MAGNIFICATION

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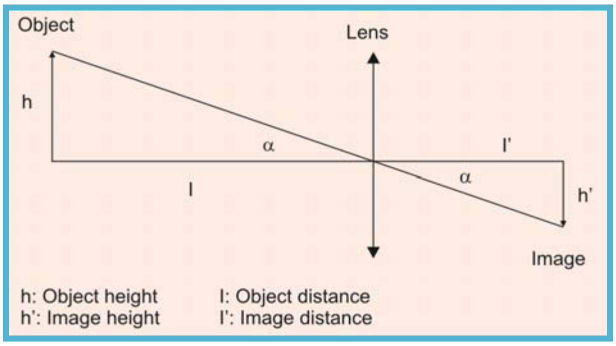
INTRODUCTION

This chapter includes a review of:

- What are the different types of magnification
- Different methods and formulae for calculating magnification
- How to determine resolution ability
- How to predict distance required to meet resolution goal
- How to measure lens power
- How to measure Equivalent Viewing Power
- How to measure Equivalent Viewing Distance (EVD)
- How to calculate EVD for different optical systems

TYPES OF MAGNIFICATION

The basic design of all telescopes and magnifiers is based on the principle of magnification. The definition of magnification is complicated and a much disputed one. One can simply say that "Magnification is the relative increase in the size of the image of an object when it passes through a medium".

RELATIVE SIZE MAGNIFICATION	The bigger the size of the object, the bigger is the image that is formed.
RELATIVE DISTANCE MAGNIFICATION	The closer the object is to the eye, the bigger it will seem.
ANGULAR MAGNIFICATION	This is an increase in the visual angle subtended by the object on the eye by optical means. So we are neither moving closer nor making the object larger but rather we are viewing an intermediate image that is created by the optical system that we place before the eye.
LINEAR MAGNIFICATION	In low vision, we are mainly interested in linear magnification. Linear magnification is the ratio of the image size to object size. **Linear Magnification =** $\dfrac{\textbf{Size of the Image}}{\textbf{Size of the Object}}$
UNDERSTANDING MAGNIFICATION	Magnification can be understood by reverting to basic mathematical (trigonometric) principles. The magnification is specified as the ratio of the retinal image size (when it is magnified) to the retinal image size of the same object that is viewed under standard viewing conditions. The retinal image size is specified in terms of the visual angle.
REVIEWING MAGNIFICATION USING THE PRINCIPLES OF TRIGONOMETRY	Using the basic laws of trigonometry (study of right angles), the visual angle can be specified by the Greek letter alpha (α). If we want to specify the visual angle in terms of the object height and distance from the eye, then we use the tangent of the visual angle alpha. It is the ratio of the length of the opposite side (object height: h) divided by the length of the adjacent side (object distance: l). If we consider the image formation within the eye, we create a similar triangle within the eye. The visual angle remains the same since they are opposite angles, image distance to the retina is designated l' and image height on the retina is designated h\`. This is represented graphically in Fig 4-1 below.  ***Figure 4-1:*** *Graphical representation of object and image formation* The tangent of the visual angle on the object and image sides are given by: $\tan \alpha = \dfrac{h}{l} = \dfrac{h'}{l'}$ In other words, this means that the tangent of alpha is given by the ratio of the object height to object distance and this is the same as the ratio of the image height to the image distance.

TYPES OF MAGNIFICATION (CONT.)

APPLYING THIS TO THE EYE

The visual angle (alpha) at the eye when viewing an object (h) is graphically represented in Fig. 4-2. In order to determine the magnification using trigonometric principles, we would need to construct right angled triangles, thereby causing the visual angle to be halved to ½ α. This is the same on both sides of the lens. In addition, the object and image heights are also halved in the creation of the right angled triangles. The tangent of ½ α is still given by the ratio of object height to object distance and that is the same as the ratio of the image height to image distance.

