

## Making a demonstration refractor telescope from mailing tubes and surplus lenses using materials available in 2006



**Figure 1 - Mailing tube refractor built from this handout. Focal length: ~ 38" (97cm) for a negative lens and 48" (121cm) extended for a positive lens; Aperture: ~ 2" or 50mm**



**Figure 2 – Negative (Galilean) and Positive (Keplerian) PVC eyepieces and a stock 2" to 1 1/4" telescope adapter with right angle and 40mm lens**

### • Introduction

This handout is intended to provide instructions for quickly building a demonstration refractor from easily obtained hardware and office supply materials – as those materials were available in the spring of 2006. This handout is targeted to an enterprising parent or older child, school instructors, scout leaders and astronomy club educators who want to have a group project for older children. Construction involves only the use of scissors, a kitchen knife, a screwdriver and tape.

It is hoped that with these instructions, a parent and child can take an afternoon to construct a refractor with some confidence that they can make a single trip to hardware and office supply stores for materials.

This amateur telescope making project and related optics handouts are built around the user mail ordering an inexpensive (~\$15 U.S.) bag of surplus lenses –

Edmund Scientific Online. 2006. Bag of Lenses. Product No. 3082272. Count #20 per bag. <http://scientificsonline.com/>  
<http://scientificsonline.com/product.asp?pn=3009445> (accessed 5/2006)

Edmund bag of lens typically yields enough lenses to construct 4 or 5 refractor telescopes. The lenses included in the bag typically are weak – plano-convex lenses suitable for a refractor objective might have a focal length of 38 inches (965mm) and smaller double convex lenses a focal length of 8” inches (203mm).

The optical quality of these surplus lenses is low. The lenses contain many of the defects experienced by early telescope makers – spherical aberration, chromatic aberration and, for this design, a limited illuminated fraction. The resulting demonstration refractor has a similar low optical quality, but it is useable as a terrestrial daytime telescope, as a lunar scope and to observe the Moons of Jupiter.

These optical defects provide a learning opportunity. Most modern telescopes are relatively free of these defects. The demonstration refractor gives students and telescope-making enthusiasts an opportunity to clearly see these optical defects.

For the related handouts about using these lenses, see “How to make a telescope - school presentation handout/instruction sheets” << <http://members.csolutions.net/fisherka/astronote/astromath/htmatkit/MakeTelesProject.html> >>.

The value of building this demonstration refractor lies in that the refractor uses the Edmund surplus lenses. This demonstration refractor builds on lessons learned in other handouts - that also use the Edmund surplus lenses - regarding magnification and how a telescope works. The natural progression from those handouts is having older children use the same surplus lenses to test and assemble a refractor of their own making.

Other similar pre-existing designs are available on the internet and warrant consideration as an alternative activity:

- Pope, Tom and Mosher, Jim. 2006. Building a Galilean Telescope. [http://www.pacifier.com/~tpepe/Building\\_A\\_Galilean\\_Telescope.htm](http://www.pacifier.com/~tpepe/Building_A_Galilean_Telescope.htm) and [http://www.pacifier.com/~tpepe/Scope\\_Details.htm](http://www.pacifier.com/~tpepe/Scope_Details.htm) accessed 5/2006 (plans and links to other sites with plans for replicas for building a Galilean telescopes, “under \$50” U.S.D. per website)
- Williams, T. and Williams, J. (Rice Univ. Galileo Project) 1995 and 1996. Galileo Replica Telescope Student Project. (\$20 U.S.D. in 1996 per website) <http://galileo.rice.edu/> and [http://galileo.rice.edu/lib/student\\_work/astronomy95/telescope\\_design.html](http://galileo.rice.edu/lib/student_work/astronomy95/telescope_design.html) and [http://galileo.rice.edu/lib/student\\_work/astronomy96/mtelescope.html](http://galileo.rice.edu/lib/student_work/astronomy96/mtelescope.html) accessed 5/2006

- Astronomy Society of the Pacific. 2006. Refractor Kit. In Project Star Kits. <http://www.starlab.com/psprod.html> accessed 5/2006 (\$9 U.S.D. single; \$50 U.S.D. for 10)

The Project Star Refractor kit at \$50 U.S.D. for bulk purchase of 10 scopes is the lowest cost option. A single Project Star Refractor costs \$9 U.S.D.

At a cost of about \$70 U.S.D. to build the first scope, the demonstration refractor illustrated in this handout will not be significantly less expensive than a low-end 60mm commercial refractor that can be purchased (in 2006) at Christmas sales for approximately \$50-\$60 U.S.



**Figure 3 – An inexpensive Christmas sale hobby refractor**





There are some economies of scale in the design. An Edmund #3082272 bag of surplus lenses usually contain enough lenses for 4 or 5 demonstration refractors. Mailing tubes and other components can usually only be purchased in lots of 2 each. Clamps and washers are often available in lots of 2 each.


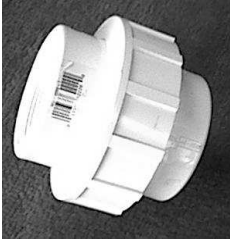

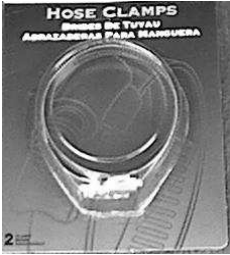
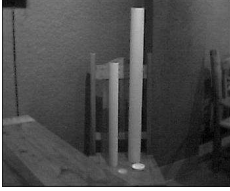

The difference between this demonstration refractors and pre-existing plans is the design is intended to be flexible. Because the lenses included in the Edmund surplus bag may have varying focal lengths, a demonstration tube design needs to be simple and extensible.

