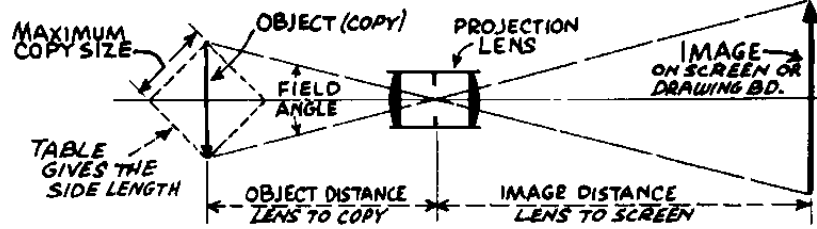


How To Build OPTICAL DRAWING DEVICES

No. 9059

...for Drawing Projectors and Cameras

OBJECT-IMAGE DISTANCES and SIZE OF COPY



LENS F. L.	FEATURE YOU WANT TO FIND	1/2x	1x	1 1/2x	2x	3x	4x	5x	6x	7x	8x	9x	10x	15x	25x
6"	TO COPY →	18"	12"	10"	9"	8"	7 1/2"	7 7/8"	7"	6 7/8"	6 3/4"	6 5/8"	6 5/8"	6 3/8"	6 1/4"
	TO SCREEN →	9	12	15	18	24	30	36	42	48	54	60	66	96	13-0
6"	COPY SIZE 20°	4 1/2	3	2 1/2	2 1/4	2	1 7/8	1 3/4	1 3/4	1 3/4	1 3/4	1 5/8	1 5/8	1 5/8	1 5/8
	COPY SIZE 30°	7	4 1/2	3 3/4	3 3/8	3	2 7/8	2 3/4	2 5/8	2 5/8	2 1/2	2 1/2	2 1/2	2 3/8	2 3/8
6 1/2"	TO COPY →	19 1/2"	13"	10 3/4"	9 3/4"	8 5/8"	8 1/8"	7 3/4"	7 1/2"	7 3/8"	7 1/4"	7 1/4"	7 1/8"	6 7/8"	6 3/4"
	TO SCREEN →	9 3/4	13	16 1/4	19 1/2	26	32 1/2	39	45 1/2	52	58 1/2	65	71 1/2	8'-8	14'-1
6 1/2"	COPY SIZE 20°	5	3 3/4	2 3/4	2 1/2	2 1/4	2 1/8	2	1 7/8	1 7/8	1 3/4	1 3/4	1 3/4	1 3/4	1 3/4
	COPY SIZE 30°	7 1/2	4 7/8	4	3 3/4	3 1/4	3 1/8	3	2 7/8	2 3/4	2 3/4	2 3/4	2 3/4	2 5/8	2 1/2
7"	TO COPY →	21"	14"	11 3/4"	10 1/2"	9 1/4"	8 3/4"	8 3/8"	8 1/8"	8"	7 7/8"	7 3/4"	7 3/4"	7 1/2"	7 1/4"
	TO SCREEN →	10 1/2	14	17 1/2	21	28	35	42	49	56	63	70	77	9'-4	15'-1
7"	COPY SIZE 20°	5 1/2	3 1/2	3	2 5/8	2 1/4	2 1/4	2 1/8	2	2	2	1 7/8	1 7/8	1 7/8	1 3/4
	COPY SIZE 30°	8	5 1/4	4 1/2	4	3 1/2	3 1/4	3 1/8	3 1/8	3	3	2 7/8	2 7/8	2 3/4	2 3/4
7 1/2"	TO COPY →	22 1/2"	15"	12 1/2"	11 1/4"	10"	9 3/8"	9"	8 3/4"	8 1/2"	8 3/8"	8 1/4"	8 1/4"	8"	7 3/4"
	TO SCREEN →	11 1/4	15	18 3/4	22 1/2	30	37 1/2	45	52 1/2	60	67 1/2	75	82 1/2	10'-0	16'-3
7 1/2"	COPY SIZE 20°	5 3/4	3 3/4	3 1/8	2 7/8	2 1/2	2 3/8	2 1/4	2 1/4	2 1/8	2 1/8	2 1/8	2 1/8	2	2
	COPY SIZE 30°	8 1/2	5 5/8	4 3/4	4 1/4	3 3/4	3 1/2	3 3/8	3 1/4	3 1/4	3 1/8	3 1/8	3 1/8	3	3
8"	TO COPY →	24"	16"	13 1/4"	12"	10 5/8"	10"	9 5/8"	9 1/4"	9 1/8"	9"	8 7/8"	8 3/4"	8 1/2"	8 1/4"
	TO SCREEN →	12	16	20	24	32	40	48	56	64	72	80	88	10'-8	17'-4
8"	COPY SIZE 20°	6	4	3 1/4	3	2 5/8	2 1/2	2 3/8	2 1/4	2 1/4	2 1/4	2 1/4	2 1/4	2 1/8	2 1/8
	COPY SIZE 30°	9	6	5	4 1/2	4	3 3/4	3 5/8	3 1/2	3 1/2	3 3/8	3 3/8	3 3/4	3 1/4	3 1/8
8 1/2"	TO COPY →	25 1/2"	17"	14 1/4"	12 3/4"	11 1/4"	10 5/8"	10 1/8"	9 7/8"	9 3/4"	9 5/8"	9 1/2"	9 3/8"	9"	8 7/8"
	TO SCREEN →	12 3/4	17	21 1/4	25 1/2	34	42 1/2	51	59 1/2	68	76 1/2	85	93 1/2	11'-4	18'-5
8 1/2"	COPY SIZE 20°	6 1/4	4 1/4	3 1/2	3 1/8	2 7/8	2 5/8	2 1/2	2 1/2	2 1/2	2 3/8	2 3/8	2 3/8	2 1/4	2 1/4
	COPY SIZE 30°	9 1/2	6 1/2	5 3/8	4 3/4	4 1/4	4	3 7/8	3 3/4	3 3/4	3 5/8	3 5/8	3 1/2	3 3/8	3 3/8
9"	TO COPY →	27"	18"	15"	13 1/2"	12"	11 1/4"	10 3/4"	10 1/2"	10 1/4"	10 1/8"	10"	9 7/8"	9 5/8"	9 3/8"
	TO SCREEN →	13 1/2	18	22 1/2	27	36	45	54	63	72	81	90	99	12'-0	19'-6
9"	COPY SIZE 20°	6 3/4	4 1/2	3 3/4	3 3/8	3	2 7/8	2 3/4	2 5/8	2 1/2	2 1/2	2 1/2	2 1/2	2 1/8	2 3/8
	COPY SIZE 30°	10 1/4	6 3/4	5 5/8	5 1/8	4 1/2	4 1/4	4	4	3 7/8	3 3/8	3 3/4	3 3/4	3 5/8	3 1/2
10"	TO COPY →	30"	20"	16 5/8"	15"	13 3/8"	12 1/2"	12"	11 5/8"	11 1/2"	11 1/4"	11"	10 5/8"	10 3/8"	
	TO SCREEN →	15	20	25	30	40	50	60	70	80	90	100	110	13'-4	21'-8
10"	COPY SIZE 20°	7 1/2	5	4 1/8	3 3/4	3 3/8	3 1/8	3	3	2 7/8	2 7/8	2 3/4	2 3/4	2 5/8	2 1/2
	COPY SIZE 30°	11 1/4	7 1/2	6 1/4	5 5/8	5	4 5/8	4 1/2	4 3/8	4 3/8	4 1/4	4 1/4	4 1/8	4	3 7/8
11"	TO COPY →	33"	22"	18 1/4"	16 1/2"	14 5/8"	13 3/4"	13 1/8"	12 3/4"	12 1/2"	12 3/8"	12 1/8"	12 1/8"	11 3/4"	11 3/8"
	TO SCREEN →	16 1/2	22	27 1/2	33	44	55	66	77	88	99	9'-2	10'-1	14'-8	23'-10
11"	COPY SIZE 20°	8 1/4	5 1/2	4 1/2	4 1/8	3 5/8	3 3/8	3 1/4	3 1/8	3 1/8	3	3	3	2 7/8	2 7/8
	COPY SIZE 30°	12 1/4	8 1/4	7	6 1/8	5 1/2	5 1/8	5	4 3/4	4 5/8	4 5/8	4 1/2	4 1/2	4 3/8	4 1/4
12"	TO COPY →	36"	24"	20"	18"	16"	15"	14 3/8"	14"	13 3/4"	13 1/2"	13 1/4"	13 1/8"	12 3/4"	12 1/2"
	TO SCREEN →	18	24	30	36	48	60	72	84	96	9'-0	10'-0	11'-0	16'-0	26'-0
12"	COPY SIZE 20°	9	6	5	4 1/2	4	3 3/4	3 1/2	3 1/2	3 1/2	3 3/8	3 1/4	3 1/4	3 1/4	3 1/8
	COPY SIZE 30°	14	9	7 1/2	6 3/4	6	5 3/4	5 1/2	5 1/4	5 1/4	5 1/8	5	5	4 3/4	4 5/8
12"	COPY SIZE 53°	25 1/2	17	14	13	11 1/4	10 1/2	10	9 7/8	9 3/4	9 1/2	9 1/4	9 1/4	9	8 3/4