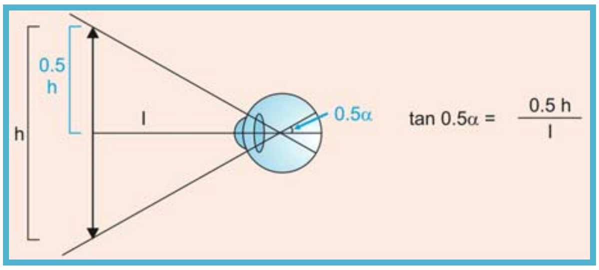


Figure 4-2: *Graphical representation of the visual angle at the eye*

The magnification is defined as the tangent of ½ α when it is magnified to the tangent of half angle alpha under the reference condition or standard viewing conditions (Fig 4-2). The tangent of ½ α is equal to half the size of the object divided by 'l', the distance of the object from the lens.

UNDERSTANDING RELATIVE SIZE MAGNIFICATION

Linear or size magnification is simply making the object larger, therefore the original height (h_0) at an object distance of *l* is made larger to an object height of *h*. We then see that there is an increase in the size of the visual angle from α to α_0, and the image height increases from α_0 to α_m, i.e. it produces a larger retinal image (Fig. 4-3).

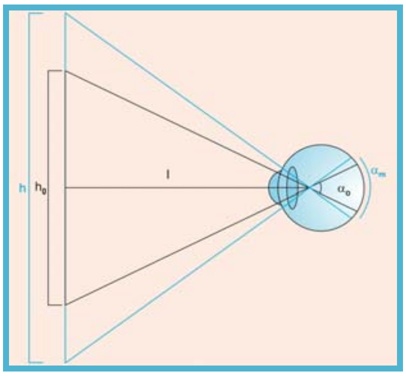


Figure 4-3: *Graphical representation changes in the image size with an increase in object size*

To mathematically determine the magnification produced by increasing the object size we can use the derivation below.

$$M = \frac{\tan 0.5\,\alpha_m}{\tan 0.5\,\alpha_0}$$

$$M = \frac{0.5\,h/l}{0.5\,h_0/l_0}$$

$$l = l_o$$

$$M = h/h_o$$

TYPES OF MAGNIFICATION (CONT.)

UNDERSTANDING RELATIVE SIZE MAGNIFICATION (CONT.)

In other words, we consider the tangent of half the magnified angle divided by the tangent of half the original angle. Substituting the definition of tangent into the equation, we are left with magnification being the ratio of height of the magnified object over the height of the original object.

This means that **the ratio of the object sizes will give us the magnification produced when an object is made larger, i.e. linear magnification.**

Similar principles and methods can be employed to determine the magnification produced by distance magnification.

UNDERSTANDING RELATIVE DISTANCE MAGNIFICATION

Distance magnification is magnification produced by moving an object closer to an individual or vice versa in order to view it more clearly. Considering it graphically, we would change the object distance from a distance l to a new distance l_0. The object size remains the same and therefore $h=h_0$. The visual angle increases from α_0 to α_m (Fig. 4-4).

If we consider the definition of magnification, we arrive at the conclusion that the magnification is given by the ratio of the original object distance to the closer object distance.

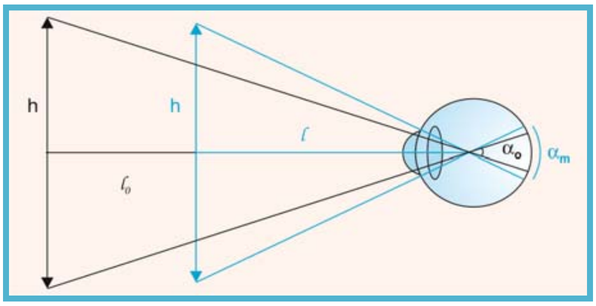


Figure 4-4: *Graphical representation of changes in the image size with a decrease in object distance*

To mathematically determine the magnification produced by decreasing the object distance we can use the derivation below:

$$M = \frac{\tan 0.5\alpha_m}{\tan 0.5\,\alpha_o}$$

$$M = \frac{0.5\,h/l}{0.5\,h_o/l_o}$$

$$h = h_o$$

$$M = l_o/l$$

An important aspect that must be considered when using distance magnification is accommodation. When the object is moved closer, a more positive dioptric power must be added to keep the retinal image in focus. Children generally have sufficient accommodation to focus on objects that are very close, however, the amplitude of accommodation decreases with age and therefore for older individuals or individuals with poor accommodative amplitude, a near add must be used to provide the individual with extra focusing power.

