Photography Without Lenses

X487.7 ART (2.0) **PINHOLE PHOTOGRAPHY AND CYANOTYPE PHOTOGRAMS**

A UCSC extension course taught by Martha Casanave and Chris Patton. This class is being offered on April 27-29, 2007, at Hopkins Marine Station, Pacific Grove, CA. These pages contain the technical information prepared for the class. [Students will receive this information in "solid" form during the course]. Questions can be addressed to Chris, at any time [even after the course] **at owamoosa@gmail.com. WEB SITE: http://owamoosa.com/pinhole (updated 1/2022)**

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Choconuts #1, non-ideal pinhole 0.5mm, 15 minute exposure on 4x5 Ilford Technical Ortho film.

"If you are following the crowd, then pinhole is not for you. You will never be famous, rich, etc. with pinhole images. BUT you will become more alive, more aware. You will learn to know yourself better. Pinhole is more of a spiritual experience than any other kind of photography. Pinhole photographers have a quiet passion about their work that cannot be expressed easily in words. It is just something we have to do!"

PINHOLE

Photography can be quite technical and very intimidating because of this. It is possible to be VERY technical with the pinhole and there are some valid scientific reasons why an engineer may want to be.

BUT, the art of pinhole is entirely different. Principle reasons for using a pinhole camera are: 1) Depth of field is essentially infinite, 2) Time dilation from long exposure times, 3) Not as sharp as real lenses, giving a dream like quality.

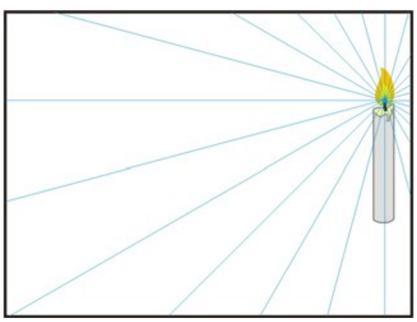
The pinhole for the camera can be as simple as a hole in a dark curtain to as complex as a laser produced platinum aperture for an x-ray telescope.

	Low Tech	Medium Tech	High Tech
ability	easy	takes practice	easy
cost	low	low	high
sharpness	low	medium - high	highest

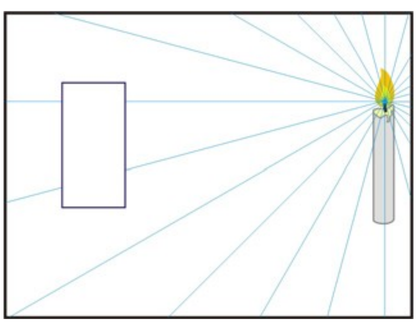
How it works: Basic Pinhole Box

Fundamental Law: Light travels in a straight line

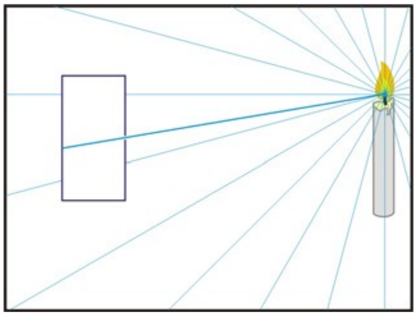
A candle emitting light behaves in this way



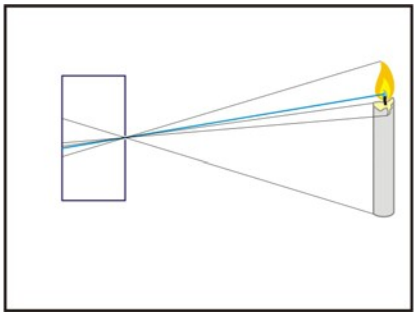
Tracing out some of the light rays illustrates this point



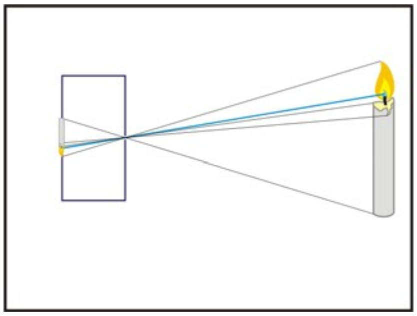
Adding a light tight box blocks light from entering



If we add a small hole at the center, some light can enter



We can trace light reflecting off of the rest of the candle in the same way. [rays not going through pinhole removed for clarity]



And form an image of the candle upside down at the back of the box

If we now add film at the back of the box [at the image plane] and a cap over the hole to control when light enters the box, we have a camera.

That's it. This is a basic pinhole camera and all that is needed to make images.

The rest is refinement and variation.

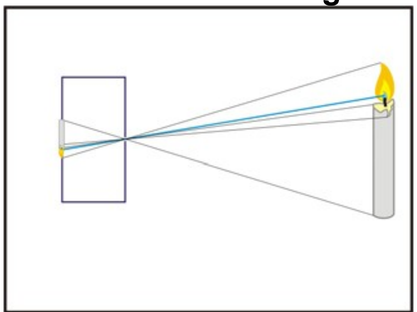
1) The reason the depth of field [also called depth of focus] is so large is because there is no lens. You do not focus a pinhole. It works because of its size in relation to the distance to the film.

2) The reason for the time dilation is because of the size of the pinholes needed. A small hole lets in very little light necessitating a long exposure. Typically this is from one half to two seconds on a sunny day, to minutes or even hours indoors.

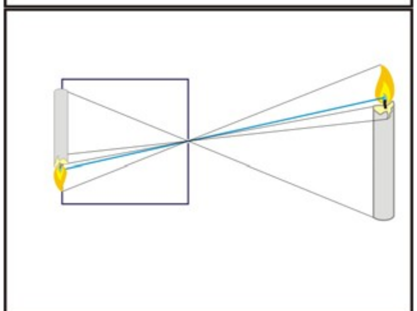
3) The reason the pinhole camera gives such 'dreamy' images is because it is not possible to make a pinhole 'sharp'. The resolution of the pinhole is limited by the size of the hole and a limitation called the 'diffraction limit'.

How it works - Wide Angle vs Telephoto

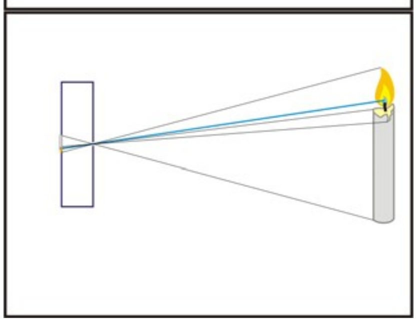
Fundamental Law: Light travels in a straight line



We saw from **Basic** that an image can be formed from a pinhole because light travels in a straight line.
Note the size of the image formed.



If we make the box longer, by tracing the light rays we can see that the image of the candle gets bigger.
This is a telephoto lens.



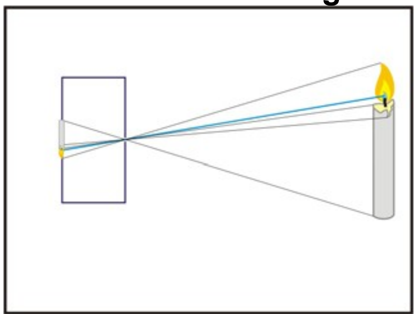
Alternatively if we make the box shorter, by tracing the light rays we can see that the image of the candle gets smaller.
This is a wide angle lens.

That's it.

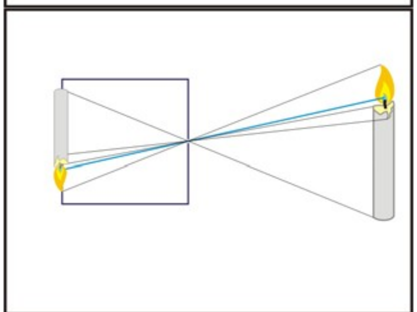
[And with lens photography this explanation is only slightly more complicated, but basically the same idea.]

How it works – Close-up

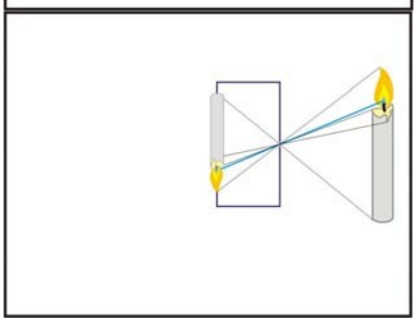
Fundamental Law: Light travels in a straight line



Our "normal" pinhole camera makes an image of a set size based on the size of the box and the distance to the object. This comes from following the light rays through the pinhole to the film at the back of our light tight box. [see **Basic**]
We can enlarge the image one of two ways:



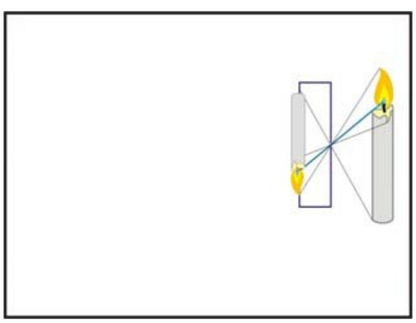
By making the box longer, we form a telephoto camera which enlarges the image.
But this requires a new box to achieve.



By moving the 'normal' box closer to the object we can also enlarge the image to the same size as the telephoto image.

The difference between using a new telephoto pinhole box and moving your current one closer can be interesting and is worth investigating.

[Hint: note the angle of the light going through the pinhole and how it is different in the two images above and the one below.]



IF we use the wide angle camera from the last page we can get a close-up image of the same size from an extreme angle.

All three cameras produce the same size image, but the angle relationships to each part of the image are very different.

Building Cameras:

35mm and any other camera with removable lens:

a) Remove lens and tape pinhole in aluminum foil over opening [see below]

Oatmeal boxes and other "found" objects [empty paint cans work great!]:

a) SINGLE SHOT! Can be loaded with only one piece of film/paper at a time.

b) Make sure it is light tight. Good to paint interior flat black. Use black opaque tape to seal edges where box is opened

c) Can produce "bizarre" images, because of the shape of the film plane [curved]

d) Does not look like a camera (candids are easy to obtain)

Holga Pinhole

a) Uses easy to obtain and process 120 film and with 12 – 16 images per roll makes it easy to do a field trip without needing a darkroom nearby

b) Camera is very inexpensive, $20, and is easy to adapt to pinhole. Minimal skill needed.

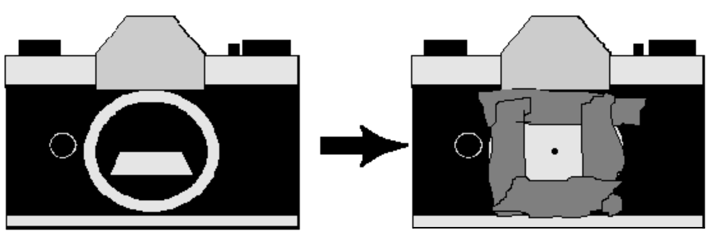
Bizarre

People have built pinhole cameras from cars, rooms, eggs, their own mouth, garbage cans, etc. You are limited only by your imagination and your ability to make it light tight.

Low Tech: (easy & low cost)

Materials: aluminum foil, black felt marker, pin, opaque tape, and a piece of cardboard.

