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# LAB REPORT: HUMAN EYE, A BIOPHYSICS LABORATORY

## 1 Overarching Goal

The human eye can be described as a complex optical instrument that focuses light rays using a muscular tissue (the eye lens) and a light-sensitive layer that converts the focused light into electrical signals transmitted to the brain. The focus of this lab report is to utilize the knowledge of our previous labs on geometriclens modeling to apply it at a fundamental level to generalize the behaviour of the human eye and study is relation to common eye disseases.

## 2 Theory

As light travels through space, its interaction with matter affects the speed at which the electromagnetic waves that carry it move through a medium. These interactions produce refraction, a phenomenon that can be described at the macroscopic scale by Snell's law, $n_1 sin(\theta_1) = n_2 sin(\theta_2)$, where $n_1$ and $n_2$ are the indices of refraction of the two media, and $\theta_1$ and $\theta_2$ are the angles measured with respect to the normal to the surface. Rather than tracking individual light–matter interactions, this description allows the overall bending of light to be predicted using simple geometric relationships.

In the geometrical optics approximation, the propagation of light through refracting surfaces is modeled using rays, which trace the direction of light and provide an intuitive picture of how images are formed. This ray-based model makes it possible to describe complex optical systems using a small set of distances and angles. When applied to ideal lenses and restricted to small angles relative to the optical axis, these relationships reduce to the thin-lens equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where:

- $f$ is the focal length (in $m$)
- $d_o$ is the object distance (in $m$)
- $d_i$ is the image distance (in $m$)

This equation provides a direct way to predict where an image will form once the focal length of the lens is known.

The focal length itself depends on the physical properties of the lens. This dependence is described by the lens maker's equation,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where:

- $n$ is the index of refraction of the lens material and
- $R_1$ and $R_2$ are the radii of curvature of the lens surfaces.

Although highly simplified, together these model captures the essential behavior of many real optical systems. In particular, it provides a useful framework for understanding the human eye as an imaging system, where changes in lens shape and focal length determine how light is brought into focus on the retina. In the case of the human eye, the lens is flexible, and surrounding muscles can change its curvature. By altering the radii of curvature, the eye effectively changes its focal length, allowing objects at different distances to be brought into focus on the retina.

# 3 Apparatus

## 3.1 Homemade Eye Model

Our setup for this section consisted of a "screen" (a plane where the light was focused), a convex lens placed 20 cm from the screen, and an object placed 22.5 cm from the convex lens. All measurements were conducted in a dark environment to allow for greater precision.

## 3.2 Variable Lens Model

### Fixed Lens Test

Before beginning the experiment, we tested the PASCO eye model by placing a 400 mm focal length lens in the SEPTUM slot and positioning an object 50 cm from the lens.

### Variable Lens

Afterwards, the variable lens was filled with water until its membrane was flat. The connecting tube was then attached to a syringe, which was filled approximately three-quarters full. The tube was reconnected to the variable lens, replacing the previous 400 mm lens in the setup.

# 4 Purpose of Each Activity

## Activity 1.

To construct a simplified physical model of the human eye and establish its correspondence with the geometrical optics framework introduced in the theory section, identifying how the retina, lens, and optical axis are represented within the thin-lens approximation.

### Activity 2.

To incorporate a variable-focus lens into the eye model in order to simulate the eye's ability to accommodate, directly applying the thin-lens equation to demonstrate how changes in focal length affect image formation on the retina.

### Activity 3.

To quantitatively determine the magnitude of the focal length adjustment required for proper retinal imaging, using the thin-lens equation to relate object distance, image distance, and lens focal length in the context of the human eye.

### Activity 4.

To analyze common eye diseases by interpreting them as deviations from the idealized optical model, using the thin-lens and lens maker's equations to understand how changes in curvature or effective focal length lead to impaired vision.

# 5 Method

## 5.1 Activity 1: Construction of a Simple Eye Model

- A converging (biconvex) lens was mounted along an optical axis to represent the crystalline lens of the human eye.
- A translucent screen was placed at a fixed distance behind the lens to model the retina.
- An illuminated object was positioned in front of the lens at varying distances to serve as the object being imaged by the eye.
- The relative positions of the object, lens, and screen were adjusted until a clear image was formed on the screen.

- The orientation and nature (real or virtual) of the image formed on the screen were observed and recorded.
- The object distance was varied while maintaining the screen position fixed, and changes in image sharpness were qualitatively analyzed.
- Observations were interpreted using the thin-lens equation to determine which optical parameters must change in a real eye to maintain focus.

