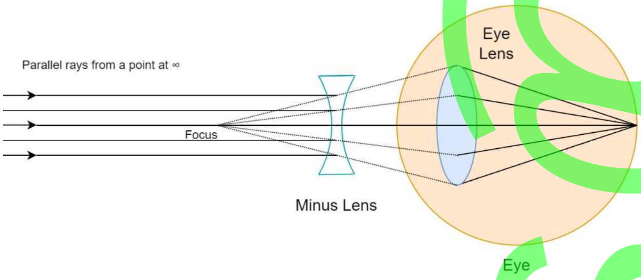

Geometrical Optics & the case for Myopia Reversibility

13:30:34, 7 March 2023 Draft Revision 0.51

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0. Abstract

Human eyes function in a manner similar to a camera and this article is an attempt at describing Myopia based upon the properties shown by the simple lens model. The cornerstone principle of the model was experimentally verified by studying the image formation properties of a mirror-less camera under hyperopic defocus using diverging (-) lens. The Relative Dioptre Scale (RDS) was devised and used as a means to quantify observation range of optical systems and represent various refractive conditions of the eye to visualize how commonly used refractive interventions (lenses and surgical procedures) work.

The resulting consistent explanation of various counter-intuitive observations related to Myopia led us to predict that commonly encountered (non-pathological) Myopia is actually an adaptative response of the eye. By natural extension, it was also shown that the same continuously adaptive process that 'initiates' Myopia in healthy eyes should be responsible for Myopia 'progression' also and can be harnessed for managing Myopia by inducing Hyperopic adaptation thereby convincingly solving the long standing mystery behind Myopia.

1. Introduction

Myopia – also called near-sightedness/short-sightedness is a refractive condition with as of publication of this article has no clear clue[1] for even its widely agreed upon scientific cause[2] let alone a treatment. Worldwide cases of Myopia are increasing at an alarming rate in the 21st Century with Singapore[3] rightly being termed as the 'Myopia capital of the World' having one of the highest rates of Myopia incidence worldwide. Myopia is a burden and is fast becoming a significant healthcare menace of the 21st Century.

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2. Carr BJ, Stell WK. The Science Behind Myopia. 2017 Nov 7. In: Kolb H, Fernandez E, Nelson R, editors. Webvision: The Organization of the Retina and Visual System [Internet]. Salt Lake City (UT): University of Utah Health Sciences Center; 1995-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470669/
3. Seet B, Wong TY, Tan DTH, et al. Myopia in Singapore: taking a public health approach, British Journal of Ophthalmology, 2001;85:521-526.

Multiple researchers have declared Myopia to be mostly dependent on Genetic[4] factors but the exact mechanism behind Myopia has so far been elusive. This has led many researchers to term long-term AL changes due to Myopia as '*eye growth*' due to its apparent 'irreversibility'.

According to the WHO's International Classification of Disease[5] (ICD-11), Myopia is defined as (with **degenerative myopia** listed under exclusions section):

A refractive error in which rays of light entering the eye parallel to the optic axis are brought to a focus in front of the retina when ocular accommodation is relaxed. This usually results from the eyeball being too long from front to back, but can be caused by an overly curved cornea, a lens with increased optical power, or both. It is also called nearsightedness.

Throughout this article, the focus will be on the commonly[6] encountered Myopia of the non-pathological type (also called spontaneous-onset or school age myopia and multiple other terms impractical to list here) with slow progression characteristics and generally observed to stabilize in the mid-twenties. From now on, the usage of the word 'Myopia' in this article should mean non-pathological Myopia unless stated otherwise. We will also propose a test condition for effectively telling apart *common* Myopia from pathological Myopia.

This article aims to be our attempt at characterization of Myopia from the standpoint of geometrical optics. In our bid to eliminate possible sources of confusion, we have strived to follow the guidelines outlined in [IMI – Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies[7]] for this article but along the way we will also point out one particular inconsistency with signs. Effort has been made to convey necessary details using simple language in a consistent way without bogging down the reader with multiple redundant description of terms.

This article is structured into four parts: Theoretical with a supplemental Appendix, experimental verification, discussions based on physical observations and conclusion.

The theoretical part on geometrical optics begins with the derivation of some basic results in Geometric optics (more derivations are supplied in the Appendix for the interested readers) which will then be used for describing the simple lens system. Throughout this article, the observation range of the systems in question was represented using the Relative Dioptre Scale (RDS) introduced in section 2.3.

The experimental part is concerned with easily replicable verification for the important theoretical result underpinning this article – shifting of the observation range under external defocus and/or screen shift.

The discussion part explains why Myopia behaves the way it does using theoretical principles (continuous adaptation theory of the eye) for various real-world observation about Myopia. We'll also describe in detail one of its multiple breakthroughs which is coming up with a myopia management regime to stabilize progression of Myopia and even reverse its course in subjects willing to devote time and effort.

4. Milly S. Tedja, Annechien E. G. Haarman, Magda A. Meester-Smoor, Jaakko Kaprio, David A. Mackey, Jeremy A. Guggenheim, Christopher J. Hammond, Virginie J. M. Verhoeven, Caroline C. W. Klaver, for the CREAM Consortium; IMI – Myopia Genetics Report. Invest. Ophthalmol. Vis. Sci. 2019;60(3):M89-M105. doi: https://doi.org/10.1167/iovs.18-25965.
5. https://icd.who.int/browse11/l-m/en#/http://id.who.int/icd/entity/1666440799
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7. Flitcroft DI, He M, Jonas JB, Jong M, Naidoo K, Ohno-Matsui K, Rahi J, Resnikoff S, Vitale S, Yannuzzi L. IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. Invest Ophthalmol Vis Sci. 2019 Feb 28;60(3):M20-M30. doi: 10.1167/iovs.18-25957. PMID: 30817826; PMCID: PMC6735818.

1.1 Conventions and terminology used in this article

Before we go on to describe geometrical optics, experimental outcomes and explain non-pathological Myopia – it is important to clarify the proper meaning of some technical terms. Specific terminologies are provided in the beginning of each section where applicable.

Before reading, We expect familiarity with these words and their meanings – assumption, definition, theoretical prediction and its subsequent verification by experiments, proofs, facts as well-established observations, result, conclusion, limited-scope, consistency etc.

Every 'correction' for Myopia that we have currently – be it glasses, contacts, LASER-based refractive surgeries, ICL etc. can be termed as refractive compensation but not actually 'curing' or reversing axial elongation resulting from Myopia. There should be no fundamental difference between optical refraction introduced by glasses, contacts or refractive surgeries.

Throughout this article, we will utilize prefixes like *compensated* eye or suffixes like an eye *wearing prescription* to denote a pesudo-emmetropic eye with refractive interventions differentiating it from a naked eye – emmetropic, hyperopic or otherwise without compensation.

The mention of the word infinity or symbol ∞ can be taken to mean optical infinity at a distance of 10 m or greater (≤0.1 D).

2. Geometrical Optics

Describing an optical system requires fundamental understanding of Geometrical optics. The Appendix accompanying this article serves as an in-depth refresher. Care must be taken to ensure consistency of units and signs according to conventions while utilizing formulas shown throughout this article to ensure correctness in calculations. The term 'image' should be taken to mean real image (in regular context) and all mentions of the word 'lens' should be assumed as referring to an ideal thin-lens unless stated otherwise.

2.1 The relation between dimensionless object (k) and image distance (j)

If we express the object (u) and image distance (v) as multiples of focal length (f) in the thin-lens relation, we gain much deeper insights into image formation by thin-lenses.

In the thin-lens relation, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ Assuming:

$$k=\frac{-u}{f}, then$$

$$\frac{1}{v}=\frac{u+f}{u\times f}$$

$$giving\ v=\frac{-k\times f^2}{-k\times f+f}=\frac{k}{k-1}\times f=j\times f$$

Hence, the relation between dimensionless object and image distance comes out to be $j=\frac{k}{k-1}$

For image formation in a converging lens, k > 1. This simply means that the object must be located beyond the focus of the converging lens. A plot of this equation results in a hyperbola symmetrical about the line x = y as shown in Figure 2.1. The vertical and horizontal asymptotes given by lines x = 1 & y = 1 correspond to the object at focus and ∞ also corresponding to its image at ∞ and focus respectively.

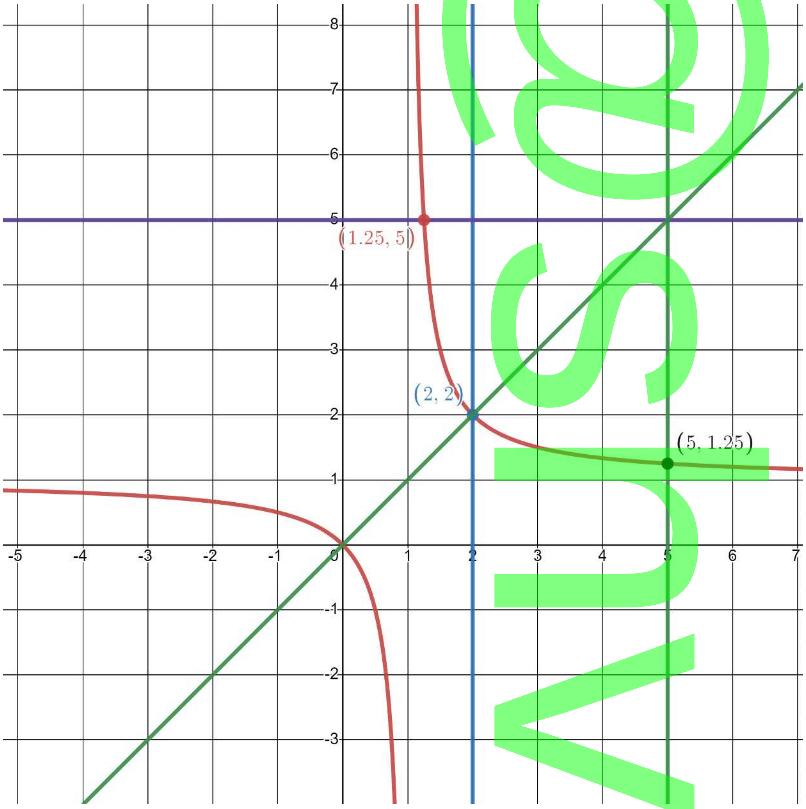


Figure 2.1: The hyperbolic plot for the dimensionless lens relation is shown in red

It is evident from the symmetry of the hyperbola in Figure 2.1 that both an object & its image's dimensionless distances form a mirror pair around the x = y line.

This is more evident if we solve for k giving $k=\frac{j}{j-1}$, which can be understood simply as interchanging k with j & j with k in the original relation.

Adding k and j together gives, $k+j=k+\frac{k}{k-1}=\frac{k^2}{k-1}=\frac{j^2}{j-1}$ which has a minimum of 4 at k = j = 2 for positive values as can be seen from the graph below in Figure 2.2.

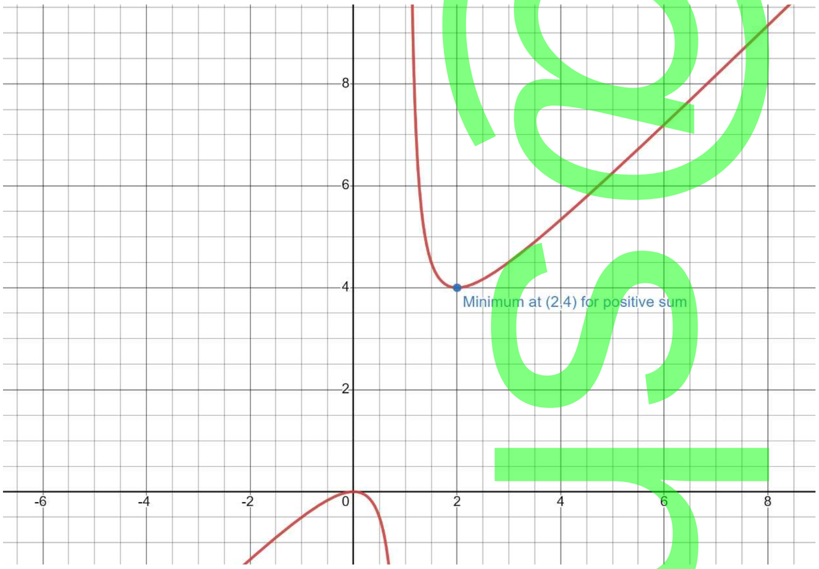


Figure 2.2: Plot showing how the sum of dimensionless image and object distance varies with image/object distance

This relation shows that for a given distance between an object and its required image, the focal length of the system that is able to image it must be one-fourth of that distance or lesser.

Thus, the (k + j) ≥ 4 rule along with the k > 1 rule for image formation serves as the baseline conditions for implementations of real world optical imaging systems involving lenses.

2.2 The simple lens system

Be it the Human eye or an optical system like a camera, the purpose is same - ‘imaging’ objects (which can be located at varying distances) onto the retina/image sensor. For a film camera, the film acts as an image sensor. For the digital camera, an image sensor chip replaces the film. The physical principles involved behind image formation remain unchanged.

We will start with an optical bench setup with a converging ideal thin-lens and an image sensor (planar screen) as shown in Figure 2.3. The screen is aligned perpendicular to the principle axis of the lens. It is important to note that the (real) image formed by all such ideal thin-lens systems at the image sensor is **inverted**.

For this simple lens system, tracing the path of light rays from an object to its eventual image is very simple. Light rays emanating from an object point encounter the lens aperture and meet the image sensor after refraction. The medium in this case can be said to vacuum/air.

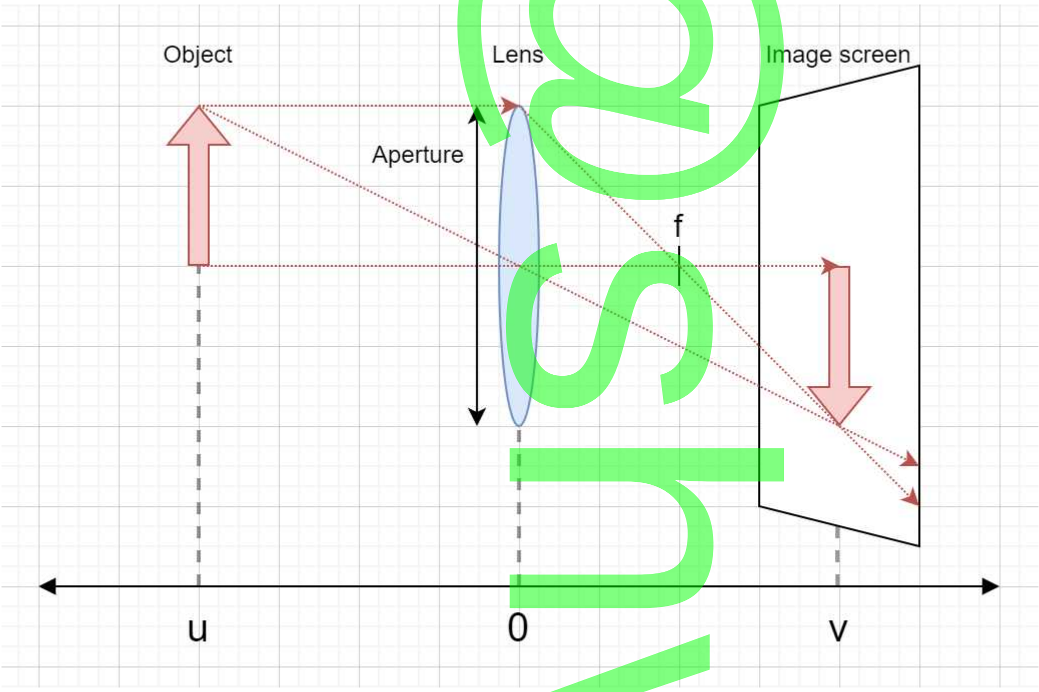


Figure 2.3: Schematic of a simple thin-lens system on an optical bench

Four parameters are needed to completely describe this combined setup of an object to be imaged and our system, if one includes the Aperture size (having no impact on image formation distance). The other three parameters are object distance (u) and the focal length (f) {both determining the image distance (v) – a dependent variable} and the screen distance (s). Distances are measured with the Optical Centre of the lens as origin.

For the formation of sharpest image possible, the screen distance (s) must coincide with the image distance (v). This will be true for all cases detailed in this section and its sub-sections. Talking of image formation will refer to the formation of a clearly focused image with the screen placed appropriately. The procedure for calculating range of distances within which screen distance (s) can vary for a given image distance (v) while still forming appreciably sharp images within a CoC (Circle of Confusion) is provided in the DoF derivation Section 8.4 of the Appendix accompanying this article.

Thus, the dependence of screen distance (s) on focal length (f) and object distance (u) is already encoded by the ideal thin-lens relation. Knowing any two, the third is easily determined.

$$s=\frac{fu}{f+u}=\frac{u}{1+\frac{u}{f}}=\frac{1}{\frac{1}{u}+\frac{1}{f}}$$

A fixed screen distance and a fixed focal length lens also fixes the distance at which an object can be imaged. It is desirable to have a system able to form images of objects located within a range of distances. Imaging objects within a distance range can be achieved by varying either the focal length (f) or the screen distance (s) or a combination of both. It is important to remember that all real-world implementations will always have some physical constraints on the 'variability' of these independent parameters within some definite range.

The range of object distances that can be imaged by a system will be referred as that system's ***observation range*** throughout this article. The farthest and nearest extremes of the observation range of a system are commonly designated as its far-point (u_{far}) and near-point (u_{near}) respectively. The Far-Point is defined as the distance of ***far***thest objects a system is able to image while the Near-Point is similarly defined as the distance of ***near***est objects a system is able to image within its constraints.

The **Field of View (FoV)** is defined as the angular-expanse of objects on the image sensor/screen. It is easily quantified from the ratio of screen height to the screen distance.

Our approach for studying changes to a system's observation range results from fixing one variable and studying how variation of other affects the range of object distances ($|u_{near}|$ to $|u_{far}|$) that can be imaged. The two resultant cases for our system corresponding to fixed independent variables focal length (f) and screen distance (s) are discussed below.

2.2.a) Constrained Observation range of system when screen distance (s) is fixed

Showing that for such a system,
*the increase in power/decrease in focal length (f) for maintaining **fixed screen distance (s)** solely depends on the object distance (u)*
can be easily done by rearranging the thin-lens law for focal length.

$$\text{By the thin lens relation}, \frac{1}{f}=\frac{1}{s}-\frac{1}{u}, s \text{ is constant}$$

$$\text{For an object at } \infty, u\rightarrow\infty \Rightarrow \frac{1}{f_\infty}=\frac{1}{s}-\frac{1}{u}=\frac{1}{s}$$

$$\text{For an object closer than } \infty, \frac{1}{f}=\frac{1}{f_\infty}-\frac{1}{u}$$

$$\Rightarrow \frac{1}{f}-\frac{1}{f_\infty}=\Delta\,Power=-\frac{1}{u}$$

$$\text{The signed term} -\frac{1}{u} \text{ is positive because object distance is negative by co-ordinate convention}.$$

For such a system, the increase in lens power needed to image objects **closer** than a reference distance depends only on the object distance (u). This increasing of lens power for imaging closer distances is commonly referred to as *accommodation* when the reference distance is taken at infinity. A system is said to be fully accommodated if the extreme of lens power range corresponding to observing objects at its near-point is reached.

Fixing screen distance requires the focal length to vary according to the observed object distances. For instance, a system with a fixed screen distance (s) of 25 cm and lens power ranging between +4 D and +9 D will have its Far and Near-points at ∞ and 20 cm respectively.

With lens power at +9 D which amounts to +5 D increase from the initial +4 D needed for imaging objects at ∞, the system forms images of objects located at 20 cm. Thus, it can be stated that this system accommodates +5 D in order to observe objects at its near-point of 20 cm.

Because screen distance (s) is fixed for this system, the Field-of-View (FOV) remains unchanged.

2.2.b) Constrained Observation range of the system when the focal length (f) is fixed

If the focal length remains fixed and the screen distance is allowed to vary instead, the dependence of observation range on screen distance is given in a similar manner by the ideal thin-relation:

$$\text{By thin lens relation}, \frac{1}{s}-\frac{1}{u}=\frac{1}{f} \text{ giving } \frac{1}{s}=\frac{1}{f}+\frac{1}{u}$$

$$\text{For an object at } \infty, u\rightarrow\infty$$

$$\text{giving } \frac{1}{s_\infty}=\frac{1}{f}$$

$$\text{For an object closer than } \infty, \frac{1}{s}=\frac{1}{s_\infty}+\frac{1}{u}$$

$$\text{The signed term} \left(\frac{1}{u}\right) \text{ is negative here}.$$

Assuming a system like the one described in section 2.2.a above but with a fixed focal length (f = 25 cm) instead, we can find out the near and far points of this system in the same manner.

The k > 1 requirement arrived in section 2.1 ensures that screen distances lesser than the (fixed) focal length of the system can't result in image formation for any physical object distance. Thus, the screen distance needs to be always greater than 25 cm and can only be increased up to infinity resulting in Far and Near-point at ∞ and 25 cm respectively.

It is evident that increase in screen distances required for imaging closer objects quickly approaches large values and even then the system is unable to image objects closer than 25 cm because there's no such physical thing as 'screen distance beyond infinity'. Contrast this to the previously described variable focal length (f) system where no such physical limit on focal length was in place preventing us from observing closer objects.

Changes to the screen distance implies changes to the overall size of the system and thus result in changes to the FOV also.

2.3 Representing observation ranges on the Relative Dioptre Scale

2.3.a) The Relative Dioptre Scale (RDS)

From the description of constrained observation ranges, the need for a tool to visualize various systems and any subsequent modifications to them was felt. We have devised Relative Dioptre Scale for this purpose which also serves as an intuitive way to visualize change in observation ranges due to induced defocus or changes to the screen distance.

The RDS is just Cartesian co-ordinate system modified for power (inverse instead of linear distances) onto which we will represent observation ranges of optical systems in this article. The x-axis of the RDS represents distances in (D or m^{-1}) with the origin representing infinity (∞). The y-axis was chosen to represent the accommodation ability of the system (also in Dioptre). Thus systems with better accommodation ability are vertically ranked/placed higher-up on the Relative Dioptre Scale.