1) Flatten a 1-inch square of aluminum foil on a piece of cardboard.
2) Blacken foil on side with the black marker
3) Gently make a hole in the center of the foil with the pin [or better yet, a fine needle from a cactus]
4) Remove lens from camera
5) Carefully tape pinhole over camera, black side towards camera



If you have a camera with an automatic exposure, then you can begin taking pictures. You will have to guess what you are taking a picture of because the image in the viewfinder will be too dark to see. Do not be afraid to get close, REAL close. Everything is in focus with the pinhole camera! [Alternatively, you can make one with a body cap that is interchangeable with your normal lenses (but see Thickness for why you still need to use foil over a larger hole in the lens cap)]

Medium Tech: (takes practice, low cost, can produce "sharp" images)

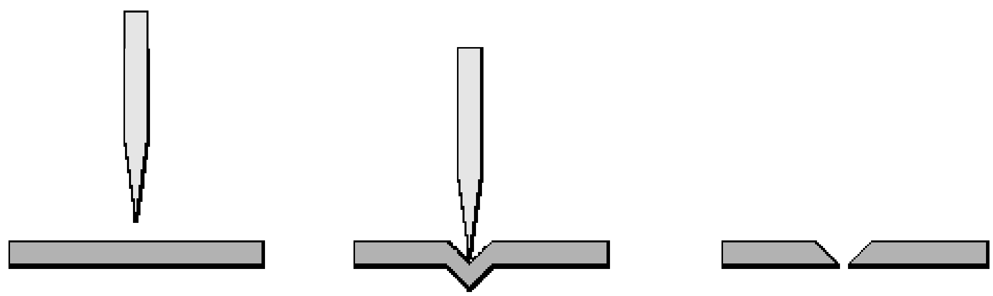
Materials: sewing needle, thin brass shim material, emery paper, measuring loupe, opaque tape, sharpie pen, cardboard.

1) Cut out a 1 inch square of brass shim and place on cardboard

2) Gently push the sewing needle into the brass, but not all the way through

3) Sand paper the "bump" on other side of the brass

4) Repeat steps 2 & 3 until a very small hole is produced

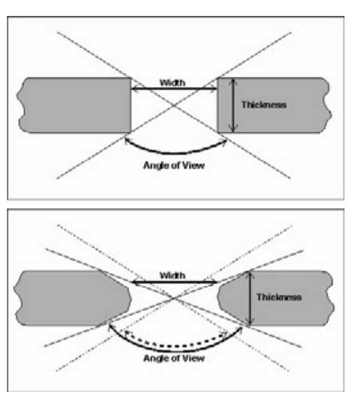


5) Measure the size of the hole with the measuring loupe. You can always make a hole larger, but you cannot make it smaller without starting over.

6) Blacken brass around the hole and tape onto camera as with the aluminum foil method.

7) Calculate the f-stop and use the camera [f-stop = distance to the film divided by the diameter of the pinhole]

This is the method that the "purist", the REAL pinhole photographers use. It is possible, with practice, to produce a better pinhole than with the commercial laser processes. This is because the edges of the pinhole are rounded, allowing for a slightly better field of view and less flair in bright sun.



High Tech: (easy, high cost, potential for "sharpest" image)

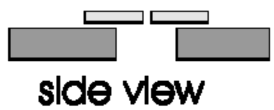
Materials: purchased pinhole (see suppliers section), brass shim material, opaque tape, Sharpie pen

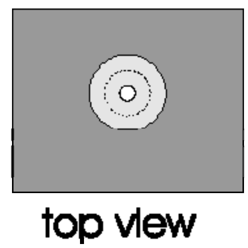
1) Make a hole in the brass larger than the pinhole but smaller than the material the pinhole in on.

2) Blacken the brass with the sharpie pen.

3) Tape the pinhole to the brass and tape the brass to the camera

4) Calculate the f-stop and use the camera [f-stop = distance to the film divided by the diameter of the pinhole]





As this method does not require the "practice" that the medium tech method, it is the method of choice where you want the sharpest image, but don't want to take the time and energy to learn a new skill. [Wait, learning to do pinhole photography is a new skill!]

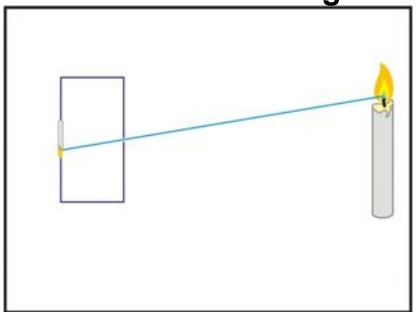
Holga Pinhole Cameras [Pinholgas]

We will be using the high tech method in class with the Holga cameras. We actually rip the lens off and throw it away! [or save it as a magnifier to look at the quality of pinholes]

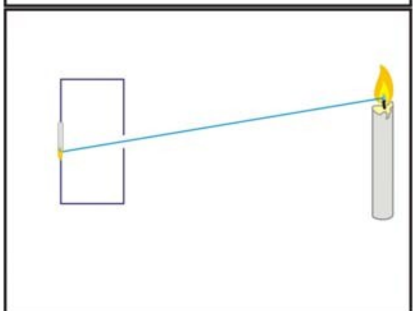
By using CN based black & white film it is possible to get the film processed quickly locally and get results to view within the class period.

How it works - Size of the Pinhole

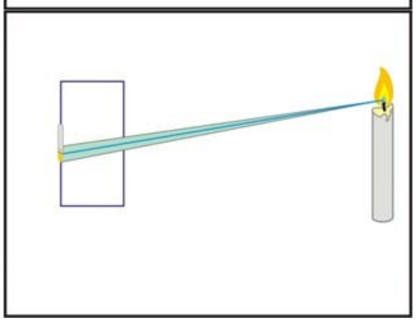
Fundamental Law: Light travels in a straight line



Under ideal conditions the light reflecting or emitting from one part of an object we wish to image can only fall on one location on our film. We get a perfect copy of our candle, upside down, on our film. However, the world is not perfect [I know this comes as a shock to all of you.]
[I have reduced the rays to just the one coming from the center of the flame to make this clearer.]



Now I will enlarge the size of the pinhole [actually ridiculously large for a real camera, but hey, these are cartoons]:



As you can now see, there is space around our ray going through the center of the pinhole. What this means is that the ray is no longer restricted to just the center and can wander over the rest of its new range. What was once a nice tiny pinpoint image of the center of the flame has expanded to cover a much larger area. In real world terms, the image is now very blurry.

RULE #2: The smaller the pinhole, the smaller this 'circle of confusion' cast onto the film plane and the sharper the image.

large pinhole

smaller pinhole

even smaller pinhole

Rule #3: Rule #2 has a limit, called the **diffraction limit**. The limit happens because under the right conditions [too small of a hole for the distance used], light can break Rule #1 and interfere with itself causing the image to spread.

So what we expect to get from an even smaller pinhole is a sharper image, but . . .

Expected

What we actually get is a blurrier image

Pinholers will debate exactly where this crossover point is and some, such as this author, will go to great lengths to achieve the "Ideal" pinhole size.

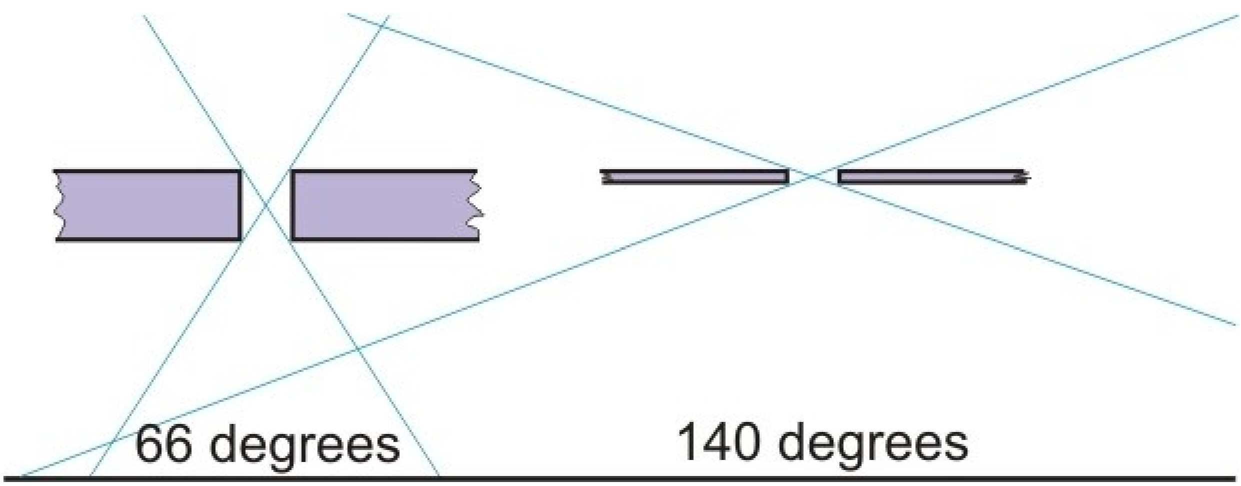
"Life is not fair." President Jimmy Carter

See formula sections for calculators/formulas for determining the ideal pinhole OR learn to embrace the fuzzy nature of existence and not worry about it. Remember, you also lose light when the hole gets smaller. Most pinholers consider this an asset though. This is what makes for those wonderful time dilations.

How it works - Thickness & Shape

Fundamental Law: Light travels in a straight line

Pinhole Thickness



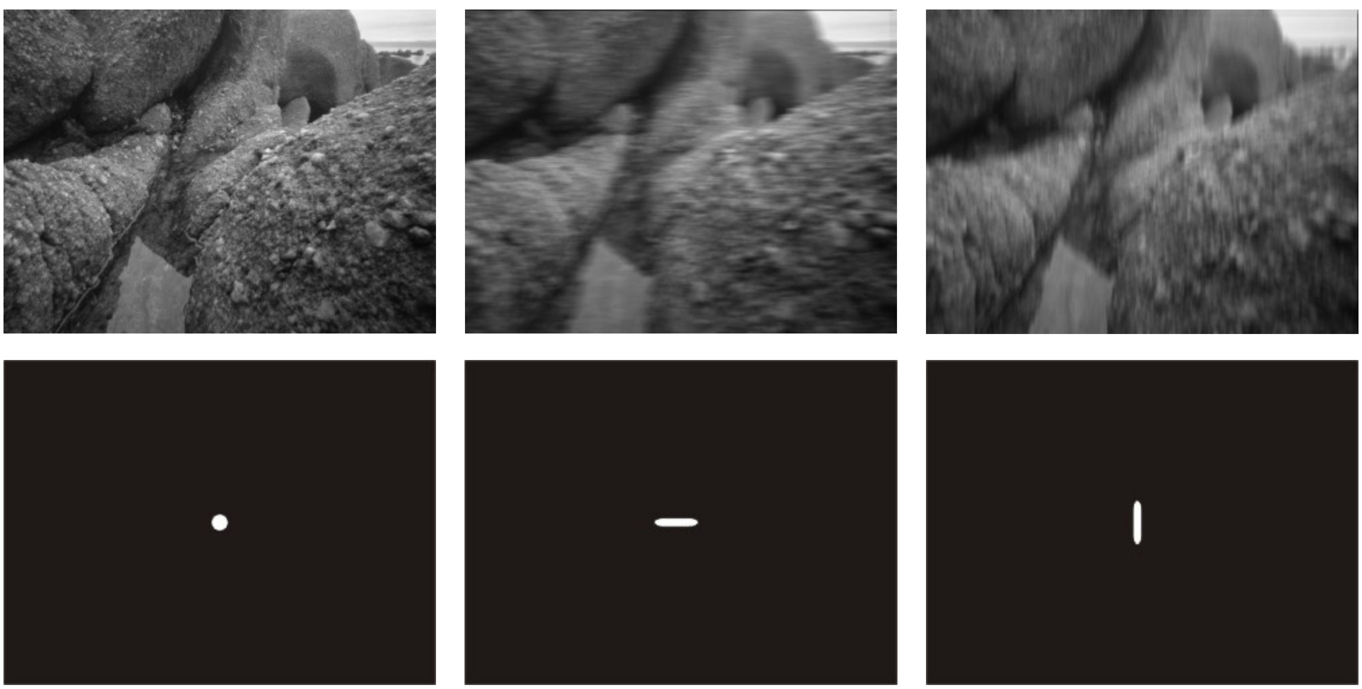
Observe the two pinholes of different thickness. The one on the left is much thicker than the one on the right.