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FOR F.L. NOT LISTED: DOUBLE-UP OR DIVIDE AS NEEDED.
 EX: FOR 24" F.L., USE 2 TIMES THE VALUES GIVEN FOR A 12" F.L. LENS

OPTICAL DRAWING DEVICES

EDMUND SCIENTIFIC CO. • BARRINGTON, NEW JERSEY



THE THREE optical instruments most used by artists are the camera obscura, the opaque projector and the camera lucida. All three are shown in the small sketches above; all three are described for homemade construction in this booklet.

By far the oldest of the trio is the camera obscura (dark chamber), which was in use prior to the year 1500. It was not until much later--1839--that Louis Daguerre invented the photographic process which was to eventually make the camera obscura the modern view camera we have today.

It can be seen that the opaque projector is just the reverse of the view camera, with lights added. This popular instrument was a long time achieving full development for lack of suitable illumination. Today, thanks to Mr. Edison and others, the familiar electric lamp makes the opaque projector a simple homemade project.

In general, a camera reduces while a projector enlarges. In either case, the object and image distances are mutually related and are reversible. The table on opposite page is specifically for projectors, but may be used for cameras by reading the magnification as a reciprocal and then reversing the object-image distances. For example, 3x can be read as 1/3x, and the conjugate distances are exactly the same, only reversed.

Both cameras and projectors can use the same lenses, the ideal being a fast photographic objective, not less than 8 in. focal length. You can expect any good photo objective to be bright and sharp over a 53 degree field. You can make-do with inexpensive homemade lenses like the simple front meniscus or plano-convex duplet, but you must expect somewhat poorer resolution.