This idea of representing observation range of optical systems on an inverse length scale stems from the inverse nature of the thin-lens relation itself. This has the important simplification of making transformations on the RDS linear with respect to changes in Power.

The ideal thin-lens relation for the simple lens system $\frac{1}{s}-\frac{1}{u}=\frac{1}{f}$ itself can also be written alternatively as Object distance (in m^{-1}) = Lens Power (in D) – Screen distance (in m^{-1}).

On the RDS, the left end of the system's observation range represents its far-point (the farthest a system can focus) while the right end represents its near-point. The observation ranges (u_{near} to u_{far}) of the systems described in section 2.2.a and 2.2.b can be represented on the RDS as shown in Figure 2.4:

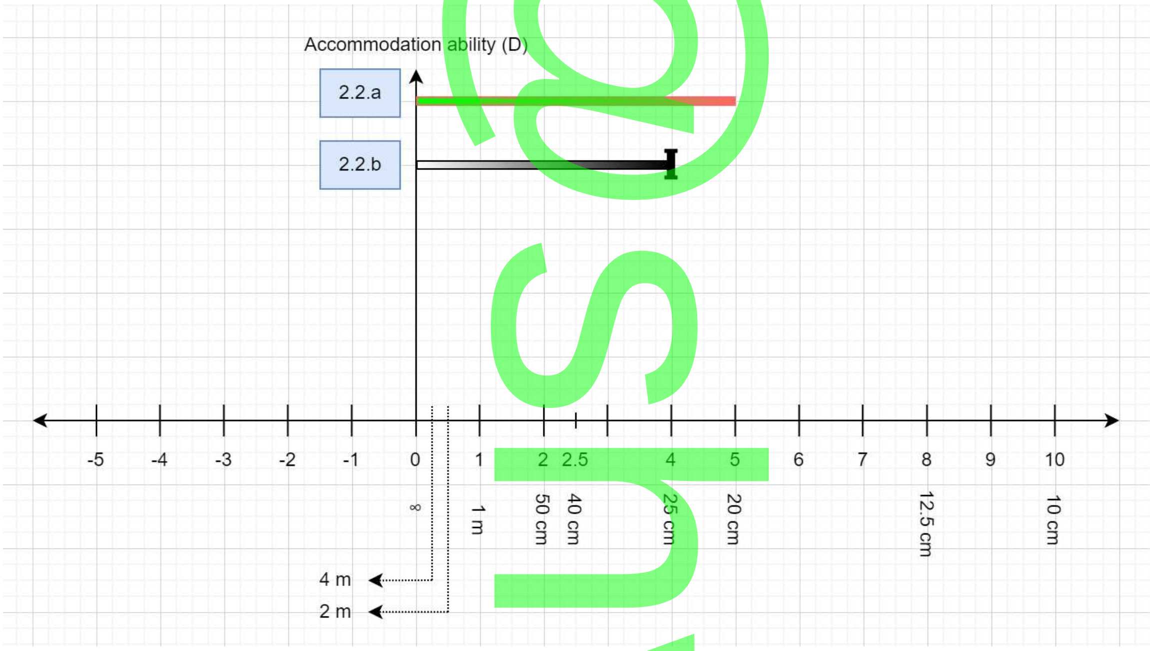


Figure 2.4: Representing observation range of systems described in section 2.2.a and 2.2.b on the RDS.

The vertical rank/height represents accommodation ability of the systems which is also equal to the length of line segments. Accommodation ability of a system can be stated as the power difference between the two extremes (near and far-point) of the observation range.

A line segment of some finite length on the RDS denotes a system with non-zero accommodation ability. A system with both – fixed focal length and fixed screen distance would be reduced to a point on the x-axis because of its fixed observation distance with no accommodation ability.

The gradient from red to green and light to dark in this instance was used to indicate limiting of the system's observation range due to physical constraints. The presence of an 'I' indicates the impossibility of any physical extension towards the right-hand direction (near-point) for the fixed focal length system described in section 2.2.b.

2.3.b) Shift in the observation range of a System due to introduction of external defocus

What happens to the system in 2.2.a when the range of variable lens power is kept same (+5 D) but increased by +1 D on both extremes (+5 D to +10 D)? Such a change can be termed as 'accommodation-shift' and the same can be easily achieved by introducing another +1 D lens ensuring that the power addition law holds (Section 8.2).

Just like before, it is sufficient to calculate the shifted far and near-points of the system (which are now 1 m and 16.66 cm). This modified system is represented on the RDS as shown in Figure 2.5. The former system in 2.2.a is represented using slightly thicker grey colour for comparison.

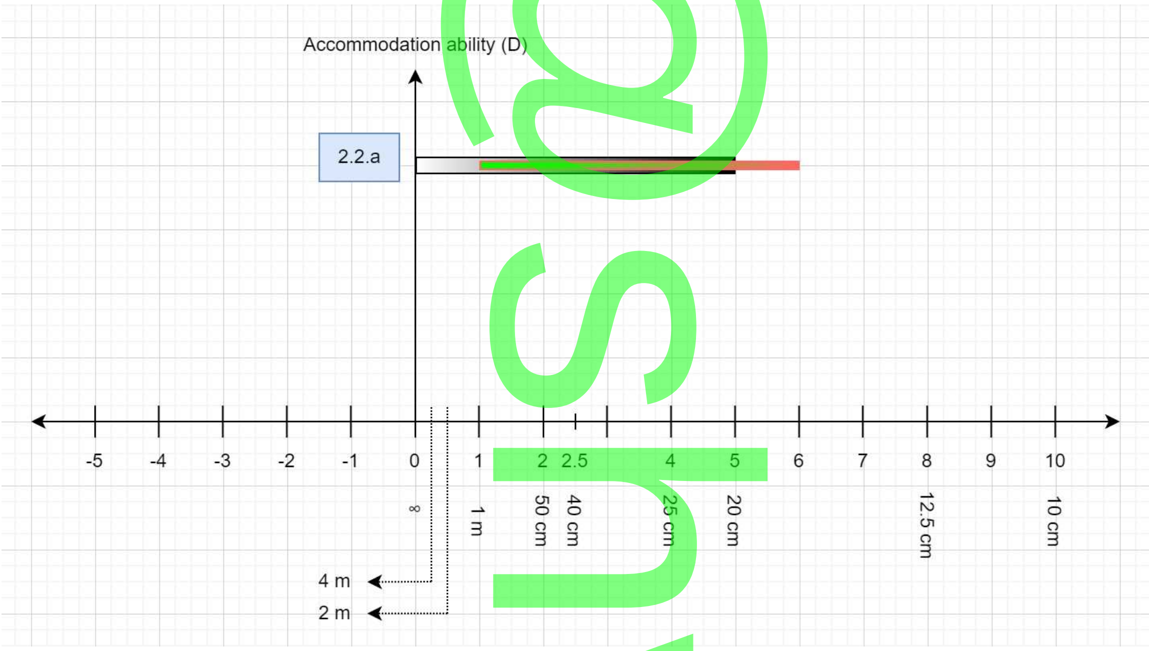


Figure 2.5 Demonstration of shifting behaviour in Observation Range after introduction of a +1D lens.

The modified system's observation range with Lens Power = +5 D to +10 D gets shifted 1 unit towards the positive/right direction (the sign of introduced accommodation-shift).

It is obvious that an increment in both extremes of the lens power range results in right-shifting of the system by the same amount on RDS. Our modifications to system in 2.2.a has resulted in the system becoming Myopic (unable to form images of objects beyond 1 m).

The inverse also holds true. It is trivial to point out that introducing a -1 D accommodation shift in our now modified system restores the original accommodation range. This is equivalent to introducing a -1 D lens or removing the previously introduced +1 D lens. Which means that the system on RDS must also move one unit towards the left direction. This is what the word 'Relative' in the RDS stands for. Relative to our modified system, the system in 2.2.a can be said to be hyperopic (unable to image objects closer than 20 cm).

It should be trivial to understand why *introducing converging (positive) lenses/removing diverging (negative) lenses* to a system is termed as ***Myopic defocus*** – because it makes the system myopic (causes shift towards right in the observation range).
Similarly, *removing converging (positive) lenses/introducing diverging (negative) lenses* to a system is called ***Hyperopic defocus*** – because it results in the system becoming hyperopic. (causes left-shift in the observation range).

2.3.c) Shift in the observation range of a System due to changing screen distance

We've already detailed the shifting of observation range of a system under induced defocus. Calculating shifting in Observation range due to changes in screen distance (s) should be as easy as recalculating the far and near-points.

For instance, the system in 2.2.a has the screen positioned at 25 cm from the lens – If we now position the screen 5 cm closer, the near-point recedes farther from 20 cm to 25 cm (1 D towards left) signifying that the system has turned hyperopic.

Similarly, if we move the screen 25cm farther from its initial position – the far-point comes closer from infinity to 50 cm (2 D towards right) rendering the system Myopic. The near-point also shifts closer by the same amount from 25 cm to 16.66 cm.

The shift in observation range due to screen distance increments act opposite to that of increments in focal lengths. Thus increase in screen distance should cause Myopic shift in observation ranges and decrease in screen distance should cause Hyperopic shift respectively.

Regarding shifting of observation ranges of a system, **reducing** (increasing) focal length is analogous to **increasing** (decreasing) screen distance. This is clear from the way we have defined dimensionless image distance $j=\frac{v}{f}$ where decreasing focal length (f) or increasing image distance (v) both serve to increase the dimensionless image distance (j) resulting in a decrease in dimensionless object distance (k) signifying Myopic shift and vice-versa.

3. Studying hyperopic defocus in a camera

This section serves as an experimental demonstration of the real-world phenomena of shifting of observation range upon introduction of external defocus as described in section 2.3.b. Experimental verification of the findings of section 2.3.c can also be achieved in a similar manner with the help of an optical bench setup. This phenomena has probably been observed and described multiple times but we still feel its inclusion complements this article.

3.1 Description of the camera setup equipment

The camera used was a Fujifilm X-S10[8] camera body paired with a FUJINON XC35mmF2[9] prime lens.

The light rays from an object first encounter the optical elements inside the camera lens and then go on to meet the image sensor just like the simple lens system described in section 2.2. This can be easily verified by simply positioning a converging lens in front of a bare camera sensor and checking for image formation in the viewfinder if the camera body has a 'shoot without lens' mode.

In the Figure 3.1 provided below, similarities between a Camera body as the image-sensor equivalent in the simple lens model is obvious.

Figure 3.1: X-S10 Camera body showing the exposed image sensor

Figure 3.2: XC35mmF2 lens showing inverted image formation

The camera lens can also be assumed to behave like an ideal lens with a variable aperture as shown in Figure 3.2. The lens comprises multiple optical elements – 9 elements in 6 groups (incl. two aspheric elements) to be exact. But for our experimental purposes, it still behaves close to an ideal converging lens evident from the inverted images it forms. The extra optical *elements* are needed to adjust focus and minimize aberrations in the image.

A dedicated Mirror-less camera offers extra features such as manual mode and advance image information like distance indication for focusing which are hard to find in a modern camera phone.

8. https://fujifilm-x.com/en-in/products/cameras/x-s10/
9. https://fujifilm-x.com/en-in/products/lenses/xc35mmf2/specifications/

The larger aperture size of the lens of a dedicated camera also results in much shallower Depth-of-Field (DOF) useful towards checking focus.

The Camera (referring to the combination of camera body paired with a lens) can image close objects roughly 31.5 cm from the lens (if we subtract 35 mm focal length from the specified close focusing distance of 35 cm from the image-sensor plane, all the way up to ∞ yielding an accommodation ability of roughly 3.25 D factoring in some headroom for focusing at infinity.

This is represented on in Figure 3.3 below.

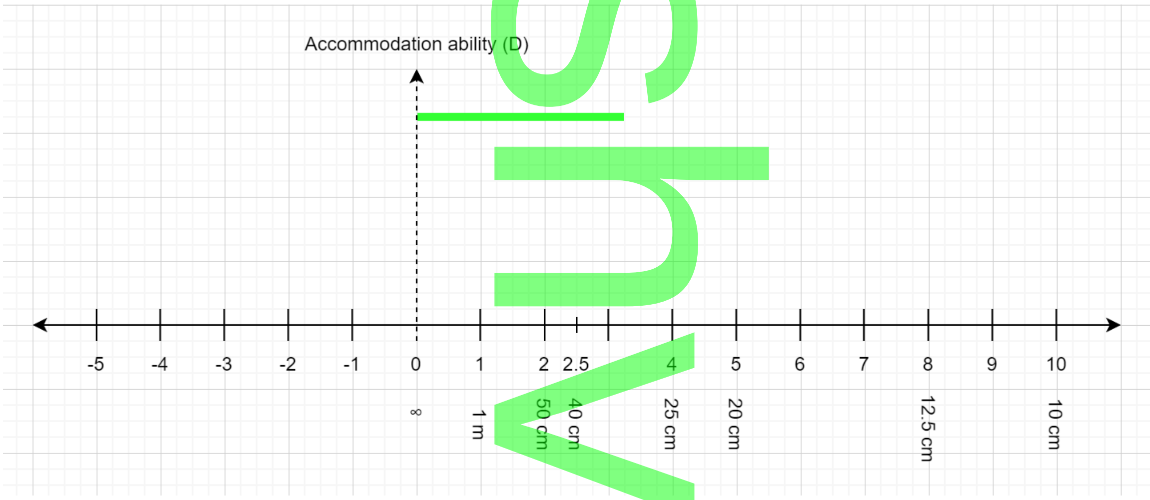


Figure 3.3: The observation range of the X-S10 + XC35mmF2 setup

3.2 Description of the experimental setup

For the experiment, the camera was positioned to image a tree at optical infinity across a field outside.

Figure 3.4 An image demonstrating the experimental setup

Figure 3.5 The image of Camera viewfinder when focused at infinity in the absence of external defocus. The sharp jagged edges of the small barbed wires behind the tree serves as a reliable indicator of checking the quality of focus in the images that follow.

The X-S10 camera body has distance scale option which shows the focusing distance reported by the lens estimated from the position of optical elements. The position of distance scale[10] in the Viewfinder is shown below with the white focus distance & the blue DOF indicator. Image formation parameters related to image-sensors like exposure or sensitivity is beyond the scope of this article.

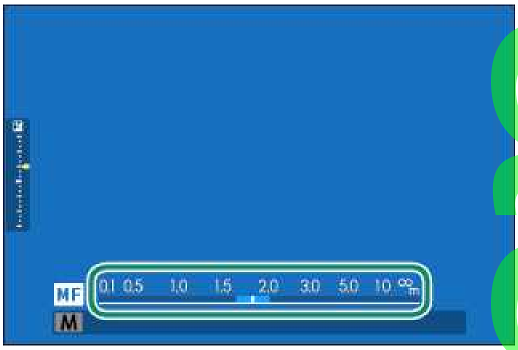


Figure 3.6 Position of Distance scale in the camera viewfinder

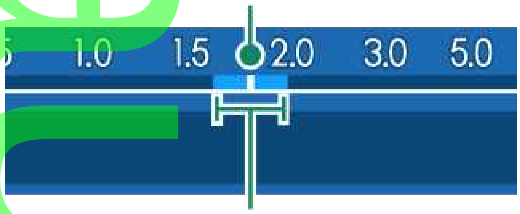


Figure 3.7 Blue DOF and White focus distance indicator

As can be verified clearly from the white mark near 10m∞ on the Distance scale in the viewfinder, the optical elements inside the camera lens are focused for our subject tree located at optical infinity in the absence of any defocus.

10. https://fujifilm-dsc.com/en/manual/x-s10/taking_photo/manual-focus/

3.3 Shift in observation range after hyperopic defocus

What happens if we place a diverging (minus) lens (induce hyperopic defocus) very close to the front element of the camera lens?

In section 2.3.b, we have already shown how the observation range would get shifted towards the left depending on the defocus. For instance, introducing a -2.5 D defocus would shift the observation range of the camera 2.5 units towards the left as shown in figure 3.8.

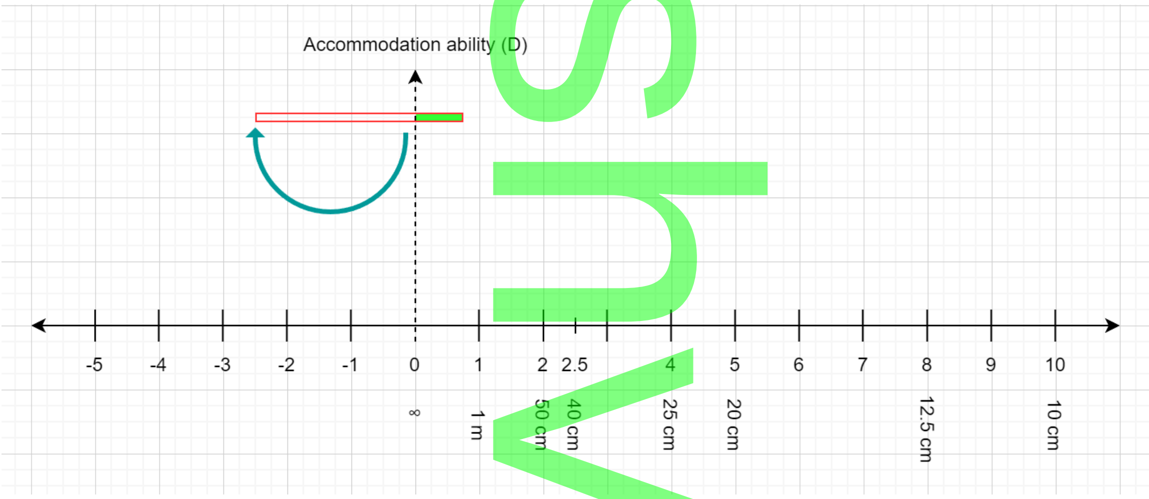


Figure 3.8: Shift in observation range after introduction of -2.5 D defocus

This can be understood as the introduced lens 'mapping' object distances to their new apparent distances or alternately as the lens apparently 'bringing' objects from infinity at its focus. The hollow red part of the observation range to the left of origin indicates unusable part of the observation range because it is physically impossible to have an object beyond infinity. The remaining useful part of observation range lying closer than infinity is represented with a solid green line. Experimental demonstration and verification for the same using the same defocus is provided in Figure 3.9.

Figure 3.9 Focusing at infinity after a -2.5 D defocus

The white focus distance indicator is close to 0.5 m mark on the distance scale clearly indicating the focus distance. Coincidentally, this is also the focal length (0.4 m) of the introduced defocus lens. Thus, focusing at an object located at infinity with the camera using hyperopic defocus of -2.5 D results in reported focusing distance of 40 cm. The test subject situated at optical infinity is still in acceptable focus like before and can be verified from the blur that results from removing the introduced lens as shown in Figure 3.10.

Due to the nature of the introduced -2.5 D defocus, we can say that the Camera is *apparently* focused at infinity even when the lens optics are *actually* reporting focus around the 40 cm mark.

Figure 3.10 Confirmation of focus at 40 cm with the -2.5 D external defocus removed

We have also repeated the experiment with a -3.0 D defocus so that the similar result can be compared as shown in Figure 3.11 below.

Figure 3.11 Focusing at infinity after a -3.0 D defocus

The camera still has our subject situated at optical infinity in focus like before. This time, the focus distance (~33 cm) approaches the close-focusing limit of the Camera lens at ~35 cm.

As one might've already observed, placing a lens in front of camera introduces some optical aberrations and some slight crop to the image. But for our limited purposes, this has not affected our ability to verify the shift in observation range under introduced defocus.

3.4 Focusing on objects closer than ∞ under hyperopic defocus

The consequence of introducing a diverging lens in front of a camera for formation of image of objects at infinity has been previously demonstrated in section 3.3.

In a way, we can say that the introduced -2.5 D defocus 'eats' away the usable portion of the effective observation range of the lens leaving only the remaining part of the observation range available for image formation. This translates as the inability of the camera to achieve *apparent* focus at objects closer than ~1.33 m with the -2.5 D defocus shown earlier by the green part of observation range shown in Figure 3.8. This close-focusing distance increases even further with the -3.0 D defocus rendering the Camera severely hyperopic in both of the cases.

Because we know the accommodation ability of a camera lens is a physical constraint imposed by how its optical elements are allowed to move inside, external defocus due to an introduced lens can't affect the accommodation ability.

4. Refractive conditions of the eye

Instead of taking the traditional approach which has historically been trying to model the complex optics of the eye structures[11], we have instead opted for the alternate route of studying simpler systems that work in a manner similar to the human eyes. Since our main interest is to study how image formation varies with observed distance inside the eye, full anatomical consideration of the Human eye is not necessary.

A labelled diagram[12] of the human eye for reference is given below in Figure 4.1.