The most obvious difference experienced is the varying angle of coverage. This is a real concern when using pinhole cameras of extreme wide angle. This effect can be exploited when you want the image to appear circular in the final result.

Another potential problem are reflections off the inside of the pinhole edges. The thinner it is the less surface area there is to reflect light, light you don't normally want interfering with your image. This can be exploited by purposely pointing at the sun to get 'flare' images.

Here is an image with mild flare [normal pinhole thickness], caused by reflections of the sun off the inside edges of the pinhole.:

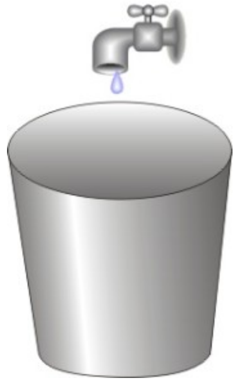
Shape of the Pinhole



Normal | Horizontal stretch | Vertical stretch

Of course much more exotic shaped pinholes can be produced. All shapes other than round will cause varying degrees of blurring over a normal round pinhole.

How it works - F/stop



Think of exposure of film in this way. Filling the bucket to the top is the amount of light needed to properly expose your film. The two drawings illustrate two ways to achieve this: Either a slow drip for a long period of time or a fast flow for a short period of time. Both will achieve the same end, filling the bucket.

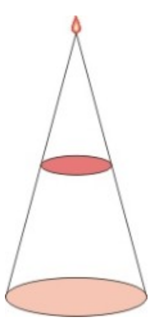
This works the same way with cameras, only using light instead of water:

1) The larger the opening [faucet turns], the more light [or water] can come in per unit time. [Aperture]
2) The longer the opening [faucet] is left open the more light [or water] comes in. [Shutter speed]

It is the combination of the two that achieves the exposure we want. There is however a third factor we need to consider if we want to make our system more universal.

3) Distance to the film affects the amount of light that reaches any particular spot. This is because light "spreads" as distance increases. We saw this when going from a wide angle to a telephoto. The image of the candle flame was small and concentrated in the wide angle camera and larger and more diffuse in the telephoto camera. BUT, for a given size hole, the same amount of light entered. Because this same amount of light had to "paint" a larger area in the telephoto camera [further away from the opening], the amount of light that reached any particular spot on the film was less.

Say we have a drop of red paint and we need to cover a white disc with this paint. The larger the disk we have to color, the more dilute will be the red pigment and the lighter the resulting shade of red:



The size of the white disc is related to the distance from the drop. The further away it is the larger it is. In this case the drop represents the pinhole and the discs represent the film. A telephoto lens, which has a longer distance to the film, therefore receives less 'light' because the image is larger and more spread out.

Putting this together we know that for film to receive a given exposure of light we must know three things.

1) The size of the opening through which the light passes [Aperture]

2) The length of time this opening is available [Shutter speed]

3) The relative distance the light has to travel, thus affecting the area that the image spreads out onto the film [Focal length]

The "F/Stop" is defined as the ratio of the Focal length divided by the size of the Aperture.

The total exposure that the film receives is then dependent on the F/Stop and the Shutter speed. Note that the size of the camera no longer matters when using F/stops. For a larger camera with the same F/Stop, the Aperture will also be larger to compensate. This makes it much easier for different photographers using different cameras to both be able to calculate the correct exposure for a given situation.

In practice the F/Stop has been agreed to be based on a system of common ratios. These are called F numbers and follow the following progression:

1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, 45, 64, 90, 128, 190, 256 and so on.

[These numbers may seem arbitrary, but they are in fact based on a formula involving the square root of two, which you don't need to know to use them. Note that every other number is a doubling or having, depending on direction of travel.]

Most lens cameras will stop at F16 or F22. Pinhole cameras typically start at F128 and go on to F1024 or higher.

All cameras follow the same rules in regards to F/Stops or F numbers.

Using the above scale of ratios:

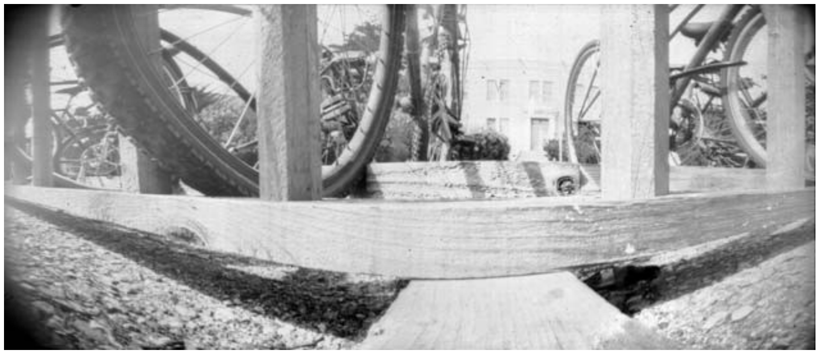
Moving one scale unit to the right reduces the amount of light reaching the film by half. [a two unit move equals 1/4, etc.]

Moving one scale unit to the left increases the amount of light reaching the film by two. [a two unit move equals 4 times, etc.]

A larger number means less light, a smaller number means more light.

The nice aspect of pinhole cameras is that this number does not change your camera is completed and the number is determined. Life just got easier again! The only variable that a pinholer can change then is the length of the exposure [shutter speed]. [Unless of course, you have more than one camera]

TIN CAN CAMERA:

Paint can pinhole camera and resulting image. 1 quart size

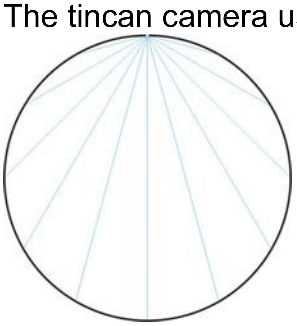
This is with the pinhole in the side of the can. It can also be on the top for an anemographic projection [distorted].

How it works – Tin can

Fundamental Law: Light travels in a straight line

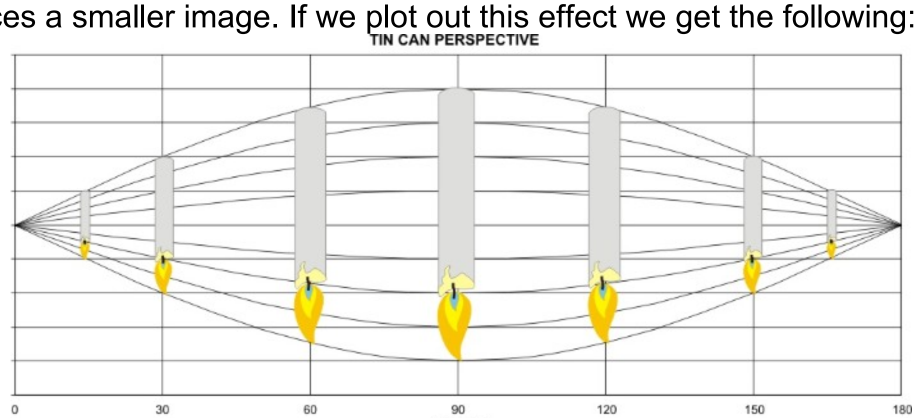
We saw how this works in the real world by viewing the **basic** pinhole camera, the **wide angle vs telephoto** camera and the **close-up** camera.

The tincan camera uses these factors to produce a purposely distorted image.



Let's look at the tin can camera from the top this time instead of from the side.

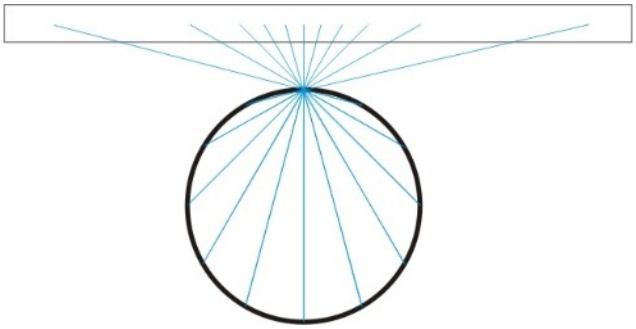
As we can see the light rays tracing into the camera are different than our normal camera BECAUSE THE FILM PLANE IS NO LONGER FLAT. To the right or left of center the distance from the pinhole to the film is shorter. Remember that a shorter distance [or focal length] produces a smaller image. If we plot out this effect we get the following:



The center of the camera produces the largest image of the candle and the edges produce the smallest [you did notice that the image is upside down in the previous examples didn't you?].

Here is an actual image taken with a tin can pinhole camera by Steve in the class of 2006 that helps illustrate this point.

You can see that the normally straight steps are curved in the way illustrated by the candle drawing. The blurring at the edges is because the can is not infinitely thin and the edges of the can and the photography paper start to block the image from being formed [see **Thickness** mentioned previously]. Other classic pinhole cameras, such as the oatmeal box or the 35mm film can work in the same way.



If the can is close to the subject the image is further enhanced by close-up effects.