USING A HAND MAGNIFIER

When an object is held at the focal point of a lens, it's image is formed at infinity (Fig. 4-5). This means that the light rays emerging out of the lens, after being refracted, are all parallel to one another. The individual viewing the object through the magnifier/lens will not require additional focusing effort and will only need to use their distance prescription since this is the same as viewing an object that is far away from the individual.

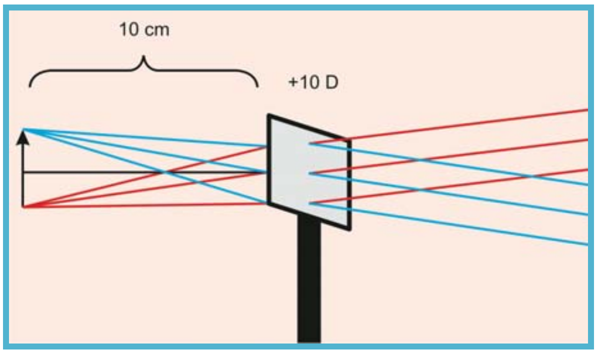


Figure 4-5: *Parallel light rays exiting a lens when an object is placed at the focal point of a lens/magnifier*

Example:

If we consider a +10.00D lens (Fig. 4-5) the focal point lies 10cm away and therefore an object placed 10cm from the lens/magnifier will produce an image at optical infinity.

When using this magnifier, the distance from the eye to the lens/magnifier does not affect the size of the image on the retina, however, the field of view through the lens will be altered with the viewing distance.

If the object viewed through the magnifier/lens is moved to a distance within the focal length of the lens, the light rays leaving the lens are diverged after refraction by the lens. Considering the optics of this situation, one would be able to see that if the object were 6.7cm away, that means that the vergence of the light reaching the lens is -15.00D. The lens adds 10.00D of power to that so the emerging vergence is -5D and a virtual upright image is produced. This image is located 20cm behind the lens. When the individual views through the lens/magnifier at a distance of 20cm from the device, then the individual will require 2.50D of focusing power in order to see the image clearly. Similarly, if the individual was viewing from a distance of 10cm from the lens, then he/she will be located 30cm from the image and therefore will require 3.00D of accommodation or lens power to obtain a clear view of the image.

It is therefore critical for the individual to monitor where the object is relative to the focal point of the lens, to decide if the image is being viewed at optical infinity in which case the patient can use their distance correction or if the patient is viewing a virtual image that's actually within arms reach and would then require some type of near add whilst being aware of the working distance. This involves a combination of distance and linear magnification, i.e. increase in the size of the image and manipulating the viewing distance.

TYPES OF MAGNIFICATION (CONT.)

USING A HAND MAGNIFIER (CONT.)	Distance magnification must be specified relative to a standard working distance. There are 2 different standard distances that are used: – 40 cm (requiring +2.5D add) – 25 cm (requiring +4D add) Most current specifications of near magnification use the 25 cm standard distance. So in that case, if a magnifier is labelled as 5X that means that the standard viewing distance of 25cm would have to be divided by 5cm in order to produce a magnification ratio of 5. A lens with a focal length of 5cm and a focal power of +20D would produce this effect. If an object is at the focal point of the lens, distance magnification is simply the ratio of a reference distance to the focal length of the lens. Or in terms of focal powers, magnification is simply the dioptric power of the lens (F), and if you were using a reference distance of 25cm, is F/4. So if you have a 20D lens, it is a lens of 5x (20/4) magnifying power. When the object is at the focal point of the lens, magnification is then simply F/4 and in the case of our +10.00D lens, it is a 2.5X (10/4) magnifying lens. If the object is inside the focal point of the lens, then the calculation of magnification must also consider the distance of the lens to the eye and the size and location of the virtual image. So it becomes a combination of distance and linear magnification. Most stand magnifiers in particular have the image inside the focal point of the lens so the emerging light is not collimated, the image is not at optical infinity and the patient has to use a near vision correction, an add. However the manufacturer will specify the dioptres of the lens in terms of their calculation for the magnification for a standard viewing distance. This may be complicated when using a stand magnifier as they are frequently not set at the focal point of the magnifier.