## 5.2 Activity 2: Simulation of Eye Accommodation

- A PASCO eye model was assembled with the retina placed in the slot labeled *NORMAL*.
- A fixed converging lens was initially inserted to represent the combined effect of the cornea and eye lens.
- An illuminated cell phone screen was positioned approximately 50 cm from the cornea, and its position was adjusted until a focused image was obtained on the retina.
- The object was translated laterally and longitudinally to observe changes in image position and focus.
- The fixed lens was removed and replaced with an adjustable-focus lens filled with water.
- Air bubbles were removed from the adjustable lens to ensure uniform refraction.
- The object distance was set to approximately 25 cm, and the lens curvature was adjusted using the syringe until a sharp retinal image was obtained.
- The procedure was repeated for an object distance of approximately 50 cm.
- Changes in lens power required for near and far vision were recorded and analyzed.

## 5.3 Activity 3: Quantitative Analysis of Eye Accommodation

- Relevant anatomical and optical parameters of the human eye obtained from preliminary work were identified.
- The lens maker's equation was used to model the dependence of focal length on the radii of curvature of the eye lens.
- The posterior radius of curvature was held constant while the anterior radius was varied over a defined range.
- For each radius configuration, the corresponding focal length was calculated.
- The results were tabulated to examine how small changes in curvature affect the focal length.
- Trends in the data were analyzed to distinguish between fine and coarse tuning mechanisms in eye accommodation.

## 5.4 Activity 4: Modeling Common Eye Diseases

- The PASCO eye model was configured to simulate normal vision using an appropriate converging lens and retina position.
- To model hyperopia, the retina was moved forward to shorten the effective eye length, and the resulting image blur was observed.
- A pupil aperture was inserted to study the effect of pupil size on image clarity.
- Corrective lenses of varying power were introduced to restore focus, and the optimal lens power was determined.
- To model myopia, the retina was moved backward to lengthen the effective eye length.
- The image formation for distant objects was analyzed under this configuration.

- Diverging or weakly converging corrective lenses were tested to compensate for the altered focal conditions.
- Observations were interpreted using the thin-lens and lens maker's equations to relate anatomical changes to optical defects.

# 6 Data

## 6.1 Activity 1: Simple Eye Model

- **Independent Variable:**
  - Object distance from the lens ($d_o$)
- **Dependent Variable:**
  - Image position relative to the screen (retina)
  - Image clarity on the screen
- **Control Variables:**
  - Lens type and focal length
  - Fixed distance between lens and screen
  - Optical alignment of the system
- **Hypothesis:**
  - If the object distance changes while the screen position remains fixed, the image will fall out of focus unless the focal length of the lens changes, consistent with the thin-lens equation.

## 6.2 Activity 2: Eye Accommodation

- **Independent Variable:**
  - Object distance from the eye model
  - Curvature (power) of the adjustable eye lens
- **Dependent Variable:**
  - Image sharpness on the retina
  - Lens power required for proper focus
- **Control Variables:**
  - Retina position set to *NORMAL*
  - Light source intensity
  - Eye model configuration
- **Hypothesis:**
  - Decreasing the object distance requires an increase in the optical power of the eye lens to maintain focus on the retina.

## 6.3 Activity 3: Quantitative Accommodation Analysis

- **Independent Variable:**
  - Radius of curvature of the anterior lens surface ($R_1$)
- **Dependent Variable:**
  - Calculated focal length of the eye lens ($f$)
- **Control Variables:**

- Posterior radius of curvature ($R_2$)
- Index of refraction of the lens material

- **Hypothesis:**
  - Small changes in the anterior radius of curvature produce measurable changes in focal length, enabling fine tuning of eye accommodation as predicted by the lens maker's equation.

### 6.4 Activity 4: Modeling Eye Diseases

- **Independent Variable:**
  - Retina position within the eye model
  - Power of corrective lenses
  - Pupil aperture size
- **Dependent Variable:**
  - Image clarity on the retina
  - Corrective lens power required for clear vision
- **Control Variables:**
  - Object distance (near or far)
  - Eye model alignment
  - Light source characteristics
- **Hypothesis:**
  - Altering the effective eye length causes defocus that can be compensated by lenses of appropriate optical power, consistent with thin-lens predictions for myopia and hyperopia.

### 6.5 Measured Data

Table 1: Measured Data

| Quantity | Value | Units |
|---|---|---|
| Sample 1 | 0.00 | m |
| Sample 2 | 0.00 | m |

## 7 Calculations

$$y = mx + b$$

## 8 Results

- Result 1: 0.00 units
- Result 2: 0.00 units
- Absolute/Percent Error: 0%

## 9 Conclusion & Questions

- Conclusion point 1
- Conclusion point 2

### Questions

1. Answer to question 1
2. Answer to question 2

# 10 Above and Beyond