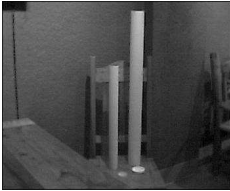



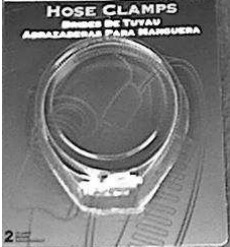

The refractor is sturdy, making it good for heavy use situations. The refractor can be turned over to group of young boys. If the tubes or lenses are damaged, it is a simple matter to replace parts from surplus materials left over after construction.




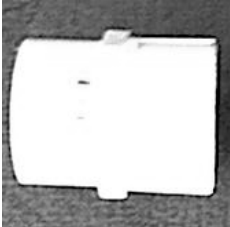

The first scope assembly takes about 45 minutes. After you are practiced, a scope can be assembled in about 15-20 minutes.






- Materials buy list

Item	Qty	Proprietary Brand	Used for	Extended Qty - Price (U.S.D.)	Photograph
<b>Optics</b>					
Surplus lenses		Edmund Scientific Online. 2006. Bag of Lenses. Product No. 3082272. Count #20 per bag	Optics	15.00	
- yielding some variations on	1	Plano-convex lens 2 in (50mm) – focal length ~38 in (965 mm) (specs may vary based on surplus lens bag)	Objective	0.00	
	1	Double-convex lens 1 1/2 in (38mm) – focal length ~203 mm (specs may vary based on surplus lens bag)	Keplerian telescope eyepiece	0.00	
	1	Double-concave lens 2 in (50 mm) – focal length ~ -4 in (100mm) (specs may vary based on surplus lens bag)	Galilean telescope eyepiece	0.00	

Item	Qty	Proprietary Brand	Used for	Extended Qty - Price (U.S.D.)	Photograph
<b>Objective lens holder assembly</b>					
					
3" PVC pressure coupler	1	ACE Hardware WV-2000-T; O.D. 3" (75mm)	Holding the objective lens	6.50	
1-1/2" to 1 3/4" O-rings	2	Checker Auto Parts	Stabilize lens in bushing	2.00	
<b>Tube assembly</b>					
3" Hose clamp	1	Checker Auto PA6848894 - 2 count	Attached objective holder to tube	3.00	
3" x 36" mailing tube	1	Staples 718193722168 - 2 count	Space objective and eyepiece	5.60	
with 2 end caps	1	Included	Objective lens cap	0.00	

Item	Qty	Proprietary Brand	Used for	Extended Qty - Price (U.S.D.)	Photograph
2" x 24" mailing tube with 2 end caps	1	Staples 718103822152 - 2 count	Vary spacing objective and eyepiece, hold eyepiece	3.30	
with 2 end caps	1		Eyepiece tube cap	0.00	
2" Electrical conduit connector	2	ACE 33211 (\$1.80 each)	Fit 2" inner mailing tube to outer 3" mailing tube	3.60	
Heavy Duty Plastic Packaging Tape	1	Staples 718103020749	Fit 2" inner mailing tube to outer 3" mailing tube	5.30	
2" Hose clamp	1	Checker Auto PA6141360 – 2 count	Optional secure eyepiece in 2" inner mailing tube	3.00	
Flat black spray paint can	1	Flat black not gloss black	Paint inside of outer and inner mailing tubes to reduce reflection	6.00	

Item	Qty	Proprietary Brand	Used for	Extended Qty - Price (U.S.D.)	Photograph
<b>Positive eyepiece assembly</b>					
PVC Coupler	1	ACE 43107 - 2" OD x 2 1/2"	Hold lens; attach to 2" tube	0.50	
1-1/2" neoprene sink washer	3	Department store (\$1.50 for a package of 6)	Stabilize lens in bushing	1.50	
PVC Bushing	1	ACE 45862 - 2" OD x 1 1/2"	Hold lens in bushing	1.30	
<b>Negative lens assembly</b>					
Adapter	1	ACE 43113 - 2" OD x 2 1/2"	Inserts into 2" mailing tube end	0.80	
Close	1	ACE 406-201 1 1/2" OD x 1 1/2"	Couples first coupler to second coupler; screws into Adapter	0.50	

Item	Qty	Proprietary Brand	Used for	Extended Qty - Price (U.S.D.)	Photograph
Pressure coupler	1	ACE 13121 – 3" OD x 2 1/2"	Holds negative lens; "Close" screws into one side	1.00	
2 5/8" OD, 2 1/4" ID O-Ring	1	ACE 56061A	Stablize larger negative lens in bushing	1.10	
1 7/8"-2 1/4" O-Ring	2	ACE 56064D (\$0.90 each)	Stabilize lens in bushing	1.80	
Plug	1	ACE 14852 – 2" OD x 2"	Secures lens in coupler	2.00	
<b>Solar viewer</b>					
Sheet of artist black foam poster board	1	Art supply store	Mask Sun for solar projection	5.00	
<b>Total</b>				68.80	

**Table 1 – Materials Purchase List**

• **Tools**

○ **To build refractor**

- Serrated kitchen knife
- Scissors
- Flathead screw driver
- 3 foot by 5 foot workspace