DETERMINING THE MAGNIFICATION OF A TELESCOPE

The magnification of the telescopic system has proved somewhat tricky to many. However, it can be simplified if one is able to understand the concept of the exit pupil.

The ocular lens in a Keplerian telescope forms a real image of the objective lens, in addition to forming an image at optical infinity of the intermediate image that we are trying to magnify. To see this, we trace rays from the edge of the objective lens through the ocular lens and you can see that we form an image of that objective lens to the right of the ocular lens. This real image of the objective lens is called the exit pupil of that telescope. In a Keplerian telescope the exit pupil is a real image that looks like its floating between you and the ocular lens (Fig. 4-6).

All the light that is captured by the objective lens and the telescope passes through the exit pupil.

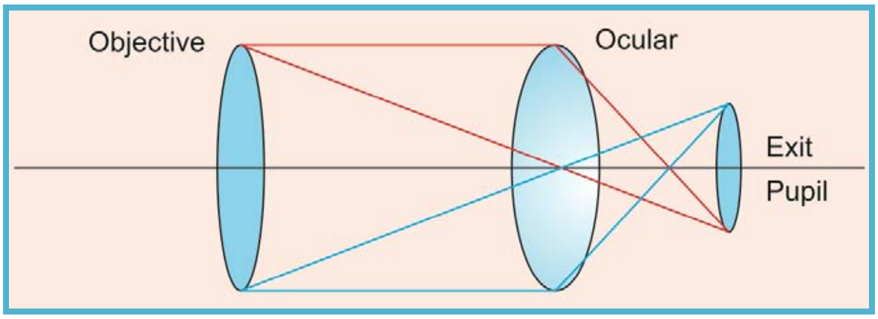


Figure 4-6: *The exit pupil in a Keplerian telescope*

For a Galilean telescope, there is a virtual image formed of the objective lens, because we are using a negative ocular lens. If we trace the rays from the edge of the objective through the ocular, we find that there is a virtual image formed, but now the virtual image is formed between the objective and ocular lenses. This is the exit pupil in the Galilean telescope (Fig. 4-7). All light rays coming from the object and destined to go through the ocular to form the virtual image, has to pass through this internal exit pupil.

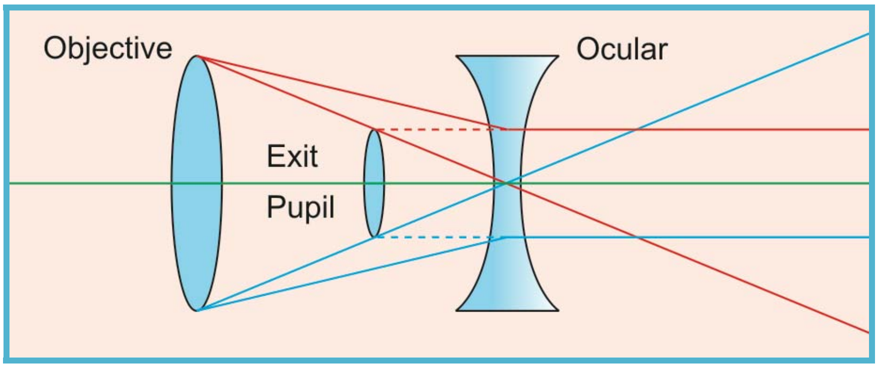


Figure 4-7: *The exit pupil in a Galilean telescope*

When using the Keplerian telescope, the most efficient use of the telescope would be when you get the exit pupil of the telescope centered on the pupil of the eye (Fig. 4-8). That way, you will get the most light into the eye.

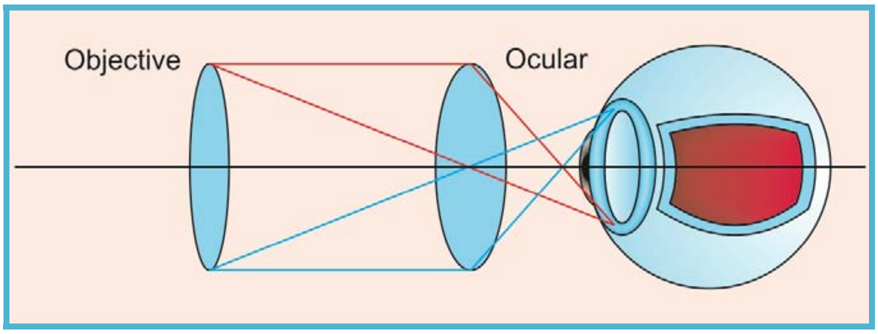


Figure 4-8: *Coincidence of the exit pupil with the pupil of the eye*

DETERMINING THE MAGNIFICATION OF A TELESCOPE (CONT.)