FOCAL LENGTH TO PINHOLE

When you don't want to do the math, you can use the tables below. This table was based on extensive calculations and corrected for reciprocity for TMAX 100 film. Daylight Calculations [Abbreviations: FL = Focal Length PH =Pinhole]

FL (mm)	FL (inches)	PH (mm)	PH (inches)	F# (f-stop)	Bright sun
25	1	0.184	0.007	135	1 seconds
50	2	0.261	0.010	191	2 seconds
75	3	0.320	0.013	234	3 seconds
100	4	0.369	0.015	270	4 seconds
125	5	0.413	0.016	302	5 seconds
150	6	0.452	0.018	331	6 seconds
200	8	0.552	0.022	382	9 seconds
250	10	0.584	0.023	427	11 seconds
300	12	0.640	0.025	468	14 seconds
400	16	0.739	0.029	541	19 seconds
500	20	0.826	0.033	604	25 seconds
1000	40	1.160	0.046	855	56 seconds
2000	80	1.650	0.065	1209	2 minutes
4000	160	2.330	0.092	1711	6 minutes

PINHOLE SIZE TO FOCAL LENTH

As you often already know the size of the pinhole you have.

comments	PH (mm)	PH (inches)	FL (mm)	FL (inches)	F#
EMSci grid	0.075	0.0030	4.2	0.165	56
EMSci grid	0.100	0.0039	7.5	0.295	75
EMSci grid	0.150	0.0059	17	0.669	113
EMSci grid	0.300	0.0118	68	2.677	225
sewing needle #13	0.305	0.0120	70	2.756	229
hobby drill #80	0.343	0.0135	88	3.465	257
sewing needle #12	0.356	0.0140	95	3.740	267
hobby drill #79	0.368	0.0145	102	4.016	276
EMSci grid	0.400	0.0157	120	4.724	300
hobby drill #78	0.406	0.0160	124	4.882	305
hobby drill #77	0.457	0.0180	157	6.181	343
sewing needle #10	0.457	0.0180	157	6.181	343
hobby drill #76	0.508	0.0200	194	7.638	381
hobby drill #75	0.533	0.0210	213	8.386	400
sewing needle #9	0.533	0.0210	213	8.386	400
hobby drill #74	0.572	0.0225	245	9.646	429
EMSci grid	0.600	0.0236	270	10.630	450
hobby drill #73	0.610	0.0240	279	10.984	457
sewing needle #8	0.610	0.0240	279	10.984	457
hobby drill #72	0.635	0.0250	302	11.890	476
hobby drill #71	0.660	0.0260	327	12.874	495
sewing needle #7	0.686	0.0270	353	13.898	514
hobby drill #70	0.711	0.0280	379	14.921	533
hobby drill #69	0.742	0.0292	413	16.260	556
sewing needle #6	0.762	0.0300	435	17.126	572
hobby drill #68	0.787	0.0310	465	18.307	591
EMSci grid	0.800	0.0315	480	18.898	600
hobby drill #67	0.813	0.0320	495	19.488	610
hobby drill #66	0.838	0.0330	527	20.748	629
sewing needle #5	0.851	0.0335	543	21.378	638
hobby drill #65	0.889	0.0350	593	23.346	667
hobby drill #64	0.914	0.0360	627	24.685	686
hobby drill #63	0.940	0.0370	662	26.063	705
hobby drill #62	0.965	0.0380	699	27.520	724
hobby drill #61	0.991	0.0390	736	28.976	743
EMSci grid	1.000	0.0394	750	29.528	750

F NUMBER PROGRESSION [F16 and above]

F-stop	Comments	ASA100 (F16 rule) [no reciprocity]		
		Sunny	Cloudy Bright	Overcast
16		1/100 S	1/50 S	1/25 S
22	<- About the limit for most 35 mm lenses	1/50 S	1/25 S	1/12 S
32	<- F32 to F90 are common settings for view camera lenses	1/25 S	1/12 S	1/6 S
45		1/12 S	1/6 S	1/3 S
64		1/6 S	1/3 S	2/3 S
90	<- Start of the "pinhole" range and special purpose lenses.	1/3 S	2/3 S	1 1/3 S
128	<- Only pinholes from here on out	2/3 S	1 1/3 S	2 2/3 S
180		1 1/3 S	2 2/3 S	5 S
256		2 2/3 S	5 S	10 S
360		5 S	10 S	20 S
512		10 S	20 S	41 S
720		20 S	41 S	1 1/3 M
1024		41 S	1 1/3 M	2 2/3 M
1440		1 1/3 M	2 2/3 M	5 M
2048		2 2/3 M	5 M	10 M
2880		5 M	10 M	20 M
4096		10 M	20 M	40 M

Since pinhole f-numbers are usually not even as in the above table, here is a formula that can help:

Bright Sunny day exposure in seconds = ((f# x f#)/ASA) x 0.0039

OR = (f#/16)^2 / ASA (gives the same answer)

If you have a hand held light meter, set it to the proper ASA and read the value at F16, then use this formula to find the exposure:

Seconds = ((f# x f#)/ASA) x (f16 exp) x 0.39

OR = (f#/16)^2 x (f16 exp)

DON'T FORGET RECIPROCITY FAILURE! -see the data sheet that came with your film

REMEMBER each jump in F# is a halving of the amount of light available

One of the neatest things about pinhole photography is the time dilation effect. Long exposures are not a "bad thing".

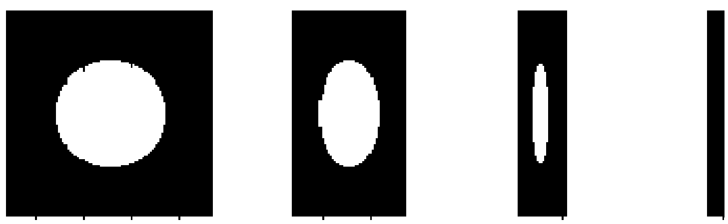
In a one-hour exposure, people and cars will disappear!

MULTI-HOLE

Rules:

1. Each pinhole will cast its own image onto the film plane
2. The range or width of the image produced is determined by
   a. The angle from the perpendicular
   b. The chamber shape designed into the camera
   c. The thickness of the metal used to produce the pinhole

2a may not be obvious. Looked at head-on, a perfect pinhole looks round, but as you get further and further away from head-on, the hole looks more and more oval until it disappears. The thicker the material the faster this will occur, but even an infinitely thin material disappears at 90° (edge on). And the smaller the hole, the less light gets through and the darker will be the image on the film plane.



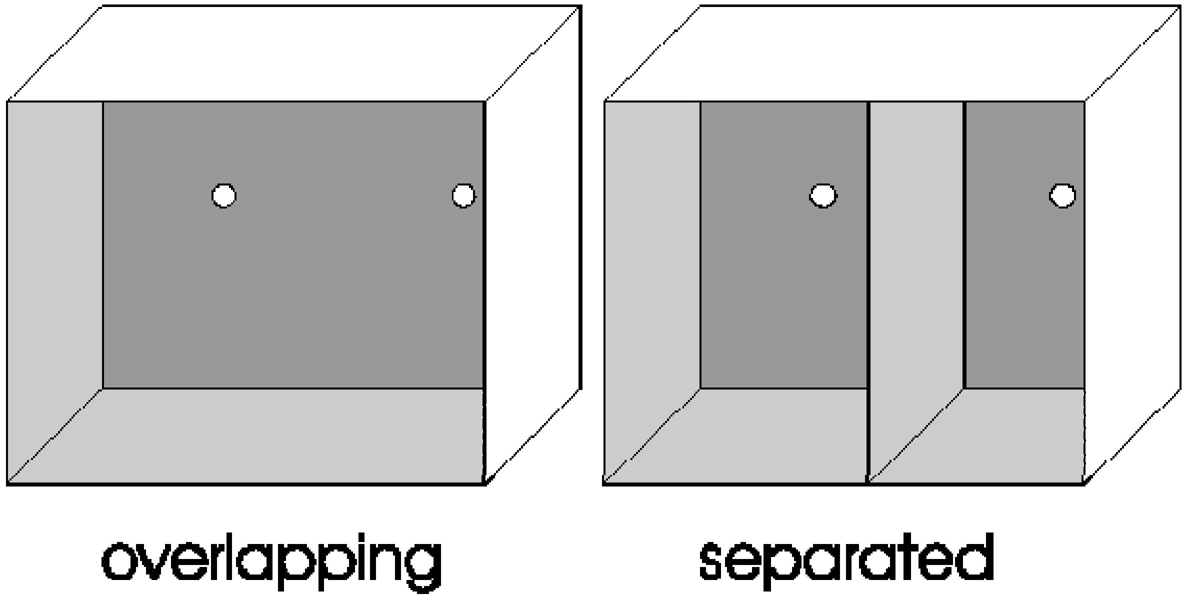
So in practical terms this means there is a "fall off" in the image away from the center.

The closer pinholes are to each other the more likely there will be overlap in the images unless there is something structural to prevent this from happening. Pinholes are VERY wide angle. So, even on a 4x5 camera with a 33mm focal length pinhole, almost the entire frame will be covered. [equivalent to an 11 mm lens on a 35 mm camera]

This gives us two possibilities:

1. Overlapping images or double exposures from different angles to the subject
2. Side by side images with different angles to the subject

From this we can add intentionally, a third possibility. Time. One pinhole need not be uncovered at the same time as another, hmm……

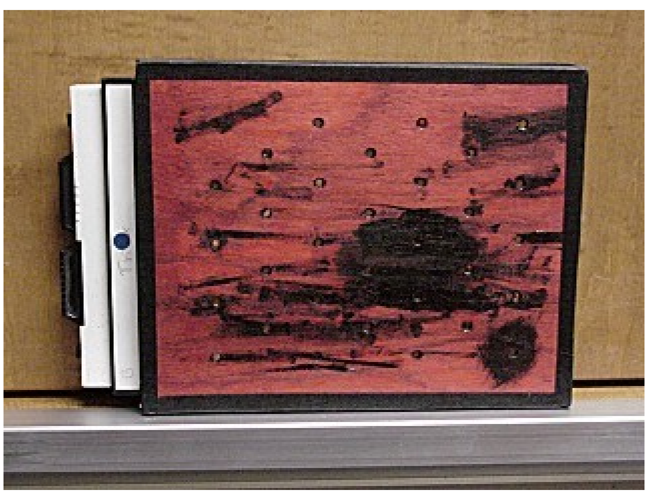


(The separated pinholes would produce a stereo pair, hmm, 3D pinhole!)

Part of the magic of pinhole is the infinite number of possibilities, but don’t forget the aesthetic side! Good subjects and composition are still the best images. We should not depend on "special effects".

BugCam

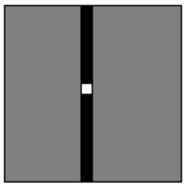
This is an example of the extreme in multi-hole cameras. “Bugcam” consists of 32 ideal pinholes of about 12mm focal length onto 4x5 film (overlapped)(bad paint job optional).



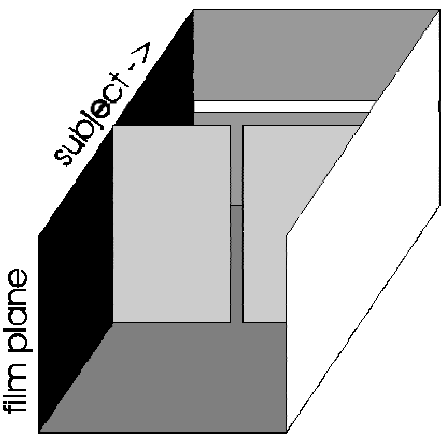
DOUBLE SLIT

In pinhole photography it's the distance from the pinhole to the film plane determines the focal length of the pinhole. What would happen if the horizontal focal length were different from the vertical focal length? How would you ever achieve this monstrosity?

We use two slits at different distances from the film. Interestingly, what the film sees is not a slit but a rectangle, because one slit is vertical and the other is horizontal.



Seen in 3D we get something like:



The slits have been exaggerated to be made visible

Confusing but:

The vertical slit determines the horizontal focal length and vice-versa.

The width of the opening of the slits is the same as the ideal pinhole diameter. Remember the front and back slits are at different distances/focal lengths and need to be different widths.

The length of the slit is determined by where it is in relation to the opposing slit and is determined easiest by looking.

The best material to make the slits from is single edged razor blades. BE CAREFUL! Use a measuring loupe to set the distance from the blades. Art supply stores sell razor blades that are 6 inches long for cutting that new "plastic" clay. These work great on larger cameras.