MANY DIFFERENT LENSES can be used



SINGLE ACHROMAT - f/4
USUAL NARROW-FIELD LENS IS FOR CAMERAS OR PROJECTORS



FRONT MENISCUS - f/11
CHEAPEST LENS IS NOT BRIGHT BUT FAIRLY SHARP AT f/8 OR f/11



Simple Lens DUPLET - f/8
FAIRLY BRIGHT, FAIRLY SHARP-- THIS IS POPULAR HOMEMADE LENS



COOKE TRIPLET - f/3.5
BEST MEDIUM-PRICE LENS FOR EITHER CAMERA OR PROJECTOR



RAPID RECTILINEAR - f/8
THIS OLD-TIMER IS FAIRLY SHARP BUT DIM AT f/8



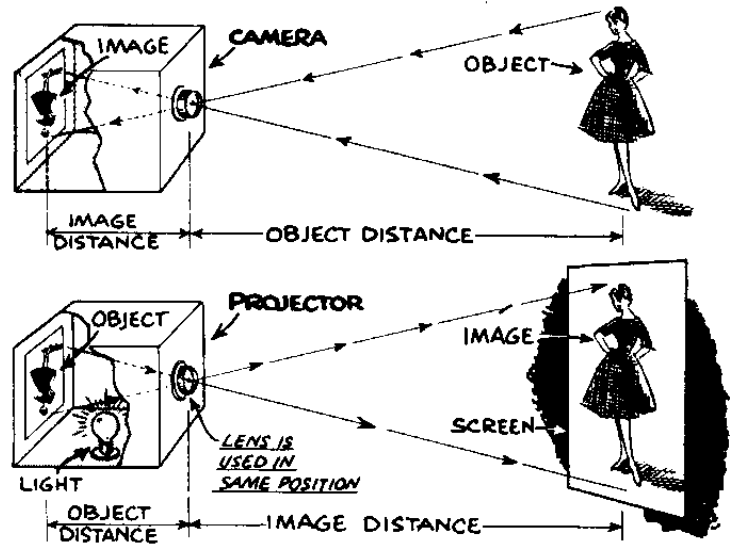
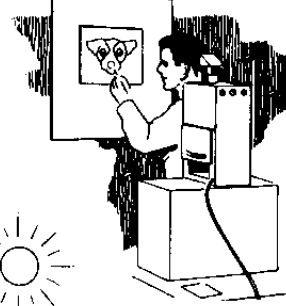
PETZVAL - f/4.5
BRIGHT AND SHARP AT CENTER BUT POOR AT EDGE



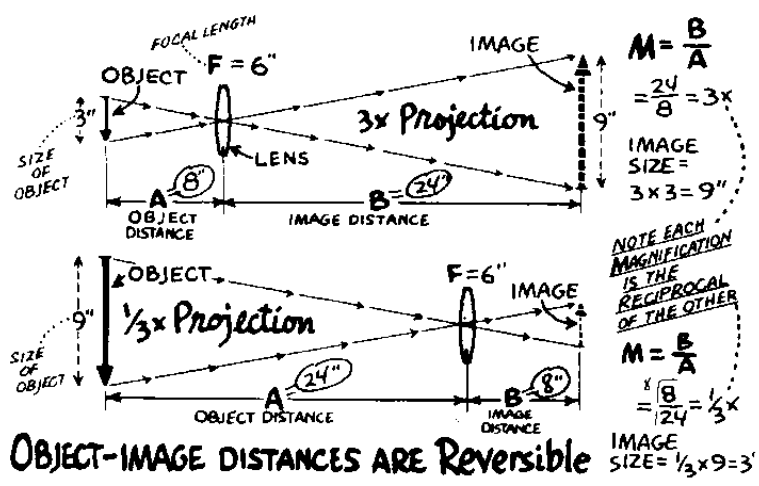
DAGOR - f/6
EXCELLENT DEFINITION OVER WIDE, FLAT FIELD



METROGON - f/6
SLOW, BUT WIDE FLAT FIELD AND NO DISTORTION



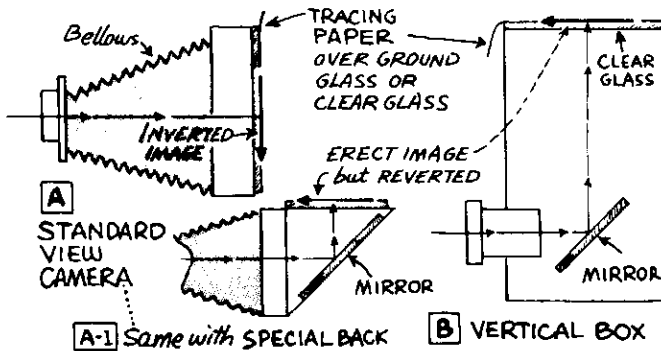
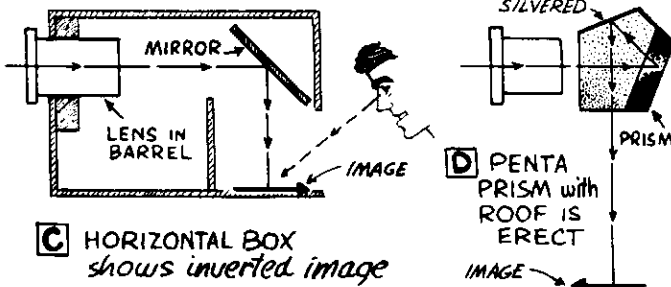
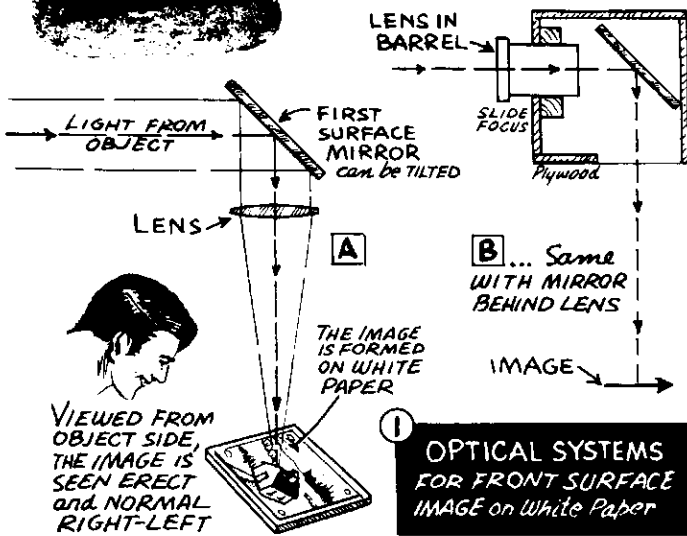
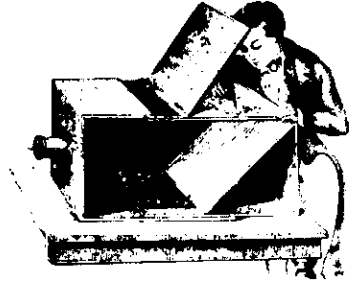
A PROJECTOR IS A CAMERA IN REVERSE