In the case of the Galilean telescope, you cannot get the eye into the exit pupil, so you want to get the eye as close as you can to the telescope. Because the exit pupil is inside the telescope, the size of the exit pupil will be expanding as it moves away from the plane where it is in focus. So the eye's pupil will limit the amount of light that actually gets into the eye. That is why Galilean telescopes tend to be dimmer than Keplerian telescopes. A much brighter image is obtained with a Keplerian telescope.

An interesting feature of telescopes is that you can use the exit pupil to calculate the magnification of the telescope.

i.e. $\mathbf{M = diameter_{objective} / diameter_{exit\ pupil}}$

A simple method to determine the magnification of a telescope is to measure the size of the objective lens and exit pupil with a ruler. The ratio of the objective lens and exit pupil will indicate the magnification of the telescope.

The same procedure can be performed on a Galilean telescope, although measuring of the exit pupil is difficult as it is located inside the telescope.

ACHIEVING RESOLUTION GOAL AND PRESCRIBING NEAR AIDS

DETERMINE RESOLUTION ABILITY FOR READING	**1.** Have patient read chart at a distance you are sure they will be in focus. This often requires a reading addition be be used to provide correct focus **2.** Take note of the size of the smallest print read with acceptable efficiency **3.** Note the working distance (from spectacle plane for presbyopes)
PREDICT DISTANCE REQUIRED TO MEET RESOLUTION GOAL	For example, consider two patients who wish to read print the size of that in the telephone book. The resolution goal is 0.8M (6pt) print.

Table 4-1: *Near aids prediction for two patients with a goal print of 0.8M*

	Patient X	**Patient Y**
Age	20 yrs	70 yrs
Smallest print read	2.0M (16pt)	4.0M (32pt)
Viewing distance	12cm	32cm
Addition	None	2.50D (old glasses)
Accom. Demand	8.0D	0.50D
Prediction		
For 0.8M print ratio is	2.0/0.8 = 2.5x	4.0/0.8 = 5x
So required viewing distance	12/2.5 = 5cm	32/5 = 6.3cm

So to read the telephone book print, patient X requires a viewing condition with:

Equivalent Viewing Distance (EVD) of **5cm**

Equivalent Viewing Power of **20D**

ACHIEVING RESOLUTION GOAL AND PRESCRIBING NEAR AIDS (CONT.)

VERIFY THAT PREDICTED EVD ALLOWS RESOLUTION GOAL	Using an appropriate resolution when necessary, check that patient gets clear focus at the required distance from the spectacle plane and that the resolution goal can actually be achieved. If not (very rare if proper charts are used and conditions are controlled) make appropriate adjustments.
CONSIDER OTHER OPTICAL SYSTEMS TO PROVIDE THE SAME EVD	Options to consider: • Spectacles with reading addition • Hand held magnifier • Stand magnifier • Near vision telescope • Video magnifier or other projection system In all these cases, you must understand what the magnifying systems are doing. They must provide the required **Equivalent Viewing Distance** (EVD).
SPECTACLES WITH READING ADITION	Their action is simply to allow a closer working distance. For presbyopes the focal length of the addition sets the EVD. For example, patient Y (from the above mentioned example) requires a 16D add to read 0.8M print. For pre-presbyopes the EVP is determined by adding the add power and the accommodation. The EVD is the reciprocal of this sum. The EVD is the actual working distance from the spectacle plane. Patient X must work at 5cm to read 0.8M print. This would require 20D of power. Given that he was comfortable at 12cm with 8D accommodation. Provide a +12D addition and with 8D accommodation this allows work at 5cm.

