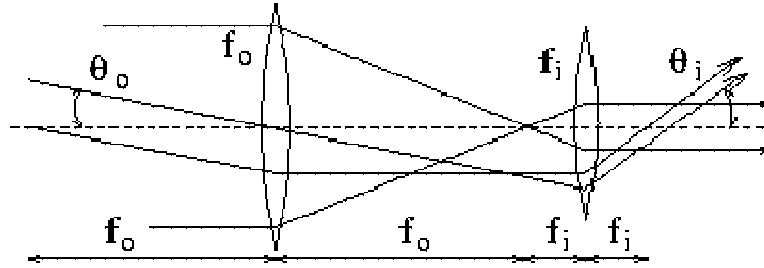


How to make a Keplerian (“Kept-Larry-lan”) Telescope



- **Find the focal length of the big lens – the objective lens**

Uses: Yardstick, ruler, big lens.

With the Sun overhead, hold the big lenses over some concrete or paper on table. (If it is overcast, ask your presenter to use a collimated light source.)

Place the Sun behind you and over your shoulder. Move the lens so the image of the Sun focuses to a point or the smallest possible circle. (Be careful you do not set the paper on fire!) Measure the focal length on the yardstick or ruler.

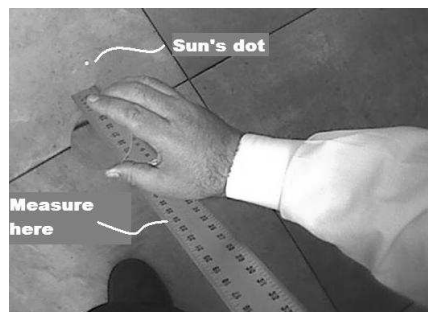


Figure 1 - Finding the focal length (75 cm lens) with a yardstick and the Sun – make the light circle as small as possible

If the Sun is overcast by clouds, use a light bright light source -



Figure 2 - Finding the focal length (20cm lens) with a ruler and light source – make the light circle as small as possible

Use the ruler or yardstick to measure the distance from the middle of the lens to the flat surface. Just estimate – you do not have to be accurate.

A third method to find the focal length of a lens is to sight along a yardstick. Slowly move the lens away from your eye. As the lens approaches one focal length, the image will magnify to infinity and invert.

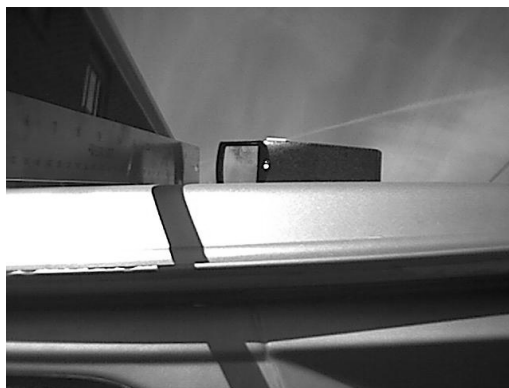


Figure 3 - Finding the focal length (17cm lens) with a ruler and positioning the lens at the point where a distant image first inverts

This third method is sensitive your vision. If you wear eyepieces, the power of your eyeglass lens will change the measurement. In the preceding figure, a tree across the street is seen in the lens upside down.

Again, just estimate the focal length distance. It is not important to be precise.

Big lens focal length is _____ inches or _____ centimeters.

The big lens is a positive lens – also called a “convex” lens. It is “positive” because it sticks “out” from the middle.

- **Find the focal length of the small lens – the eyepiece lens.**

Small lens focal length is _____ inches or _____ centimeters.

The small lens is also a positive lens.

- **What is the sum of the two focal lengths?**

Lens	Focal length
Big lens	
Small lens	+
Sum of focal lengths	=

- **Make the telescope**

Materials: Yardstick, big lens, small lens, and some way to hold the big lens, e.g. – coffee cap lid, putty, laundry clothes pin.

Gather everything you need.

Put the yardstick on a table with one end at the edge of the table. Make sure you point the yardstick away from the Sun.

Use the coffee cup lid, the dry clothes pin or the putty to hold the big lens upright on the yardstick.

Put the big lens on the yardstick a couple of inches short of the “Sum of the focal lengths” that you added above.



Figure 4 - The telescope set up on the yardstick

Hold the small lens in your hand. At the end of the yardstick, look through the small lens towards the big lens. Move the small lens back and forth towards and away from the big lens.