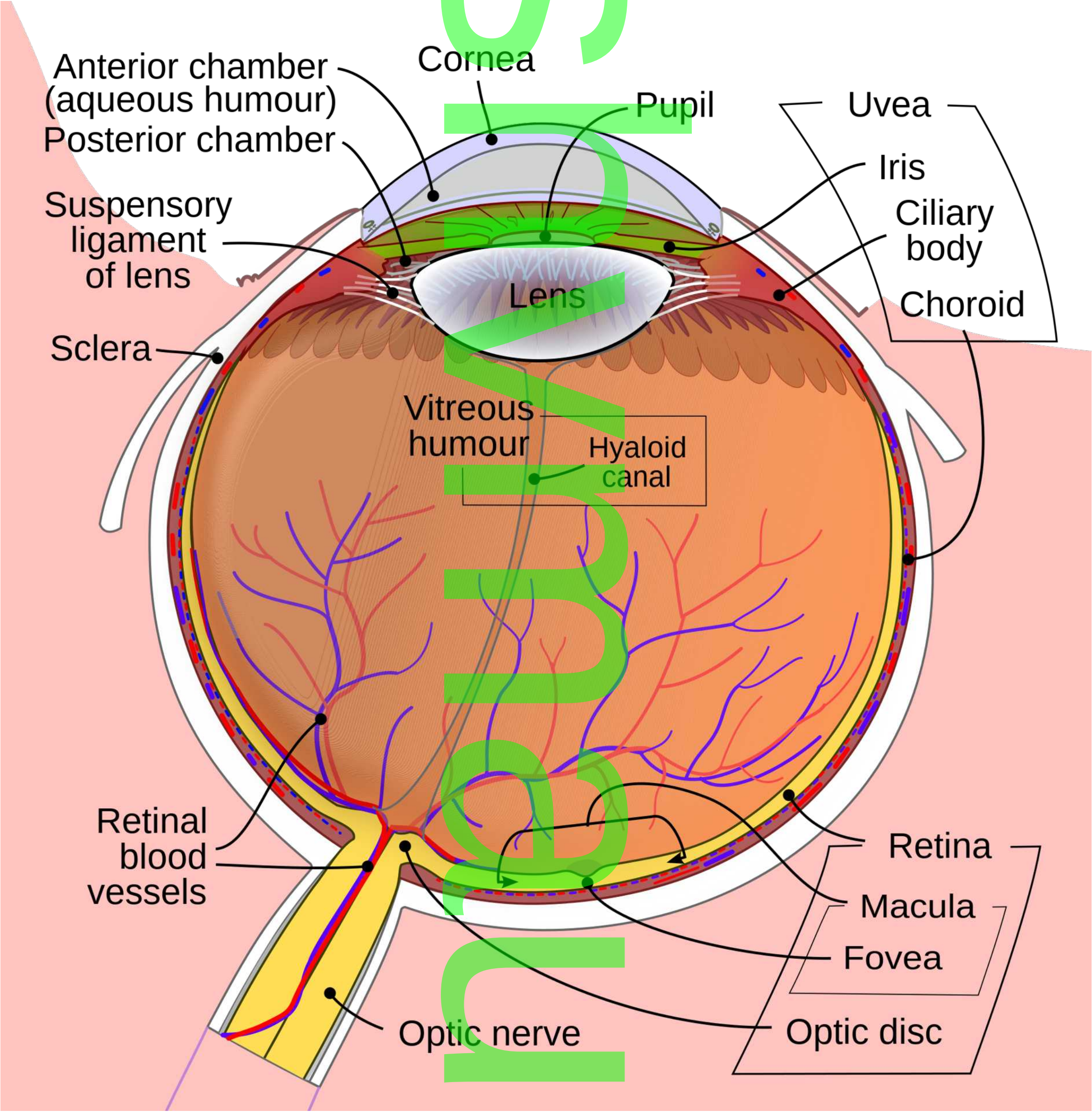


Figure 4.1 Labelled diagram of the human eye. It shows the lower part of the right eye after a central and horizontal section.

11. Navarro R. The Optical Design of the Human Eye: a Critical Review. J Optom. 2009;2(1):3–18. doi: 10.3921/joptom.2009.3. Epub 2010 Nov 4. PMCID: PMC3972707.
12. Image: Rhcastilhos. And Jmarchn., CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

4.1 Eyes compared to a camera and the simple lens system

The role optically active components play inside the eye will be explained in the order in which a light ray entering the eye traces its path towards retina.

Cornea→Aqueous humor→Eye lens→Vitreous humor→Photoreceptors on Retina

The Pupil is a hole in the Iris equivalent to the aperture opening of the simple lens system while the aqueous & vitreous humors act as a medium of travel for light, leaving us with remainder of the optical components of the eye as:

Cornea→Eye lens→Photoreceptors on Retina

The similarities[13] with a Camera or simple lens system become obvious once we consider that the cornea and eye lens play the role of the fixed and variable power elements respectively with the retina acting as an image sensor. The cornea, the eye lens and the mediums around them combined together converge light rays onto a spot on the retina. This similarity is enforced from the fact that our eyes too form an inverted image on the retina just like the simple lens system.

It follows that the frequently mentioned long-term AL changes comprising axial component of the Myopia result from changes to the cornea (which involves changes to corneal curvature and ACD) and the scleral shape which also involves physical distancing of the retina. This imaginary distance of the retina from the optical centre of the eye (involving the lens and cornea) will referred throughout this article as RD short for Retinal Distance and should be treated as the focal length counterpart for the eye. Changes to the eye lens forming the refractive component of the Myopia will be dealt separately in later sections.

4.1.a) Observation range of an emmetropic eye

One can assume the near-point of an emmetropic human eye to be 25 cm without any loss of generality. It represents the closest distance of continuous focus an adult emmetropic eye should be able to maintain without immediate fatigue/discomfort under daily circumstances. This is represented with a red dashed vertical line at the +4 D mark on the RDS. An elder person might not be able to observe objects this close because of presbyopia. Throughout this article, use of the word emmetropic without any prefix should mean *an emmetropic eye with intact accommodation ability* (≥ 4 D). An ordinary emmetropic eye should be able to observe objects from 20-25 cm (near point) up to infinity (far-point) and its observation range is shown in the Figure 4.2.

13. Sánchez López de Nava A, Somani AN, Salini B. Physiology, Vision. [Updated 2022 Jul 7]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK538493/

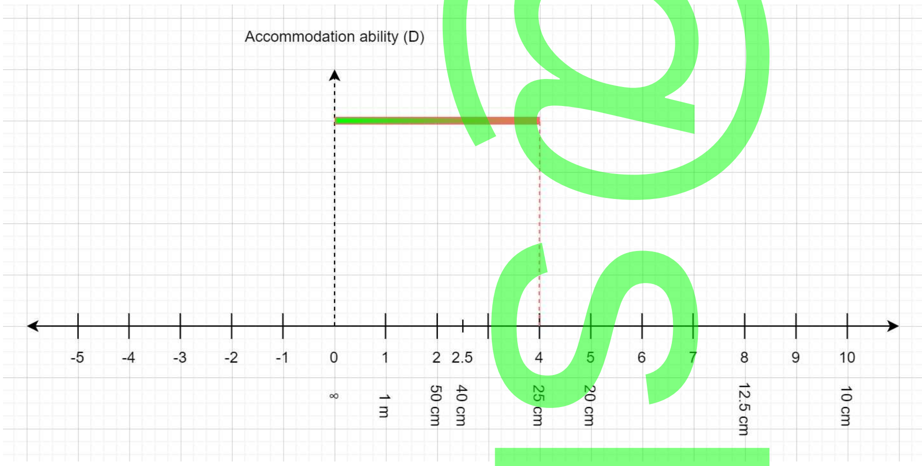


Figure 4.2 The observation range of an emmetropic eye (with observation range as 25 cm up to ∞)

4.2 Myopia

Before we discuss the observation range of a Myopic eye, it is important to state that the expected behaviour of a myopic eye after wearing best possible refractive compensation is pseudo-emmetropic with its far-point near infinity already shown in Figure 4.2. We emphasize that it might not always be possible to determine observation range of the eye in this manner due to its requirement being best possible refractive compensation be close to pseudo-emmetropy. The hurdles can result from presence of severe optical aberrations impacting visual acuity regardless of distance or the subject's inability to achieve consistent focus from other factors.

For instance, a subject wearing -1 D prescription reporting ability to focus at objects ranging from 25 cm all the way up to infinity in a visual acuity test (pseudo-emmetropy) is sufficient information to determine observation range of their (uncompensated) myopic eye. It is this observation range that gets shifted towards left after refractive interventions as described in section 2.3.b.

Simply put, knowing the near and far-points of a myopic eye **after** proper refractive compensation, the actual observation range can be determined by 'negating' the prescription as shown in Figure 4.3. The far-point of the resulting observation range should corroborate with the concept of BCVA[14] (Best ~~Compensated~~ Corrected Visual Acuity) in the absence of severe optical aberrations in the eye.

14. Lü YP, Xia WT, Chu RY, Zhou XT, Dai JH, Zhou H. [Relationship between best corrected visual acuity and refraction parameters in myopia]. Fa Yi Xue Za Zhi. 2011 Apr;27(2):94-7. Chinese. PMID: 21604445.

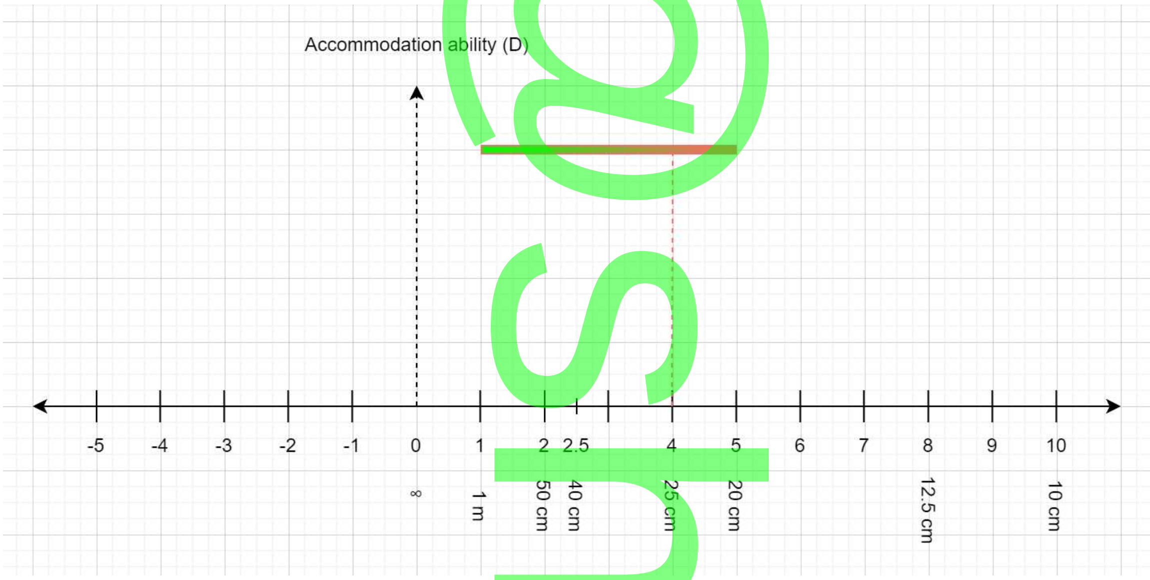


Figure 4.3 The observation range of a myopic eye with 1.0 D Myopia

It can be then argued that **Myopia** results in a refractive state ~~error~~ in which the eyes' far point (the maximum distance at which the eye can **focus properly**) is closer than/no longer located at infinity. Astigmatism, floaters and retinal imperfections can independently affect final image quality at focus even after best possible refractive interventions.

4.3 Hyperopia and Presbyopia

Hyperopia/far-sightedness can be said to result from the axial changes to the eyeball such that images of closer objects are formed behind the retina. The near point of a hyperopic eye recedes farther from an acceptable close-up distance (taken as 25 cm throughout this article). Hyperopia is much less commonly encountered than Myopia.

As previously demonstrated for Myopia, observation ranges resulting from hyperopia too can be represented in the same manner provided the best possible refractive intervention achieves pseudo-emmetropy. The procedure is the same as before: determination of the observation range (far and near-points) after best possible refractive compensation and then its 'negation' to get the hyperopic observation range.
For instance, an eye that needs +2 D prescription to achieve pseudo-emmetropy will have its hyperopic observation range as shown in Figure 4.4:

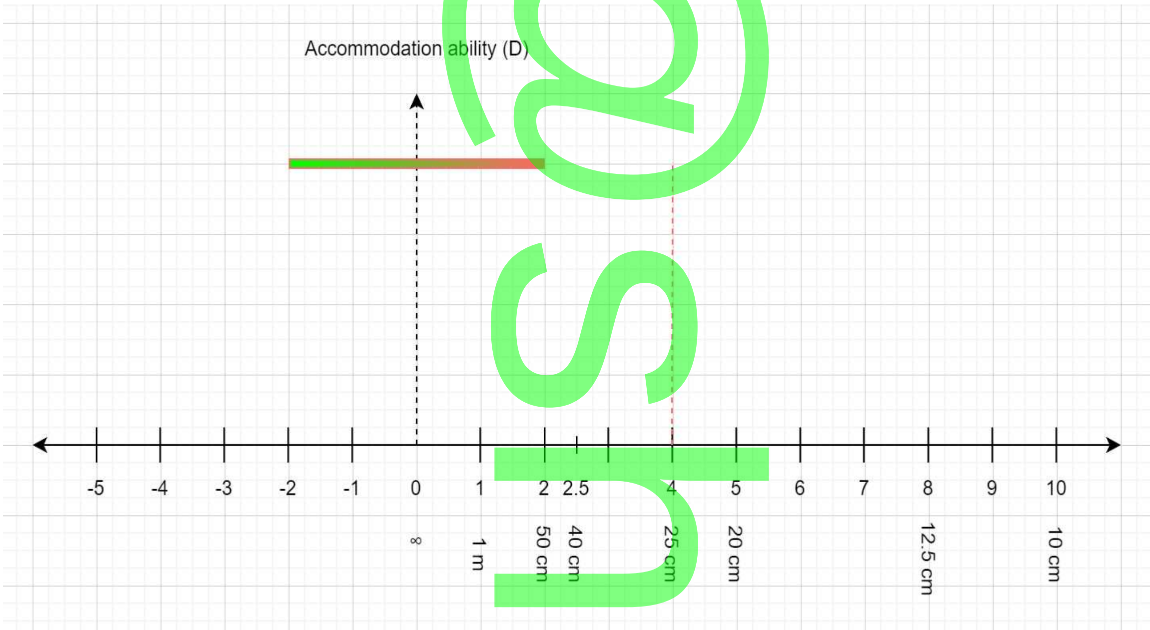


Figure 4.4 Observation range of a hyperopic eye requiring +2 D refractive compensation to achieve pseudo-emmetropy.

It should be now intuitive to understand how wearing a positive lens (+2 D in this case) restores pseudo-emmetropic observation range by shifting the hyperopic observation range towards right.

4.3.a) Presbyopia

For both hyperopia and Myopia involving mostly axial changes, the accommodation ability depends mostly upon ciliary function and remains unaffected by changes in AL. This is akin to screen distancing discussed in section 2.3.c while presbyopia involves reduction in the accommodation ability of the lens which is a function of the ciliary. Thus, presbyopia is not the same as hyperopia even when both result in the same observed difficulty involving focusing at close-up objects. A presbyopic eye can be still emmetropic in the sense that the ciliary muscle remains in a relaxed state while focusing at infinity.

For instance, the observation range of an emmetropic eye but presbyopic eye unable to see objects closer than 40 cm is shown in Figure 4.5. It is this observation range that gets shifted 1.5 units towards right after wearing +1.5 D reading prescription for close objects allowing the eye to focus at 25 cm. Notice the lower height (rank) compared to the plots we've shown so far.

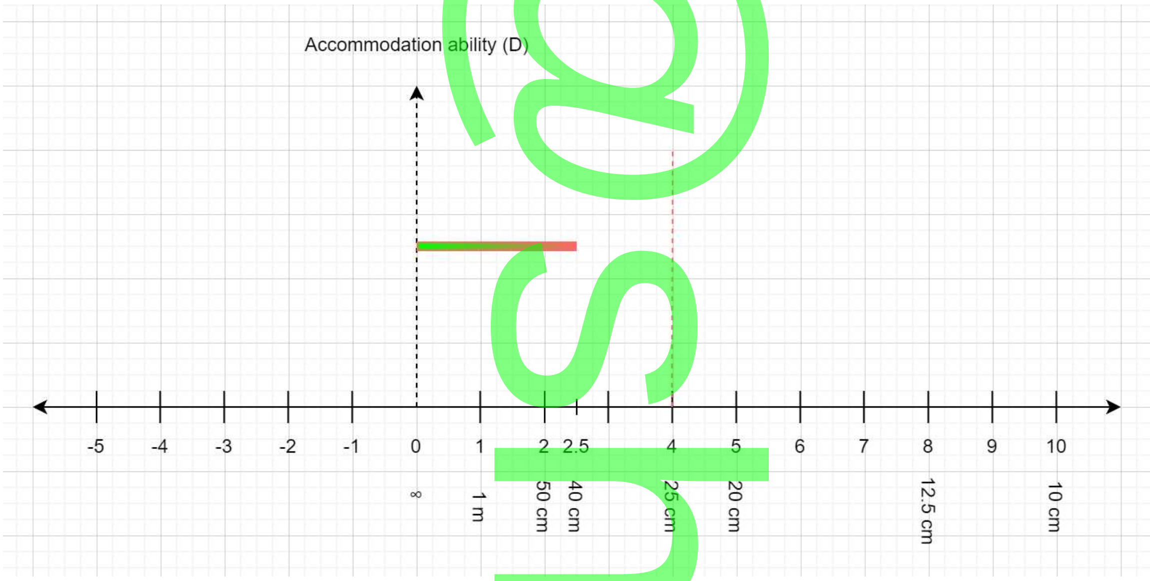


Figure 4.5 Observation range of an emmetropic eye with -1.5 D presbyopia

This is the primary reason why presbyopia commonly requires 'bi-focal arrangement' of glasses – because of the lack of accommodation ability to cover the complete visual range even after wearing prescription for other refractive conditions like Myopia and Hyperopia. The commonly accepted cause for Presbyopia as age-related worsening of accommodation is usually explained[15] as some combination of decreased elasticity of the eye lens and weakening of the ciliary muscle. It follows that presbyopia management requires interventions in line with measures aimed at delaying ageing beyond the scope of this article.

4.4 Focusing vs. Exposing & Actual vs. Apparent focus

Having already differentiated between image distance (v) and screen distance (s) for the simple thin-lens system in section 2.2, We will extend similar differentiation in the context of exposing and focusing for the eyes also. This is required to be able to indicate the physical possibility that can involve for instance, an eye **focused** at infinity but **exposed** to a nearby white wall. The focusing part is extremely important as it allows us to quickly dismiss some of the other common but wrong explanations for refractive conditions. Even if a myopic eye is exposed to and observing infinity, it will still be *focused* at a point closer than infinity. The characteristic blur resulting from Myopia/Hyperopia can then be explained as *exposing* eyes to distances farther/closer their respective far/near-point. Thus, Myopia and Hyperopia should actually be seen as refractive conditions (inability to focus) distinct from refractive errors impacting visual acuity regardless of distance focused.

Keeping up with our terminology used in Section 3 of this article for observed focusing behaviour of the camera, we will refer to focusing after refractive intervention as *apparent* focus in order to distinguish it from *actual* focusing achieved without refractive intervention. The term **apparent focusing** refers to the focusing involving the eye + lens combination while **actual focusing** refers to 'unassisted' focusing involving only the eyes.

It is obvious that for ***apparent*** focus at some distance, a myopic eye must be ***actually*** focusing at a distance closer than the said distance. For a hyperopic eye to achieve apparent focus at the same distance, it must be actually focused farther than the distance in question. Refractive interventions in this context can be stated to act as a mapping between actual and apparent observation ranges.

15. Bentley S, Findley A, Chiva-Razavi S, Naujoks C, Patalano F, Johnson C, Arbuckle R, Wolffsohn JS. Understanding the visual function symptoms and associated functional impacts of phakic presbyopia. J Patient Rep Outcomes. 2021 Nov 3;5(1):114. doi: 10.1186/s41687-021-00383-1. PMID: 34731344; PMCID: PMC8566618.

A diagram explaining this for Myopia is given in Figure 4.6:

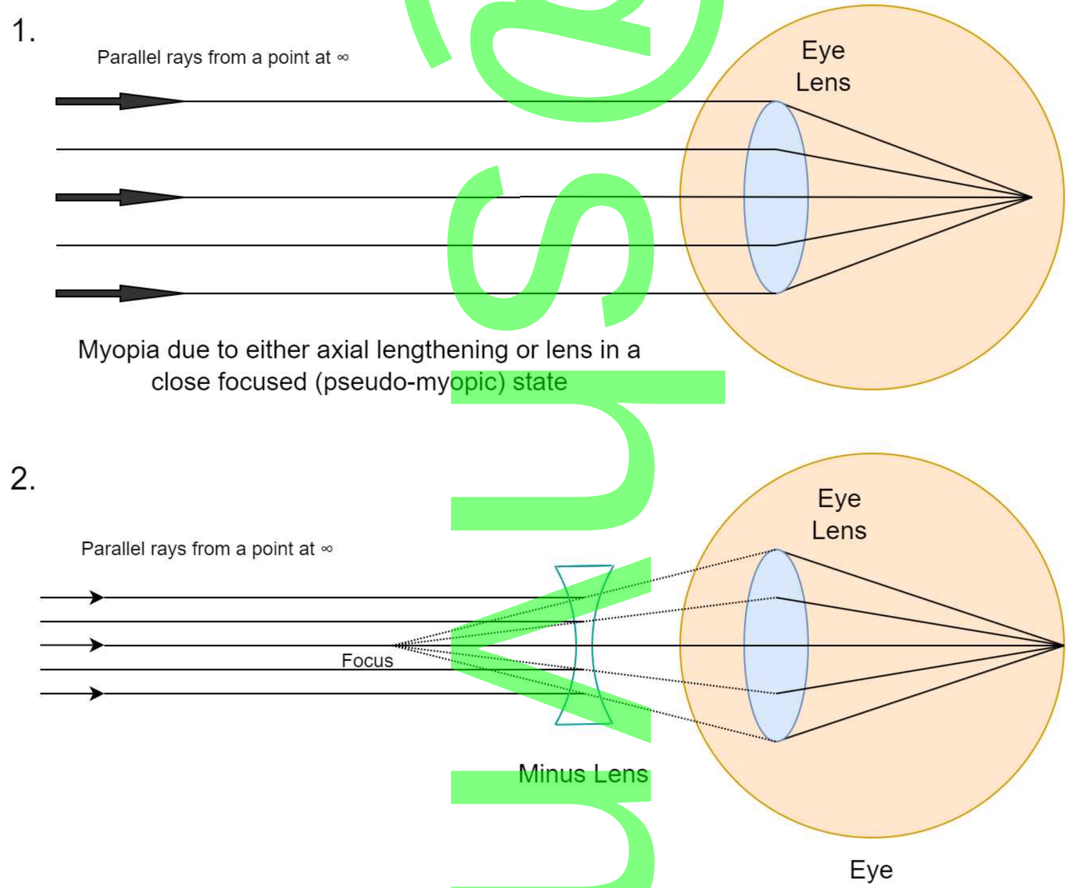


Figure 4.6 A diagram showing how refractive interventions work for Myopia.

In geometrical optics speak, the introduced minus lens can be assumed to introduce extra divergence to the incoming light rays so as to shift the resulting image plane to coincide with the plane of 'far-shifted' retina. It is simple to understand why the compensated eye in the figure must actually focus at a distance closer than its apparent focusing distance.