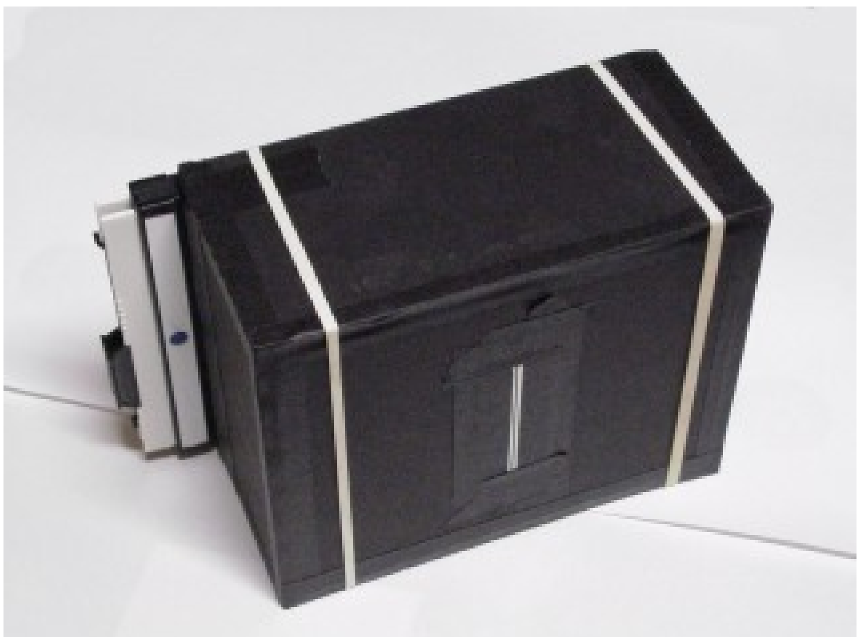
DUST is the biggest problem with these cameras. A single piece of dust on one slit equals a vertical or horizontal line on the final image.

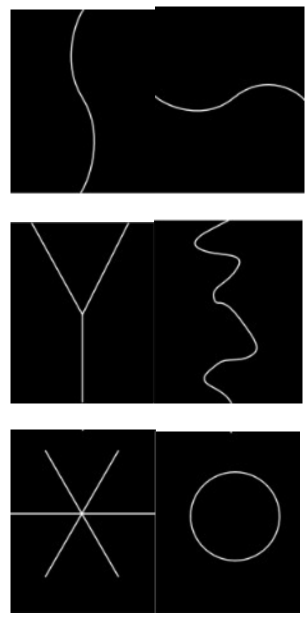
Because of the sizes involved, it will be easier to implement this camera in 4x5.

Creative:

1) Uncovering the slit in a time wise fashion, so though the entire slit receives the correct exposure, it is not uncovered at the same time.
2) Turning the double slit during an exposure [this will have to be designed into the camera]
3) Instead of razor blades, use a "slit" photographed onto high contrast film, such as litho film. **It need not be straight! Hmm….**

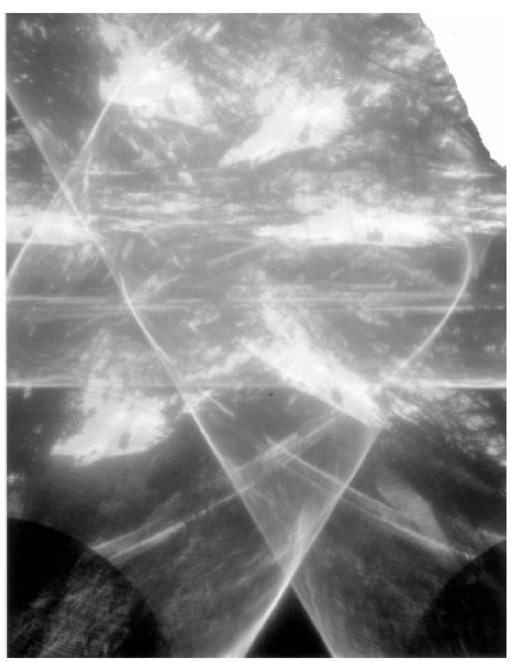
<u>Measurements</u> - see Foam Core 4x5 chapter for more exact measurements for slit widths.





A Double Slit camera, in 4x5, using 2 ½ razor blades for the slits.

Sine wave slit



Star and circle slits

The Zone Plate [and Pinsieve, Pinplate, or Photon Sieve]

Zone plates are becoming increasingly useful as a way of focusing X-rays. They are used in X-ray telescopes in astronomy and in X-ray lithography for experimental printed circuit fabrication.

Basically the zone plate is a way of doing non-lens photography similar to the pinhole but allowing **more light** to get to the film. This makes the "effective" f# lower allowing for shorter exposures. Practically this means about 3 stops or 1/8 the exposure time. Not bad, this would bring F2048 to F256, a vast improvement. It has the disadvantage, in that the depth of field also drops with this increase in aperture, so ideally, zone plates need to be focused as well.

This is one of the least understood areas of non-lens photography. It took me quite some time to find the proper equations and information. Most pinhole books and literature mention them, but don't give enough information for the lay person to make their own. Well no more, the secret is about to be revealed!

see web site for the MATH: http://pinhole.stanford.edu

DEFINITION: ZONES - these are alternating areas of clear (or white) and opaque (or black).

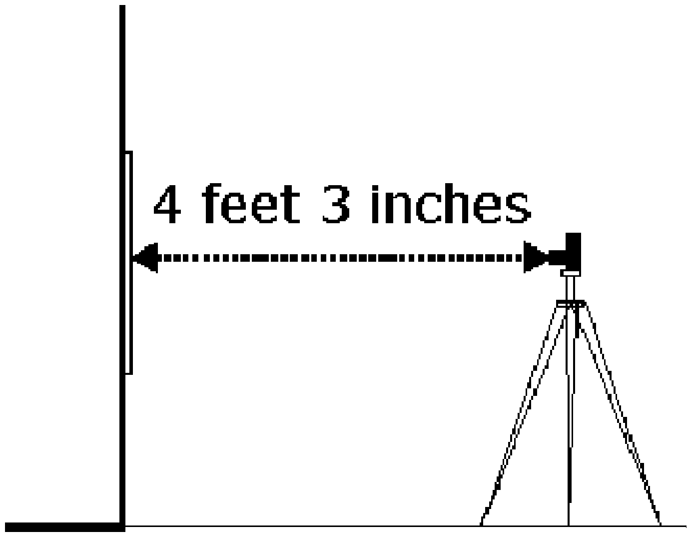
By using a drawing program such as Corel Draw or Adobe Illustrator on the PC/MAC, we can draw out the zone plate at say 25X normal size quite easily.

We then photograph the drawing from the correct distance with the appropriate high resolution lens and film, then develop and mount the resulting image on our zone plate camera.

To make it easy this chapter contains 6 zone plate images, all at 25x normal size. [25mm, 50mm, 75mm, 100mm, 125mm, 150mm]

If you photograph this printout from 4 feet 3 inches with a 50mm lens, you will get all 6 focal length zone plates on one negative. [Or a 36 exp roll will make enough for an entire class].

1. Print the zone plates from this manual. (Or better yet, draw your own from the equations for better quality)
2. Paste to a larger sheet of white mount board.
3. Set against or attach to a wall that is evenly lit.
4. Measure off the required distance from zone plate to camera.
5. Camera lens should be at exactly the same height as the center of the zone plate image.
6. You should be directly in front of the zone plate image, being to one side or the other will distort the image.
7. Take a series of exposures. Bracket exposures +/- 2 stops in at least ½ stop intervals. (First time only, after you determine correct exposure you will not need to do this every time)
8. Process film for high contrast (see below)
9. With a high-powered loupe, assess images and pick out the cleanest ones.
10. Cut out resulting image and mount to a brass shim with appropriate sized hole to allow the zone plate to be visible. Mount to camera.



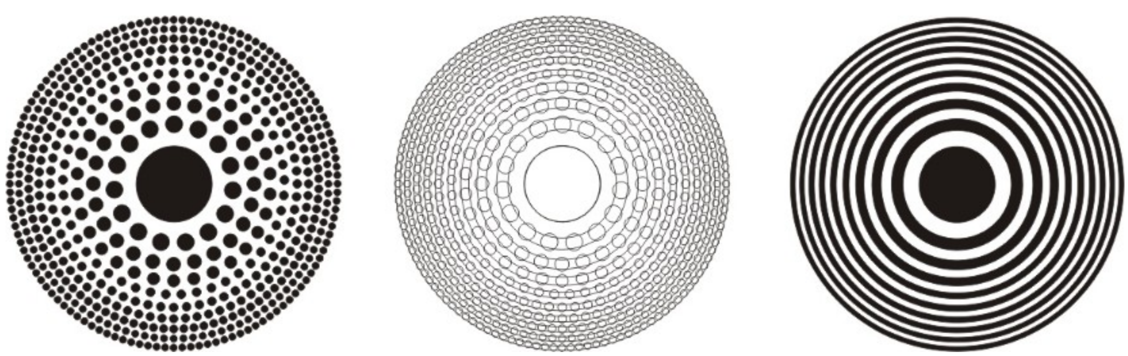
FILM & DEVELOPING: I recommend Kodak Technical Pan film TP-135-36, an extremely high resolution, high contrast film. It is best to bracket exposures. The film is VERY sensitive to exposure changes. In full sunlight the exposure will be around 1/1000 second at F5.6 / F8 (ASA 200). **NOTE:** F16 is usually not the best aperture to use. F8 tends to be sharper on most normal 35mm camera lenses.

Develop in paper strength Dektol for 3 minutes at 68° F. You can probably substitute your own favorite paper developer. Even better if you use a Kodalith type developer. Photographer's Formulary has one available [see Suppliers]

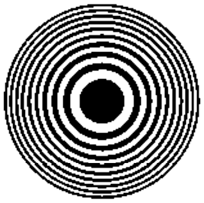
FOCUS

You will get an image if you mount one of these zone plates and just use it. However, unlike pinhole "lenses", zone plates need to be focused to get optimum results. Fortunately, so much more light comes though, at least in daylight conditions, you should be able to do this. Here a bellows unit or extension tubes may be needed to get the correct "focus". [or low tech sliding paper tubes, etc.]

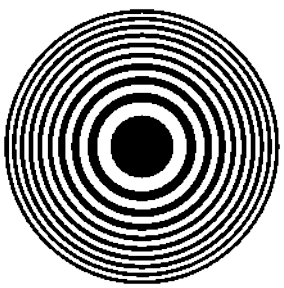
A Pinsieve is very similar to a Zoneplate and is based on the same calculations. The figure below shows the relationship.



