Telescopes: magnification and beyond

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Telescope labels

- 4x12, 6x16, 8x20, etc.
  - First number is the magnification when afocal
  - Second number is the objective lens diameter in mm

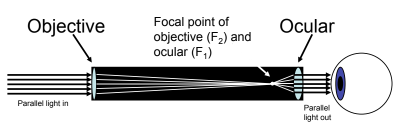
Prescribing TS magnification

- Minimally 20/40 through the telescope
  - Good for most distance activities
    - Reading street signs, recognizing faces, etc.
- Calculating the needed magnification
  - Acuity denominator divided by 40
    - Example: Acuity 20/200. 200÷40 = 5
      - A 5X telescope will make 40 foot letters the size of 200 foot letters
    - Example: Acuity 10/40 = 20/80. 80÷40 = 2
      - A 2X telescope will make 40 foot letters the size of 80 foot letters

Keplerian TS

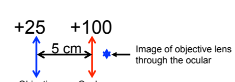
- Two plus lenses
- Ocular
  - Closest to the eye
  - Higher powered
- Objective
  - Farthest from the eye
  - Lower powered

Basic Keplerian optics

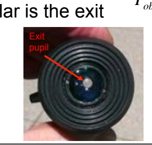


Afocal Keplerian: parallel light in, parallel light out. Light comes to a focus at F_2 of the objective, which is coincident with F_1 of the ocular.

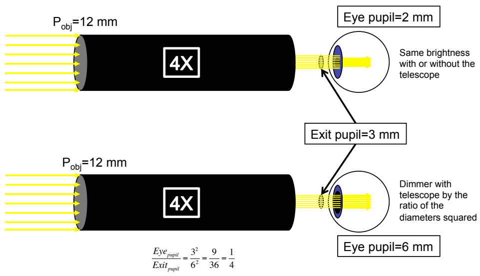
More Keplerian optics



- To be afocal the lenses need to be the sum of their secondary focal lengths apart
  - Tube length = $\frac{1}{P_{obj}} + \frac{1}{P_{oc}}$
- The magnification is determined by the formula: $M_{ts} = -\frac{P_{oc}}{P_{obj}}$
- Image of the objective through the ocular is the exit pupil of the telescope
  - Exit pupil important for retinal illumination
  - It's outside a Keplerian telescope
  - Size of the exit pupil is = $\frac{Diameter_{obj}}{M_{ts}}$



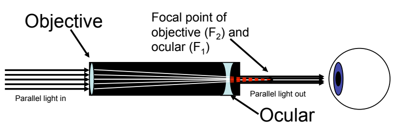
Keplerian exit pupil



Galilean TS

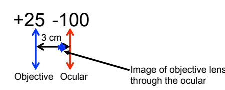
- Plus objective, minus ocular
- Ocular
  - Closest to the eye
  - Higher powered
- Objective
  - Farthest from the eye
  - Lower powered

Basic Galilean optics



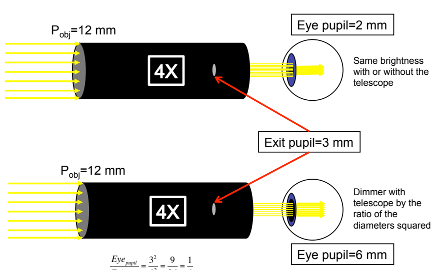
Afocal Galilean: parallel light in, parallel light out. Light is converged and would come to a focus at F_2 of the objective (as shown by the red dashed lines), which is coincident with F_1 of the ocular. However, the light never comes to a focus, but instead, it is diverged by the ocular lens to parallel.

More Galilean optics



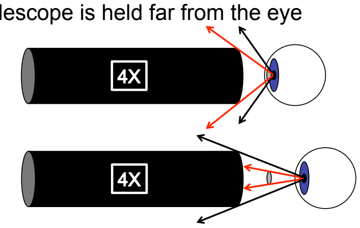
- To be afocal the lenses need to be the sum of their secondary focal lengths apart
  - Tube length = $\frac{1}{P_{obj}} + \frac{1}{P_{oc}}$
- The magnification is determined by the formula: $M_{ts} = -\frac{P_{oc}}{P_{obj}}$
- Image of the objective through the ocular is the exit pupil of the telescope
  - Exit pupil important for retinal illumination
    - And field of view
  - It's inside a Galilean telescope
  - Size of the exit pupil is = $\frac{Diameter_{obj}}{M_{ts}}$

Galilean exit pupil



Keplerian TS field of view (FoV)

- Typically, the ocular lens limits the FoV of a Keplerian telescope
  - The exit pupil could limit FoV but only if the telescope is held far from the eye

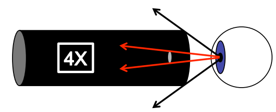


Keplerian TS FoV

- The ocular lens will subtend an angle of 40-50°
  - If the TS is a 4X, about 10-12.5° of object space will be magnified to fill up the 40-50° of image space
- In linear terms, the FoV will be approximately the distance to the object divided by the magnification of the TS
  - If the patient is 40 cm from the computer using a 4X, the FoV will be approximately 10 cm