4.5 The 'sign' and severity designation of a refractive state

From the standpoint of Geometrical Optics, using (+)[16] sign for representing degree of Myopia encodes the 'compensating' behaviour refractive interventions with opposite (-) sign have on the observation range of a myopic eye. Following our sign conventions allows for natural interpretation of statements conveying information about under-prescription without confusion such as "A person with 2.5 D Myopia wearing -2.0 D under-prescription."

The inverse of this should apply for Hyperopia. Presbyopia happens to be reduction in accommodation ability resulting in an additional (+) compensation requirement for observing closer distances and needs to be denoted with a negative sign.

According to WHO, High Myopia is defined at 5.0 D 'Spherical Equivalent' or more. In other texts, High Myopia is defined as 6.0 D 'Spherical Equivalent' or more. We will do away with spherical equivalents for reasons that will become apparent later and will prefer to handle SPH and CYL components of the refraction separately.

16. Fredrick DR. Myopia. BMJ. 2002 May 18;324(7347):1195-9. doi: 10.1136/bmj.324.7347.1195. PMID: 12016188; PMCID: PMC1123161.

It is clear from the strictness of focusing criteria that a myopic eye is unable to focus beyond its far-point and a hyperopic eye can't focus closer than its near-point. The position of these points compared to an emmetropic eye should determine the severity of myopia/hyperopia. In the context of observation ranges, severity of a refractive state can be defined as one with threshold lack of overlap between the actual observation range and its best compensated counterpart as shown below in Figure 4.7. This overlap factor can be the value required for threshold Myopia which is 0.5 D (WHO).

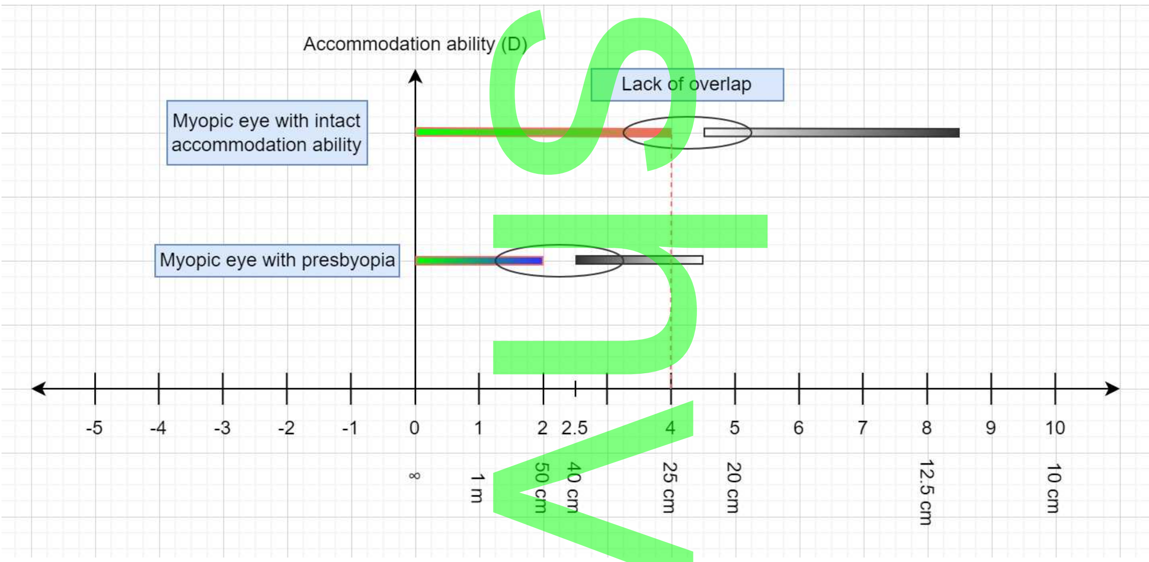


Figure 4.7: The 'overlap' criteria for determining severity of Myopia. The observation range in grey represents the uncompensated observation range without any refractive interventions.

The following arguments are in favour of our overlap criteria for determining severity of refractive states:

1. Encodes the prediction that a person fulfilling the criteria should be unable to focus at any 'reasonable' working distance without refractive intervention. Conversely, subjects with low myopia should be able to focus closer than their far-point comfortably without requiring refractive compensation.
2. Yields nearly equivalent classification as the existing scientific consensus values deviating only in the presence of Presbyopia.
3. Gives consistent thresholds for both refractive conditions of Myopia and Hyperopia.
4. Predicts an increase in risk posed by refractive conditions with age due to Presbyopia. A non-severe case of Myopia in adulthood can transition into high myopia after onset of presbyopia.
5. We have stated severity of Myopia depending on factors affecting observation range which may or may not be significantly affected by actual refractive errors like astigmatism in practice. This is one of the reasons behind avoiding 'spherical equivalents' in the definition.

Severe Myopia also indicates the difficulty faced by eye's extraocular muscles when focusing close to its near-point (for highly severe myopia, even the far-point may be out of reach). For subjects requiring greater powers as is the case for severe myopia, deviation from power addition rule discussed in section 8.3 needs to be taken into accounted.

5. Discussions

The refractive conditions we have previously discussed so far can be represented in Figure 5.1 for comparison.

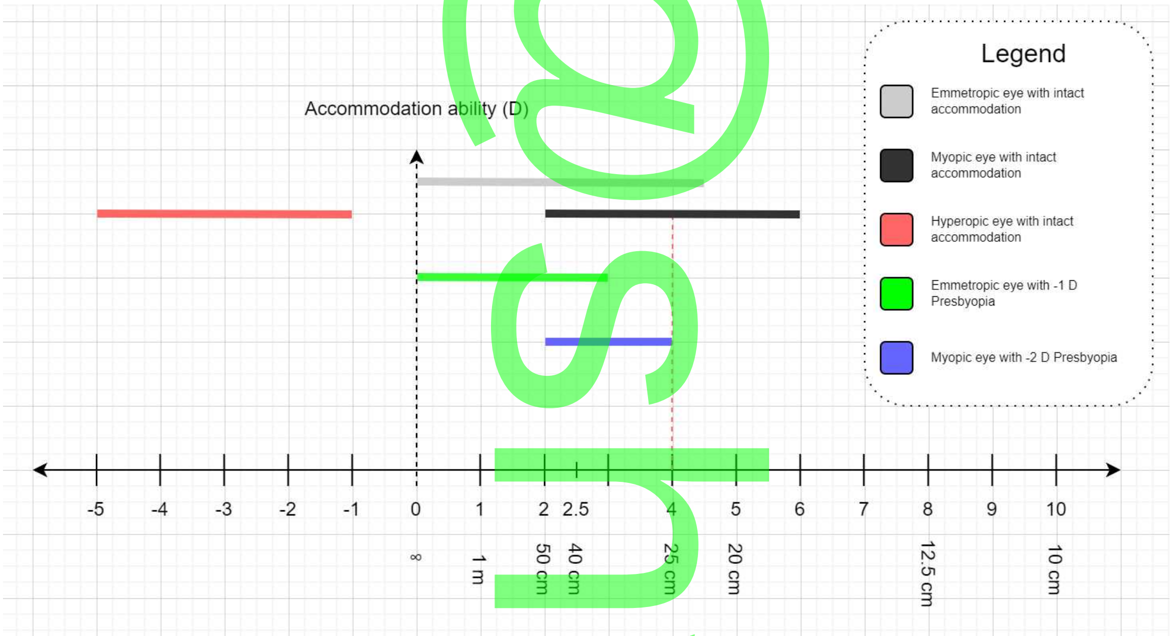


Figure 5.1: Observation ranges of multiple refractive conditions of the eye for comparison:

The observation range shown in purple is what many mean by the phrase that Presbyopia gets compensated[17] by Myopia. For the observation ranges in green and purple, presbyopia is -1 D and -2 D respectively. This is the reason behind why prescription for comfortably viewing closer distances needs to take into account presence of other refractive conditions. It is also obvious why Myopic people require hyperopic shift in observation range for emmetropia and vice-versa.

5.1 The 'Mystery' of Myopia according to the Continuous Adaptation Theory

This section develops the Continuous Adaptation Theory (CAT) based on the simple lens model whose primary objective is to explain observed counter-intuitive behaviours associated with myopia and devise a method for Myopia management.

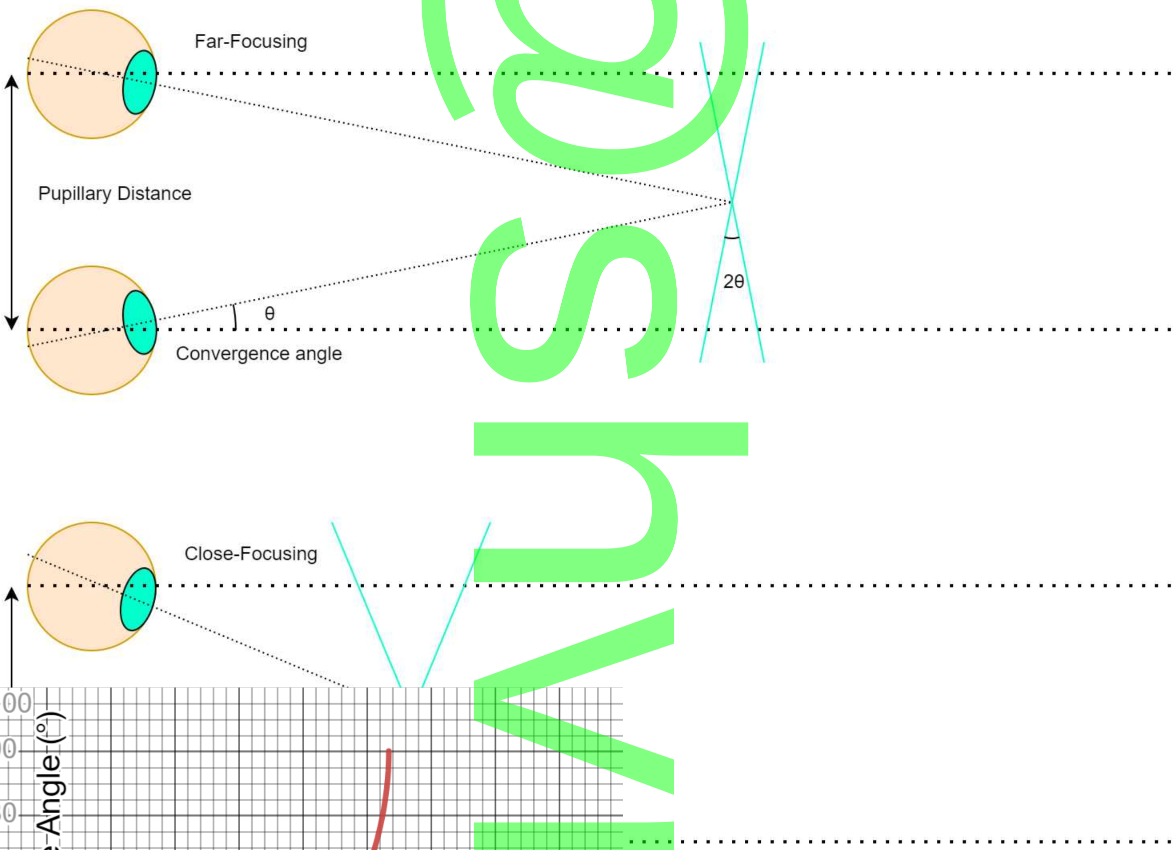
5.1.a) Accommodation-convergence reflex

Our two eyes form a stereoscopic pair for depth perception which necessitates the presence of simultaneous convergence[18]. Convergence is basically the simultaneous tilting of the axis of both eyes towards the object point in focus to form an aligned image. We'll mainly focus upon the aspects of convergence related to Myopia where we will characterize how the accommodation-convergence reflex should differ for myopia compared to emmetropic subjects in order to maintain singular vision with accommodation distance.

For an adult emmetropic eye focusing on an object equidistant from both eyes, the relation between convergence angle θ and power of lens resulting from ciliary accommodation can be given by $\theta = \sin^{-1}\left(\frac{IPD \times Accommodation\,Power}{2}\right)$, where IPD refers to the InterPupillary Distance. The angle between the respective image planes depicted in blue happens to be the sum of convergence angle for both eyes shown in Figure 5.2.

17. Yang A, Lim SY, Wong YL, Yeo A, Rajeev N, Drobe B. Quality of Life in Presbyopes with Low and High Myopia Using Single-Vision and Progressive-Lens Correction. J Clin Med. 2021 Apr 9;10(8):1589. doi: 10.3390/jcm10081589. PMID: 33918687; PMCID: PMC8069619.

18. Linton P. Does vision extract absolute distance from vergence? Atten Percept Psychophys. 2020 Aug;82(6):3176-3195. doi: 10.3758/s13414-020-02006-1. PMID: 32406005; PMCID: PMC7381460.



9°.

Figure 5.3: A plot of convergence angle with accommodation (IPD: 63 mm)

As can be seen from Figure 5.3, the reflex should act in a linear fashion even beyond the usually encountered accommodation ability for the eye (+4 to +5 D). All definitions of severe myopia need to account for the observation that the extraocular muscles responsible for convergence start hitting their limits at close-up distances characteristic of severe myopia. For such people, refractive interventions become a necessity. It is not a mere coincidence that the contraction range of the extraocular muscles responsible for convergence is in line with the contraction range of the ciliary muscle responsible for accommodation inside the eye.

For an emmetropic eye with its far-point closer to infinity, the reflex acts at all observed distances. The same applies to a pseudo-emmetropic Myopic eye with best possible refractive compensation having its apparent far-point at infinity. For an uncompensated Myopic eye having its far-point at a distance closer than infinity, the eyes start accommodating only when convergence 'reaches' distances closer than the far-point. For distances beyond the far-point, the eyes continues to remain in a relaxed state. This can be termed as introduction of **convergence lag** due to Myopia. In both cases, it can be said that the reflex starts acting only when the observed distances come closer than the far-point of the eye.

We suspect that conflict[19] of the accommodation-convergence reflex can play a role influencing reports of initial discomfort associated with wearing inadequate or over-prescribed lenses. It is commonly observed that the discomfort stabilizes in a few days hinting that the convergence reflex could also get calibrated within this time-frame.

One must also note the increasing angle between the image planes corresponding to each eye as the focusing distance comes closer. The roughly cylindrical nature of the image plane distortion with its axis perpendicular to the line joining both eyes should hint at its association with a component of astigmatism at closer distances. It predicts presence of minor levels of astigmatism in emmetropic subjects involved with near-work. We leave it for interested researchers to investigate how this particular form of cylindrical distortion affects the eye's optical characteristics and biometry.

It is possible that fully compensating this form of astigmatism can result in experienced discomfort and development of further astigmatism in subjects mainly involved with near work – (progression of astigmatism). It is better that astigmatism of this type be left slightly uncompensated unless it perceptibly affects visual acuity.

5.1.b) Variable time-scale processes of the eye

A lot has been already described about accommodation in multiple texts. Put simply, contraction of ciliary muscle relaxes the suspensory ligaments holding the eye lens, allowing it to become thicker resulting in the shortening of focal length necessary for observing closer distances. Accommodation happens to be a very short-term (almost instantaneous) response because it is controlled by the ciliary ***muscle***. A high-quality video of accommodation in action[20] has been accessed here: https://youtu.be/1yIpyitm6eE

Axial changes take place on a relatively long-term time frames mostly due to changes involving the cornea and the outermost scleral shape of the eye which is non-muscular in nature and requires time-scales of months and longer. Commonly encountered Myopia involves changes mostly axial in nature.

There are two ways in which the observation range of the simple lens system can be shifted: by accommodative *shift* or by changing screen distance described in section 2.3.b & 2.3.c respectively. The same should be applicable for the Human eyes also. We already know that shifting of the retina (screen shift) occurs during Myopia as a component of axial elongation. It is only natural that accommodative-shift of some sort also happens inside the eye.

This accommodative-shift contributing towards the refractive component of myopia must involve the ciliary body because only the ciliary muscle physically attaches to and changes the focal length of the eye lens. Accommodative shift can thus be explained as change in ciliary muscle state resulting into increased relaxed and accommodated power of the eye lens.

Prediction P1: We predict that the aforementioned accommodative shift acts as a medium-term (happening on the time-scale of days to weeks) **bridging** process between the two well known short-term (accommodation) process involving the ciliary body and the processes that results in long-term axial changes. P1 also implies the existence of a biological pathway capable of responding to and alleviating shifts state of the ciliary muscle by inducing axial changes in the eye.

19. Yao Zhou, Jufan Zhang, Fengzhou Fang, Vergence-accommodation conflict in optical see-through display: review and prospect, Results in Optics, Volume 5, 2021, 100160, ISSN 2666-9501, https://doi.org/10.1016/j.rio.2021.100160.
20. Goldberg D. Computer-animated model of accommodation and theory of reciprocal zonular action. Clin Ophthalmol. 2011;5:1559-1566 https://doi.org/10.2147/OPTH.S25983

This prediction stems from the distinct but continuous structures of iris, the ciliary body and the choroid (the layer between the retina and the sclera) forming the uvea. It is not immediately apparent how short-term observed changes to the thickness of the choroid fit into this overall descrption.

5.1.c) Observation range changes during Myopia

The eye experiences continuous changes to its structure and observation range while undergoing refractive state changes. From the observation range of a Myopic eye and multiple real-world observations, it can be said that a myopic eye gains additional close-range capability while *sacrificing* capability to observe distant objects as shown in Figure 5.4.

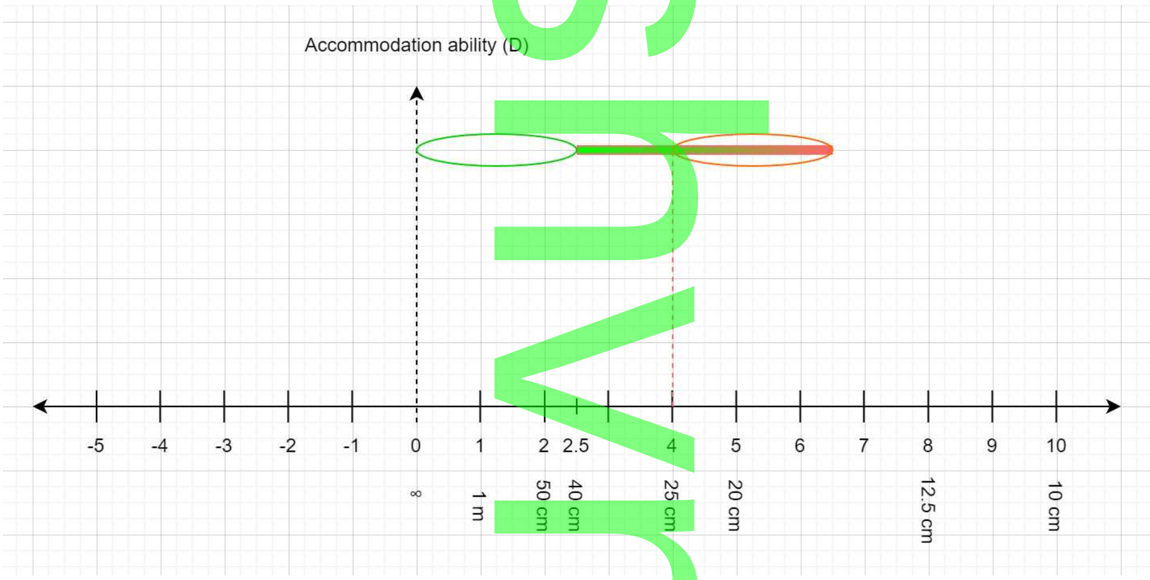


Figure 5.4: Compared to an emmetropic eye, the gained close-range observation capability by a Myopic eye is shown with an orange oval while its sacrificed observation range for distance objects is shown with a green oval.

This observed behaviour is in line with the shift in observation range due to screen-shift or accommodation-shift already described in section 2.2. The orange oval denotes the range of distances from myopic near-point to its emmetropic counterpart while the green oval denotes the range of distances from myopic far-point up to infinity (its emmetropic counterpart). It is obvious that the power gained at the near end is almost equal to the power lost at the distant end of the observation range.

Prediction P2: We will assume that human eyes try to adapt continuously towards the **exposed** visual stimulus with the aim of keeping the ciliary muscle within its normal working range. It might even be possible to derive this assumption from other elementary assumptions in the near-future but will not be attempted here. P2 is the building block for the Continuous Adaptation Theory (CAT) of the eye that is essential towards explaining many commonly encountered ‘counter-intuitive observations’ about Myopia still unexplained by the frameworks of existing research efforts.

Because the ciliary accommodation ability is limited, an under-utilised extreme of the observation range should result in an even stronger adaptive response. For Myopia, this extreme of the observation range corresponds to focusing at distant objects. The aforementioned observation of Myopia initiation/progression resulting from the eye gaining additional close-range capability while sacrificing capability to observe distant objects can be explained as shift in equilibrium resulting from adaptive requirements from close-range stimulus driven by under-utilisation of distant vision capability.

We are already in a position to answer the first among one of the many unexplained mysteries of Myopia: Why it is observed that some people do not experience Myopia even with 'significant' near-work habits[21]? We now have an answer in the form of sufficient utilisation of distant vision keeping in check the adaptation due to near-work. We predict no net shift in an eye sufficiently utilising both ends near and far of its observation range. It also explains why long-duration near-work correlates[22] with Myopia but is not sufficient towards being a cause for Myopia with the simple implication being under-utilisation of distant vision capability (not the same as near-work) should also be correlated with Myopia. This is also corroborated by multiple review studies[23] on Myopia.

Put simply, under-utilisation of distant vision capability should be treated as a more important consideration factor for Myopic adaptation resulting in the observation range of the eye (continuously) shifting *away* from observing farther distances *towards* closer distances. An eye doing long-duration near-work but sufficiently utilising distance vision capability should signal eye-strain from long-duration near-work without becoming Myopic. It also hints that emphasis towards proper utilisation of distance vision capability must be a requirement for management of Myopia.

5.1.d) The mechanism behind Myopic adaptation

We have previously described how eyes have adaptative processes differing in the time-scale of their operation. These short-term, medium term and long-term processes together maintain the equilibrium state of the eye. We have also described how the observation range of an emmetropic eye shifts during the development of Myopia.