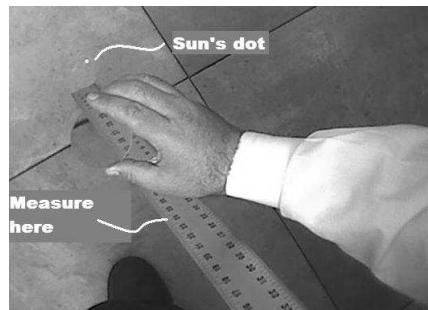
- **To build optional solar posterboard**
  - 2" inch door hole drill
- **Optional materials (assumed owned)**
  - 2" to 1 ¼ " telescope focuser adapter
  - Right-angle mirror
  - 30mm and 20mm eyepieces
  - Ladder (as a mount for the refractor)
  - Bungee cords (used to lash refractor to ladder)
- **Building the demonstration refractor**
  - **Find the focal length of the positive objective and positive eyepiece lens**

For the positive objective and positive Keplerian eyepiece lens, find the focal length of the lens using the Sun method.

Uses: Yardstick, ruler, big lens.

With the Sun overhead, hold the lenses over some concrete or paper on table.

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

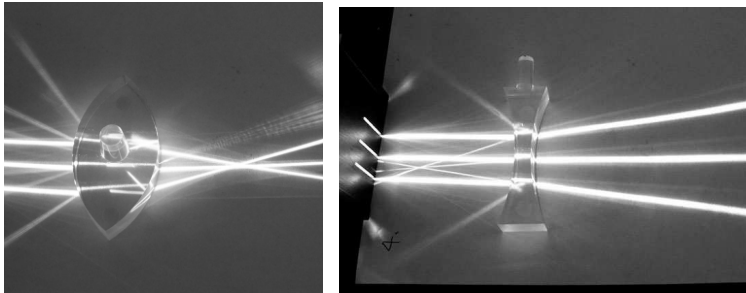
Positive objective lens's focal length is \_\_\_\_\_ inches or \_\_\_\_\_ centimeters.

Positive eyepiece lens's focal length is \_\_\_\_\_ inches or \_\_\_\_\_ centimeters.

o **Find the focal length of the negative eyepiece lens**

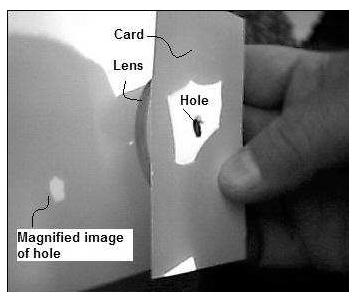
For the negative eyepiece lens used for making a Galilean telescope, find the focal length of the lens using the spot test method.

A negative lens diverges light rays, but still has a focal length.



**Figure 5 – Light traveling through a positive lens (left) and negative lens (right) compared**

The focal length of a negative lens can be measured using the spot test. Take a piece of paper and using a pencil, poke a hole in it. Measure the size of the hole with a ruler in millimeters. Put the ruler on the ground outdoors with the Sun overhead. Now hold the paper and hole over the negative lens with the Sun directly overhead. Move the lens and paper back and forth until the circle of light passing through the lens is twice the size as the hole in the paper.



**Figure 6 - Measuring the focal length of a small negative lens**

The lens is now one focal length from the ground. Measure the distance from the center of the lens to the magnified image of the hole.

Negative eyepiece lens focal length is \_\_\_\_\_ inches or \_\_\_\_\_ centimeters.

- What is the sum of the two focal lengths of the positive objective and the positive eyepiece lenses?

Lens	Focal length
Objective lens	
Positive eyepiece lens	+
Sum of focal lengths	=

- What is the difference of the two focal lengths of the positive objective and negative eyepiece lenses?

Lens	Focal length
Objective lens	
Small negative lens	-
Difference of the focal lengths	=

- Build the objective lens assembly



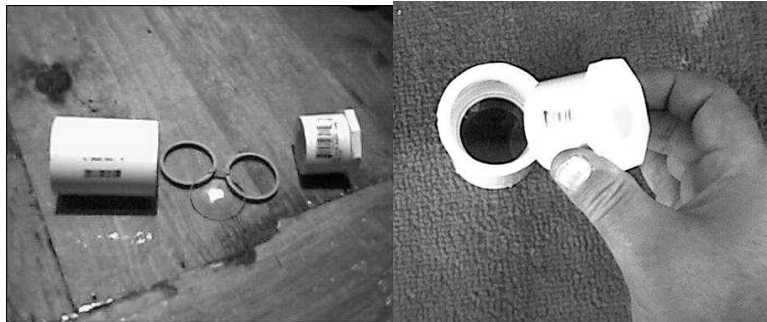
Figure 7 – Assemble the objective lens

Secure the positive double convex lens between the halves of the compression union. Do not over-tighten. The easiest way to tighten the compression union while holding the objective lens centered is to put your finger on the objective lens. Then tighten the upper part on to the lower part.



**Figure 8 – Tightening the assembly**

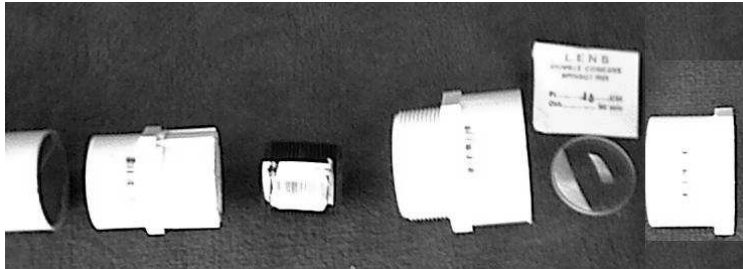
- **Build the positive eyepiece lens assembly**



**Figure 9 – Assemble the positive eye piece**

Just push the parts gently together. If you jam the parts together, a screw driver or pipe wrench can be used to pull them apart. Use as many ring washers as necessary so the plug can be inserted gently but securely into the coupler. Although two are shown in the preceding figure, I used three. Your situation will vary.

