added go into an inner orbit, now apparently with vacant space, instead of filling the outermost orbit. Thus a range of atoms, or elements, are formed that are going to get heavier, but whose chemical properties are going to be very similar. This is what happens to the range of elements known as the Lanthanides or Rare Earths. Lanthanum is the most common element of the group, and the Earth name comes from their chemical similarity to a group of elements known as the Alkaline Earths. The best known of the latter is Calcium. The Rare Earths aren't particularly rare, but they are devils to separate because of their similarity in properties. Ion Exchange resins can, and are, used, as some of the Rare Earths find uses where high purity of the individual element is needed. Gadolinium, in the middle of the series, is used in phosphors for X-ray and TV screens. I reproduce Table 94 (as Figure 3), from Heslop and Robinson's "Inorganic Chemistry", mainly because the quaintness of the elements' names, but also because the last column shows that as the atoms get heavier, they get smaller.

Figure 3.

TABLE 94

	Symbol	*Z*	*Electron configuration*			*Common ionic charges*			*M^{3+} radii*
Lanthanum	La	57		$5d^1$	$6s^2$		3		1.06
Cerium	Ce	58	$4f^2$	—	$6s^2$		3	4	1.03
Praseodymium	Pr	59	$4f^3$	—	$6s^2$		3	4	1.01
Neodymium	Nd	60	$4f^4$	—	$6s^2$		3		1.00
Promethium	Pm	61	$4f^5$	—	$6s^2$		3		–
Samarium	Sm	62	$4f^6$	—	$6s^2$	2	3		0.96
Europium	Eu	63	$4f^7$	—	$6s^2$	2	3		0.95
Gadolinium	Gd	64	$4f^7$	$5d^1$	$6s^2$		3		0.94
Terbium	Tb	65	$4f^9$	—	$6s^2$		3	4	0.92
Dysprosium	Dy	66	$4f^{10}$	—	$6s^2$		3		0.91
Holmium	Ho	67	$4f^{11}$	—	$6s^2$		3		0.89
Erbium	Er	68	$4f^{12}$	—	$6s^2$		3		0.88
Thulium	Tm	69	$4f^{13}$	—	$6s^2$		3		0.87
Ytterbium	Yb	70	$4f^{14}$	—	$6s^2$	2	3		0.86
Lutetium	Lu	71	$4f^{14}$	$5d^1$	$6s^2$		3		0.85

Thus by using an element at the bottom of the list, you can pack more electrons into a given volume of material. As these are heavy elements anyway, you can *really* pack on the weight.
It is this density of Electrons that controls also the interaction of the glass containing it, with light. The more Electrons per cubic inch, the higher the Refractive Index. For

reasons that I have not yet figures out the Lanthanide glasses with their high RI, have relatively low Dispersions. We can therefore make lenses with chromatic aberration correction and with improved correction for spherical aberration.

5. A Texas connection?
Where do the Rare Earth mineral originate? Up until 1906, there was a producing deposit in Llano County, when it was abandoned. William Niven, exploring for Gadolinium, on behalf of Thomas Edison, discovered Rare Earth ores at Barringer Hill, Llano County. He also discovered a Uranium deposit in the same place. The site isn't mined now because it is at the bottom of Lake Buchanan! In the 30's, the Buchanan Dam was constructed, and the site was flooded. Personally, I'm a little concerned that a Uranium deposit is along my water supply route, but in fact any Uranium that got out into the water would be reprecipitated rapidly, and due to it's weight would settle out almost immediately.

6. Conclusions.
I have tried to show that by having a range of glass properties available to the lens maker, we can have better-corrected lenses. All of the relevant science has been skimmed over in a very perfunctory manner, but my intent was to just outline the thinking behind the use of these glasses. The thinking must be reasonably correct because most lenses now use these glasses.

Here are several things to think about:
There can be one lens component that can be included that has *no* Dispersion.
What is it?
How many lens components might be needed to correct for three wavelengths?
Why can we not have a very large number of components in our lenses?
Why, if spherical aberrations are caused by spherical lens surfaces, (they are), do we not always use other surface shapes?