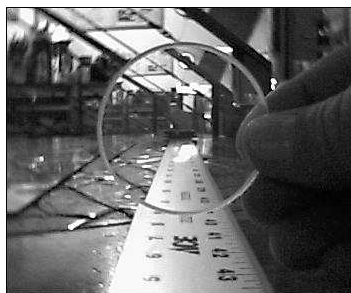


Figure 5 – Looking down the yardstick through the little and big lenses to see telescopic magnification

The telescope will come into focus when you are holding the two lenses apart as the same distance as the “Sum of the focal lengths.”

When the telescope comes into focus, you will see a magnified image.

Or just hand-hold both lenses at just about the right length – the “Sum of the focal lengths” above.



Figure 6 – Or just hand-hold the lenses apart at about the “Sum of the focal lengths” distance you found above – big lens further from your eye – little lens closer to your eye

Although you can hand-hold your lenses to make a telescope, it is easier to hold and point the lenses when they are fixed inside a tube – making the familiar shape of the *refractor telescope* also called a *refracting telescope*.



Figure 7 - A basic refractor hobby telescope – a tube that holds two lenses apart at the “Sum of the Focal Length” distance

- How much bigger is the image that you see in your telescope as compared to the actual object?

Lens	Focal length
Big lens (divided by)	
Small lens	/
Magnification	=

- The image you will see in the telescope is *virtual*. What is a *virtual* image?

While holding up your telescope, move your head backwards and forwards from the little or eyepiece lens. Notice that the magnified image does not, like most things in the world, get bigger and smaller as you move your head closer to further away from the eyepiece lens.

Images in the world are *real* or *virtual*.

Real images are what we experience for most nearby objects. Ask a friend to stand 10' feet (about 3 meters) away. Look at your friend's head. Move closer and then further away from your friend. The *angular size* or *apparent size* of their head will become bigger or smaller.

Virtual images are different. If you move closer or further away from the object, they stay the same size. *Virtual images* are all around you. Look at a distant mountain top or a tall building – more than one or two miles (about 2 or 4 kilometers) away. Now take a couple of steps backwards away from the distant object and then a couple of steps closer to the distant object. The *angular size* or *apparent size* of the distant mountain top or building, unlike your friend's head, will not appear to get bigger or smaller.

When you look in the little or eyepiece lens of the telescope, the magnified image that you see is *virtual*. If you move your head back and forth, the *apparent size* or *angular size* of the image stays the same.

- **Other things to look for in the magnified telescope image.**

You may see a fuzzy ring around a clear image in the middle. This is called “coma.”

You may see color fringes – blue or yellow – around the object in the image. This is called “color aberration.”

- **Why is the image in the telescope *virtual* – it doesn't change apparent size when I move my head backwards and forwards from the eyepiece. Why does it do that?**

Telescopic magnification in a Keplerian telescope occurs at a special case when the focal lengths of two positive lens overlap when they are separated at the sum of their focal lengths.

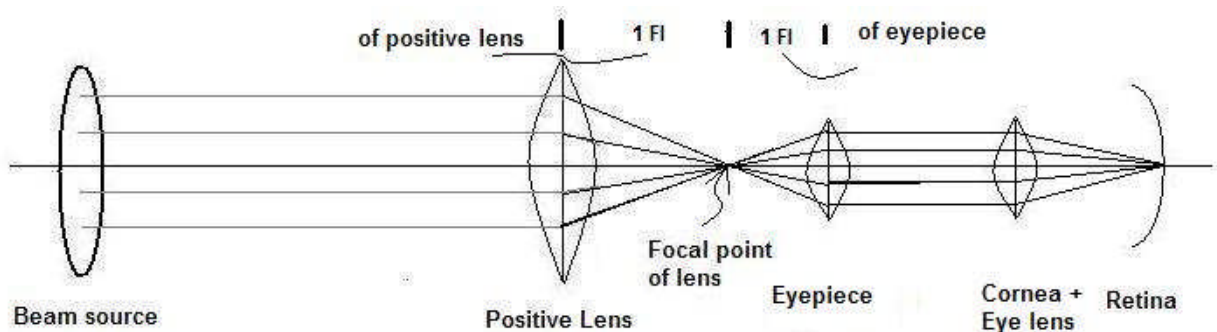


Figure 8 - A Keplerian Telescope - a special case of magnification of a distant object

Light rays from a distant star are parallel. They are called a *beam source* of light.

When the lenses are aligned so their focal lengths overlap and a beam of parallel light rays pass from the left to the right through the telescope shown in Figure 8, most of the light exits the eyepiece also in parallel light rays. So, it does not matter how far you stand behind the eyepiece. The parallel light rays still produce an image with the same apparent size.

You can see this by focusing your telescope on the bright full Moon and using a long focal length lens (more than 20mm). By carefully positioning your eye, you can stand about two feet away from the eyepiece and still see the Moon in the eyepiece.