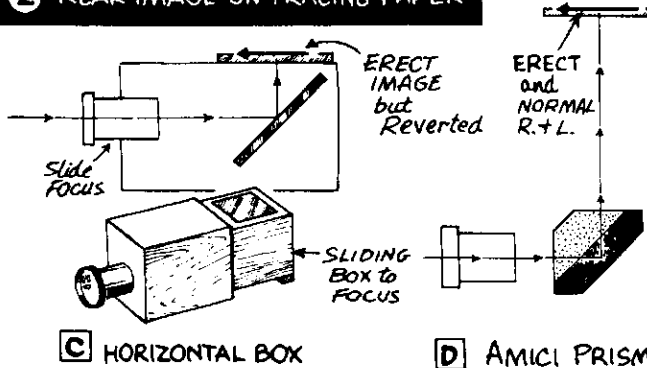
OBJECT-IMAGE DISTANCES ARE Reversible



CAMERA OBSCURA the Drawing Camera



2 REAR IMAGE ON TRACING PAPER



IN ITS long lifetime the camera obscura has been an entertaining viewing device, a familiar sight at seaside resorts. The lens objective of such an instrument gives an angular magnification of 1-power for each 10 inches of focal length, so that even a small tent show could offer views equal to modern binoculars. The best-known U.S.A. installation is the one at San Francisco with a lens of 150 inches focal length providing a view 15 times larger than the naked eye view.

TWO SYSTEMS. Visual camera obscuras usually show the picture on a white surface, while drawing cameras employ the equivalent of a ground glass. This is made up by placing a sheet of tracing paper over a sheet of clear glass. Sometimes tracing paper is used over ground glass, and this is the method you will use if you already have a large format camera with ground glass back. However, clear glass and tracing paper will show a brighter picture than the double translucent surfaces.

Fig. 1 shows four optical systems for producing the image on white paper or other white surface. Style 1-A is most common. This will show an erect and normal right-left image, but only if you stand with your back to the object viewed. The arrangement at C is rarely used because the image is seen inverted; system D shows how the image can be erected with a Penta prism with roof. Unfortunately, you will not find many such prisms in war surplus, the largest currently (1971) being 1-1/8 inch clear face, being Edmund No. 3259.

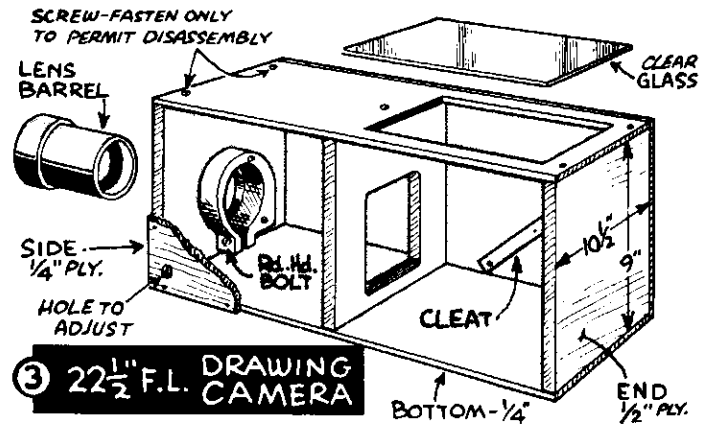
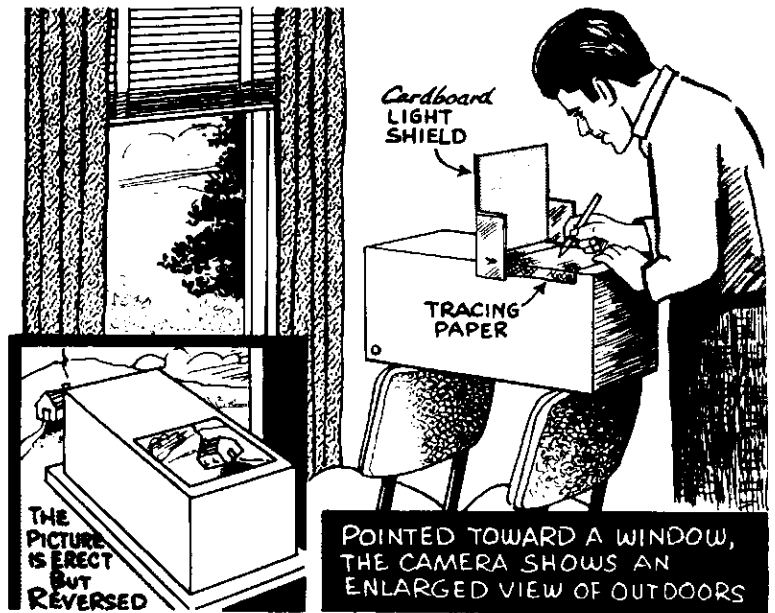
Fig. 2 shows examples of optical systems where the image is received on tracing paper. For many years, style 2-C has been most common and most popular. If you have a large format view camera, you can use it "as is" for drawing, the only addition being the sheet of paper over the ground glass. An erecting back can be easily made of plywood, as shown. A drawing camera made with an Amici prism, Fig. 2-D, will show a normal right-left erect image. Once plentiful in war surplus stocks, the Amici prism is now somewhat hard to find in large sizes, the largest in current Edmund stocks being 1-5/16 inch clear face.

The mirror used in most drawing cameras can be either first or second surface. If the mirror is used close to the lens, it need not be very large and so will not be too expensive in a top quality first surface

mirror. For larger mirrors, inexpensive second surface mirrors can be used, preferably not over 1/8 in. thick. The second surface mirror will sometimes show a faint second image, which fault tends to increase with the thickness of the glass.