- **Build the negative eyepiece lens assembly**



**Figure 10 – Assemble the negative eyepiece using the double concave negative lens**

Use as many O-rings as necessary so the plug can be inserted gently but securely into the coupler. Although three are shown in the preceding figure, I used two. Your situation will vary.



**Figure 11 – Assembled the negative eyepiece**

- **Prototype the telescope layout**

Prototyping the telescope layout involves deciding how long to make the outer telescope tube. The inner tube at most moves into the outer tube enough so that the negative eyepiece lens will focus. At most it moves out far enough so the positive eyepiece lens will come into focus. Both the negative and positive eyepieces are positioned relative to the focal length of the big objective lens.

From the handouts on “How to make a Galilean Telescope” and “How to make a Keplerian Telescope”, the general rules for constructing these telescopes are:

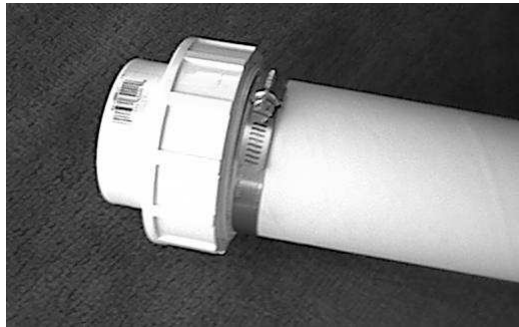
The image formed by the objective is a real image. It is formed at the distance of the positive objective lens’s focal length that you found above.

For the Galilean telescope, the lenses are positioned so they have the distance between them equal to the “Difference of the focal lengths” that you subtracted above.

For the Keplerian telescope, the lenses are positioned so they have the distance between them equal to the “Sum of the focal lengths” that you subtracted above.

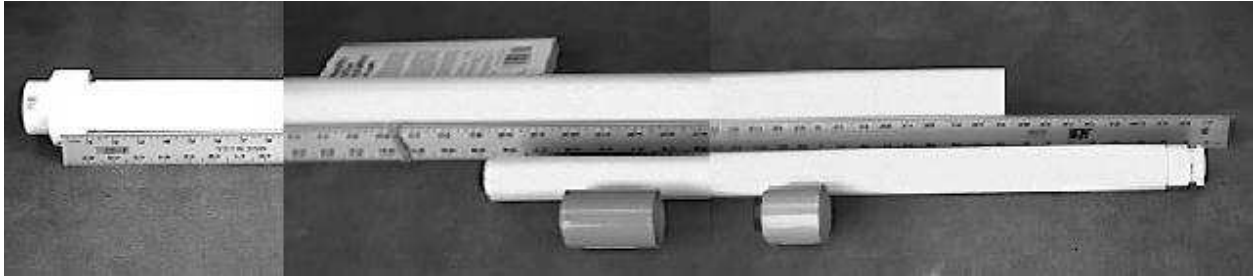
Let’s prototype the telescope.

Temporarily mount the objective lens on one end of the large 3” tube. Optionally, secure to the 3” tube with the large hose clamp.



**Figure 12 – Mount the objective in the large tube**

Lay the tube next to a yardstick. Find where the image formed by the objective is a real image. It is formed at the distance of the positive objective lens’s focal length that you found above. This is called the *focal plane* of the objective.



**Figure 13 – Layout the scope parts and find where the real image of the objective will form – at the objective’s *focal plane***

In our working example, telescope, the focal length of objective positive lens’s was 38 inches (965 mm). The positive eyepiece lens’s focal length is about 8 inches (203 mm). The negative eyepiece lens’s focal length is about 4 inches (100mm) or *minus* 4 inches.

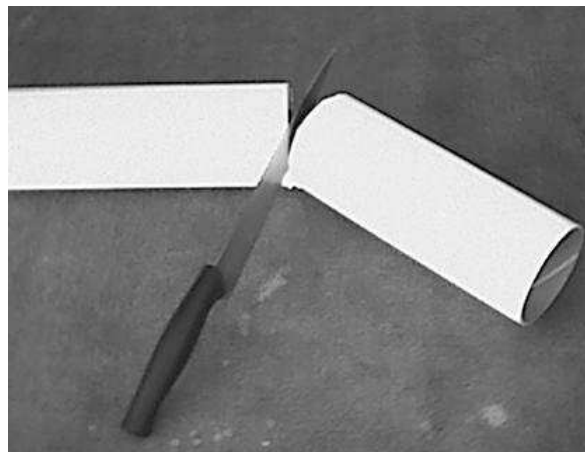
In the working example (your computations will be different), the positive eyepiece lens must be at 38 inches plus 8 inches or equal to 46 inches from the objective lens to be focus. The negative eyepiece lens must be 38 inches *minus* 4 inches or equal to 34 inches from the objective lens to be in focus.

Test the position of the negative eyepiece lens, the positive eyepiece lens and the inner smaller mailing tube to determine where the larger 3 inch mailing tube should be cut-off.

In the working example, I decided to cut the outer mailing tube at 30 inches.