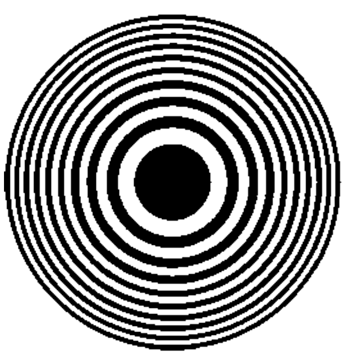
25X ZONEPLATES



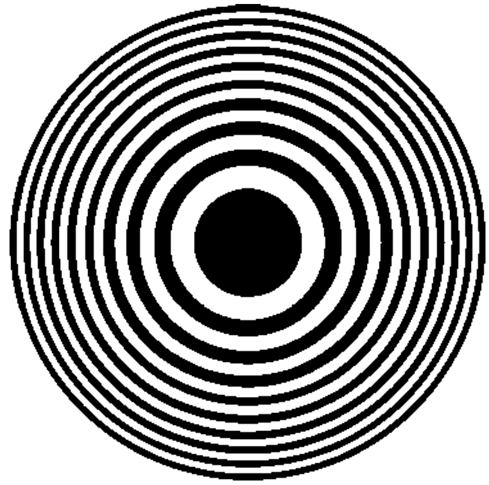
25mm



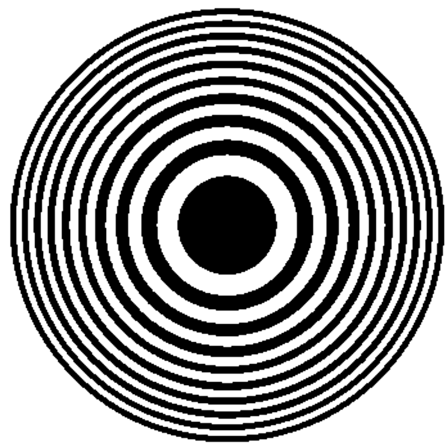
50mm



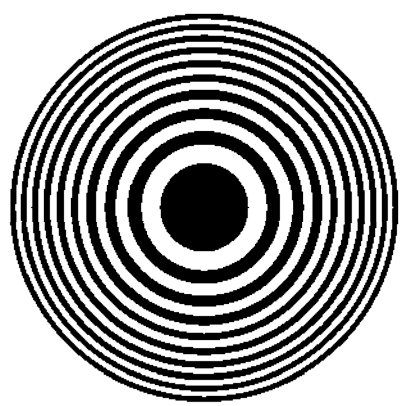
75mm



150mm

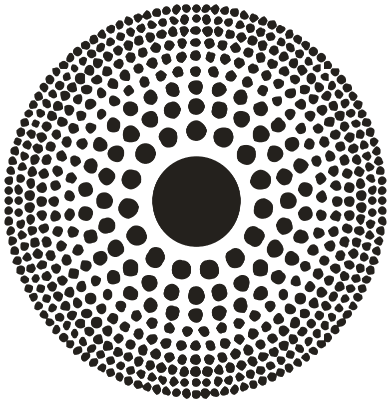


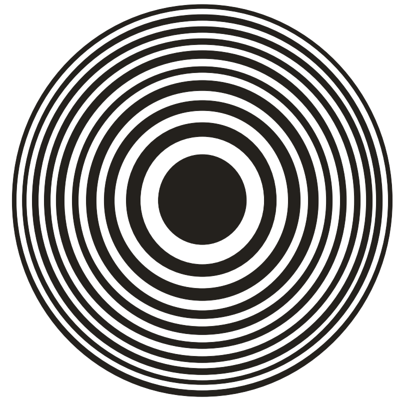
125mm



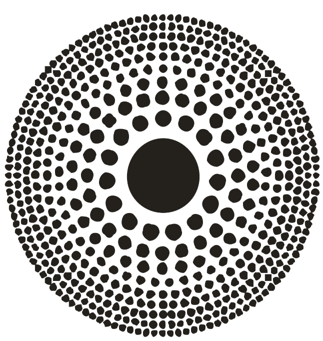
100mm

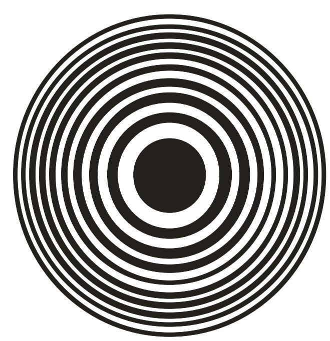
Photograph from 4’ 2.5” w/ 50mm lens





25X images of 75mm above and 50mm below





VIDEO PINHOLE

Follows the same rules as regular pinhole cameras, the only difference is that the CCD sensor is substituted for the film.

IT IS ESSENTIAL TO GET A LOWLIGHT CCD CAMERA. Remember those F#s for pinholes! Also, with video, there is no way to adjust the exposure to be longer than 1/60 of a second (video frame rate). So the typical several second to several minute exposure of a large format pinhole will not work here

There are inexpensive B&W cameras available. See suppliers. You will need a VCR or other capture device to use this camera, as it is just the camera not a camcorder. (In fact, on most camcorders, it is impossible to remove the lens, so they are not suitable for pinhole video). Some of these suppliers sell the entire pinhole video camera, so you do not have to come up with a pinhole yourself.

Size in mm	Focal Length	F#	Angle
0.075	4.2	56	wide angle
0.100	7.5	75	normal
0.150	17.0	113	telephoto

NOTE: because of the small size of a 1/3 inch sensor, the focal lengths corresponding to wide angle, normal and telephoto are different than for 35 mm.

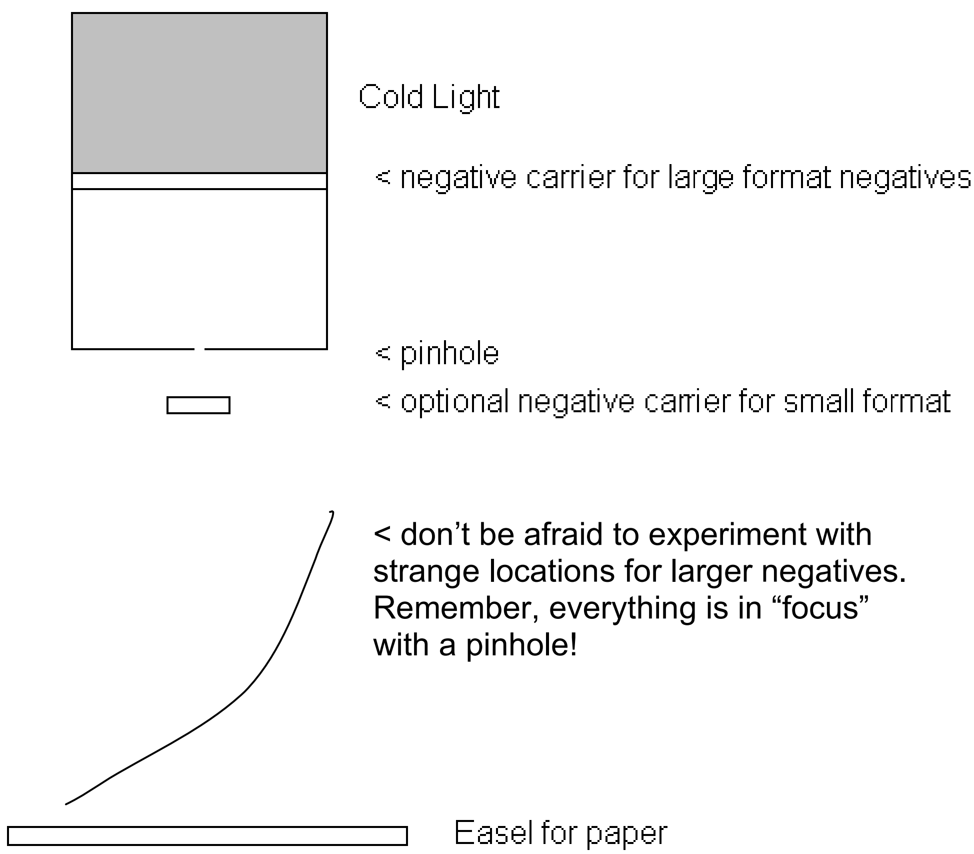
Incredible images from the "bugs eye view" are possible. Images can be captured into a computer and used as is or captured onto a VCR for some bizarre special effects.

The Pinhole Enlarger

"This is admittedly more an intellectual curiosity than anything practical, but here it is."

That is what I used to think! Now I **know** that it is definitely practical and expands what you can do with the pinhole.

You can adapt an existing enlarger or build your own box. To be truly ideal, you should use a diffuse light source instead of a condenser for the illumination, as the condenser has lenses. There is not much light coming through this contraption, get the brightest light source you can. Aristo, a company who makes cold lights, offers a hi-intensity bulb for their light boxes. Alternatively you could use a point source enlarging head, remove the condensers, and put a piece of flashed opal glass at the negative plane. You could also use a slide projector, opal glass, and cardboard to keep it light tight. [Light tight is important, as any stray light will ruin your print].



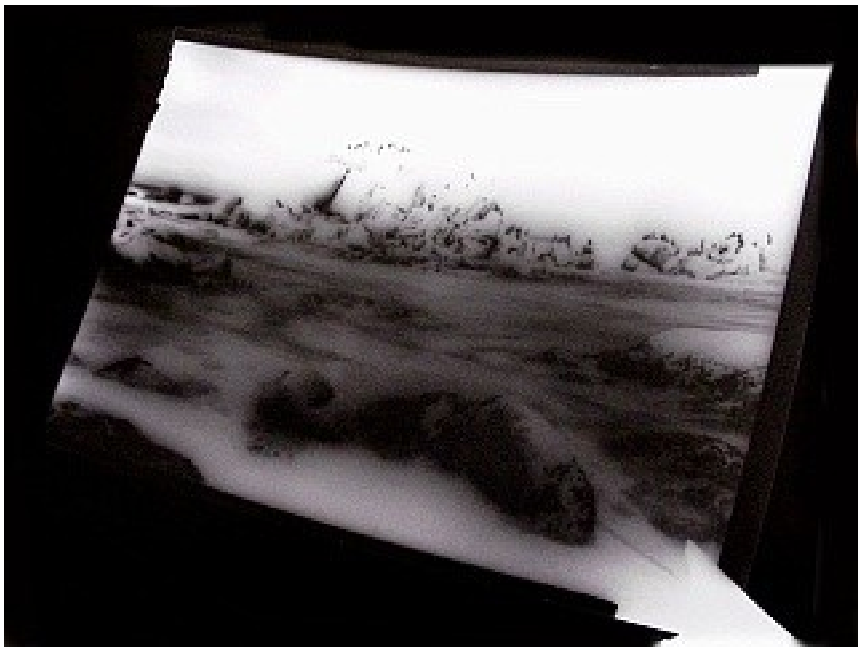
Note the optional location for smaller format negatives! Something you can't do on your regular enlarger!

The pinhole to easel distance determines the pinhole size. And since as this distance gets bigger, resolution goes down, you are better off with a wide angle pinhole. see pinhole size to focal length. Expect some really long exposures! (minutes to even hours, depending on the size of the pinhole, brightness of light source and enlargement)

Creative Part:

YOU DON'T NEED TO KEEP THE NEGATIVE FLAT! That's right, the advantage of pinhole, that everything is in focus, means just that. If the negative is tilted, curled, etc. it will still be in focus! Note the location of the small format negative. You can also place a large format negative under the pinhole and tilt it to an extreme, as in the example below. [most of the detail is lost because of the conversion to digital, not because of the pinhole enlarger]

"Take chances, get messy!" Ms Frizzle of the Magic School Bus [kids TV program]



You can also curl, etc. the paper you are printing on to.

Note the "halation" around areas that are dark on the print. The opposite of the halation you get in the negative where light areas spill over.

Hyperfocal Cameras

The idea is to choose a focusing distance, such that, the maximum amount is in focus at one time for the **lens** you are using. Yes, I said lens. Hyperfocal cameras are sort of hybrids between pinhole cameras and lens cameras. In practice this means from infinity to some defined near focus point. There are a large number of factors that influence this number, focal length, film format, f-stop, etc.