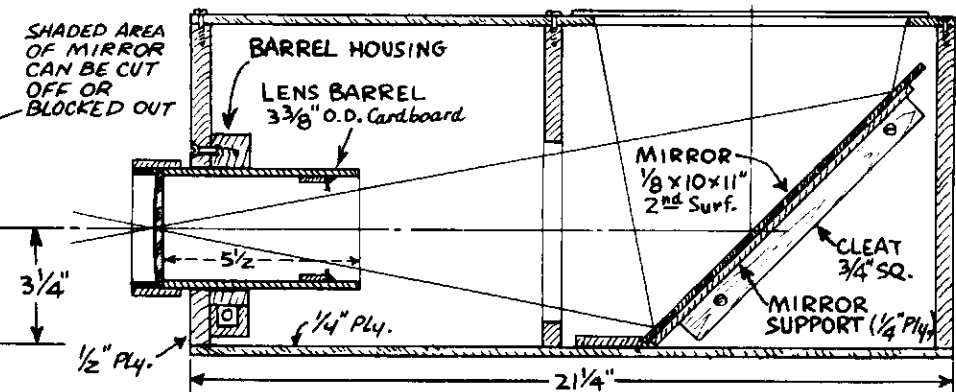
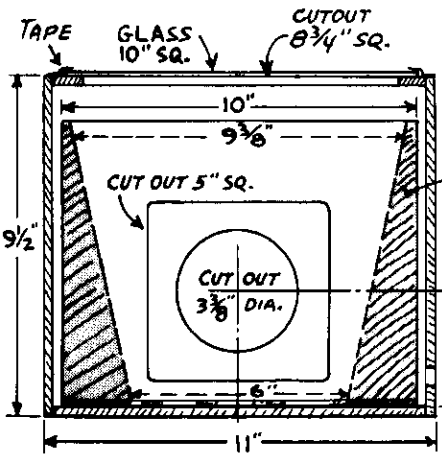
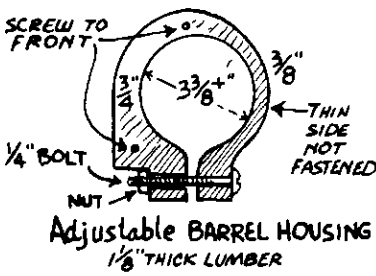
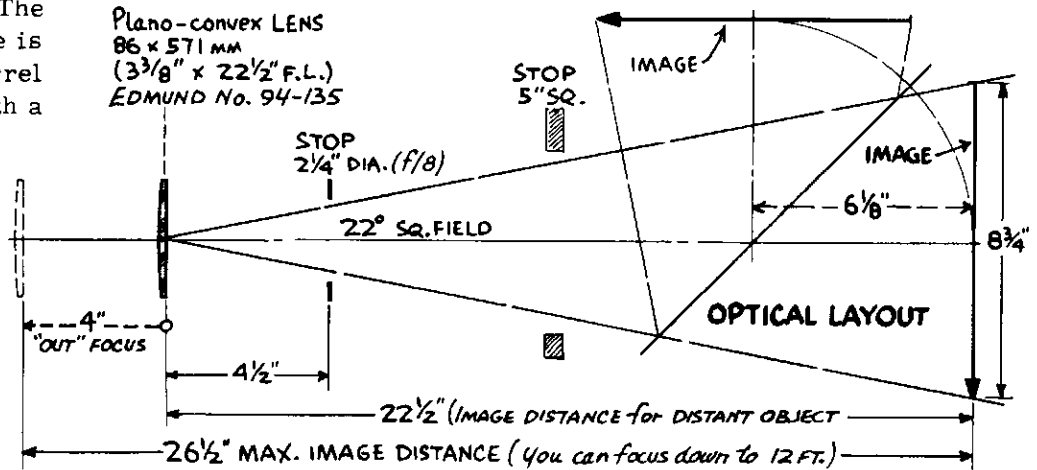
22-1/2" DRAWING CAMERA. A specific design in a horizontal box with simple lens of 22-1/2 inches focal length is shown in Fig. 3. This is satisfactory with a thin mirror purchased at the local "dime" store. The general construction calls for a plywood box which is easily hammered together, except the top is screw-fastened for easy removal for cleaning or adjustments. The box may be painted flat black inside if desired, although the bare plywood itself is a good non-reflective surface. If desired, the face of the mirror may be painted or blocked off with tape to expose only the surface actually used in forming the image.

The drawing or viewing surface is plain double-thick glass of the grade used for window glass. Tracing paper is used over the glass to provide an image screen; the image is seen erect but reverted. If you want to revert to normal, you simply flip the tracing paper sketch for final redrawing on the actual drawing board surface. A cardboard shade may be needed to shield the image from light; the one shown is held in place with a rubber band. The simple plano-convex objective is mounted in a cardboard barrel and is stopped down to f/8 with a



3 22 1/2" F.L. DRAWING CAMERA

Plano-convex LENS
86 x 571 MM
(3 3/8" x 22 1/2" F.L.)
EDMUND No. 94-135

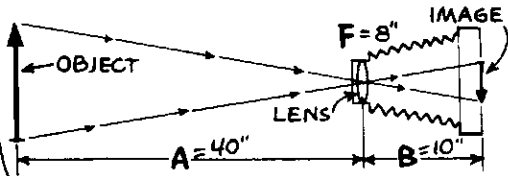


4

Camera ARITHMETIC

SYMBOLS

A... IS DISTANCE FROM LENS TO OBJECT
 B... IS DISTANCE FROM LENS TO IMAGE
 F... IS FOCAL LENGTH OF LENS
 M... IS LINEAR MAGNIFICATION



$M = \frac{1}{4} \times$ (THE IMAGE IS $\frac{1}{4}$ THE SIZE OF OBJECT)