- **Make the outer tube**
  - **Cut**

Cut the outer tube to length using the serrated kitchen knife.



**Figure 14 – Cut the outer tube to length**

- **Paint the large and small tube interiors flat black**

Spray flat black paint into the both ends of the tube in order to reduce tube reflections. It is not necessary to paint the last three or four inches of the tube interiors near the outside of the each end of the tube. Those parts of the tube will always have a solid part inserted in them.

- **Attach the objective lens holder assembly**

The objective lens is currently attached to a “clean” tube end. Remove it and reattach it on the cut end of the tube. Secure the objective lens to the tube with the large hose clamp.

- **Make the objective lens cap**

Take the waste portion of the large tube. Close one end of with a mailing tube cap. Cut it to 3 to 5 inches in length.



**Figure 15 – Objective lens cap**

This waste tube fits over the objective lens and serves as a lens cap.

- **Make the inner tube**

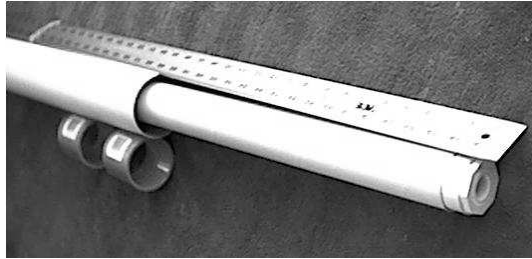
The inner mailing tube (1) slides in and out of the outer mailing tube and (2) holds the eyepiece lenses. The plastic packaging tape is used to build up the diameter of the inner 2 inch mailing tube until it slides smoothly but firmly inside the 3 inch outer mailing tube.



**Figure 16 – Materials used to make the inner mailing tube**

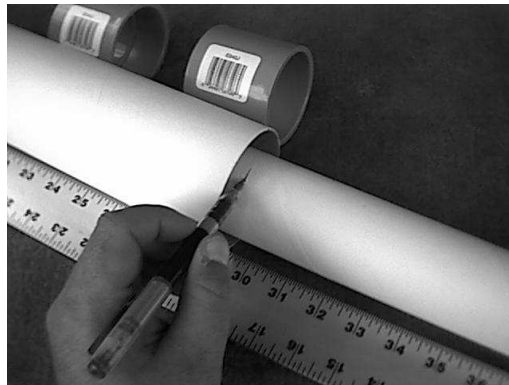


- **Prototype where the electrical conduit connectors will be placed around the inner tube**



**Figure 17 – Layout the inner tube spacers**

Begin laying out the inner mailing tube and spaces. Fully extend the tube so the positive eyepiece is near focus. For the working example, that is 38 inches plus 8 inches or equal to 46 inches from the objective lens. The spacers cannot be further “down tube” than this point. Mark this location on the inner tube with a pen:



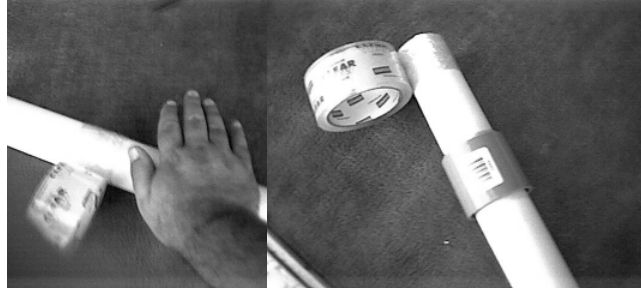
**Figure 18 – Mark the maximum down tube location that the spacers can be placed around the inner tube**

The first spacer will be placed at one end of the inner mailing tube.

- **Wrap the inner tube so the electrical conduit connectors are securely held to the inner tube**

To secure the spacer around the inner tube, wind the clear packaging tape around the tube until the conduit spacer securely fits on the tape.

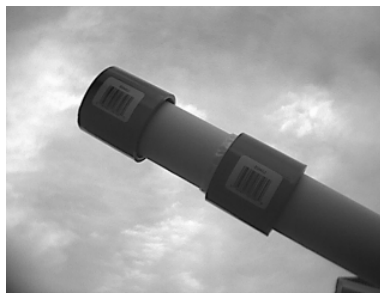
The easiest way to wind the packing tape around the inner tube is to lay the tube on a flat surface and then wind the tape on to the tube by rolling the inner mailing tube forward.



**Figure 19 – Rolling the inner mailing tube on a flat surface to build up a layer of packing tape around the tube**

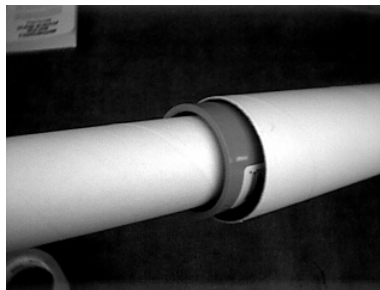
Repeat the process with the second spacer. It can be placed anywhere between the first spacer and the pen mark you made above. The spacer should be placed closer to the pen mark so the two spacers, acting together, will hold the inner tube squarely centered inside the outer tube.

The end result is the two spacers will securely and firmly slip around the inner mailing tube.