The onset of Myopia has been mainly predicted to result from the ciliary muscle 'tiring' out during long-duration near-work and developing some form of (accommodative) spasm in the ciliary (pseudomyopia[24]). Doing near-work closer to the focusing limit of the ciliary muscle should theoretically bring faster exhaustion of the ciliary. This accommodation requirement of the ciliary should then translate into an adaptive requirement towards Myopia.

Without 'suitable' interventions, the ciliary muscle starts developing accommodative-shift (in the medium-term time-span of days to weeks) in order to relieve the accommodative stress caused by long-duration near-work. It can be expected that a person with myopic ciliary shift should possess markedly better capability of doing near work for a longer time period along with suppression of near-work induced eye-stress.

Myopic shift in the ciliary could also result in discouragement towards utilisation of distance vision capability in the form of excessive tear formation, rapid/uncontrolled blinking, increased sensitivity towards bright lights and signalled discomfort (HARE[25]) establishing a subtle feedback loop that should promote further progression of Myopia.

21. Low W, Dirani M, Gazzard G, Chan YH, Zhou HJ, Selvaraj P, Au Eong KG, Young TL, Mitchell P, Wong TY, Saw SM. Family history, near work, outdoor activity, and myopia in Singapore Chinese preschool children. Br J Ophthalmol. 2010 Aug;94(8):1012-6. doi: 10.1136/bjo.2009.173187. Epub 2010 May 14. PMID: 20472747; PMCID: PMC4041336.
22. Huang HM, Chang DS, Wu PC. The Association between Near Work Activities and Myopia in Children-A Systematic Review and Meta-Analysis. PLoS One. 2015 Oct 20;10(10):e0140419. doi: 10.1371/journal.pone.0140419. PMID: 26485393; PMCID: PMC4618477.
23. Lagrèze WA, Schaeffel F. Preventing Myopia. Dtsch Arztebl Int. 2017 Sep 4;114(35-36):575-580. doi: 10.3238/arztebl.2017.0575. PMID: 28927495; PMCID: PMC5615392.
24. Khalid K, Padda J, Pokhriyal S, Hitawala G, Khan MS, Upadhyay P, Cooper AC, Jean-Charles G. Pseudomyopia and Its Association With Anxiety. Cureus. 2021 Aug 24;13(8):e17411. doi: 10.7759/cureus.17411. PMID: 34589322; PMCID: PMC8459808.
25. Christopher J, Priya Y, Bhat V, Sarma G. Characteristics of Headache in Children Presenting to Ophthalmology Services in a Tertiary Care Center of South India. Cureus. 2022 Feb 1;14(2):e21805. doi: 10.7759/cureus.21805. PMID: 35251869; PMCID: PMC8890450.

Prediction P1 stated earlier is essential towards explaining this missing link between how accommodative requirements from near-work translate into eventual long-term axial changes during Myopia. The under-utilisation of distant vision capability in the presence of accommodative shift lets long-term adaptive processes to initiate Axial Changes in order to alleviate this myopic shift as long as the shift in ciliary is maintained. The subsidence of external factors forcing myopic adaptation results in equilibrium being established again with the ciliary gradually returning to its previous state with the axial changes in place observed as stabilization of Myopia.

Because accommodative-shift is a novel concept towards understanding Myopia, physical details about shift in the ciliary are hard to come by. We speculate that the reported observation of ciliary body thickening[[26], [27]] in Myopic subjects can serve as an indicator for myopic ciliary shift.

We've already mentioned that a component of astigmatism should result from increasing angle between image planes resulting from closer observation distances in section 5.1.a. Another form of astigmatism can be said to result from changes that the ciliary undergoes and then reverses during the process of developing accommodative shift factored with changes to retina and cornea from long-term AL changes. The 'recalibration' of the accommodation-convergence reflex as introduction of convergence lag mentioned earlier is also predicted to happen alongside myopia.

An important consequence of the Continuous Adaptation theory is that it does away with the 'eye-growth' dichotomy and simultaneously explains many contradictions in the commonly accepted age-bound theory explaining progression and stabilization during mid-twenties for Myopia. Keeping up with the 'unconventional' theme of this article's explanations about Myopia, this explanation too is supported by the documented observation that average human eyes stop growing and attain[28] their full adult size by three years.

Science can not accommodate two contradicting explanations for eye-growth – on one hand there is an observed actual 'all around' eye globe growth (eye globe development) completing around the age of three years. On the other hand, we still have theorists regarding Myopia as some sort of 'irreversible' eye-growth that continues well into the mid-twenties before eventually stabilizing. Resolving this contradiction and explaining both of these two observations must mean that any axial changes to the eye mostly elongating the eyeball as observed in Myopia should arise purely from environmental and lifestyle factors translating into reasons outlined above and must be treated in a different manner from actual eye-growth that gets completed during early-childhood.

This suggests at the possibility that Myopia stabilization happening during mid-twenties should boil down purely to changes brought by environmental and lifestyle factors from attaining adulthood and conscious improvements in viewing habits including eye-strain awareness during long duration near-work. It also makes it trivial to explain why some subjects can still experience continued 'Myopia progression' throughout their adult lives.

5.1.e) Influence of lighting conditions on Myopia

This section aims to describe the influence lighting levels have on Myopia.

26. Bailey MD, Sinnott LT, Mutti DO. Ciliary body thickness and refractive error in children. Invest Ophthalmol Vis Sci. 2008 Oct;49(10):4353-60. doi: 10.1167/iovs.08-2008. Epub 2008 Jun 19. PMID: 18566470; PMCID: PMC2994597.
27. Dinesh Kaphle, Katrina L. Schmid, Leon N. Davies, Marwan Suheimat, David A. Atchison; Ciliary Muscle Dimension Changes With Accommodation Vary in Myopia and Emmetropia. Invest. Ophthalmol. Vis. Sci. 2022;63(6):24. doi: https://doi.org/10.1167/iovs.63.6.24.
28. Bhardwaj V, Rajeshbhai GP. Axial length, anterior chamber depth-a study in different age groups and refractive errors. J Clin Diagn Res. 2013 Oct;7(10):2211-2. doi: 10.7860/JCDR/2013/7015.3473. Epub 2013 Oct 5. PMID: 24298478; PMCID: PMC3843406.

The pupil of the iris[29] evolved as an aperture control mechanism to regulate the amount of light entering the eye. [Pupil size[30] in adults varies from 2 to 4 mm in diameter in bright light to 4 to 8 mm in the dark.] We will refer to environmental lighting conditions in terms of how it relatively affects the pupil size in ordinary eyes: pupil constricted (bright) and pupil dilated (dim/dark) lighting conditions. The pupil is fully dilated in the absence of light.

The simple lens model predicts that dilated pupil's shallower Depth of Field in lower light conditions should result in extra accommodation demand on the ciliary compared to brighter lighting conditions for the same observed distance. It is pretty well known at this point that near work done under pupil dilated lighting conditions is correlated with Myopia[31]. There is also an established body of research on Myopia being the 'default' behaviour of various species of animal eyes when subjected to form deprivation in dim/dark environments ([32],[33] and [34]). Retinal Ganglion Cells (RGCs) are known to play a crucial role in influencing[35] adaptive processes of the eye in this regard.

Prediction P3: We suggest that there is a high chance that lower than adequate levels of light during near-work accelerates adaptation towards Myopia described in the previous section. We've already discussed how adaptive requirement from long-duration near-work and under-utilisation of distant vision capability together should induce myopic adaptation. In this context, lower light levels can be said to accelerate the rate of Myopic adaptation. This also explains why highly myopic people can show sensitivity to bright lighting environment which normally do not considerably affect ordinary emmetropic subjects.

Inadequate lighting as a factor should be the last remaining puzzle piece in our understanding of environmental factors affecting Myopia. Because low light levels result in reduction of available light information, it also results in increased development of alignment errors and aberrations thereby making Myopic adaptation inherently 'inferior' in this regard.

5.1.f) The equivalence between an emmetropic eye & an eye with best possible refractive compesation

Because our eyes lack any capability to detect presence of specific refractive interventions, behaviour shown by a compensated myopic/hyperopic (pseudo-emmetropic) eye should not differ considerably from an emmetropic eye. An emmetropic eye and a pseudo-emmetropic eye with best possible

29. Bloom J, Motlagh M, Czyz CN. Anatomy, Head and Neck, Eye Iris Sphincter Muscle. [Updated 2022 Jul 19]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK532252/l
30. Spector RH. The Pupils. In: Walker HK, Hall WD, Hurst JW, editors. Clinical Methods: The History, Physical, and Laboratory Examinations. 3rd edition. Boston: Butterworths; 1990. Chapter 58. Available from: https://www.ncbi.nlm.nih.gov/books/NBK381/
31. Muralidharan AR, Lança C, Biswas S, Barathi VA, Wan Yu Shermaine L, Seang-Mei S, Milea D, Najjar RP. Light and myopia: from epidemiological studies to neurobiological mechanisms. Ther Adv Ophthalmol. 2021 Dec 19;13:25158414211059246. doi: 10.1177/25158414211059246. PMID: 34988370; PMCID: PMC8721425.
32. Marcus H.C. Howlett, Sally A. McFadden, Form-deprivation myopia in the guinea pig (Cavia porcellus), Vision Research, Volume 46, Issues 1–2, 2006, Pages 267-283, ISSN 0042-6989, https://doi.org/10.1016/j.visres.2005.06.036.
33. Zhou X, Lu F, Xie R, Jiang L, Wen J, Li Y, Shi J, He T, Qu J. Recovery from axial myopia induced by a monocularly deprived facemask in adolescent (7-week-old) guinea pigs. Vision Res. 2007 Apr;47(8):1103-11. doi: 10.1016/j.visres.2007.01.002. Epub 2007 Mar 9. PMID: 17350070.
34. Ji FT, Li Q, Zhu YL, Jiang LQ, Zhou XT, Pan MZ, Qu J. [Form deprivation myopia in C57BL/6 mice]. Zhonghua Yan Ke Za Zhi. 2009 Nov;45(11):1020-6. Chinese. PMID: 20137422.
35. Kim US, Mahroo OA, Mollon JD, Yu-Wai-Man P. Retinal Ganglion Cells-Diversity of Cell Types and Clinical Relevance. Front Neurol. 2021 May 21;12:661938. doi: 10.3389/fneur.2021.661938. PMID: 34093409; PMCID: PMC8175861.

refractive compensation should be equivalent when it comes to their observation ranges and far-points. A shift towards myopia should appear the same whether it occurs to an emmetropic eye (termed onset of Myopia) or a myopic eye (termed Myopia progression).

This equivalence compels us to suggest that (both environmental and habitual) factors causing onset of Myopia in an emmetropic eye should also cause Myopia progression in a compensated Myopic eye as well. Myopia progression needs to be viewed as onset of Myopia in an eye already compensated for Myopia.

Conversely, for a myopic eye to experience reversal of Myopia – it goes without saying that the same must be apparent from the shifting of its far-point towards left (increasing the distance at which it can focus properly). We have already established experimentally that a compensated myopic eye apparently observing infinity is actually focused at its far-point closer than infinity in Section 4.4. We have chosen to call this as 'clamping' of the actual far-point by refractive interventions. One can even state it the other way around: expecting reduction in Myopia for a myopic eye with its far-point clamped by refractive intervention is equivalent to expecting the far-point of an emmetropic eye to shift farther away from infinity (like in hyperopia) which is not known to happen in the latter case. Nothing happens in both cases simply because relaxation of the ciliary muscle does not constitutes accommodative stress necessitating adaptive requirement.

From both theoretical and experimental standpoints, the observation regarding 'distance viewing with best possible refractive intervention not resulting in Myopia reduction' can not be considered conclusive towards deciding the reversibility of non-pathological Myopia. It follows that reversibility of Myopia depends on the real behaviour shown by the eye only when actual adaptative requirement are imposed.

We have tabulated our findings in the Table 1 below:

Table 1: Similarity of behaviour between a compensated Myopic eye and an emmetropic eye

Compensated Myopic eye	**Emmetropic eye**
No observed reversal of Myopia even after viewing distant objects with best possible refractive compensation	No observed shifting of far-point beyond infinity even after viewing distant objects
Myopic adaptation is observed as Myopia progression	Myopic adaptation is observed as Onset/beginning of Myopia
Some population observes myopia stabilization even with near-work habits.	Some population observes no myopia even with near-work habits.
Apparent Far-point lies close to infinity	*Actual* far-point lies close to infinity

These statements suggest that the refractive state of a myopic/hyperopic eye should be as '*valid*' as an emmetropic eye from the continuous adaptation standpoint. Thus, non-pathological myopia should not be termed as an error, disorder or disease. These attributes and the lack of other abnormalities inside the eye should be helpful towards differentiating commonly encountered Myopia from pathological Myopia. This is necessary from the self-consistency of our Continuous Adaptation Theory and the resulting equivalency between an emmetropic eye and a pseudo-emmetropic eye.

5.2 Myopia management based on continuous adaptation theory and its implementation details

Myopia management denotes interventions concerned with reversal/stabilization of Myopia and must be distinguished from existing refractive compensation strategies such as lenses, contacts and surgical procedures whose goal is to compensate for Myopia by improving visual acuity (subjective refraction[36]).

Currently 'accepted' treatment options[37] including but not limited to atropine administration, orthokeratology (commonly called Ortho-K), relative peripheral myopia-inducing devices, or prism/bifocals differ considerably from our findings in this article when it comes to management of Myopia. It come to us as no surprise then that all these treatment options also carry reports of rebound Myopia upon cessation – an indication that the underlying cause of Myopia is still unaffected based on our Continuous Adaptation Theory of the eye.

The natural and obvious end-goal for any theory capable of consistently and convincingly explaining various counterintuitive observations about Myopia should be its ability to arrive at a physically viable method whose outcome results in an experimentally significant reversal of Myopia. The following sections contain our attempt at devising a method for Myopia management from the Continuous Adaptation Theory of the eye.

5.2.a) Predicting requirements for Reversing Myopia from Continuous Adaptive Theory

If Myopia is indeed a 'valid' refractive state of the eye as a consequence of adaptation, it naturally follows that there must be a way to shift the direction of this adaptive process towards reversing Myopia. To come up with a method that results in stabilization/reversal of Myopia (here after referred to as our method for myopia management), we need to determine 'duals' or principles opposite to the previously observed established behaviours about Myopia from the Continuous Adaptation Theory. The resulting duality provides a consistent framework for the physical requirements for Myopia management.

To summarise our findings in this article, section 5.1.c covers why accommodative stress from long-duration near-work coupled with the under-utilisation of distant vision capability should induce Myopia. Section 5.1.e describes our prediction on how low-light should accelerates the shift towards Myopia. Section 5.1.f points out how observing no change in Myopia even while viewing distant objects with best possible refractive compensation can not be sufficient to conclude irreversibility of Myopia.

It follows that requirements towards inducing hyperopic adaptation must result from Myopic defocus in a 'suitable' environment and reduction of existing accommodative stress due to near work causing myopia in the first place. This emerges from the idea that an emmetropic eye and an eye with very low levels of Myopia should differ only in their ability to observe distant objects and from the fact that observation at the relaxed end of the ciliary muscle does not constitutes accommodative stress towards adaptive requirements.

The summarised findings and their corresponding duals are outlined below:

Observed requirements that result in Myopic adaptation	**Predicted 'Duals' for inducing Hyperopic adaptation**

36. Kaur K, Gurnani B. Subjective Refraction Techniques. [Updated 2022 Dec 6]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK580482/
37. Chuang AY. How to effectively manage myopia. Taiwan J Ophthalmol. 2017 Jan-Mar;7(1):44-47. doi: 10.4103/tjo.tjo_24_17. PMID: 29018754; PMCID: PMC5525606.

Near-work until exhaustion near the ciliary extreme introducing accommodative stress resulting in adaptive requirement.	Adequate Exposure to distances beyond the ciliary extreme resulting in Myopic defocus towards adaptive requirement.
Under-utilisation of the ciliary extreme corresponding to the far-point.	Management of near-work to reduce accommodative stress causing Myopic adaptation in the first place.
Myopic adaptation should be accelerated by pupil dilated lighting conditions.	Hyperopic adaptation should require pupil constricted lighting conditions.

These duals form the breakthrough of our continuous adaptation theory that underpins the physical requirements for inducing hyperopic adaptation on management of near work to reduce accommodative stress causing myopic adaptation and exposure towards myopic defocus under pupil constricted lighting conditions such as those that occur on a clear sunny day. These 'duals' expand our theoretical framework that can now explain why earlier attempts[38] at reversing Myopia failed so far using reduced prescription for Myopia.

The distances beyond far-point (myopic defocus) that needs to be observed by a myopic eye under pupil constricted lighting conditions can be said to lie inside the green oval for a myopic eye shown in Figure 5.4. Throughout this article, we will refer to this as ADV (short for Actual Distance Viewing). Because hyperopic adaptation requires pupil constricted lighting conditions, it follows that it should also occur slightly faster (Superior than Myopia) due to more available information in bright lighting environments.

The framework of Continuous Adaptation Theory predicts that the eyes should try to adapt continuously towards all visual stimulus encountered during a typical day – which implies that some of the hyperopic adaptation during the day should get 'compensated' by accommodative stress from regular work during the remainder of the day and will always result in a net discrepancy between **ideal** Myopia reversal rates predicted from axial change rates[39] only. This means that any net changes towards myopic adaptation or hyperopic adaptation happen slowly.

The adaptive nature of the process also results in an obvious implication that the requirements for Myopia reversal should be far stricter than the requirements for Myopia stabilization alone. This can be called 'dual' of the clinical observation about how some subjects with significant near-work habits do not become Myopic. It implies observing a subset of subjects experiencing stabilization of Myopia (no reversal of Myopia) even with ADV.

Most if not all of the physical details regarding Myopia management in this article result from years of personal endeavours towards researching Myopia culminating into limited scale trial spanning more than a year including the entire time spent documenting and writing this article. It would have been near-impossible otherwise to gather experimental insights into hyperopic shifting of human eyes from theoretical deliberations alone.
Interested readers can contact for Auto-refractor readings & prescriptions showing reduction in author's Myopia from attempting the very process described in this article.

38. García García M, Breher K, Ohlendorf A, Wahl S. To Correct or Not Correct? Actual Evidence, Controversy and the Questions That Remain Open. J Clin Med. 2020 Jun 24;9(6):1975. doi: 10.3390/jcm9061975. PMID: 32599775; PMCID: PMC7356996.
39. Scott A. Read, Michael J. Collins, Beata P. Sander; Human Optical Axial Length and Defocus. Invest. Ophthalmol. Vis. Sci. 2010;51(12):6262-6269. doi: https://doi.org/10.1167/iovs.10-5457.

We are confident from the theoretical nature of our Continuous Adaptive Theory and its consistent explanations of various peculiar observations about Myopia that rigorous clinical trials performed on a larger population would only lead to its further validation.

We feel that these duals already provide sufficient information to come up with an experimental trial for Myopia Management aimed towards observing 'actual' Myopia reversal. The following sections are our attempts at listing necessary implementation details for the same. They describe the details of our method in the form of a targeted regime ready for implementation in the form of a clinical trial towards Myopia management.

5.2.b) Saturation time for hyperopic stimulus and 'relative' lack of near work

The question of what should be the recommended time interval of myopic defocus for myopia management emerges from the observation of peaking of maximum axial length reduction (referred from now on as saturation) around 50 minutes as mentioned in [The time course of the onset and recovery of axial length changes in response to imposed defocus[40]]

"The first statistically significant reduction in axial length occurred after 40 minutes of exposure to myopic defocus, with a mean reduction of -8 ± 9 μm (p = 0.017). This change peaked shortly after, reaching a maximum axial length reduction of −10 ± 8 μm at 50 minutes (p = 0.001)."

We recognise that the article in question is not a long-term study on axial changes. But even then, the observation of a saturation time and its approximate duration being somewhere around an hour mark should stick. The presence of a saturation time is in itself an obvious indicator that the eye takes periodic breaks. This suggests that a person wanting to ensure maximum hyperopic adaptation towards reversing myopia should aim for saturation. The time to achieve saturation naturally increases if done in small chunks instead of one go. For preliminary trials, the initial duration of observation time for ADV to surely achieve saturation in the absence of further experimental data should be taken close to an hour (more than 50 min). Subjects should be encouraged to determine long-term saturation time for ADV on their own from the signals given by their eyes.

Promoting hyperopic adaptation for reversal of Myopia demands under-utilisation of near-focusing capability of the ciliary mentioned in previous section to reduce accommodative stress due to near-work as much as possible. This constitutes the 'extra requirement' part to reverse Myopia after stabilising it. This load reduction of near-work can be achieved in two ways – reducing the time spent by ciliary in its closely accommodated state or increasing the distance at which near-work is done.

The former can be achieved by reducing time spent doing near-work and is the obvious, most effective but largely impractical approach. This also cements the importance of taking regular breaks as signalled/indicated by the eye and looking at far-away objects during breaks. The already established recommendation[41] in the form of 20-20-20 rule is handy in this regard.

The second approach refers to mitigations that reduce load on the ciliary due to near-work. This can be done by physically increasing the distance at which near-work is done or by utilising refractive interventions. Prescription guidelines for reducing near-work loading on the ciliary muscle is discussed separately under section 5.2.d.

5.2.c) Implementation details of ADV for preliminary trial

Having elaborated the 'saturation' and near-work management aspect for Myopia reversal, we will now describe the detailed physical requirements for ADV. ADV as described should be seen as a

40. Delshad, S., Collins, M.J., Read, S.A. et al. The time course of the onset and recovery of axial length changes in response to imposed defocus. Sci Rep 10, 8322 (2020). https://doi.org/10.1038/s41598-020-65151-5
41. Sheppard AL, Wolffsohn JS. Digital eye strain: prevalence, measurement and amelioration. BMJ Open Ophthalmol. 2018 Apr 16;3(1):e000146. doi: 10.1136/bmjophth-2018-000146. PMID: 29963645; PMCID: PMC6020759.

targeted method for High Environmental Illuminance viewing using high-intensity outdoor light for imposing myopic defocus conducive towards hyperopic adaptation.