Not all the light rays take a path through the lens shown in Figure 8. Some travel in the path added to Figure 8 –

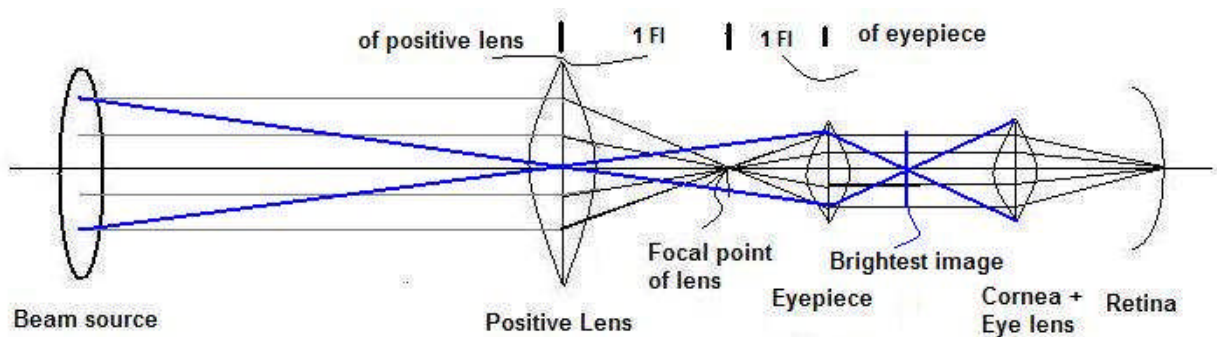


Figure 9 - A Keplerian Telescope – some rays pass through the center of the positive lens and come to a focal point to the right of the eyepiece

You can see this by focusing your telescope on the bright full Moon and using a long focal length lens (more than 20mm). The brightest image will be at about the eyepiece's focal length behind (or to the right) of the eyepiece. This is called the *eye relief distance of the eyepiece*. You can still stand about two feet away from the eyepiece and still see the Moon in the eyepiece, but the image will be dimmer because fewer light rays are reaching your eye.

- **If you drop your lens and the glass breaks, tell an adult and ask them to help sweep the glass up. Do not look at the Sun through a lens. You'll go blind.**
- **Make a microscope – a backwards Keplerian telescope**

A Keplerian telescope uses two positive lens to magnify large objects at a distance. The larger lens with the longer focal length is nearer the object. The smaller lens with the shorter focal length is near the eye.

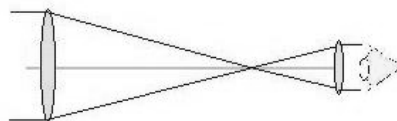


Figure 10 - Kelperian telescope - Larger lens nearer the object

But you can also reverse two positive the lenses and make a microscope. In a compound microscope, the smaller lens with the shorter focal length is near the closeby small object. The larger lens with the longer focal length is near your eye.

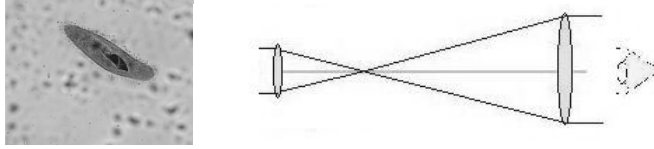


Figure 11 - Microscope - Larger lens nearer the eye – smaller lens nearer the object

To make a microscope from the lenses in your kit, look at a picture hanging on a wall. Hold the small lens about one focal length away from the picture. Then look through the larger lens at the “Sum of the focal length” distance that you found above. A magnified image of the a small part of the picture will come into focus.

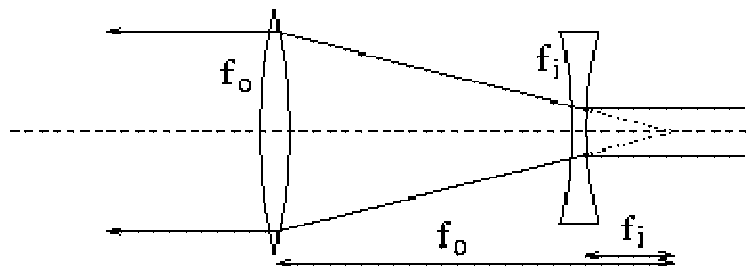
If your arms are not long enough to hold the lenses, but both lenses on the yardstick in holders. Have a friend hold an object – like a leaf or blade of grass - one focal length away from small lens. Look down the large lens.