**Figure 20 – Spacers mounted on the inner mailing tube**

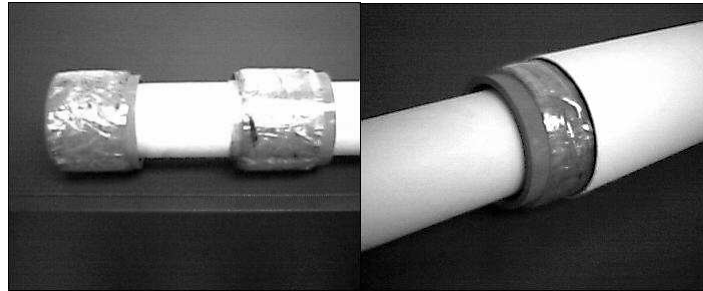
There will still be space between the outside diameter of the electrical connectors and the inside diameter of the 3" outer mailing tube.



**Figure 21 – Residual space**

- **Wrap the electrical connectors so the inner tube securely slides within the outer tube**

Repeat the wrapping process on the outside of the electrical connectors until a layer of packing tape is built up. When finished the inner tube will firmly slide with friction and resistance inside the outer tube.

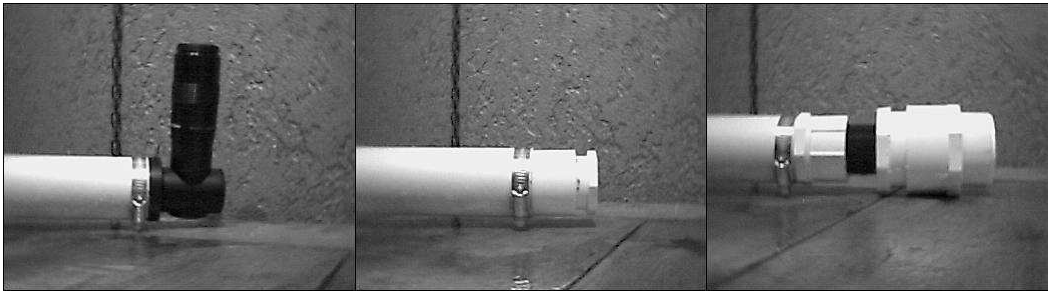


**Figure 22 – Finished inner tube wrapping (left) inserted into outer tube (right)**

- **Paint tube interior flat black**

If you have not already painted the interior of the inner 2” mailing tube black, do so now. The last few inches of the eyepiece end of the tube do not need to be painted. Eyepieces, when inserted, cover this area.

- **Join the inner and outer tubes**
- **Add the second 2” hose clamp to secure eyepieces to the inner tube**



**Figure 23 – Second hose clamp secures eyepieces**

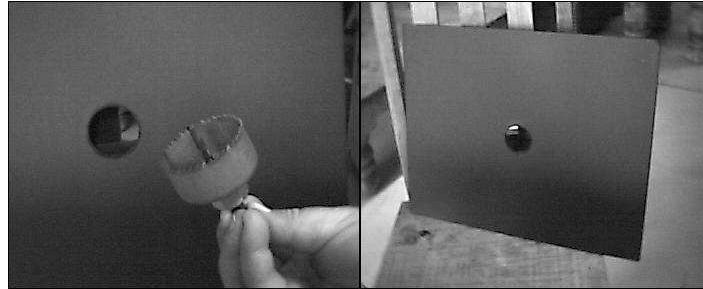
The small 2” hose clamp can be hand tightened. A small coin can be used to tighten it further if you are concerned about an expensive eyepiece falling off the back of the inner mailing tube.

- **Make the solar projection light mask**

Cut a 16 inch by 24 inch piece from the artist foam-board.

Using the door hole drill, drill a 2" hole into the center of the foam-board.

To use, remove the 2" hose clamp from the inner tube and slip the foam-board onto the inner tube.



**Figure 24 – Drill a 2" hole in the center of the solar mask**



**Figure 25 – The solar mask installed on inner tube**

- **Use notes**

- **Optical quality**

As stated above, the optical quality of this demonstration refractor is low, because the quality of the Edmund surplus lenses is low. The refractor is useable as a terrestrial refractor and passable for demonstrating beginner lunar observation.

With the positive eyepiece two or three Jupiter moons will be visible.

When standard telescope lenses are used, the scope will show three or four Jupiter moons with chromatic aberration.

- **With the positive and negative lenses**

These lenses can be used to demonstrate the erect image produced by a Galilean telescope and the inverted image of a Keplerian telescope.

- **With standard 40mm, 30mm and 20mm telescope eyepiece lenses**

Using the standard 40mm, 30mm and 20mm telescope eyepieces either with or without a right angle, improvements in the quality of the image and basic TFOV/AFOV math can be demonstrated.

- **Additional study topics**

- **Chromatic aberration**

With a standard 40mm, 30mm and 20mm telescope eyepieces on a bright planet or star, chromatic aberration can be demonstrated. The low-quality Edmund surplus lens plano-convex lens has strong chromatic aberration. On Jupiter and Arcturus, it is possible to move the tube inside focus and have the object turn red and to move the tube outside focus and have the object turn blue.

- **Spherical aberration**

In terrestrial viewing with the positive and negative PVC eyepieces, spherical aberration is evident.

- **Illuminated fraction (tube interference)**

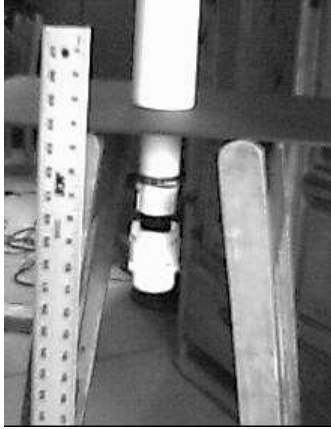
In terrestrial viewing with the positive and negative PVC eyepieces, a distinct illuminated circle is visible in the center of the TFOV.