ADV demands regularly exposing entire visual field to distant 'target objects' with good contrast involving blur from myopic defocus (observation beyond far-point by reduction or elimination of prescription power) in bright daylight until saturation. The idea behind exposing entire visual field to distant 'target objects' having good contrast under very bright lighting emerges from the concept of conveying maximum light information to the Retinal Ganglion Cells (RGCs) of the retina. When it comes to pupil constricted lighting conditions, sunlight on a clear sunny day is our benchmark. This also means that we must exclude viewing the Sun directly because the Sun is a point object in the visual field even if one ignores the harms[42] directly viewing the Sun has on the eyes. It is imperative that the subjects keep the Sun behind them at all times to minimize risk of exposure to harmful UV radiation.

Regarding observation of distant sunlit objects, subjects should place no demands or special emphasis in the way objects are being observed. They should try to see distant objects naturally in a relaxed manner without squinting, forcing or stressing the eyes in any manner. Walking should be preferred than sitting at one spot because that walking exposes continuously variable imagery on the retina.

There should be no difference from the way an emmetropic or a refractively compensated (pseudo-emmetropic) subject normally observes objects at a distance. The best analogy we can give is similar to trying to read a distant signboard or resolving fine details presented by a distant structure. We expect contrasting patterns in both vertical and horizontal meridians to be useful and implore researches to come up with precise target object requirements and explore such synthetic target patterns for ADV.

Figure 5.5 Image demonstrating ideal observation environment for ADV

An image showing ideal ADV environment satisfying our guidelines is shown in figure 5.5. The Sun is behind the observer and most of the objects in the image are more than 20 m away with the farthest being more than 100 m away constituting an ideal observation target. The difference between an object at 4 m compared to an object located at 20 m is 0.2 D, a difference that should be significant for subjects with lower levels of myopia.

42. Chawda D, Shinde P. Effects of Solar Radiation on the Eyes. Cureus. 2022 Oct 29;14(10):e30857. doi: 10.7759/cureus.30857. PMID: 36465785; PMCID: PMC9709587.

Because the lighting requirement is for the eyes only, being under direct sunlight or doing it from shade is immaterial. The benefits of ADV should not depend on whether the body is exposed to Sunlight or not. People residing in hot climatic conditions should be attempting ADV from a cool and shaded place to combat the sweltering heat outside. Swamp (desert) coolers are also an effective option.

It remains to be seen how the strategic requirements posed by ADV pans out for myopic subjects living in inclement climatic conditions receiving little sunlight during the year. Artificial lighting that recreate the bright daylight environment might prove useful according to some suggestions. [NBK470669: "In countries where the intensity of outdoor light is generally lower, because of air pollution or short duration of natural daylight – such as Canada or Scandinavia in the winter, or Beijing year-around – sunlight therapy could be supplemented in the form of SAD lights (approved and used for Seasonal Affective Disorder)"]

The lack of any previous large-scale experimental trial also means that the ideal value of myopic defocus to use during ADV is in dire need for determination. It is hard to predict what level of Myopic defocus becomes 'too much' for the eye to adapt or whether such a limit even exists at all without regular biometry achievable only in an advanced and highly monitored research setting. It is our suggestion that familiar concept of 'saturation' defocus could exist for myopic defocus resulting in the eyes hitting an adaptive rate limit once defocus is greater than a certain threshold for ADV.

This leads us to suggest that subjects with non-severe Myopia should be able to perform ADV with no prescriptive compensation at all. Our limited scale testing verified this to be indeed true. This leads us to recommend doing ADV without wearing any glasses or contacts for subjects with non-severe Myopia resulting in a greatly simplified implementation because practising ADV without refractive interventions should directly approach emmetropy (ensuring exposure to maximum possible defocus information towards emmetropization). Subjects experiencing difficulties should taper down slowly towards no prescriptive compensation utilising their existing prescription to view distant targets during the initial days of their ADV sessions.

Due to the similar lack of any previous experimental data regarding the time interval between ADV sessions, we suggest that subjects should be doing ADV sessions consistently on a daily basis. Effective Myopia management requires augmenting daily ADV sessions with refractive intervention guidelines detailed in next section for the rest of the day.

5.2.d) Refractive compensation guidelines for Myopia management.

We have previously established that observing objects closer than the myopic far-point while wearing prescription results in more physical contraction of the ciliary muscles compared to viewing directly without wearing anything. This should also mean that glasses for non-severe Myopia should be worn on a need basis – only for vision requirements farther than the myopic near-point. As myopia reversal progresses, this far-point should get closer to ∞ reducing dependence.

In accordance with our duals established in section 5.2.a, refractive interventions can ensure that the subject's quality of life remains relatively unaffected from the process of managing Myopia while simultaneously ensuring that near-work incidence on ciliary muscle is minimized.

For the purpose of Myopia management as outlined in this section, conventional glasses emerge as the best piece of equipment because they are easy to wear and remove in accordance with varying refractive demands during the day, cheaper, reliable, safer for the eyes, and allow easier to manage powers in the long run compared to contacts.

Within few weeks of daily ADV sessions, it should be expected for an eye to gradually start experiencing difficulties both while wearing their normal prescription during the day (over-prescription resulting from reduction in Myopia) and in the form of subtle aversion from near-work.

Such developments should result from the gradual disruption of myopic feedback loop in the ensuing weeks of daily ADV sessions. The natural course of action suggested is that refractive interventions should be implemented in the order in which they become apparent during Myopia management. Subjects should change things one at a time and that too only when indicated by the eye.

The disruption of myopic feedback loop from ADV sessions means that refractive demands of the eye become somewhat complicated and slightly reduced prescription should be needed than the regular prescription (for near-work beyond the myopic far-point) so as to lessen the feeling of eye-strain during near-work. As such situations arise, the signalled comfort of the eyes towards worn prescription should be prioritized. The eyes should signal immediate discomfort for both over and too much under-correction and the same should be avoided. As long as the worn prescription is kept within this narrow range of comfort according to the signals given by the eyes, we expect ADV to continue resulting in effective hyperopic adaptation for the eyes.

This concept of refractive intervention is an important aspect of myopia management and requires strictly individual implementation because of the varying near-work requirements of subjects, their present refractive state and preferences/tolerance to defocus. The adaptive nature of the eye makes it obvious that the refractive compensation requirements from the standpoint of reducing accommodative load for a system as dynamic as the human eye can not be accomplished using one refraction value. For the ease of understanding, we have tabulated these guidelines in the table below.

Refractive compensation guidelines for Myopic subject with non-severe Myopia.

Working distance	Daylight (outdoors on a sunny day)	Evening/Night
For ADV until saturation	Without wearing any prescription	NA
Long distance work	Reduced Prescription with sunglasses according to the need	Regular Prescription
Near-work at a distance just beyond the myopic far-point	Reduced Prescription	Reduced Prescription
Near-work done at a distance closer than the myopic far-point	Non-severe Myopics should be able to observe objects closer than their far-point comfortably without needing prescription	
Life-critical task such as driving, operating heavy industrial machinery and other dangerous work	Best Possible Refractive compensation for maximum visual acuity possible to prevent incidents and to comply with applicable local laws	

Coming to the actual lenses used, we would suggest using 'normal' clear lenses without any special coating such as blue light blocking filters because of the reasons given below:

1. Increased costs of lenses that will need to be replaced eventually in the near future as Myopia reversal progresses.
2. Provides no clinically established shielding against Myopia as evident from multiple research attempts into investigating their benefits[43].

43. Wong NA, Bahmani H. A review of the current state of research on artificial blue light safety as it applies to digital devices. Heliyon. 2022 Aug 15;8(8):e10282. doi: 10.1016/j.heliyon.2022.e10282. PMID: 36042717; PMCID: PMC9420367.

3. Nearly every recent computing device with a display already has an inbuilt blue-light reduction/night-comfort feature. [Windows Night Light[44] and Apple Night Shift[45]]. The intended physical purpose of blue-light glasses is already achieved at the display source for modern computing devices.
4. We suspect that blue-light glasses can suppress the ability of the eye to signal eye-stress due to extended near-work (DES) which deters from our guidelines of regular breaks as essential in order to reduce near-work load on the ciliary muscle.
5. We also suspect that Blue-light glasses are less effective as refractive compensation than regular clear-classes due to decreased availability of light in dark conditions that can result in delayed improvement towards Myopia. For subjects wanting fast management of their Myopia, this is not something they might want.
6. Blue light lenses can not replace the utility and eye-protection offered by outdoor sunglasses under direct sunlight.

These guidelines result in a slightly more complicated answer for the most commonly asked question in myopia – "When should I wear glasses?"

These guidelines are only meant as a starting point for the implementation trial of our management method for Myopia. It is expected that the eye's refractive need will change during the course of the trial as Myopia reversal progresses. The evaluation criteria always remains the fastest and safest reversal of Myopia. We fully expect some of these tentative guidelines to fail or get superseded by further understanding gained by future trials.

5.2.e) The mechanism behind Hyperopic adaptation

Section 5.1.d already covers our attempts at describing how myopic adaptation takes place.

This section attempts to describe the mechanism of Myopia reversal based on our observations upon year long implementation of the trial regime described in the preceding sections. For lower degree of Myopia, subject's experience should reduce to only a subset of what has been described in this section.

The initial days of ADV sessions should be relatively uneventful with slow spontaneous onset of brief moments of visual clarity (referred to as clear flashes from now on) vanishing immediately after blinking with long reset time (minutes to hours) between each consecutive clear flash. This suggests that just like Myopia, the ciliary is the first to respond to hyperopic adaptation.

Within weeks of regular ADV sessions, besides a perceptible increase in clarity, clear flashes should become more frequent and longer in duration while gaining the capability to 'survive' between blinks. This development alone with the occurrence of significant clear flashes coinciding with going outside in daylight should be enough to conclusively dispel the common hypothesis that these clear flashes result from formation of tear film[46] on the cornea. ADV can also result in transient intervals of blurrier than usual vision on some days signifying that the structures inside the eye are being repaired/rebuilt.

It can be naturally deduced from the anatomy of the eye that clear flashes must arise due to increase in focal length (decrease in power) of the eye lens because of their instantaneous nature. In the case of Myopia, adaptive requirements for closer distances result from accommodative stress on the ciliary muscle. However, the opposite of this can not be true because the ciliary muscle can not get 'tired or exhausted' in its relaxed state – hence the designation, overshoot in 'negative accommodation[47]'. It also explains the commonly reported instances of 'ciliary spasms' in myopic people observing

44. https://support.microsoft.com/en-us/windows/set-your-display-for-night-time-in-windows-18fe903a-e0a1-8326-4c68-fd23d7aaf136
45. https://support.apple.com/en-in/HT207570
46. Chang AY, Purt B. Biochemistry, Tear Film. [Updated 2022 Jun 11]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK572136/

spontaneous brief flashes of clear vision under pupil constricted viewing conditions when not wearing their glasses. We will prefer to use the more descriptive term 'clear flashes' instead.

Within weeks, ADV sessions should force the establishment of a feedback loop with behaviour opposite to the previously described myopic feedback loop – resulting in perceived eye-strain/aversion towards near-work. We fully expect that experiencing discouragement from near work could serve as a reliable indicator that hyperopic adaptation is taking place. For a person experiencing active myopia progression, this process can take some extra time signifying disruption of existing myopic shift (reversible component of refractive Myopia) and development of hyperopic ciliary shift.

After regular ADV sessions spanning even longer time-frames (months), subjects should be able to experience a perceptible level of visual clarity that comes on automatically when going outside on a sunny day – a telltale indication of hyperopic ciliary shift. The observed levels of sheer improvements in vision alone at this stage should be more than enough to convince any remaining sceptics about the reversibility of Myopia. By prediction, long-term axial changes should soon follow to compensate/alleviate this hyperopic response of the ciliary if sufficient lack of near-work is maintained. Measurable reduction in myopia starts becoming apparent after this stage is reached. This stage continues translating into improvements to baseline vision with time as long as the eyes remains Myopic and emmetropization is incomplete.

We have already stated in section 5.1.f that reversibility of Myopia should depend upon the success of inducing hyperopic adaptation. Successful observation of hyperopic ciliary shift would also cement the bi-directional nature of the accommodative shift as the precursor of axial changes for both myopic and hyperopic adaptations. The very observation of hyperopic ciliary shift alone should be sufficient to confirm that the predicted[48] *active emmetropization mechanism* is nothing but the exact same process that we have detailed in this article inducing Myopia or Hyperopia in accordance with the imposed visual stimulus. The process of Emmetropization naturally involves ocular re-alignment for distance vision and even result in eventual changes to the eyeball shape in the long-term (months). Some subjects can also report feeling changes to the extraocular eyeball muscles resulting from realignment both during and after ADV sessions.

It is equally important to mention that most of the aforementioned clarity gains during ADV sessions vanishes swiftly in pupil dilated lighting conditions. This behaviour from the eyes could be looked as a source of frustration upon witnessing the clarity gained during the day vanishing in the night. This observation is so important from the standpoint of light's role in influencing adaptive behaviour of the eye that we predict that it should result from the interaction of the iris restricting 'headroom' for negative accommodation (responsible for clear flashes), effortlessly explaining why loss of clarity occurs swiftly under pupil dilated lighting conditions. We leave the process of finding a suitable term for this restrictive effect of the iris towards ciliary relaxation under pupil dilated lighting conditions.

The aforementioned interaction of iris with the ciliary could pave way towards explaining why Myopia has been observed as the default behaviour of the eye when subjected to form-deprivation. Form-deprivation whether from eye-sutures/diffusers besides resulting in loss of visual information and image-contrast should also result in pupil dilated lighting[49] conditions due to loss of light intensity. A conclusive way to test this hypothesis should require inducing form-deprivation while also simultaneously maintaining pupil constricted lighting conditions.

47. Raz A, Marinoff GP, Landzberg KS, Guyton DL. Substrates of negative accommodation. Binocul Vis Strabismus Q. 2004;19(2):71-4. PMID: 15180591.
48. Wildsoet CF. Active emmetropization--evidence for its existence and ramifications for clinical practice. Ophthalmic Physiol Opt. 1997 Jul;17(4):279-90. PMID: 9390372.
49. Zhihui She, Li-Fang Hung, Baskar Arumugam, Krista M. Beach, Earl L. Smith, The development of and recovery from form-deprivation myopia in infant rhesus monkeys reared under reduced ambient lighting, Vision Research, Volume 183, 2021, Pages 106-117, ISSN 0042-6989, https://doi.org/10.1016/j.visres.2021.02.004.

5.2.f) Precautions, Safety and candidate requirements for the clinical trial

Subject selection criteria:

Managing Myopia requires active integration into daily lifestyle and trial candidates should be willing to devote the (an hour or two) of their daily time towards achieving saturation requirements.

The novel nature of the idea and the presumed lack of any widespread experimental outcomes besides ours forces means heavy emphasis on precautions as a first line of safety. We recommend limiting the first run of trials to **Non-severe** candidates ONLY having good ocular health without any adverse event history and screened for presence of any musculoskeletal disorders. Further information from the outcome of the preliminary trials on non-severe myopics will prove useful towards narrowing down additional requirements for subject with severe myopia and their eventual transition into non-severe Myopia if possible.

It is recommended that the subjects exercise caution during the initial transition period of the trial, starting with 'less brighter' objects first and take regular breaks until acclimatisation is completed within few weeks. We expect the majority of candidates to experience excessive-tearing and strong aversion signals from the eyes in the form of eye-strain and minor headache during the beginning of the trial due to the aforementioned sensitivity of a myopic eye towards bright light. It is also recommended that observation duration too should be gradually ramped up towards saturation over the course of multiple days under constant monitoring so as to prevent the possibility of any adverse complications from over exertion.

Safety of ADV:

The only part of our method resulting in any significant stress on the eye involves ADV. Regular ADV sessions towards inducing hyperopic adaptation should have a risk profile similar to the risks associated with the onset/progression of Myopia because the same adaptive process responsible for Myopia MUST result in hyperopic adaptation also.

We would also like to point out sentiments of experts about outdoor therapies like ours that involve High Environmental Illuminance trials: ["Outdoor-light therapy may offer the ideal treatment for myopia. Not only does encouraging children to play outside combat other major health concerns – such as childhood obesity, juvenile diabetes, and depression – but also, light therapy presents little to no serious health concerns or side-effects compared to those of other available myopia-treatments."[50]]

Important Warning for personal safety and compliance with applicable laws:
The subjects should be strictly made aware of the potential life-threatening dangers of doing critically important work involving life at risk without wearing best possible refractive correction. Put simply, safety of personal and other's lives while driving during low-light conditions such as night-time or working in dangerous conditions including but not limited to operating construction, industrial, or heavy-machinery/equipments should always be prioritized and best possible refractive compensation must always be worn under such conditions.

Subjects are expected to use fair judgement and not jeopardise their own and other's lives for Myopia management. Because ADV involves observing blur from Myopic defocus and significant reduction in visual acuity is involved, it is only imperative that personal safety must be prioritised and ADV should always be attempted in a safe environment. We request subjects to always keep the above mentioned warnings in mind before implementing our method for managing myopia.

50. Carr BJ, Stell WK. The Science Behind Myopia. 2017 Nov 7. In: Kolb H, Fernandez E, Nelson R, editors. Webvision: The Organization of the Retina and Visual System [Internet]. Salt Lake City (UT): University of Utah Health Sciences Center; 1995-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470669/

5.2.g) Predicting the time taken for Reversal of Myopia

There are two approaches to predict the time taken for myopia reversal. Both approaches should yield similar estimates.

The first approach emerges from the consideration that both myopic and hyperopic adaptation should be the outcome of the same adaptive process. Which means both myopic and hyperopic adaptations should bear rough similarity on the order of time-scales on which they take place. By our prediction, time required for Hyperopic adaptation can be estimated from the data on Myopia progression[51]. The observed rate of hyperopic adaptation should only be slightly faster than the progression rate of Myopia because it requires pupil constricted lighting conditions with more available information.

The second approach involves figuring out the relation between axial length of the eye with the retinal distance from the optical centre of the eye (RD) and then employing the simple lens model's screen shift relation. The second approach is described below.

For an emmetropic eye, the RD should also be equal to the combined focal length of the lens and cornea when the eye is focused at infinity. The lens formula should then give the required shift in RD for focusing an object at the Myopic eye's far-point. To determine retinal distancing from AL measurements, we have assumed Myopic RD to be proportional to AL denoting the ratio RD/AL as β.

$$\begin{gathered} \textit{Lens relation:} \\ \frac{1}{s} - \frac{1}{u} = \frac{1}{f} \\ \textit{Here, elongated (myopic) RD serves as screen distance } (s) \\ \textit{and emmetropic eRD serves as focal length } (f) \end{gathered}$$

$$\frac{1}{RD} + \frac{1}{-u} = \frac{1}{f}$$

$$\textit{emmetropic } RD\ (f) = \frac{-u \times RD}{-u + RD}$$

$$\begin{gathered} \textit{if we assume } RD/AL \textit{ as } \beta \textit{ then} \\ \textit{Elongation in Axial Length } \Delta AL \textit{ due to Myopia} = AL - \frac{f}{\beta} = \frac{\beta \times (AL^2)}{-u + \beta \times AL} \end{gathered}$$

$$\begin{gathered} \textit{For instance, a myopic eye wearing prescription of } -4\,D \\ \textit{corresponding to a far-point of roughly } 25\ cm \\ \textit{will give } u \textit{ as } -25\ cm \textit{ for the formula.} \end{gathered}$$

If the axial length and degree of Myopia of a non-severe Myopic eye is known, this formula gives change in AL that must be necessary for emmetropia if β is known. Measuring the long-term rate of AL changes arising out from regular ADV sessions could then yield a rough estimate of the time for emmetropization. We want to emphasize that any calculations based on the second approach require long-term data on sustained axial shortening which is currently lacking due to the lack of any viable method to reverse Myopia in the first place.

51. Verkicharla PK, Kammari P, Das AV. Myopia progression varies with age and severity of myopia. PLoS One. 2020 Nov 20;15(11):e0241759. doi: 10.1371/journal.pone.0241759. PMID: 33216753; PMCID: PMC7678965.

5.2.h) Changes to Field of View due to Axial Length Changes

FoV depends on the screen distance which in the case of eyes can be said to be the distance of the central part of the retina from the combined optical centre (RD) of the lens and the cornea. Axial elongation due to Myopia results in the physical distancing of the retina from the optical centre of the eye while the region of retina responsible for clear vision can be said to remain mostly unchanged at least for cases of non-severe Myopia.

The resulting FoV reduction can be estimated from *emmetropic AL* ÷ *myopic AL* assuming the proportionality of AL with Retinal Distance (RD). For instance, emmetropic AL of 23 mm and Myopic AL of 25 mm result in myopic FoV being roughly 0.92× (times) that of the emmetropic FoV.

Because so far there's no mainstream 'confirmed' observation of reversal of Myopia, any investigation into Field-of-View characterization regarding Myopia is virtually non-existent. The closest we were able to find something regarding FoV changes in highly myopic subject was this study[52]. Still, we suggest that effects of FoV reduction start resembling 'tunnel vision effect' for subjects with severe Myopia. This also implies that people managing to make significant reversal of their Myopia should experience widening of FoV due to axial changes accompanying hyperopic adaptation.

6. Conclusion, Remarks & Further Research

Our observation range based approach using the Continuous Adaptation Theory for Myopia might seem controversial but it manages to consistently explain the vast majority of peculiar behaviour observed in Myopic subjects that is still unexplained by existing frameworks. The observations from our limited experimental testing so far points towards Non-pathological Myopia as just a 'valid' refractive state of the eye brought on by external environmental and habitual/lifestyle factors.

To summarise our findings so far: onset/progression of (non-pathological) Myopia should result from accommodative stress due to near-work in pupil-dilated lighting conditions when combined with significant under-utilisation of distance vision capability. This should then result in development of myopic shift in the ciliary muscle. Long term axial elongation results from the eye's eventual attempts towards alleviating this accommodative shift in the ciliary muscle.