Formulas Example

1	$B = (M+1) \times F$	$B = (\frac{1}{4} + 1) \times 8 = \frac{5}{4} \times 8 = 10"$
2	$B = \frac{F \times A}{A - F}$	$B = \frac{8 \times 40}{40 - 8} = \frac{320}{32} = 10"$
3	$B = A \times M$	$B = 40 \times \frac{1}{4} = 10"$
4	$A = \frac{B}{M}$	$A = \frac{10}{\frac{1}{4}} = 10 \times \frac{4}{1} = 40"$ <small>TO DIVIDE BY A FRACTION YOU INVERT AND MULTIPLY</small>
5	$A = \frac{F}{M} + F$	$A = \frac{8}{\frac{1}{4}} + 8 = (8 \times 4) + 8 = 40"$
6	$A = \frac{F \times B}{B - F}$	$A = \frac{8 \times 10}{10 - 8} = \frac{80}{2} = 40"$
7	$M = \frac{B}{A}$	$M = \frac{10}{40} = \frac{1}{4} \times$
8	$M = \frac{F}{A - F}$	$M = \frac{8}{40 - 8} = \frac{8}{32} = \frac{1}{4} \times$
9	$M = \frac{B - F}{F}$	$M = \frac{10 - 8}{8} = \frac{2}{8} = \frac{1}{4} \times$
10	$F = \frac{A \times M}{M + 1}$	$F = \frac{40 \times \frac{1}{4}}{\frac{1}{4} + 1} = \frac{10}{\frac{5}{4}} = 10 \times \frac{4}{5} = 8"$
11	$F = \frac{B}{M + 1}$	$F = \frac{10}{\frac{1}{4} + 1} = \frac{10}{\frac{5}{4}} = 10 \times \frac{4}{5} = 8"$
12	$F = \frac{A \times B}{A + B}$	$F = \frac{40 \times 10}{40 + 10} = \frac{400}{50} = 8"$

* ALSO FOR PROJECTORS and ENLARGERS

cardboard ring, as shown. This lens will cover a 9-in. square field with fair sharpness; the f/8 speed is quite bright for outdoor scenes assuming you are indoors shooting through an open window or doorway. If you want to use the camera outdoors, you must provide a complete light shield. One way to make this is by stitching a skirt of black cloth to a black umbrella, the handle of which fits into a socket on the top of the box.

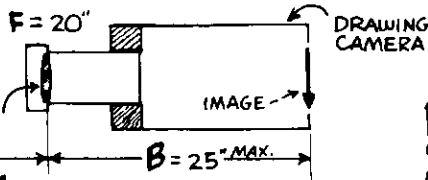
CAMERA ARITHMETIC. All the formulas needed to solve drawing camera problems are given in Fig. 4. You can also use the same formulas for enlargers and projectors, or for any positive lens where the object is more than one focal length from the lens. There are always four quantities involved, and if you know or can specify any two of these, the other two can be calculated. Typical problems are worked out in Fig. 5, showing the use of the formulas. It will be apparent that the size of any camera box or bellows is dependent on the focal length of the lens you plan to use. If you want the camera only for sketching distant objects, the distance from lens to drawing surface will be one f.l. or a little more. On the other hand, if you want to draw objects full-size, the distance from lens to drawing surface will increase to two focal lengths, while the object itself will also be at two f.l. Between these two extremes, you have all the intermediate magnifications from 1x to 1/1000x.

In some optical and camera books, magnifications below 1x are called minifications or reductions. However, you will find the system of all-positive magnifications easier to handle because every situation is treated as a magnification and is determined by the same formulas. Specifically, a fractional M., such as 1/2x, is easier to understand and work with than a 2x reduction, although both specifications mean the same thing--the image is to be 1/2 the linear size of the object.

In building a drawing camera, the most im-

5

Problems



$F = 20"$
 $B = 25"$

Problem: WITH MAXIMUM EXTENSION OF 25", HOW CLOSE CAN YOU FOCUS?

Find: DISTANCE A

Formula 6

$$A = \frac{F \times B}{B - F}$$

$$= \frac{20 \times 25}{25 - 20} = \frac{500}{5}$$

$$A = 100" (8 \text{ FT. } 4 \text{ IN.})$$

Problem:

WITH SAME CAMERA, HOW MUCH EXTENSION (DISTANCE B) IS NEEDED TO FOCUS AT 6 FT. (72")?

You Know: $F = 20"$
 $A = 72"$

Formula 2

$$B = \frac{F \times A}{A - F}$$

$$= \frac{20 \times 72}{72 - 20} = \frac{1440}{52}$$

$$B = 27.7 \text{ inches}$$

Problem:

WITH MAXIMUM EXTENSION OF 25" (DISTANCE B), WHAT FOCAL LENGTH LENS WOULD BE NEEDED TO FOCUS OBJECTS AT 36"?

You Know: $B = 25"$
 $A = 36"$

Formula 12

$$F = \frac{A \times B}{A + B}$$

$$= \frac{36 \times 25}{36 + 25} = \frac{900}{61}$$

$$F = 14.8 \text{ inches}$$

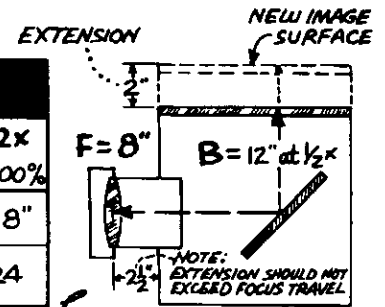
THE IMAGE IS TO BE 1/100 (OR 1%) THE LINEAR SIZE OF OBJECT