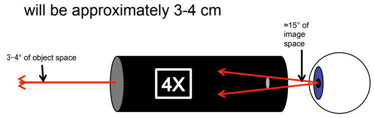
Galilean TS FoV

- The exit pupil limits the FoV of a Galilean telescope
  - Because the exit pupil is inside the telescope and small

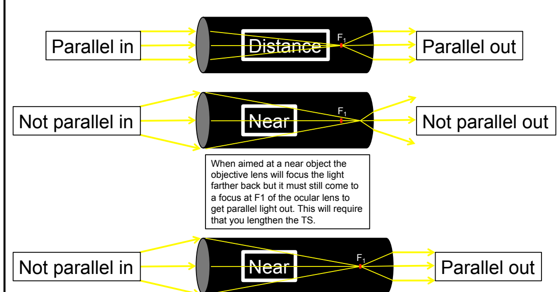


Galilean TS FoV

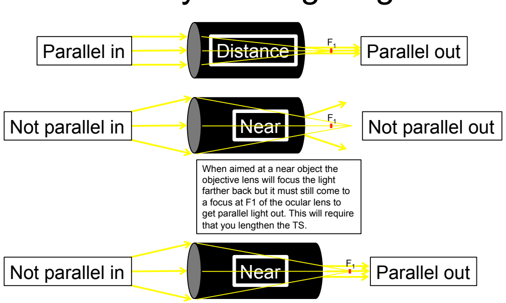
- The exit pupil will subtend an angle of ≈15°
  - If the TS is a 4X, about 3-4° of object space will be magnified to fill up the 15° of image space
- In linear terms, the FoV will be approximately the distance to the object divided by the magnification of the TS and further divided by 2.5 or 3
  - If the patient is 40 cm from the computer using a 4X, the FoV will be approximately 3-4 cm



Focusing a Keplerian TS for near by altering length

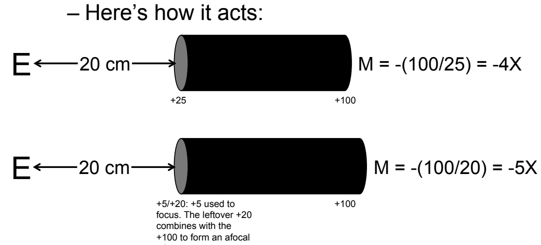


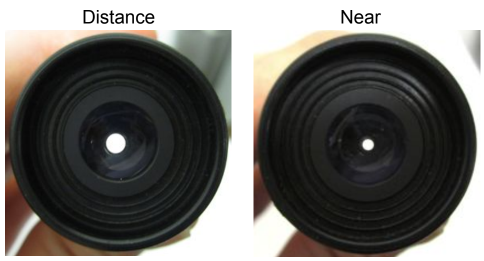
Focusing a GalileanTS for near by altering length



Focusing a Keplerian TS for near by altering length

- Increases the magnification
  - Here's how it acts:

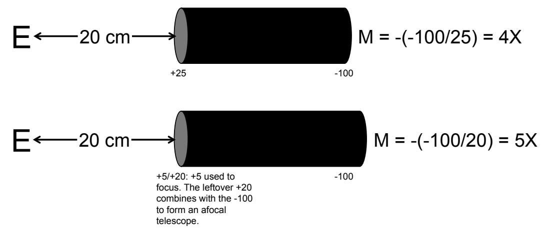




Could affect brightness when used at near

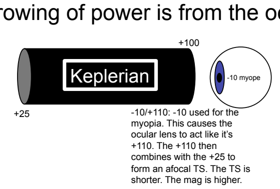
Focusing a GalileanTS for near by altering length

- Increases the magnification
  - Here's how it acts:



Focusing a TS for refractive error

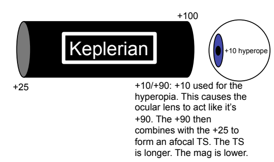
- Concept is similar to focusing for near
  - The difference is that the TS acts as if the borrowing of power is from the ocular



M = -(110/25) = -4.4X

Focusing a TS for refractive error

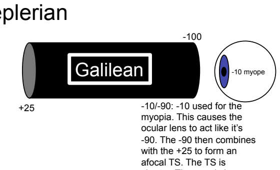
- Keplerian and hyperopia
  - Different result than myopia & a Keplerian



M = -(90/25) = -3.6X

Focusing a TS for refractive error

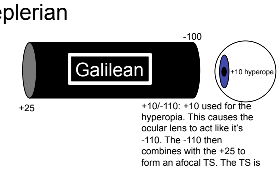
- Galilean and myopia
  - The result is not the same as with a Keplerian



