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EDITORIAL

GRIN optics

Óptica de gradiente de índice

"Light travels along straight lines". We always have believed this claim from childhood. However, as we grow in size and knowledge, we realize that in some cases something is wrong with it. Geometrical Optics gives us the tool to study the nature of the light trajectories: the Fermat Principle. This principle is closely related with other fundamental principle of Physics: the Principle of Minimal Action. Thus, the Fermat Principle leads to the lagrangian equations of light movement, i.e., the Euler equations of the trajectories, in which we can see that some media can bend the light trajectories. Well, what about in the outer space where no medium is? The light can even be bent in outer space due to the presence of heavy gravitational sources, which modify the space-time and the trajectories of light in this relativistic framework. This is the well-known phenomenon of the gravitational lensing by the General Relativity and predicted by Einstein, what is another history. However, returning to the Euler equation of trajectories, we can guess that there will be a material in which is possible that the refractive index will change its value in different positions inside the medium. These media are called gradient-index media or GRIN media.

These GRIN media are part of our daily life. Thus, when the air increases its temperature as it is closer towards a hot surface, the refractive index decreases, and this explains the mirages, unfortunately for the lost and thirsty explorers in deserts. Furthermore, the refractive index of the atmosphere changes with pressure and this causes that, even in the case of turbulence absence, we see the stars in a slightly different position. Variations in the refractive index of the media are also part of living creatures. Sigmund Exner in 1889 published his investigations about the GRIN lenses in insect eyes. And, of course, the crystalline lens of the human eye has a GRIN structure. Finally, in the technological world, GRIN materials are part of objective lenses, microscopes, binoculars, endoscopes, DVD and BluRay players, fiber optics in telecommunications, or copy lens to name a few examples.

We already know about the lens behavior made of homogeneous material, but what about a lens made of an inhomogeneous one? The remarkable imaging properties of the GRIN media were study as early as 1854 by James Clerk Maxwell and by proposing his "fish-eye" lens. The presence of an inhomogeneous medium in a lens has two effects in its imaging properties. The first one has to do with the refraction at the surface, since the local refractive index change with the incident ray height. This is similar to a change on the local curvature of the surface. The second effect is related with the light transfer through the medium. The trajectory is bent, and thus, unlike the homogeneous media, this bending contributes to the aberrations of the rays.

There are three basic GRIN media: axial, radial, and spherical. This has to do with the distribution of the refractive index inside the media. Of course, more complex GRIN media involve mixture of those distributions. That means that GRIN materials have an additional degree of freedom in designing optical systems, i.e., the shape of that refractive index distribution. Further, it improves the optical quality of their images while reducing the number of elements meeting the performance criteria required. This reduction could reach a factor of three when using radial GRIN elements. Nowadays, the production of glass and plastic GRIN materials is difficult but efforts are spent in in improving the capabilities of creating GRIN materials for lenses.

Our eye optics, as well as other animal eyes, manufactures its own GRIN material. Thus, part of our cornea having an axial GRIN, and our crystalline lens having a mixture of axial and radial GRIN, are comprised of cell layers that raised them to have their GRIN structure. It is important to characterize it and to understand its role in the quality of the retinal images, given the effect of GRIN material has on the aberrations of the optical system. Furthermore, in the case of our crystalline, its GRIN structure changes, as the eye gets older and, likely when it accommodates. Thus, our crystalline is an aspheric lens with a complex GRIN material that is important to be characterized in both conditions.

Two lines in Physiological Optics research should converge to a fully understand of this issue. On the one hand, the experimental works which try to obtain data in a noninvasive way of the GRIN distribution of the lens. And on the other hand, GRIN lens models that take experimental retinal image data to reproduce them. It is expected that some day both lines will agree in the explanation of the GRIN nature of the lens. Meanwhile, efforts are continuously made since Liou and Brennan in 1997 proposed the first GRIN lens model in an anatomically accurate eye model. Many questions are currently investigated, such as the age as well as accommodation dependence, misalignment with respect to the cornea, and peripheral refraction among others, and this is why GRIN lens models are improved.

This means that much work remains to be made, but current innovative and noninvasive biomedical techniques used in determining the lens index distribution, together with the theoretical GRIN optics works in proposing theoretical models, will give us a fully understanding why we benefit at some extent from having GRIN materials in our optics eye.

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José Antonio Díaz Navas
Associate Professor, Departamento de Óptica,
Universidad de Granada, Granada, Spain

E-mail: jadiaz@ugr.es