One could use a normal photographic lens set to a hyperfocal distance and proceed, but this looses the "look and feel" of the pinhole camera. So, even though we are going to use a lens in this case instead of a pinhole, it would be nice to maintain as much of the aesthetic as possible.

50mm @ F128 on Ilford Technical Film, Ortho, 4x5

"Out the Back Door" © 2000 c.patton

I have been investigating using simple lenses for use in hyperfocal cameras. The simplest is a plano-convex lens. Curved on one side and flat on the other. These can be had from Edmund Scientific for under $20 [order their Industrial Optics catalog or see their web site]. The next step up would be a two element achromatic lens, cost about $30-40. This offers superior color correction, but is unnecessary if we use ortho film or a colored filter.

Other possibilities include older lenses. I made one camera from a Zeiss Anastigmat, 75 mm, from 1891, found on a junk bench at a camera store. Don't overlook parts of lenses either. Taking apart an old 8mm movie camera will yield lots of fine optics.

The easiest to use format for making these cameras is 4x5. Film can be had from Freestyle Camera for very little money. The only other supplies are a few film holders [used from swap meets or often in camera stores] and some black foam core board from an art supply store to make the camera itself out of. The camera is made in very much the same way as for a pinhole. [see making a 4x5 foam core pinhole camera]

Hyperfocal cameras work best in wide angle lengths. The advantage of a hyperfocal camera over a pinhole is more light and sharper focus. The disadvantage is more light and limited focus range. In a pinhole camera you do not need to worry about focus at all. In a hyperfocal, there is a minimum focus. For a 50mm lens [extreme wide angle for a 4x5], the minimum focus is 1/2 foot. Not so bad. But by the time you get to 150mm [normal lens for a 4x5] it is now closer to 4 feet. Not so good if you are used to a pinhole camera.

Another factor is the positioning of the lens. In a pinhole camera, if you are off a couple of millimeters, so what. But in a hyperfocal camera, even a fraction of a mm off will ruin the effect.

The size of the F-stop is less of a problem, even though the table looks scary. If you are off a little bit here, it usually means just making some adjustment in the exposure. One source of F-stops are those electron microscope grids mentioned in the pinhole section [see suppliers]

If you want to see the math involved in generating these tables, see Hyperfocal Math [also useful if you want to use an existing lens on a 35mm - 8x10 camera, as a hyperfocal lens]

NOTE: Simple lenses, though a lot less expensive, are not the same as expensive large format lenses. Without all the corrections of the higher priced lenses, the simple 1-3 element lenses project a different kind of image. Space is not flat, but rather curved. The area of sharpest focus will be different at the center of the image than at the edges. If a lens does not "work" for you in one orientation, try flipping it over, so the curved side is towards the subject or now towards the film. Like the artistic "Holga" camera users, do not be afraid to experiment and see in a different way.

Tables: [4x5 camera]

Lens extension, mm		
FL (mm)	**F90**	**F128**
50	58	62
55	63	67
60	68	71
65	73	76
70	77	81
75	82	86
80	87	91
85	92	96
90	97	101
95	102	106
100	107	111
105	112	116
110	117	121
115	122	125
120	127	130
125	132	135
130	137	140
135	142	145
140	147	150
145	152	155
150	157	160

FOCUS: [in feet!]

	Focus camera at:		Near Limit of Focus	
FL (mm)	**F90**	**F128**	**F90**	**F128**
50	1.2	0.9	0.6	0.4
55	1.5	1.0	0.7	0.5
60	1.7	1.2	0.9	0.6
65	2.1	1.4	1.0	0.7
70	2.4	1.7	1.2	0.8
75	2.7	1.9	1.4	1.0
80	3.1	2.2	1.6	1.1
85	3.5	2.5	1.8	1.2
90	3.9	2.8	2.0	1.4
95	4.4	3.1	2.2	1.5
100	4.9	3.4	2.4	1.7
105	5.4	3.8	2.7	1.9
110	5.9	4.1	2.9	2.1
115	6.4	4.5	3.2	2.3
120	7.0	4.9	3.5	2.5
125	7.6	5.3	3.8	2.7
130	8.2	5.8	4.1	2.9
135	8.9	6.2	4.4	3.1
140	9.5	6.7	4.8	3.3
145	10.2	7.2	5.1	3.6
150	10.9	7.7	5.5	3.8

Size of F-stop (mm):

[lens extension taken into account]

FL (mm	F90	F128
50	0.64	0.48
55	0.70	0.52
60	0.75	0.56
65	0.81	0.60
70	0.86	0.63
75	0.92	0.67
80	0.97	0.71
85	1.03	0.75
90	1.08	0.79
95	1.14	0.83
100	1.19	0.86
105	1.25	0.90
110	1.30	0.94
115	1.36	0.98
120	1.41	1.02
125	1.47	1.06
130	1.52	1.10
135	1.58	1.14
140	1.63	1.17
145	1.69	1.21
150	1.75	1.25

Foam Core 4x5 Pinhole Cameras

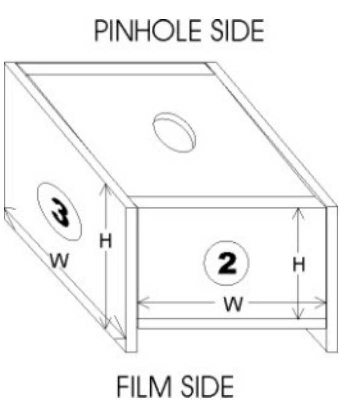
1) List of materials needed

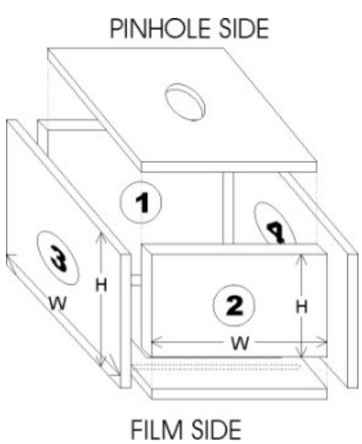
	App. $
a) Metal ruler, 18"	$4
b) Xacto or mat knife and extra blades	$4 + $4
c) Double sticky tape	$2
d) Black opaque tape	$5
e) Black foam core board (usually comes in 30" x 40" sheets)	$11/sheet
f) Black mat board, 4 ply (about 1/16" thick)	$5

2) Image of finished camera [in this case a double slit 4x5]

Note the rubber bands used to hold the film holder in place

3) Box and Exploded views of camera.





5) Measurements

Film panel - see Foam Core Back on next page
Pinhole panel - 4 3/4" wide by 6 1/16" long
Panel #1 - 4 3/4" wide by (focal length needed + 1/2", i.e. 3" FL = 3 1/2" high)
Panel #2 - 4 3/4" wide by (focal length needed - 3/16", i.e. 3" FL = 2 13/16" high)
Panels 3 & 4 - 6 7/16" wide by (focal length needed + 1/2", i.e. 3" FL = 3 1/2" high)
Extra Support Struts – (4) 4 3/4" wide X 1/2" high, (4) 5 11/16" X by 1/2" high.
These are placed underneath the film panel and pinhole panel inside the box to help support the film panel [not shown previously for clarity]

If after trying your camera, you are still having trouble with light leaks, you can try using an additional piece of black foamcore board or matt board to cover the back of the camera, allowing the film holder to slip in from the side.

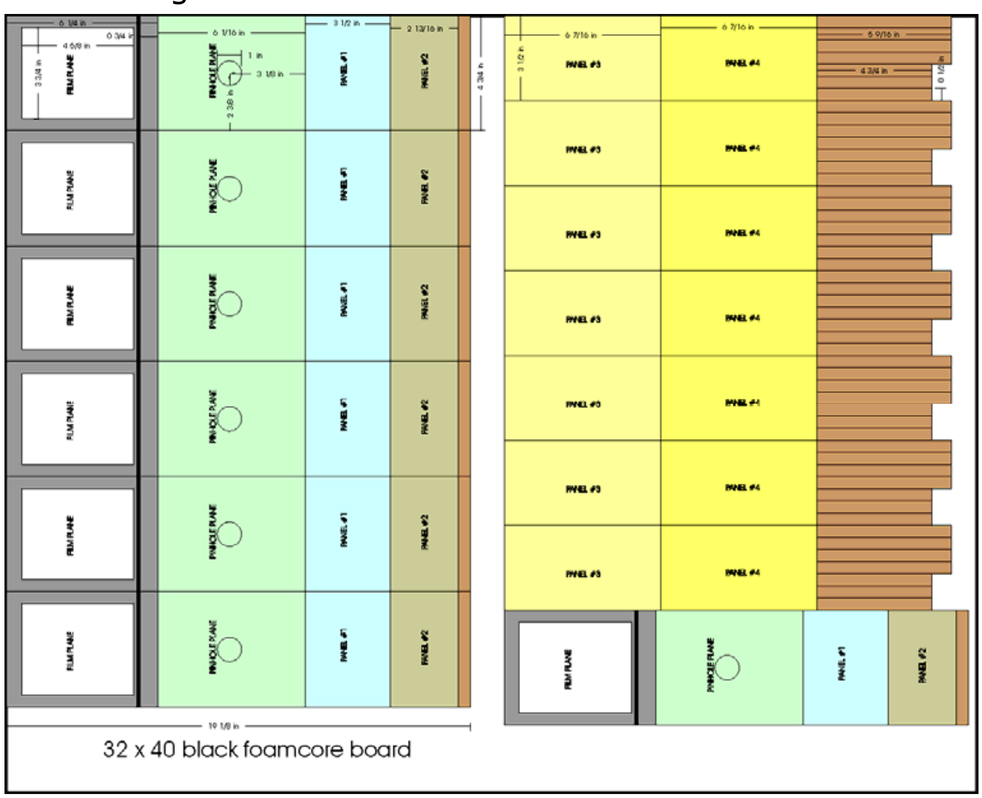
6) Assembly

a) Measure and cut panels
b) Mark with pencil on panels 1,3,4 where the support struts will go.
c) Assemble panels 1,2,3,4 using panel #1 to align to.
d) Add support struts
e) Add film panel