- **Focal length and right-angle mirror use**

With a right-angle mirror and telescope eyepiece, it is possible to demonstrate how the sum of the right-angle distance still nearly positions the focal length of the objective and eyepiece show they overlap. The computation will not be exact because the right-angle mirror slightly refracts the light and changes the total focal length of the prime focal plane.

- **Negative projection (of the Full Moon or Sun's image)**

Standing the refractor with the Sun mask installed between two chairs, with the negative eyepiece pointing towards the ground, it is possible to project an image of the Full Moon or Sun on to a piece of paper.

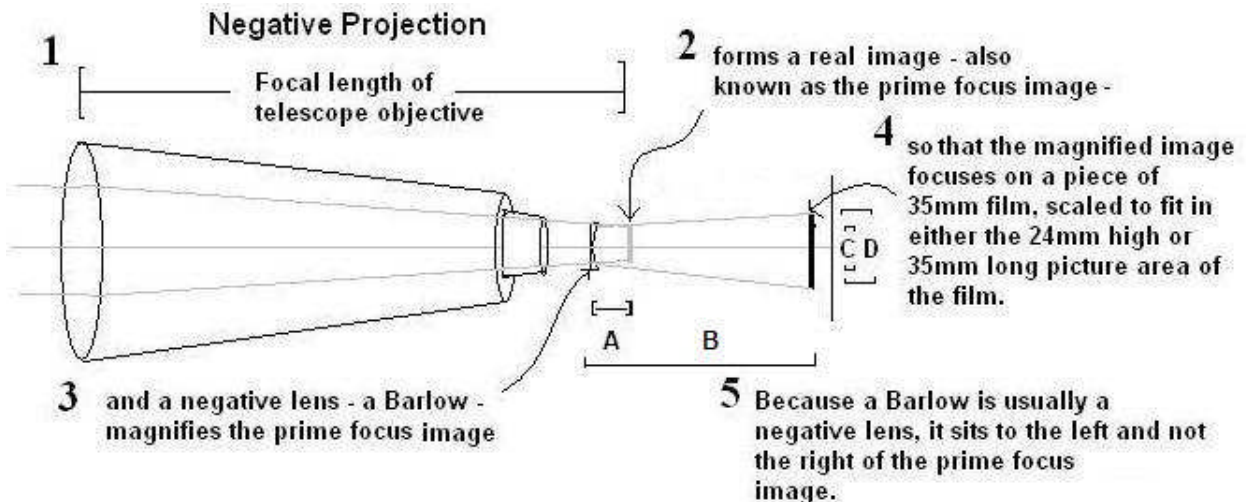


**Figure 26 – Projecting an image of the Full Moon or Sun using negative projection**

As usual, a telescope should never be pointed at and directly viewed with the eye. Instant blindness will result.

In negative projection, the real image created by the objective lens – called the prime focal place at prime focus - is projected by a negative eyepiece lens.

Projection occurs for a negative lens when it is at a working distance between 0 and 1 focal length from the prime focal plane. At 0 focal lengths from the mirror the image is magnified 1x. As the negative lens moves further from the prime focal plane, but short of 1 focal length, a magnified image is projected further outside focus. See the handout “Hand magnifiers”.



**Figure 27 – Negative projection**

In our working example, the focal length of the objective is 38 inches. The focal length of the negative eyepiece lens is 4 inches. As the negative lens is moved between 0 and 4 inches from prime focus, a magnified image is projected.

The distance between the lens and prime focus is generally termed the “A” distance. Two questions arise from positioning the negative lens between 0 and one focal length:

First, for any “A” distance and any focal length of the negative eyepiece lens, how much is the projected image magnified?

Second, where is the magnified image projected to? This is the distance between the lens and the projected and magnified image. It is called the “B” distance.

Some simple math gives the answers:

$$M = F / (F - A)$$

$$M = B/A \text{ or } B = M \times A$$

Where M is magnification, F is the focal length of the negative lens and A and B are distances from the negative lens.

For the working example, the negative lens has a focal length of 4 inches. The working distance is between 0 and 4 inches from prime focus at 38 inches. At a zero “A” distance, there is no magnification. At nearly 4” from prime focus, the negative lens will have its highest magnification.

If the lens is positioned 2 inches from prime focus, then:

$$M = 4" / (4" - 2") = 4/2 = 2x$$

$$B = 2 \times 2" = 4"$$

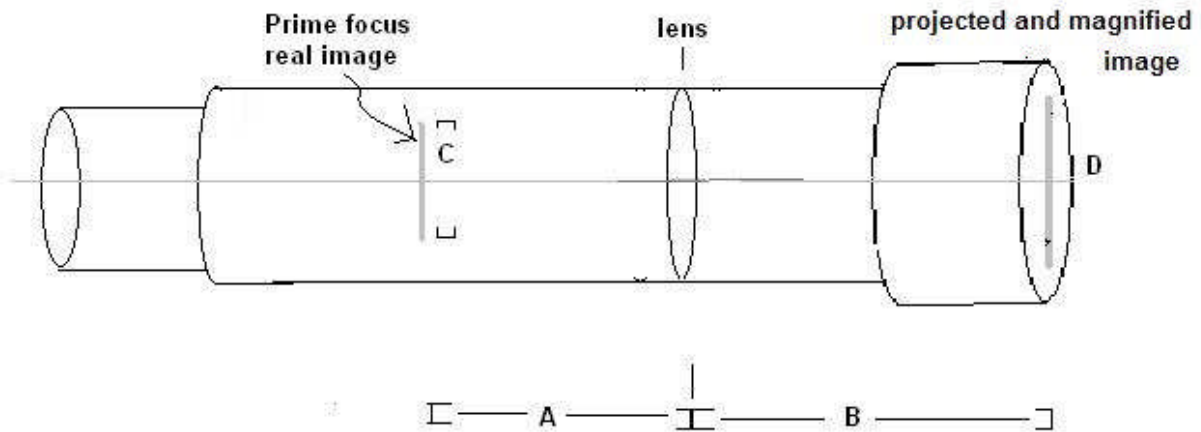
4 inches from the negative lens, an image will be projected that is 2 times the size of the image at prime focus. At 3 inches, the projected image will be magnified 3x at 9 inches from the lens. At 3 ¾ inches, the projected image will be magnified 16x at 60 inches from the lens.

A helper can hold the yardstick next to the scope to demonstrate that to negatively project an image, the negative eyepiece is moved inside focus of the real image at the focal plane.

This demonstration can become a jumping off point for a discussion of positive eyepiece projection as it typically done in astrophotography. See Edmund’s *Photography with your telescope* for more information.

- **Positive projection (of the Full Moon’s image)**

Positive projection uses a positive lens to project and magnify an image. In positive projection, the positive eyepiece lens is used at a working distance of one to two focal lengths from the real image created by the objective lens. At one focal length, the projected is maximally magnified and projected. At two focal lengths, there is 1x magnification. See the handout “Hand magnifiers”.



**Figure 28 – Positive projection of an image**

Because the positive lens is positioned outside focus, we cannot use our demonstration refractor with its positive eyepiece to show positive projection. The working placement of the eyepiece lens, the “A” distance, is one to two focal lengths of the eyepiece lens.

In our working example, that is 8”. So the positive lens would have to be positioned between 8” and 16” inches outside of the prime focal plane at 38 inches. The inner tube does not extend that far.

We can use a smaller 30mm telescope eyepiece to show positive projection. Because the 30mm telescope eyepiece lens has a positive projection working distance between 30mm and 90mm (1.2” to 3.5 “), the inner mailing tube can be extended into the lens’s working range.

Because the intensive light and heat of the Sun can damage a telescope eyepiece, this demonstration should be done using the Full Moon.

As with negative projection, a couple of questions arise regarding positive projection. First, for any “A” distance and any focal length of the positive eyepiece lens, how much is the projected image magnified? Second, where is the magnified image projected to? This distance is the distance between the lens and the projected and magnified image. It is called the “B” distance.

Some simple math gives the answers:

$$M = F / (A-F) \quad (\text{Note reverse of terms in denominator})$$

$$M = B/A \text{ or } B = M \times A$$

Where M is magnification, F is the focal length of the positive lens and A and B are distances from the positive lens.

For our working example, the 30mm positive lens has a focal length of 30mm and is positioned 45mm from the prime focal plane of the objective.

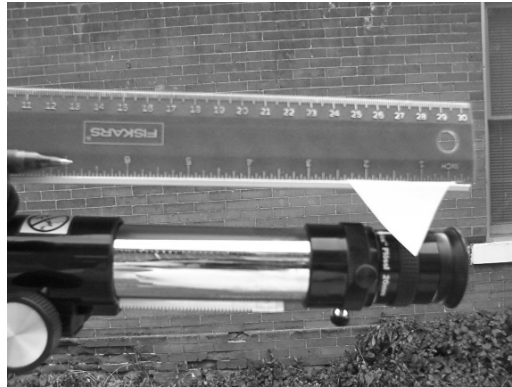


$$M = 30\text{mm} / (45\text{mm}-30\text{mm}) = 30\text{mm}/15\text{mm} = 2x$$

$$B = 2 \times 30\text{mm} = 60\text{mm}$$

If the positive lens is positioned at 32mm from the prime focal plane, the magnification will be higher. At 32mm from prime focus, the image will be magnified 15x and the image will focus at 450mm from the eyepiece lens.

To locate prime focus, put a low focal length telescope lens in the scope. A 9mm is a good choice. A 20mm lens is used in the following photograph of a low-end Christmas refractor:



**Figure 29 – Finding the prime focal plane**

Measure back from the center of the eyepiece lens, a distance equal to the focal length of the eyepiece. The prime focal plane is approximately at this location.

- **Legal disclaimer**

**As always, never point a telescope at the Sun and look through the eyepiece. You will go blind.**

- **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

- **Further reading**

Consolmagno, Guy et al. 2000. (3<sup>rd</sup> ed). *Turn Left at Orion: A Hundred Night Sky Objects to See in a Small Telescope--and How to Find Them*. Cambridge University Press. ISBN: 0521781906

Edmund Scientific. 2001 (reprint). *Popular Optics*. Edmund Pub. No. 30094-45. <http://scientificsonline.com/>  
<http://scientificsonline.com/product.asp?pn=3009445>

Edmund Scientific. 1998 (reprint). *Photography with your telescope*. Edmund Pub. No. 9078 (positive and negative projection tables)

- **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>

ScopeStuff. 2006. Website. <http://www.scopestuff.com/>  
[http://www.scopestuff.com/ss\\_adap1.htm](http://www.scopestuff.com/ss_adap1.htm) ( 2" focuser adapter)

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