Optical models of the human eye have existed for almost 500 years. Early models were proposed by Leonardo Da Vinci (fig(i)) and Kepler (fig(iii)) in the early 1500’s and 1600’s respectively. These were revolutionary at the time. They were designed to simulate the behavior of the eye and were based on the laws of physics. However, they were not accurate and did not account for the complex anatomy of the eye.

In 1983, Karl Landstein proposed a model that accurately simulated the behavior of the eye. This model was based on the laws of physics and accounted for the complex anatomy of the eye. It was also the first model to simulate the behavior of the eye in 3D.

The second section deals with aspherical off-axis models, while the third section describes a recent model with advancement in modeling of the lens. The final section discusses current research we are undertaking in developing a physical model of the human eye for testing of oculometric instruments.

### Crystalline lens

Early models used a constant refractive index for the lens. Enhancing this, a nucleus section with a higher refractive index was modeled. This advanced to having a shell structure with the refractive index increasing slightly with each shell approaching the center of the lens. The theoretical eye proposed by Landstein had seven shells with refractive index varying from 1.38 to 1.41 in the center, to 1.40 in the outer shell. To achieve this, the advantage of the shell model is that the ray tracing needed to determine the path of the ray can be done with well-established and simple equations. However, aberration calculations are much more difficult and multiple factors are produced due to the shell structure. A better approach is to have a gradual increase or decrease in refractive index as you approach the center. These are called GRIN lenses and are more accurately correct. They can be represented by a mathematical equation. Light rays are then refracted by the outer surface and posterior surface just as if the lens had a constant refractive index. But in between they undergo a continuous refraction. This causes the path of the light ray to follow a curved path. Shown in fig(v) is the refractive index profile of a GRIN lens proposed by Gharib and Dainty in 2007 for a 20°, 30° and 40° old eye.

### Off-axis/ spherical

To better predict optical performance, spherical or aspherical on-axis models are used when building single-angle models. It is necessary to include aspheric surfaces. Also, wide field models are important where the optical system is modeled.

### Design of a Physical Model

The goal when developing the model is to replicate the performance in reflection of each ocular surface while maintaining the correct optical path difference between each medium. Aberrations are presently ignored. When light is transmitted through the eye, four images due to reflection can be seen corresponding to the anterior and posterior cornea, and the anterior and posterior crystalline lens surfaces. These images are called Purkinje images and their location is in the posterior and anterior surfaces. Fig(i) shows a real eye based on Escudero-Sanz and Navarro’s model eye. Fig(ii) shows an eye modeled using N-BK7 glass and water. Fig(iii) shows an eye modeled using N-BK7 glass and Liquid Paraffin, a common immersion fluid. The optical path difference between each medium is preserved with the radial of each interface the only variable used. The glass chosen is N-BK7 which is suited due to its low refractive index which is needed to model both the cornea and lens. Two different fluids have been considered to model the aqueous and vitreous humour. The far light paraffin shows the best match. The power and BFL of the eye modeled with the liquid paraffin is also more accurately correct.

### References