MEASURING AND PRESCRIBING STRONG LENS POWERS

For plus lens magnifiers, the image size is dependent on the equivalent power - not the back vertex power or the front vertex power. The lensmeter measures only vertex powers. For plano-convex lenses, the front vertex power is equal to the equivalent power.

For strong single vision lenses, aberrations become important. For lenses in the range of 10-18D, use cataract aspheric lenses. For 20D and above, special series lenses are required (bi-aspheric lenses AO, Igard or doublets designs for vision, Keeler)

MEASURING EQUIVALENT POWER

Take a suitable distant (3 meters or more) object. Measure its height (h) and the distance (d). For example, if a window 1 meter wide is 4 meters away, then:

h = 1.0 m

d = 4.0 m

With the lens being tested, form an image on a translucent screen, making sure that the image is in focus.

Measure the height (h) of the image. Calculate the image distance. The object-height to object-distance ratio (here ¼) will be equal to the image-height to image-distance ratio. If the height is 1.5cm and given the 1m to 4m ratio, the image distance is 6cm. This image distance is equal to the Equivalent Focal Length.

So the Equivalent Power is 16.6D (100/6 cm).

The image distance in this relationship is measured from the nodal point, not the lens vertex.

MEASURING EQUIVALENT VIEWING DISTANCE (EVD)

SPECTACLES	• For presbyopes, the equivalent focal length of the near addition gives the EVD. • For pre-presbyopes: accommodation should be estimated and added to the lens power to give the equivalent viewing power. The reciprocal is the Equivalent Viewing Distance. **Example:** A young patient expected to contribute 5.00D accommodation, using a +20D lens (measured by the above technique) **EVP = 20 + 5 = 25D** **So EVD = 4cm**
HAND HELD MAGNIFIERS	If held at some distance from the eye, (further than the focal length of the magnifier) then best resolution will be determined by the focal length of the lens and that is the EVD. Here for best resolution, presbyopes should use their distance Rx and pre-presbyopes should not accommodate. If the lens is held close to the spectacle frame, then there will be some additive effect of lens power and the add or accommodation. Here for best resolution, presbyopes should use their addition and hold the lens close-by. Pre-presbyopes should accommodate to maximize resolution.

MEASURING EQUIVALENT VIEWING DISTANCE (EVD) (CONT.)

STAND MAGNIFIERS

- Most are fixed focus
- The object distance is fixed so the image distance is fixed
- The image will be larger but more remote than the object
- The enlargement ratio is constant
- The enlargement ratio is the transverse or lateral magnification, or the ‘multi-acc factor’
- The clinician must know where the image is located and how much it is enlarged

EVD =Acc. Stim. Distance/Enlargement Ratio

TO LOCATE THE IMAGE POSITION FOR A STAND MAGNIFIER

Rest a close focussing telescope against the lens of the stand magnifier (use 4x or 2.75x Walters) (Fig. 4-1a). Focus on some print seen through the magnifier. Now take the telescope and find the distance to which it is focussed (Fig. 4-1b). Look at a wall and move back and forth until it is seen in clear focus. Measure the distance from the wall to the telescope objective.

When the image plane is fairly close to the lens, then the telescope might not focus to that distance. In which case, focus the telescope to its closest distance (make telescope as long as possible) and then move back until image through magnifier is clear (Fig. 4-1c). Measure distance from telescope to lens. Now find the distance to which telescope is focussed (Fig. 4-1d). Allow for telescope-to-lens separation and determine the distance from image plane to the lens of the magnifier.

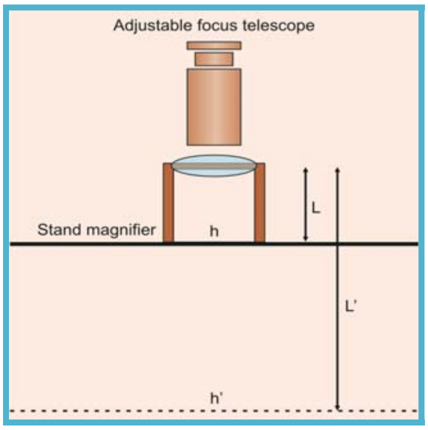


Figure 4-1 (a)