Because we have predicted Myopia as a 'valid' refractive state of the eye, a tabulation of the conditions required for myopic adaptation vs hyperopic adaptation is being provided below:

Function	Onset/Progression of Myopia	Hyperopic adaptation
Visual observation	Saturation levels of near-work coupled with the under-utilisation of distance vision capability	Saturation levels of ADV with limitations on near-work including periodic breaks to alleviate ciliary load
Adaptive shift from equilibrium due to	accommodative stress on the ciliary muscle	Myopic defocus
Promoter Lighting Conditions	Pupil dilated/Form deprivation	Pupil constricted
Accommodative shift in the ciliary/feedback loop	Myopic	Hyperopic
Shift in Observation Range (far-	Towards Right	Towards Left

52. Yanming Chen, Ji Liu, Yining Shi; Evaluation of visual field changes of high myopic eyes in a Chinese population at northwestern China.. Invest. Ophthalmol. Vis. Sci. 2015;56(7):2952.

point and near-point)		
Secondary refractive errors	Results in aberrations and refractive errors like astigmatism	Should correct aberrations and refractive errors
Field of View	Shrinks	Expands
Time taken	Existing reports on Myopia progression rates	slightly faster than Myopia progression due to extra information availability

6.1 Key takeaways

We expect the readers to realise that Managing Myopia requires long-term commitment along with multiple habitual and lifestyle interventions from a person willing enough to reverse it completely. From modifying their lifestyle to reducing the impact of near-work stimulus to a minimum to not letting go of any chance of viewing distant objects during breaks – it is theoretically very simple but practically very difficult.

The author recognise the tediously slow and time intensive nature (taking months and years) for the Myopia reversal process outlined in this article. Still, it is our firm conviction that the results outlined are still of utility for maintaining post-refractive surgery outcomes and preventing Myopia progression/stabilization of Myopia.

Perhaps the remaining things now is large-scale physical verification and validation of the multitude of findings and most of the predictions featured in this paper. This also requires figuring out how eyes deduce the direction of adaptation even from Myopic blur and the underlying biophysical technicalities.

At the same time we want to stress that our simple lens model can not differentiate between peripheral and central components of vision or predict myriad of other factors that can play a role towards towards promoting Myopia in the human eye. We leave it for researchers with superior knowledge and access to sophisticated instruments.

Still, even with its limited scope we have managed to point out and explain many inconsistencies and contradictory observations about Myopia that have long puzzled mainstream researchers. The continuously adaptive aspects of the eye also answers many questions about evolution of eyes as a visual organ in the history of mankind.

Although this article provides a method for satisfying necessary conditions for observing stabilization and/or reversal of Myopia, the article should not be taken as against wearing glasses/contacts or refractive interventions in general. The goal of this article is to reduce subject's dependence on glasses and promote safe and minimally invasive management of Myopia.

6.2 Challenging the status quo and existing explanations for Myopia

In all the mainstream research texts we have encountered so far, the cause for Myopia is still stated as unknown. This article is an attempt towards explaining multiple observed mysteries of Myopia based on the foundation of optics and we expect it to *irreversibly* change the status quo around Myopia.

The physical requirements for ADV outlined in the article for reversing Myopia should be enough on their own to n why reversal of Myopia eluded observation by mainstream researchers till date. The response of the eyes towards ADV under pupil constricted lighting conditions is so important that we feel confident declaring it as the 'discrimination' test for pathological Myopia which by definition should result from disruption of the very adaptation mechanism we have described in this article. It also follows that pathological Myopia should be distinguished on the basis of additional complications aside from the refractive state of the eye.

Because the Continuous Adaptive Theory requires treating both myopia and its potential reversal as adaptive consequences, its theoretical framework has no place for the concept of curing Myopia or rebound Myopia. The framework of Continuous Adaptation Theory also throws existing explanations for Myopia progression and Myopia stabilization out of water and replaces them with a single unified explanation based on the equivalency mentioned in 5.1.f.

If the eyes are experiencing Myopic adaptation again, environmental factors making the eye myopic must be dominating and the same should apply for experiencing reversal of myopia. We expect even long-term subjects with childhood myopia to start experiencing clear flashes within their first few session of ADV. This should serve as a demonstration for the capability of the eyes to respond and begin adapting within days of ADV initiation.

Because myopia has so far been regarded as permanent and non-reversible by mainstream consensus, even a single contradictory observation that results from following the predictions of this article is enough to conclusively and firmly disprove/dismantle the existing framework describing Myopia. It also probably means that genetics at most can increase susceptibility towards developing non-pathological Myopia and not actually cause it.

The 'unconventional' explanations offered by this article should also means that experimental verification of claims of this article should serve to abandone all connotations of the term 'irreversible' with AL elongation treating it as 'eye growth'. Axial shortening might prove to be slow and notoriously difficult to achieve through means of ADV but it is certainly not irreversible.

The dangers[53] of severe myopia arise purely due to the consequences of the structural changes brought on by excessive axial elongation and need to be regarded as secondary consequences of severe myopia and not the condition itself. This also means that wearing glasses for Myopia or refractive surgeries do nothing when it comes to severity of Myopia which we assume is already taken as granted in this field.

Obesity[54] in another such condition with similar complications. We are tempted to draw parallels of non-pathological Myopia with non-pathological Obesity in this regard. Obesity is also a valid bodily state resulting from adaptive mechanisms of the body and is not termed as a disease. Obesity is also not cured but can be reversed by controlled food intake, lifestyle interventions and exercising. Surgeries for Obesity like Liposuction are refractive surgeries equivalent for Myopia. All diseases and risks accompanying obesity are due to the complications due to the changes caused by obesity and not due to obesity itself.

6.3 Corporate responsibility of Myopia

From a minimal necessary intervention standpoint for managing Myopia, we are of the opinion that LASIK, Orthokeratology[55] and other Scleral remodelling interventions should not be tried/enforced

53. Williams K, Hammond C. High myopia and its risks. Community Eye Health. 2019;32(105):5-6. PMID: 31409941; PMCID: PMC6688422.
54. Panuganti KK, Nguyen M, Kshirsagar RK. Obesity. [Updated 2022 Aug 8]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK459357/
55. Jakobsen TM, Møller F. Control of myopia using orthokeratology lenses in Scandinavian children aged 6 to 12 years. Eighteen-month data from the Danish Randomized Study: Clinical study Of Near-sightedness;

unless the subject has exhausted the aforementioned lifestyle and habitual interventions towards achieving significant myopia reduction first.

The key role played by accommodative-stress towards Myopia should also mean recognising the contribution made by lack of 'official' near-work breaks in the increasingly prominent IT jobs. We expect companies and lawmakers to recognise the importance of ADV towards both preventing and managing Myopia and provide facilities and incentives for the same.

6.4 The informal 'Law of Myopia'

Given time, a person with non-pathological Myopia should be able to focus at infinity without refractive interventions at par or better than their current visual acuity with best possible refractive compensation.

This law is our bold prediction signifying that best possible visual acuity should be improved or at worse maintained at its current level due to the error correcting, superior nature of hyperopic adaptation if a subject with non-pathological myopia chooses to reverse their Myopia.

6.5 Further research

Predicting and verifying the existence of an adaptive mechanism inside the eye that reverses Myopia should present a massive unexplored opportunity in front of the research community.

We implore fellow researchers to tackle these highly important topics.

1. Optimal values of refraction for both pupil constricted and pupil dilated lighting conditions that promotes fastest rate of myopia reversal should be the utmost priority of research endeavours post publication of this research.
2. Whether severity criteria mentioned in this article can actually be extended for Hyperopia and whether Myopic adaptation is possible for Hyperopic subjects using principles outlined in this article.
3. Optimisation of distant object target requirement for ADV.
4. Characterization of the biological adaptive pathways inside the eye for both Myopic and hyperopic adaptations.
5. Experimental studies to detect form-deprivation hyperopia by inducing form-deprivation under pupil constricted lighting conditions.
6. Investigating further the role played by interaction of iris with ciliary when under pupil constricted lighting conditions.

TReatment with Orthokeratology Lenses (CONTROL study). Acta Ophthalmol. 2022 Mar;100(2):175-182. doi: 10.1111/aos.14911. Epub 2021 Jul 7. PMID: 34233094; PMCID: PMC9292027.

7. Info

7.1 Ethics declarations

The author declares no competing interests.

7.2 Rights and permissions – Open Access

7.3 Credits/Acknowledgments

- Sir Abhay Kumar Singh (Ex. Faculty ALLEN Career Institute, Kota and Founder/Director of Abhay's IIT Physics Teaching Centre) for teaching Physics in the rigorous way it should be taught.
- Jake Steiner of https://endmyopia.org for originally dedicating a website towards comprehensive resources for physical evidence-based Myopia reversal.
- Diagrams created using https://app.diagrams.net and 3D modelling using SketchUp sketchup.com/
- Math created using https://www.mathcha.io
- Graphs using https://www.desmos.com/calculator
- LibreOffice https://www.libreoffice.org

56. https://creativecommons.org/licenses/by-sa/4.0/

8. Appendix

This appendix is our attempt at giving proofs of important results in geometrical optics.

8.1 Ideal (planar profile) lens and the relation between object and image distance

In this article, we will focus on deriving the relationship between object and image distances for the (real) image forming converging (convex) lens only. This relation is commonly referred to as the thin-lens relation. Although, all the illustrations and considerations in this article are in 2D, they extend and apply equally well to the 3-Dimensional real world.

A lens with curvature only along one axis is widely known as Cylindrical (CYL) lens while a lens having curvature along both axes is denoted as Spherical (SPH) lens. It is important to note that the words *cylindrical* and *spherical* were meant with regard to lens curvature along axes only and has little to do with the profile of the lens. The axis (symmetry) of a cylindrical lens lies along the direction in which the curvature remains constant with the idea being rotation about the axis should be indistinguishable. This is also necessary from the point of unique determination of the axis of a cylinder shown in Figure 8.1 below.

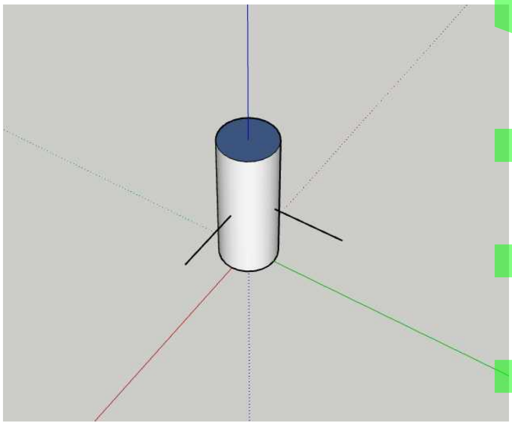


Figure 8.1 The blue line perpendicular to the flat surface of the cylinder is the axis of this CYL lens.

An ideal lens itself can be completely described with only **two** physical parameters along with its principal axis – its **focal length** along the axis and its **aperture**. These two parameters are sufficient to explain the vast majority of image formed by real-world lenses and their observed behaviour in physical experiments. Ideal lenses are theoretical objects with interesting properties of their own from a purely mathematical perspective.

8.1.a) Definition of an Object and its Image in Geometric Optics

An object can be considered to be a *collection of object points*. From every object point, rays of light can be assumed to **originate/diverge** in all directions.
Similarly, an image is considered to be a *collection of image points*. At each image point, rays of light from some object point can be assumed to **terminate/converge.**

It becomes useful to express Aperture size, object and image distances as some multiple of focal length. This Appendix utilizes dimensionless normalized distances with respect to focal lengths in order to simplify derivations at no loss in generality.

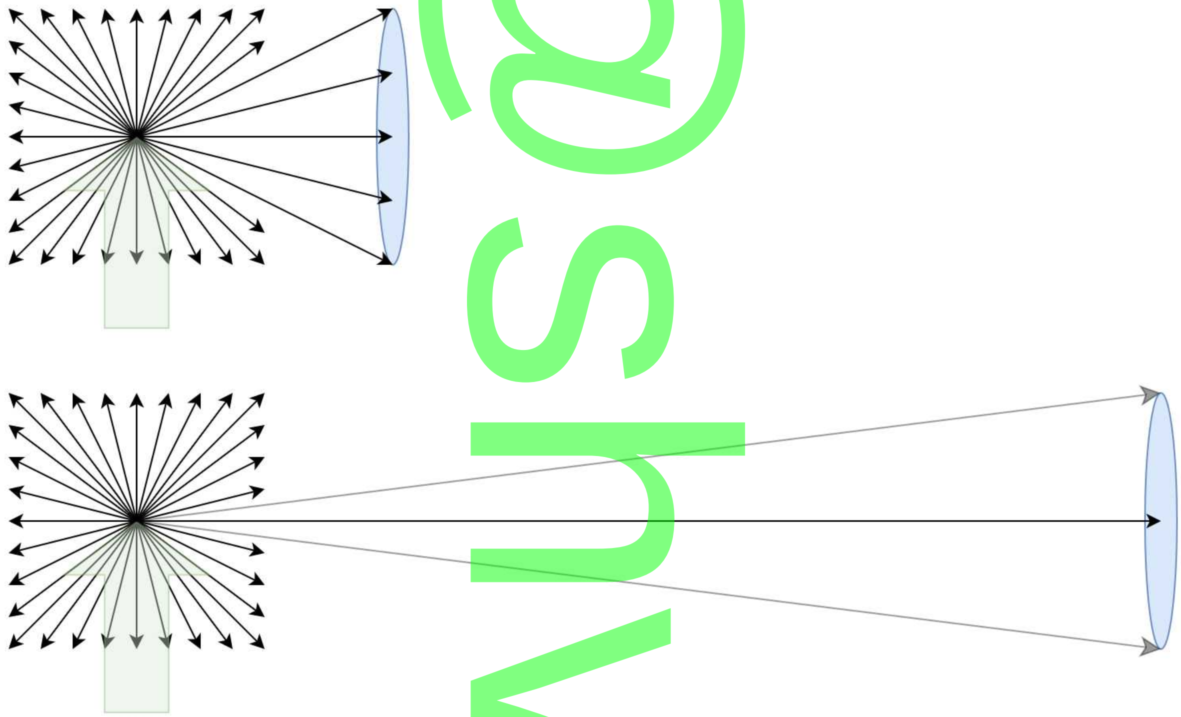


Figure 8.2 Schematic of light rays hitting the same lens at two distances

An object point (on an object) emits rays of light in all directions. At larger distances, angle between rays emitted by a point on an object starts decreasing with the rays themselves appearing almost parallel at very large distances from the lens.

An application of the definition above is to consider the commonly mentioned *'virtual images'* in many texts to have properties more like objects rather than images because light rays seem to (diverge) originate from them. From the sake of theoretical consistency, it makes more sense to use the term **virtual object** instead of the term *virtual images*.

For analysis of systems consisting of multiple optical elements, the '*virtual image*' formed by an object and lens combination can be replaced by the virtual object without affecting the rest of the system. Any subsequent observation of such a virtual object by our eyes or a camera then results in the formation of an actual (real) image. The use of the word image in this article should always be taken to mean real image.
For formation of an image point, demonstrating the intersection of any two rays emerging from an object point is sufficient. A point on an object and its image will always have a one-to-one correspondence.

8.1.b) Calculating deviation of a ray incident on an ideal lens

Assumption 2a: The focal length defines the convergence/divergence point (focus) for all rays parallel to the principle axis of the lens. The extent of admission of such parallel rays on the lens profile is given by the Aperture size. This is akin to a parabolic concave mirror bringing all incoming rays parallel to its axis on its focus.

In this sense, an ideal lens is essentially a theoretical object and we needn't concern ourselves with the implementation details of how it achieve such 'focusing' of rays. This also means that these rays in question can be anything – light, radio waves, sound waves etc. establishing the purely theoretical nature of the relation.

Assumption 2b: All rays of light passing perpendicular to the principle axis (ray-front **not** normally incident on the lens profile) pass unchanged (due to the inherent thinness and planar nature of the lens profile).

Any light ray incident on the lens profile will have a tangential component passing through the lens profile unchanged and a component normally incident to the lens profile which must pass through its focus. Sometimes, the lens is referred to as 'thin' to denote this aforementioned property of not affecting rays tangential to the lens profile.

The ray diagrams given below demonstrate application of this rule to show deviation for various incident rays by breaking them into their normal and tangential components with respect to the lens profile.

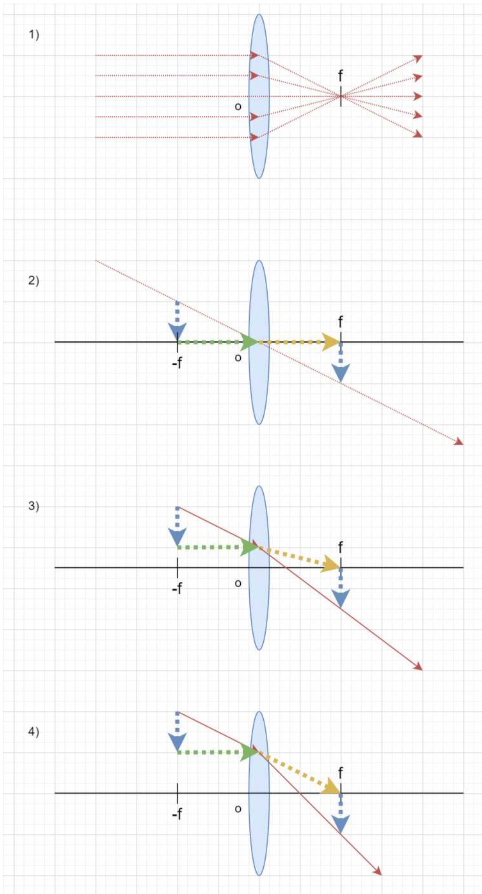


Figure 8.3 Application of Assumption 2b

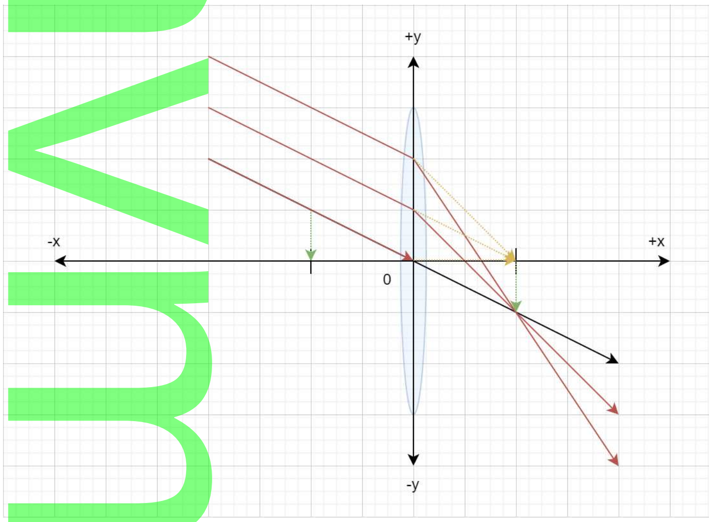


Figure 8.4 Demonstration of focusing of oblique rays from infinity at focus

In all three cases, we can observe that the length of the vertical dashed component is the same when determined at equal distances from both sides of the lens (in this case, it is at the focus). The amount of deviation a ray undergoes depends on both where it is hitting the Aperture and the angle it makes with the lens profile.

Consideration of these assumptions results in simplified rules for all rays incident on an ideal thin converging (+) lens and is sufficient to explain image formation by ideal lenses. A verification of this simple rule for an edge case corresponding to image formation at 2f is provided below in Figure 8.5.

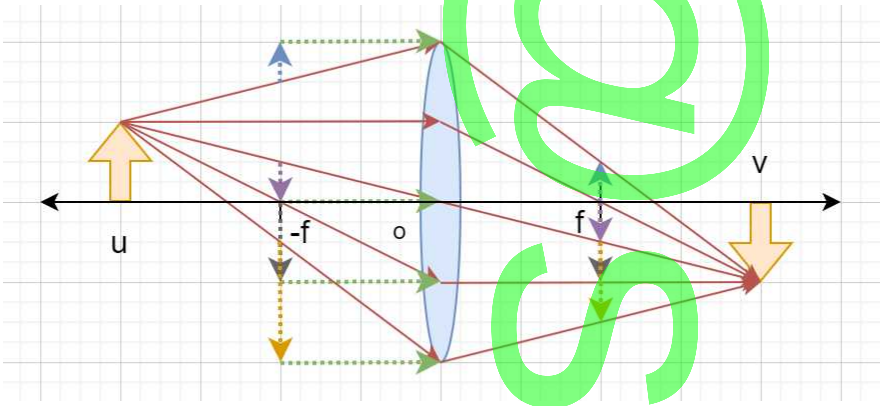


Figure 8.5 Demonstration of the edge case corresponding to image formation at 2F

In this particular edge case, we've shown the convergence of five such rays at a single point when demonstrating that only two meet at the image point should have been sufficient.

The most commonly stated rules for image formation in school textbooks namely:

1. A ray of light parallel to the principle axis passes through focus.
2. A ray of light passing through optical centre of the lens passes unchanged.

Can be explained in a similar manner by the assumptions 2a and 2b stated above. Rule 2 given above determines the magnification ratio because the image point will always lie on the ray passing unaffected through the optical centre of the lens.

8.1.c) Deriving the relation for normalized object and image distances (k and j relation):

For a converging lens with a given focal length, two distinct cases of rays intersection are possible according to rules outlined in the previous section 8.1.b:

1. **Virtual *object*** formation when *u* (object) is at a distance less than the focal length *f*. Light rays appear to be coming from a virtual object point on the virtual object.
2. **Image** formation when *u* (object) is at a distance greater than the focal length *f*. Light rays from a point appear to be converging to an image point.