6

IMAGE DISTANCE (B) for VARIOUS MAGNIFICATIONS

F.L.	1/100x OR 1%	1/25x OR 4%	1/10x OR 10%	1/8x OR 12.5%	1/6x OR 16.6%	1/5x OR 20%	1/4x OR 25%	1/3x OR 33.3%	1/2x OR 50%	3/5x OR 60%	2/3x OR 66.6%	3/4x OR 75%	1x OR 100%	1 1/2x OR 150%	2x OR 200%
6"	6.1"	6.2"	6.6"	6.8"	7"	7.2"	7.5"	8"	9"	9.6"	10"	10.5"	12"	15"	18"
8"	8.1	8.3	8.8	9	9.3	9.6	10	10.7	12	12.8	13.3	14	16	20	24
10"	10.1	10.4	11	11.3	11.7	12	12.5	13.3	15	16	16.7	17.5	20	25	30
12"	12.1	12.5	13.2	13.5	14	14.4	15	16	18	19.2	20	21	24	30	36
16"	16.2	16.6	17.6	18	18.7	19.2	20	21.3	24	25.6	26.7	28	32	40	48
20"	20.2	20.8	22	22.5	23.3	24	25	26.7	30	32	33.3	35	40	50	60
24"	24.2	25	26.4	27	28	28.8	30	32	36	38.4	40	42	48	60	72
1"	1.01"	1.04"	1.10"	1.13"	1.17"	1.20	1.25"	1.33"	1.50"	1.60"	1.67"	1.75"	2"	2.5"	3"

FOR FOCAL LENGTHS NOT LISTED, USE VALUES FOR 1" F.L. and MULTIPLY BY F.L. OF YOUR LENS



Ex: A Drawing Camera has MAX. M. of 1/2x

Problem: WHAT HIGHER M. CAN YOU GET WITH A 2" EXTENSION?

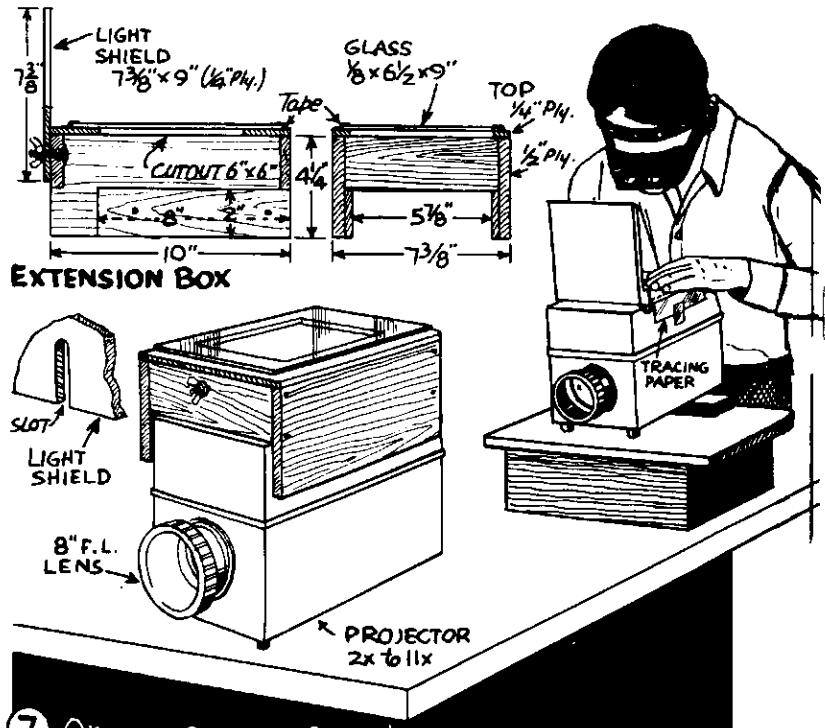
Solution:

PRESENT B = 12" (from table)
add 2" EXTENSION

NEW B = 14"

...the TABLE SHOWS THIS WILL GIVE 3/4x

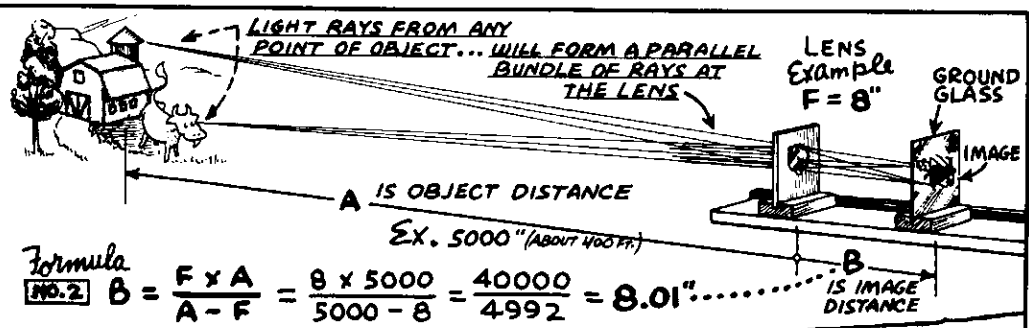
portant dimension is the image distance. This is the length of box or bellows you must provide. Fig. 6 table gives the distance for various f.l. lenses at different magnifications. The equivalent percentage magnification is also given. The percentage magnification is favored in the graphic arts.