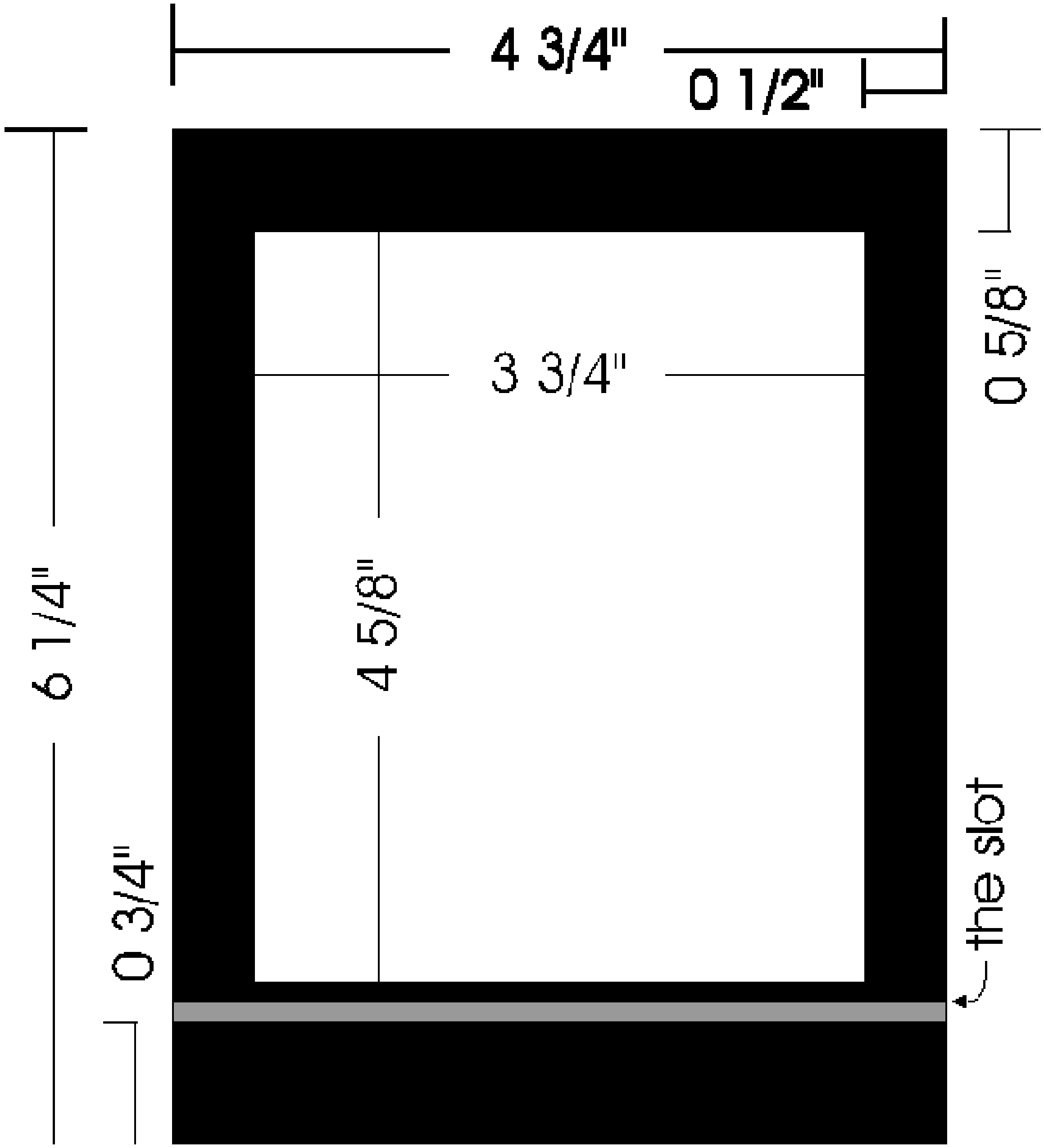
7) Front panel options

a) Straight pinhole designs, zone plates and hyperfocal cameras
b) Multiple holes, overlapped and separated
c) Double slit and double zone
i) Two front panels needed [pinhole side]. The second panel is recessed into the interior of the box the desired amount for the second focal length. The measurements of the box will be based on the longest focal length used.

If you are an instructor and want to make “kits” for your students then you can make (7) three inch foam core pinhole cameras from each piece of 32x40 inch foam core board.



PATTERN FOR 4x5 FOAM CORE BACK



DIMENSIONS FOR OTHER VIEW CAMERA FORMATS:

Description	**4x5**	**5x7**	**8x10**
Width	4 ¾	5 7/8	9 ¼
Length	6 ¼	8 3/8	11 5/8
Inside Width	3 ¾	4 7/8	8
Inside Length	4 5/8	6 ¾	9 5/8
Distance to "slot"	¾	5/8	13/16
From top to inside	5/8	¾	¾
outside to inside width	½	½	5/8

NOTE: I would recommend double-checking these measurements with an actual film holder in hand. Especially where the "slot" goes.

CYANOTYPES

NOTE: NO CYANIDE COMPOUNDS SHOULD EVER BE MIXED WITH AN ACID

Traditional Mix:

Solution A:
25% ferric ammonium citrate (green scales)
Solution B:
10% potassium ferricyanide

mix equal parts A and B just before use, coat paper, dry, expose and develop by washing in water.
Source: Historic Photographic Processes - A guide to Creating Handmade Photographic Images, Richard Faber, 1998

Variation 1:

Solution A:
20% ferric ammonium citrate (green scales)
Solution B:
14% potassium ferricyanide

mix equal parts A and B just before use, coat paper, dry, expose and develop by washing in water.
>>> This is the formula that I use for my own work. 5-10 minute exposure to full sun depending on the density of the negative. For paper I like to use Epson Double Matt Inkjet paper. VERY smooth finish and high resolution, reasonable cost and faster washing than thicker art papers.
Source: Alternative Photographic Processes, Kent Wade, 1978

Variation 2:

Solution A:
22% ferric ammonium citrate (green scales)
Solution B:
16% potassium ferricyanide

mix equal parts A and B just before use, coat paper, dry, expose and develop by washing in water.
Source: Breaking the Rules, A Photo Media Cookbook, Bea Nettles, 1977

NOTE: Too little Potassium ferricyanide will result in color bleeding into the whites. Too much will cause the exposure to be longer. [in above formulas, the Traditional has the lowest ratio and Variation #2 the highest]

Single solution. Mix up just before use: [same as variation #1 above]
in 20ml of water add
2 grams of ferric ammonium citrate (green scales) and dissolve. Then add 1.4 grams potassium ferricyanide and dissolve.
Expose in a contact printing frame to full strength sunlight for 2-5 minutes. wash in water and dry. You can intensify with 3% hydrogen peroxide or half strength household bleach.

WEB SITES

There are tons of web sites, but most don't say that much. Some are commercial sites trying to get you to buy books, pinholes, or cameras. Worth checking out to see other people's work and what the community is thinking. Author's web site: **http://pinhole.stanford.edu** The site contains more information than in this manual, including lots of MATH. Co-instructor's [Martha Casanave] web site: **http://marthacasanave.com/**

Another class that makes use of some of the materials from this site can be found at: http://classes.asn.csus.edu/vail/art163%20/163home.html

Check out Paul Prober's site. Great explanation of macro pinhole photography! http://www.huecandela.com

THE site of Mr. Pinhole himself, Eric Reiner http://www.pinholeresource.com/

http://www.pinhole.com/ -lots of workshops posted, as well as books.

http://www.smithsonianmag.si.edu/smithsonian/issues00/may00/pinhole.html -short description

http://dir.yahoo.com/Arts/Visual_Arts/Photography/Pinhole_Photography/ -links to other sites

http://www.skypoint.com/members/escargo/ppp.html - more links

http://GLSmyth.com - personal site, alternative processes, etc.

http://www.papercams.com/ - pinhole cameras constructed out of photographic paper.

Photograms:

http://www.photograms.org/

http://www.photogram.org/

http://depts.washington.edu/rural/RURAL/resources/photogram.html

http://photography.about.com/od/photograms/Photograms_Cameraless_Images.htm

http://www.eastman.org/amico2000/htmlsrc/manray_sld00001.html

http://www.eastman.org/fm/amico99/htmlsrc2/moholy_sld00002.html

http://www.billwest.com/

http://anniehalliday.com

Cyanotypes:

http://www.photogs.com/bwworld/cyanotypes.html

http://www.alternativephotography.com/gall_cyanotypes.html

SUPPLIERS

Sources for pinholes and pinhole cameras (see web sites for other suppliers)

Call or write Eric and Nancy@
Pinhole Resource [http://www.pinholeresource.com/]
Star Route 15. Box 1355
San Lorenzo, NM 88041
Phone (505) 536-9942

Highly recommend Eric's book "Pinhole Photography: Rediscovering a Historic Technique"

Freestyle Photographic Supplies [http://www.freestylephoto.biz/]

5124 Sunset Blvd.
Hollywood, CA 90027
United States
1-800-616-3686

They have inexpensive film & paper, plus pinhole cameras, cyanotype chemicals and paper.

Electron Microscopy Sciences [http://www.emsdiasum.com/ems/default.html]
Email: sgkcck@aol.com
In PA (215) 646-1566 * Toll-Free (800) 523-5874 * Fax (215) 646-8931

See section of catalog with copper pinholes
[http://www.emsdiasum.com/microscopy/products/grids/gilder.aspx]

Other Electron Microscope supply houses:

Ted Pella, Inc. [http://www.tedpella.com/]
P.O. Box 492477
Redding, CA 96049-2477
1-800-637-3526
1-916-243-2200
tedpel@snowcrest.net
tedpel@aol.com

SPI Supplies [http://www.2spi.com/]

PHONE: 1-(800)-2424- SPI
1-(610)-436-5400
FAX: 1-(610)-436-5755
569 East Gay Street, West Chester, PA 19380
P.O. Box 656, West Chester, PA 19381-0656

Apertures that might work well for pinholes can be found here
[http://www.2spi.com/catalog/apt/leo-naolab-novascan-zeiss.html].
I would recommend the platinum apertures. The gold foil ones would be too fragile to handle in a camera situation.

Marlin P. Jones & Assoc. Inc. [http://www.mpja.com/]
Has surplus video cameras and pinhole video cameras real cheap! [less than $100]

35mm Camera

Check out the Voightlander Bessa-L. This camera has TTL metering and Leica screwmount [which means you can make a 22mm pinhole camera fairly easily]
[see B&H photo at http://www.bhphotovideo.com/]

4x5 and 8x10 Cameras

Check out Bender Photographic [http://www.benderphoto.com/]. They have 4x5 and 8x10 kits for $329.50 and $429.50 respectively. I have made the 4x5 and it would work great for pinhole and zone plate work. As some single focal length pinhole cameras can cost as much, why not put together a pinhole camera with interchangeable "lenses"? They also sell film holders for above.

They also have a multi-focal length pinhole camera kit for only $89.95. This is not plywood, but real hardwood. Looks like an excellent camera kit.

For Hobby supplies, check out:

Micro-Mark hobby supplies, small tools, etc. [http://www.micromark.com]

> finger drills [http://www.dxmarket.com/micromark/products/60934.html]
> Rogers Drill bit set, #61-80
> [http://www.dxmarket.com/micromark/products/82416.html]
>
> This is sort of a strange place. Things look much better than they really are. I have been disappointed half the time. Buy one before ordering lots of any particular item.

Home Depot has shim stock. Get brass at 1-2 thousandths of an inch. [2 is easier to work with for the beginner, 1 will give a better hole with practice] Hobby shops and machinist's shops will have shim stock as well. [also Micro-Mark listed above]

Home Depot is also a good site for empty paint cans [one qt. size holds a 4x10 inch piece of film or paper. Other sizes as well.]. These make great pinhole cameras. The pinhole can be made right in the side of the can! I am not sure I would trust the lid to be light tight. Black tape over the crack will help. Cheap enough you can make lots of them to take on a field trip without reloading.

Black foam core, Exacto knives, etc. can be had at art supply stores. Black tape comes from camera stores [$17/roll] or even cheaper at art supply stores [$5/roll].

Photographers' Formulary [http://www.photoformulary.com/]

> P.O. Box 950, 7079 Hwy 83 N, Condon Montana, USA 59826-0950,
> E-Mail: formulary@blackfoot.net
> FAX 1 (406) 754-2896
> 1 (800) 922-5255 or 1 (406) 754-2891

Great source for chemicals and chemistry kits, including cyanotype and Van Dyke brown.