Both of these cases can be seen in Figure 8.6 below with an object of same height placed at varying distances with an additional illustration of an object situated exactly at the focus (no intersection of light rays):

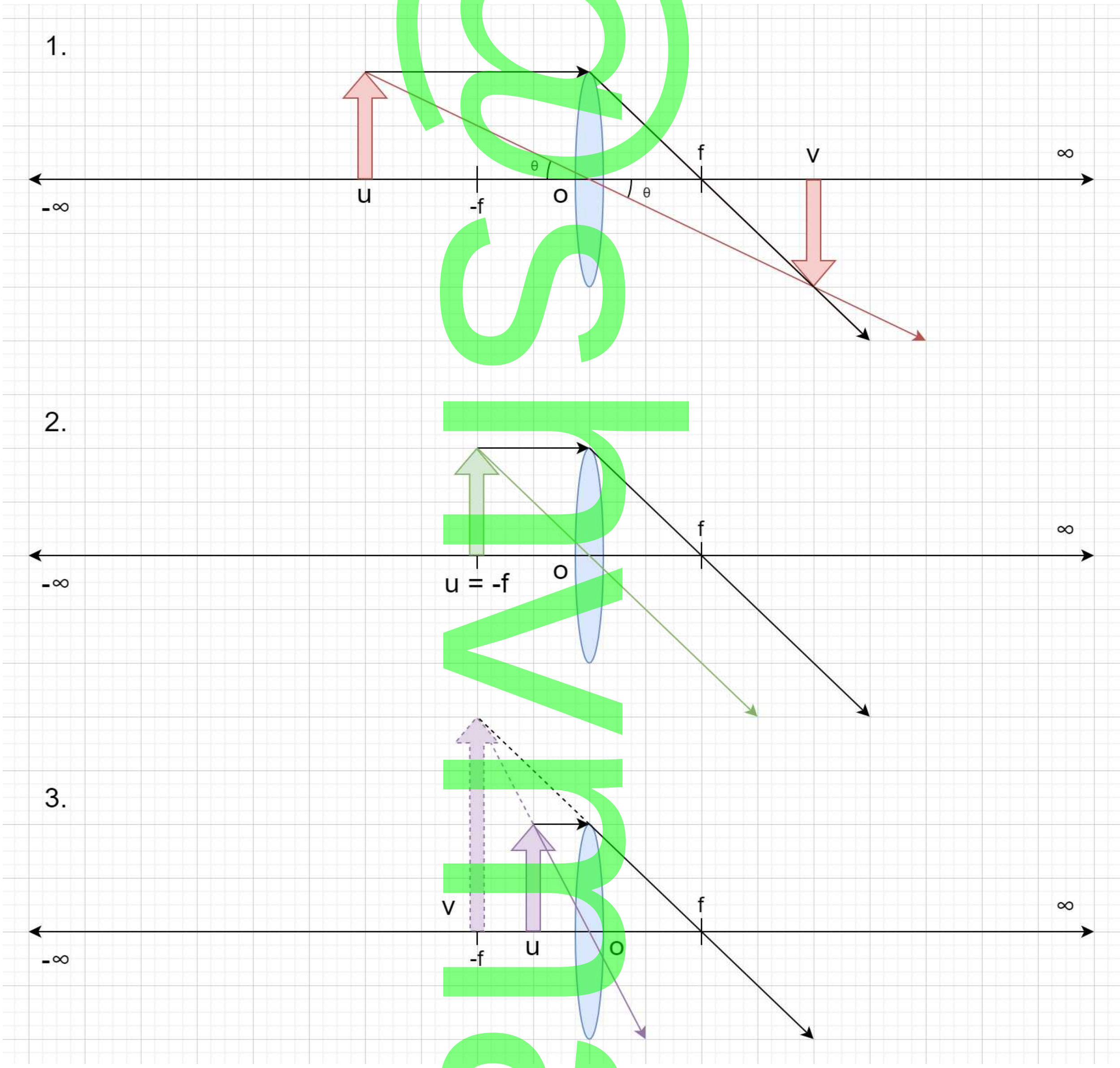


Figure 8.6 Demonstration of virtual object and image formation for a converging lens

In all the three situations, the ray that passes through focus has the same slope $-h/f$ where h is the height of object. But, the slope of line passing through the optical centre depends on the object distance in all three.

Depending on whether this slope is greater than or lesser than the line passing through focus determines where these two lines meet and whether an image is formed or not. Precisely, a light ray emerging from a point on an object of height h located to the 'left' of focus passing through the optical centre will always have a less negative slope.

The derivation for a converging lens:

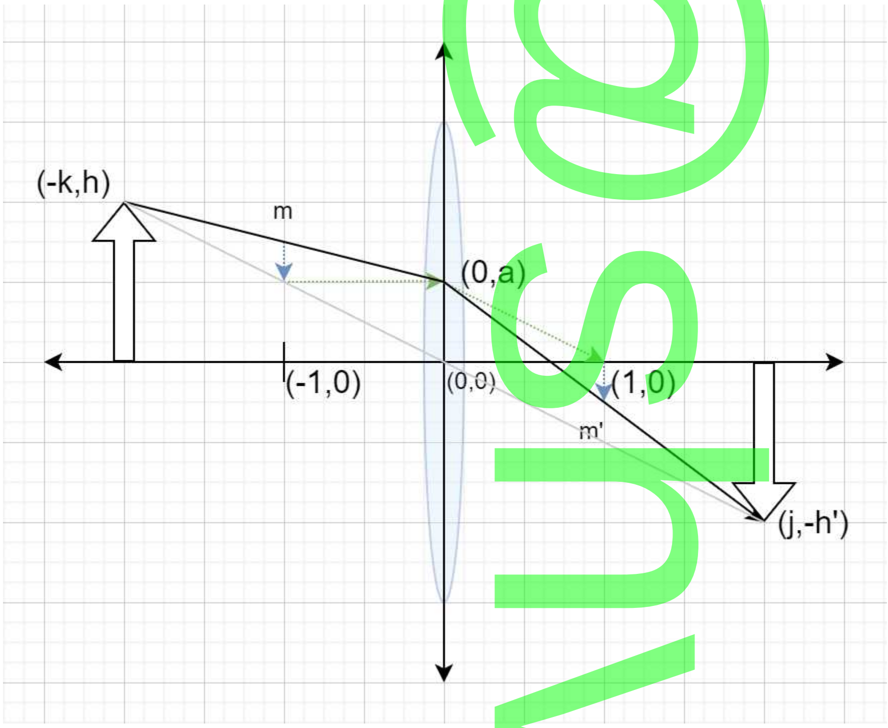


Figure 8.7 Ray diagram for derivation of dimensionless k & j relation

$$We\ will\ normalize\ object\ and\ image\ distances\ as\ follows:$$
$$u = -kf\ and\ v = jf$$

$$for\ image\ formation,\ k > 1\ which\ means\ u > f\ or\ -u < -f$$
$$slope\ m\ when\ the\ object\ point\ is\ (-k, h)\ is\ given\ by$$
$$m = \frac{a-h}{k}$$
$$for\ point\ (0, a)\ on\ the\ lens\ profile\ (y-axis)$$
$$For\ image\ formation,\ all\ such\ lines\ must\ pass\ the\ point\ (j, -h')\ after\ refraction$$
$$The\ slope\ after\ refraction\ (m')\ is\ given\ by,$$
$$m' = \frac{a-(-h')}{-j} = \frac{a+h'}{-j}$$
$$The\ slope\ after\ refraction\ according\ to\ Assumption\ 2\ must\ be$$
$$m' = m - a \implies \frac{a+h'}{-j} = \frac{a-h}{k} - a$$
$$Now,\ it's\ already\ known\ from\ the\ magnification\ criteria\ that$$
$$\frac{k}{j} = \frac{h}{h'} \implies h' = \frac{hj}{k}$$
$$\implies \frac{a + \frac{hj}{k}}{-j} = \frac{a-h}{k} - a$$

$$\implies \frac{ka+hj}{k} = \frac{hj - aj + kaj}{k}$$
$$\implies ka = kaj - aj$$
$$giving,\ k + j = kj$$
$$which\ completes\ the\ derivation\ of\ k\ and\ j\ relation.$$

$$To\ recover\ the\ thin-lens\ relation,$$
$$we\ can\ substitute\ k = -\frac{u}{f}\ \&\ j = \frac{v}{f}\ giving$$
$$-\frac{u}{f} + \frac{v}{f} = -\frac{vu}{f \times f}$$

$$\implies -u + v = -\frac{vu}{f}$$
$$\implies \frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

For calculation of image distance, we assume the right-handed co-ordinate system's origin to be centred on the lens. A simple thin-lens always has two foci due to symmetry. It depends on the signed power (converging or diverging) of lens that determines the sign of focal length and consequently its active position relative to the object. In this article, we are concerned with real images and hence only the converging lens. The results though are equally applicable to both with appropriate co-ordinate conventions.

For a converging (+) lens, the focus is on the opposite side of the lens from object.

$$magnification(m) \text{ is defined as } \frac{image\ height}{object\ height}=\frac{h'}{h}=\frac{image\ distance(v)}{object\ distance(u)}=-\frac{j}{k}$$

$$since,\ j=\frac{k}{k-1}$$

$$m=\frac{1}{1-k}=\frac{1}{1+\frac{u}{f}}=\frac{f}{f+u}$$

8.2 Deriving the power (inverse of focal length) addition rule:

The power addition rule can easily be derived from the thin-lens relation by considering two 'thin' lenses with different focal lengths placed together such that the distance between them can be neglected.

Here, v and u denote the image and object distances respectively with subscripts denoting which lens they are referring to.

The power of a lens is the inverse of its focal length. The Dioptre (m^{-1}) is one such derived SI unit of power.

Assuming focal length f_1 for Lens L_1 and f_2 for Lens L_2. Then the image distance for Lens L_1 is given by,

$$v_1=\frac{u}{1+\frac{u}{f_1}}$$

Because the distance between the two lenses is negligible, this resultant image now gets further refracted as an object by lens L_2. The corresponding final image formation distance is given by (where $u_2 = v_1$).

$$v_2=\frac{v_1}{1+\frac{v_1}{f_2}} \Rightarrow v_2=\frac{\frac{u}{1+\frac{u}{f_1}}}{1+\frac{\frac{u}{f_2}}{1+\frac{u}{f_1}}}=\frac{u}{1+\frac{u}{f_1}+\frac{u}{f_2}}=\frac{u}{1+u(\frac{1}{f_1}+\frac{1}{f_2})}$$

This implies that the combined lenses act as a lens of focal length $\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f}=P_1+P_2$ which is basically the law of addition of lens powers.

For a combination of more than two lenses closely put together, we can proceed by combining two lenses together at a time until only one remains.

The term focal length or lens power always implies the same physical property.

8.3 Distance between optical system (eye/camera) and introduced lens

Wearing a lens in this context means placing that lens closely (whether in the form of glasses, contacts) in front of an optical instrument (Human eye or a camera).

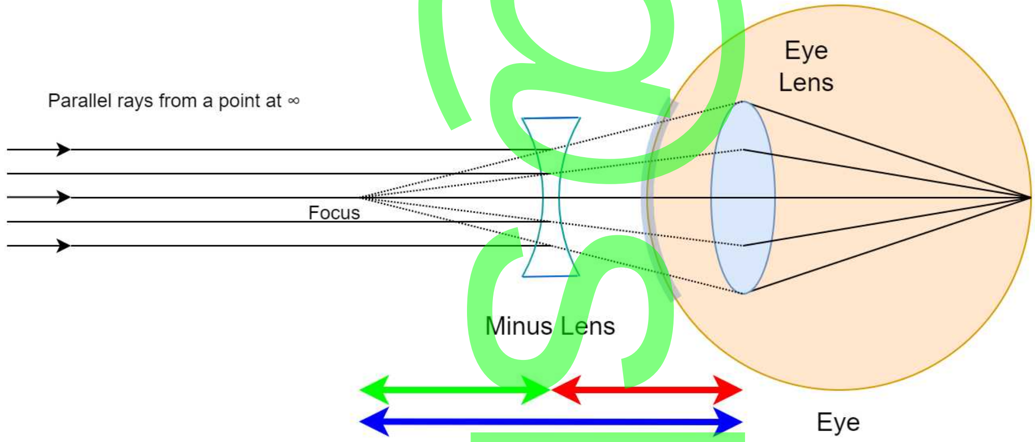


Figure 8.8 Calculating change in power due to distance between lens and eye's optical centre

Consider a myopic eye, unable to focus beyond the strict distance of 51 cm. Let's assume the eyeglasses place the lens at a distance of 1 cm from the eye's optical centre. For contacts, this distance is even closer. It is intuitively clear that the diverging lens in this case must cause the object at infinity to appear 50 cm in front of the lens for this eye to achieve apparent focus at infinity.

The actual power of the eye is ~1.96 D. The power of diverging (-) lens required is -2.0 D. The difference between them is smaller than the commercially available power increments available for prescription lenses which is usually not lesser than ±0.25 D. From the example outlined above we can see that the distance between eye and lens doesn't becomes significant unless we start dealing with higher powers for severe Myopia (~4 to 5 D).

Consider a severely myopic eye, unable to focus beyond 5 cm. Assuming the glasses place the lens at a distance of 1cm just like before, then it is intuitively clear that the diverging lens in this case must cause the object at infinity to appear 4 cm in front of the lens for this severely myopic eye to achieve apparent focus at infinity other factors not withstanding.

The actual power of the eye is 20 D. The power of lens required for Myopia compensation is -25 D. The difference between them (5 D) has become very significant now!

Note: Most auto-refractor machines themselves usually have an error not lesser than ±0.125 D.

8.4 Derivation of Depth of Field (DOF) using k & j relation:

An object must be situated at $(-\infty, -f)$
for it to form an image at $(f,\ \infty)$ *on the other side of the convex lens.*

In common usage, lens aperture (A) *is usually denoted as* $F-$*number or* $\frac{f}{N}$.

$$A = \frac{f}{N},\ \text{where N is some dimensionless number.}$$

For instance, $F2$ *or* $\frac{f}{2}$ *implies* $N = 2$ *in both the cases*
and it denotes that the aperture opening size / diameter is half of the focal length.

Following this convention,
$\frac{f}{2N}$ *denotes the half-width of aperture size / opening*
or radius if the aperture is circular

we have accordingly

$$\theta_u = \tan^{-1}\left(\frac{1}{2Nk}\right)$$

$$\theta_v = \tan^{-1}\left(\frac{1}{2Nj}\right)$$

To derive D.O.F. we need to solve the inverse problem:

for a fixed value of j *i.e., imaging distance,*
find the range of k *for a particular value of* N,
for which Circle of Confusion (C.o.C.) is less than a threshold value.

We can make C.O.C. dimensionless by dividing it by f *to get another quantity* r

$$r = \frac{C.O.C.}{f}$$

thus obtained both extreme values of u *and* v *obey*

$$u_d > u > u_c :: v_d < v < v_c$$

where the subscript denotes (c)loser and (d)istant object / image respectively

This can be understood as a consequence of the hyperbolic relation between object and its image.

These same relations must apply to k *and* j *also*

$$k_d > k > k_c :: j_d < j < j_c$$

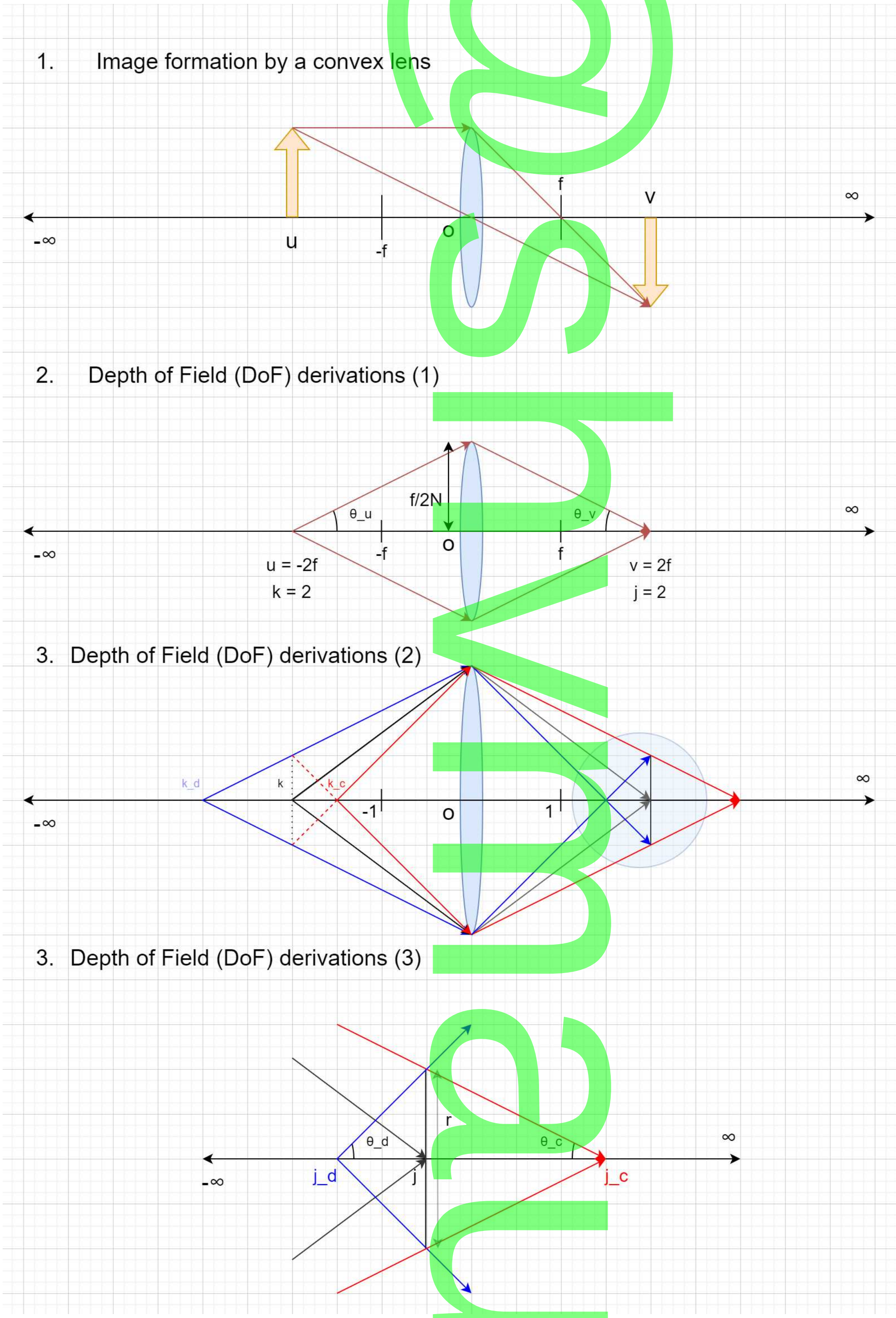


Figure 8.9 DOF derivations (to scale)

Sample DOF diagrams are given for ease of visualization.

$$\textit{From consideration of the quadrilateral formed at image junction, we can see that}$$

$$(j - j_d)\tan\theta_d = (j_c - j)\tan\theta c$$
$$\implies \frac{j - j_d}{2Nj_d} = \frac{j_c - j}{2Nj_c} = \frac{r}{2}$$

Three quantities equal to each other means that we will get 3C2 = *three equations.*

$$\textit{equating the first two parts, we get:}$$
$$\frac{j - j_d}{j_d} = \frac{j_c - j}{j_c}$$
$$\implies j_c \times j - j_c \times j_d = j_c \times jd - j \times j_d$$

$$\textit{rearrranging we get,}$$
$$j = \frac{2j_c \times j_d}{j_c + j_d}$$

This equation can be checked by putting j_c *and* j_d *equal to* j

Equating the first and second terms separately with r*, we get:*

$$\frac{j - j_d}{2Nj_d} = \frac{r}{2}$$
$$\frac{j_c - j}{2Nj_c} = \frac{r}{2}$$

$$\textit{which gives,}$$
$$j_c = \frac{j}{1 - Nr} \;\&\; j_d = \frac{j}{1 + Nr}$$

we can now invert these according to the relation we got earlier

$$\text{which is } k = \frac{j}{j-1}, \text{ giving}$$

$$k_c = \frac{j_c}{j_c - 1} = \frac{\frac{j}{1-Nr}}{\frac{j}{1-Nr} - 1} = \frac{j}{j-1+Nr}$$

$$\text{and } k_d = \frac{j_d}{j_d - 1} \Longrightarrow \frac{\frac{j}{1+Nr}}{\frac{j}{1+Nr} - 1} = \frac{j}{j-1-Nr}$$

$$k_d - k_c = j \times \left(\frac{1}{j-1-Nr} - \frac{1}{j-1+Nr}\right)$$

$$\text{here, } k_d - k_f \text{ denotes } \frac{D.o.F.}{f}$$

$$\Longrightarrow D.o.F. = f \times j \times \left(\frac{j-1+Nr-(j-1-Nr)}{(j-1-Nr)\times(j-1+Nr)}\right)$$

$$\Longrightarrow D.o.F. = \frac{2f \times j \times Nr}{(j-1-Nr)\times(j-1+Nr)}$$

$$= \frac{2f \times j \times Nr}{(j-1)^2 - N^2 r^2}$$

How to use this formula for calculations:
firstly calculate j from k.

then putting the respective values of f, N, j & r
in the above formula will give you the D.o.F. in the unit of focal length.

Two DOF scenarios of interest are described below:

$$\text{Nearest distance in acceptable focus when focus is at } \infty \ (j = 1,\ k \rightarrow \infty):$$

$$j_c = \frac{1}{1 - Nr}$$

$$\text{which gives } k_c = \frac{1}{Nr}$$

$$\text{the nearest object that can be focused while still having objects at } \infty$$
$$\text{in acceptable focus } (j_d = 1):$$

$$\text{giving } j = 1 + N \times r$$

$$k = \frac{j}{j-1} = \frac{1+Nr}{Nr}$$

$$\text{we already know that } j = \frac{2j_c \times j_d}{j_c + j_d}$$

$$\text{substituting } j_x = \frac{k_x}{k_x - 1} \text{we get,}$$

$$j = 2 \times \frac{\frac{k_c}{k_c-1} \times \frac{k_d}{k_d-1}}{\frac{k_c}{k_c-1} + \frac{k_d}{k_d-1}} = 2 \times \frac{\frac{k_c}{k_c-1} \times \frac{k_d}{k_d-1}}{\frac{k_c}{k_c-1} + \frac{k_d}{k_d-1}}$$

$$\text{giving } j = \frac{2k_c \times k_d}{2 \times k_c \times k_d - (k_c + k_d)}$$

$$\text{In order to find the same relationship for } k, \text{ we need to mirror } j:$$

$$k = \frac{j}{j-1} = \frac{\frac{2k_c \times k_d}{2 \times k_c \times k_d - (k_c + k_d)}}{\frac{2k_c \times k_d}{2 \times k_c \times k_d - (k_c + k_d)} - 1}$$
$$= \frac{2k_c \times k_d}{k_c + k_d}$$

This result is due to the interchangable (mirror) nature of the relation.

END of Appendix