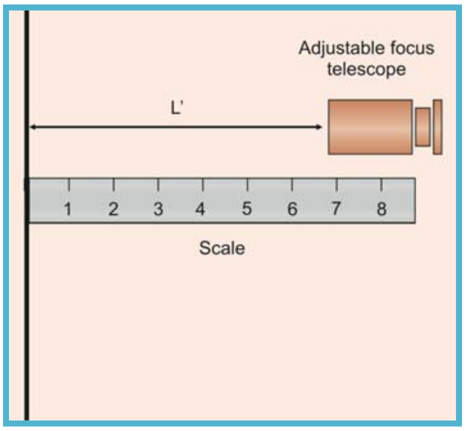


Figure 4-1 (b)

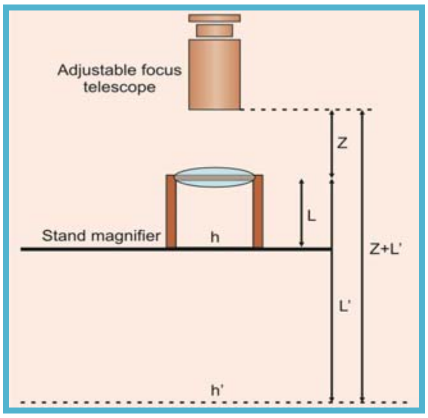


Figure 4-1 (c)

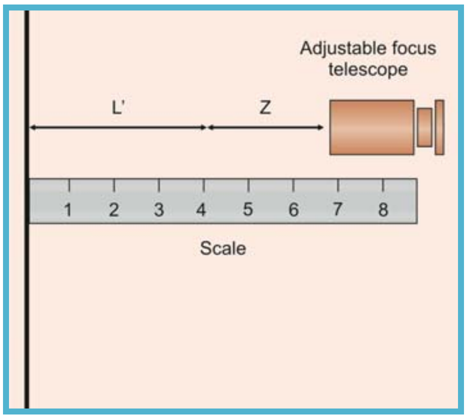


Figure 4-1 (d)

MEASURING EQUIVALENT VIEWING DISTANCE (EVD) (CONT.)

TO CALCULATE THE ENLARGEMENT RATIO	From the distance from the image plane to the lens surface (l'), determine the emerging vergence L' = 1/ l', where L' is the emerging vergence in dioptres. **If l' = 25cm** **Then L' = -4D** Measure the equivalent power (F_e) of the lens as described earlier. Neglecting signs: $\mathbf{M_t = (L + F_e) / L'}$ Example **Lens power = 20D** **Emerging vergence = 5D** **So M_t = (5 + 20) / 5 = 5x** This magnifier gives a 5 times enlargement and the image is 20cm (5D) below the lens.
TO CALCULATE THE EVD	**EVD** = actual viewing distance divided by enlargement ratio. **Actual viewing distance** = accommodation demand distance = eye-lens distance + lens-image distance = the same as the focal length of the add (for presbyopes) **For Patient Y** With a stand magnifier having image distance of 20 cm and enlargement ratio of 5x wearing a 2.5D add, he should be 40cm from the image (20cm from the lens). **In this situation, EVD = 40/5 = 8cm** Given that he could read 4.0M (32pt) at 32cm, now he should read print that is smaller by 32/8 = 4 times, so about 1M or 8pt. **For Patient X** With the same magnifier, but eye 5cm from the lens, Actual viewing distance = 20 + 5 = 25 cm **In this situation EVD = 25/5 = 5cm** Given that he could read 2.0M (16pt) at 12cm, now he should read print that is smaller by 12/5 = 2.4times, so about 0.8M or 6pt.
NEAR VISION TELESCOPES	Consider a distance telescope with a lens cap on the front to give the near focus. **EVD** = focal length of cap/Magnification of telescope **Example:** 3x telescope with 4.00D cap (25cm) **EVD = 25/3 = 8.3cm** **Example:** 6x Walters focussed for 50cm **EVD = 50/6 = 8.3cm**
VIDEO-MAGNIFIERS OR PROJECTION SYSTEMS	To measure enlargement ratio, place ruler under camera and with a second ruler measure the size of the enlarged image of a scale division. **EVD** = Actual viewing distance divided by the enlargement ratio **Example:** Viewing the screen from 40cm with a 10 times enlargement **EVD = 40/10 = 4cm**

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