M = -(-90/25) = 3.6X

Focusing a TS for refractive error

- Galilean and hyperopia
  - The result is not the same as with a Keplerian



M = -(-110/25) = 4.4X

Focusing telescopes summary

- Focusing at near by changing length (longer)
  - Increases magnification, decreases exit pupil diameter
- Focusing at near by adding a + cap
  - Magnification unchanged from afocal mag
- Focusing for refractive error with a change in the ocular lens power, wearing specs or contacts
  - Magnification unchanged from afocal mag
- Focusing for hyperopia by changing length (longer)
  - Keplerian: less magnification
  - Galilean: more magnification
- Focusing for myopia by changing length (shorter)
  - Keplerian: more magnification
  - Galilean: less magnification

Equivalent viewing distance (EVD) for telescopes

- The EVD is the distance the object would have to be in order to subtend the same angle as the image produced by the optical system
  - The EVD of a telescope is the object distance (u) divided by the afocal telescope magnification (M):

$$EVD = \frac{u}{M}$$

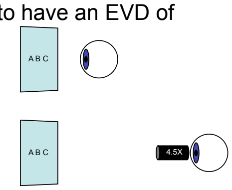
EVD example

- Patient is able to read the computer monitor when 10 cm away but wants to work 45 cm away
  - We need the telescope to have an EVD of 10 cm:

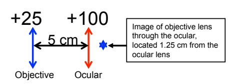
$$EVD = \frac{u}{M}$$

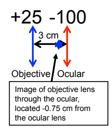
$$10cm = \frac{45cm}{M}$$

$$M = \frac{45cm}{10cm} = 4.5$$



How do you tell if a telescope is Galilean or Keplerian?



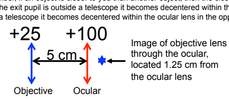


Locate the exit pupil. The exit pupil (image of the objective through the ocular lens) is located outside a Keplerian telescope and inside a Galilean telescope. Hold the telescope away from you (ocular lens towards you) and aim the telescope towards something that is light in color. Using your stereopsis, you should be able to tell that the exit pupil is either floating on the outside of the telescope or is deep inside the telescope.

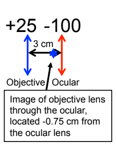
What if you don't have stereopsis or it's not so good?

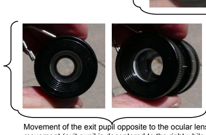
If you don't have good stereopsis or don't trust what you're seeing, you can try wiggling the ocular lens back and forth to see how the exit pupil moves relative to the ocular lens.

Remember, if an object is closer to you than another object, then the closer object will move faster as it goes past you (angular speed). Therefore, when the exit pupil is outside a telescope it becomes decentered within the ocular lens in the same direction as the ocular lens movement and when inside a telescope it becomes decentered within the ocular lens in the opposite direction as the ocular lens movement.



Movement of the exit pupil in the same direction as the ocular lens movement (exit pupil is decentered to the left while the ocular lens was moved to the left). This indicates the exit pupil is closer than the ocular lens and, therefore, outside the telescope. Indicating a Keplerian.





Movement of the exit pupil opposite to the ocular lens movement (exit pupil is decentered to the right while the ocular lens was moved to the left). This indicates the exit pupil is further away than the ocular lens and, therefore, inside the telescope. Indicating a Galilean.

Verifying the magnification of an unknown telescope

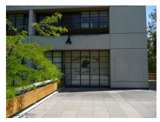
This is most easily accomplished by measuring the diameter of the objective lens and the diameter of the exit pupil. Because the image of the objective lens (the exit pupil) is always smaller by M_{ts}, the ratio of objective lens diameter to exit pupil diameter will be M_{ts}. M_{ts} = objective diameter/exit pupil diameter. Before measuring, make sure the telescope is afocal by focusing it on something very far away.

Verifying the magnification of an unknown telescope

Another method is to compare the image size in the telescope to the image size with your own eye. This is most easily done by viewing a repeating pattern.

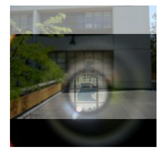
Hold the telescope in front of one eye and view the target with both eyes. This is tricky and requires that you not suppress an eye.


View through the telescope with one eye


View without the telescope in the other eye

Verifying the magnification of an unknown telescope

Once you have both eyes seeing the same target, place the images in alignment so that you can tell how much bigger the telescope image is than your eye's image. This will be the magnification.



Summary of Galilean vs. Keplerian telescopes

	Galilean	Keplerian
Optical path length	Short	Long
Image	Erect (M = positive)	Inverted (M = negative)
Prisms	No	Yes
Ocular	Single lens	2 or more lenses
Optical surfaces	4	10 or more
Exit pupil	Inside TS	Outside TS
Field of view	Smaller	Larger
Field limits	Tapered	Sharp outline
Image quality	Poorer	Better

Summary

- You will improve the care of your patient's telescope needs if you:
  - Understand TS labeling
  - Understand magnification and EVD of a TS
  - Know how the exit pupil affects brightness
  - Understand TS field of view
  - Know how to assess unknown telescopes