- **Reference table – Inches, Centimeters and Millimeters**

Inches	Centimeters	Millimeters
1	2.5	25
2	5.1	51
3	7.6	76
4	10.2	102
5	12.7	127
6	15.2	152
7	17.8	178
10	25.4	254
20	50.8	508
30	76.2	762
40	101.6	1016

- **Who invented the telescope?**

Hans Lippershey (c.e. 1570 – c.e. 1619), or more properly his children, are usually credited with making the first Galilean telescope in Common Era (c.e.) 1608. Accordingly to an uncertain popular myth, the children of Lippershey, a Dutch eyeglass maker, noticed magnification while playing with their father’s lenses. The Galilean (“Galley-lay-lan”) telescope is made with one positive lens and one negative lens.



The smaller eyepiece lens in the Galilean telescope is called a “negative” lens because it sticks “in” towards the middle, unlike the positive bigger lens that sticks “out” from the middle.

Galileo Galilei (c.e. 1564 – c.e. January 8, 1642) popularized the design of the Galilean telescope and is credited with the first use of a telescope for astronomical purposes in his c.e. 1610 book, *The Sidereal Messenger* also called *The Starry Messenger*.

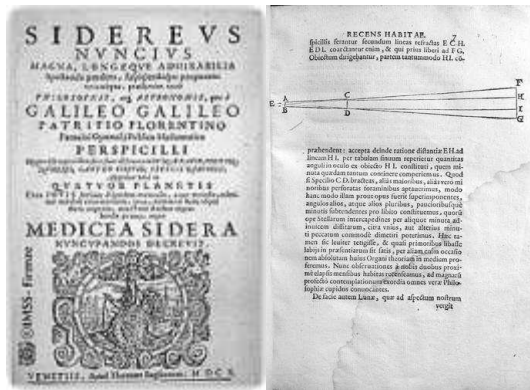


Figure 12 – Cover page from Galileo’s *The Starry Messenger* and his explanation of how a Galilean telescope works



Figure 13 – Galileo’s ink wash drawing of his first views of the Moon through a telescope (left); A page from Galileo’s journal recording his first observations of Jupiter’s Moons (right)

Can you keep a journal of what you have seen through your binoculars or telescope?

Johannes Kepler (c.e. 1571 – c.e. 1630) is credited with later inventing the Keplerian telescope, which uses two positive lenses.

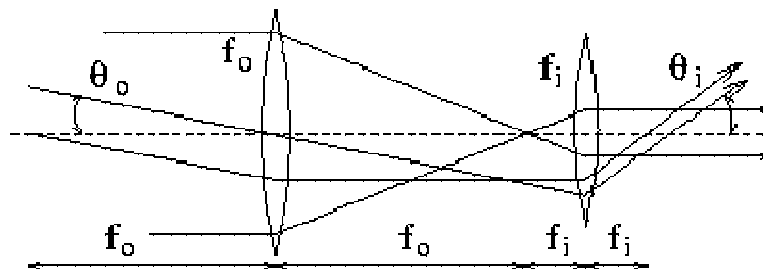


Figure 14 – Keplerian telescope diagram

The Galilean telescope was probably invented before the Keplerian telescope because of the way early lenses were made - by grinding two pieces of flat glass together. The natural result of grinding two flat glass plates together is the creation of one-half of a positive lens and one-half of a negative lens.



Figure 15 – Grinding two flat pieces of glass together to make the halves of a Galilean telescope

- **Why wasn't the telescope invented earlier? The Romans used glass extensively.**

Prior to the 14th century, the quality of glass was primitive. Ancient glass was softer and contained bubbles and dirt.



Figure 16 – Roman hanging glass bowl from 300 c.e. made of a cloudy glass

Lenses were found in a 10th century c.e. grave on a Scandinavian island near the town of Visby. The Visby lenses are thought by some to show that the Vikings invented the telescope. Because of the poor quality of lenses, it is not generally accepted that the Vikings could have used or knew how to use them to make a telescope.



Figure 17 – The Visby Lenses from the 10th century c.e. showing bubble imperfections

In the 1500's, artists in Venice invented a new high-quality and harder glass by adding flint as an ingredient.



Figure 18 - Venetian glass goblet from about 1500 c.e. made of a clear, bubble-free, hard glass

Dutch spectacle-maker Lippershey is thought to have received one of the first shipments of this new high quality Venetian glass to have been allowed out of Venice and into Europe.

• **Further reading**

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- **Materials source**

Edmund Scientific Online. 2006. Bag of Lenses. Product No. 3082272. Count #20 per bag. (2 bags yields a mixture of about 10 Kelperian and Galilean telescopes) <http://scientificsonline.com/>
<http://scientificsonline.com/product.asp?pn=3009445>

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