7 Opaque PROJECTOR used as a DRAWING CAMERA

OPTICAL Infinity

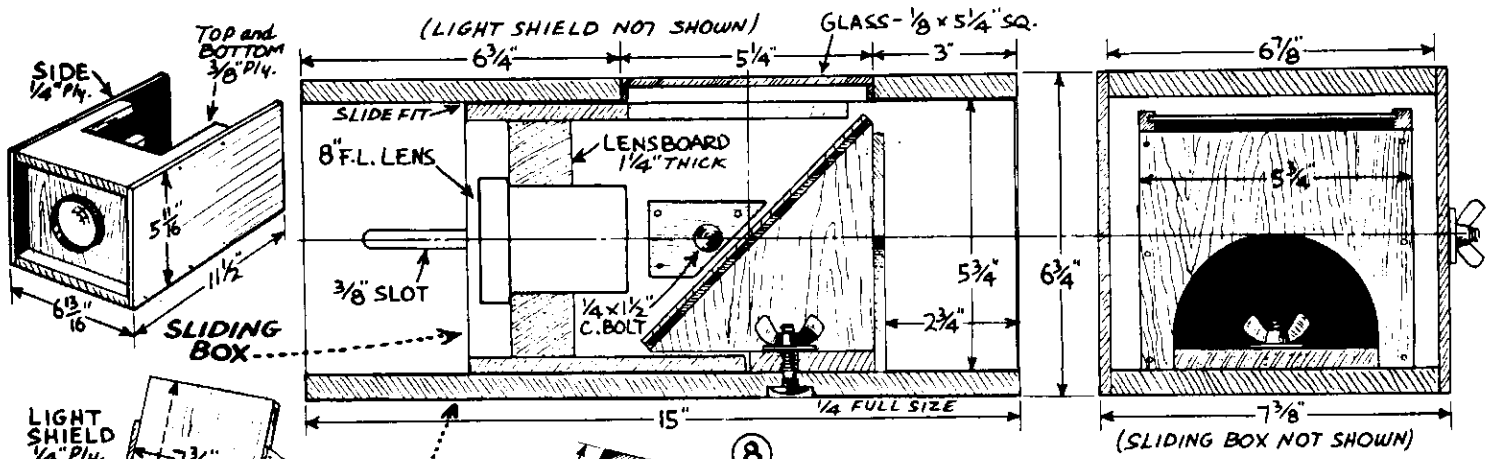
For the true infinity case, B is equal to F, and M is near zero. This occurs only for a very distant object. Practical infinity may be as little as 30 focal lengths. The simple calculations shown will reveal any departure from the true infinity case.



Formula NO. 2 $B = \frac{F \times A}{A - F} = \frac{8 \times 5000}{5000 - 8} = \frac{40000}{4992} = 8.01"$ IS IMAGE DISTANCE

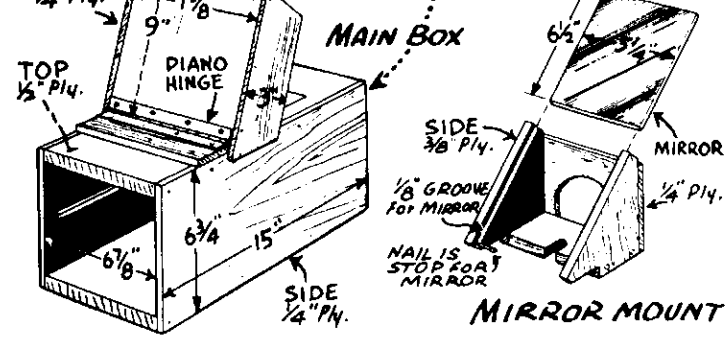
NO. 7 $M = \frac{B}{A} = \frac{8.01}{5000} = .001x$ (LINEAR) (1/1000x)

AT .001x, BARN 30 FT. (360") HIGH WOULD BE: 360 x .001 = .36" (3/8") AT IMAGE PLANE

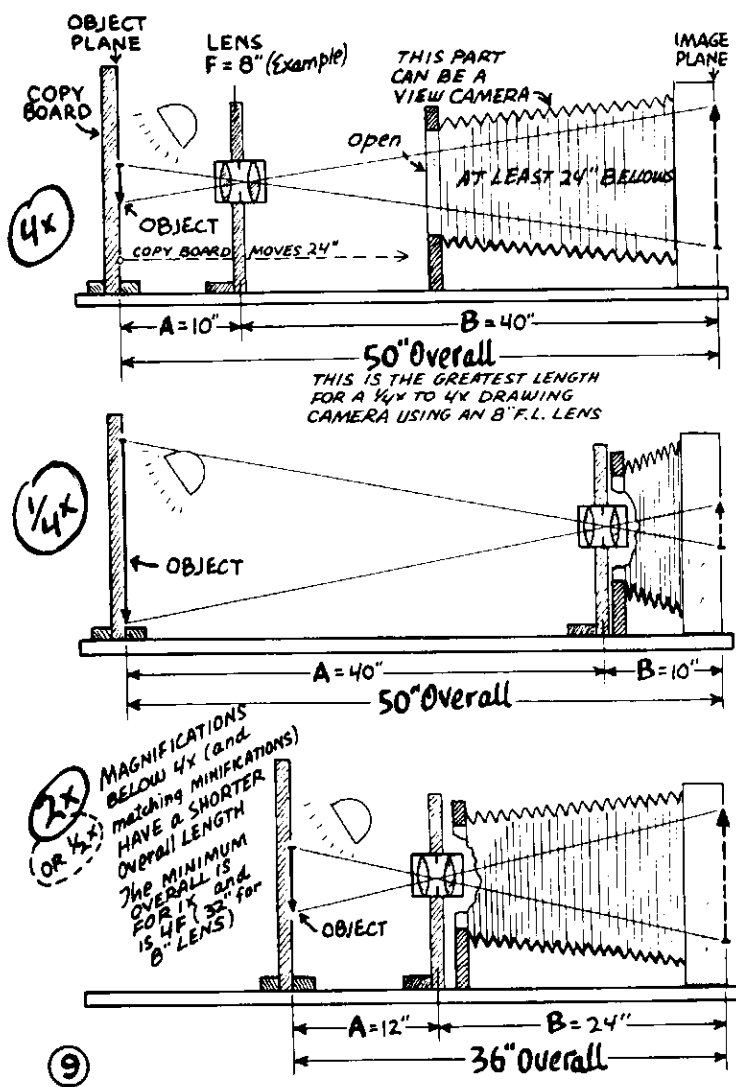


⑧ **SMALL CAMERA OBSCURA with SLIDING BOX FOCUSES FROM 17" TO INFINITY**

will want a little more magnification, and this can be obtained with an extension box, as shown. In addition to the higher M. of $\frac{3}{4}x$ or 75%, the drawing surface is increased from 5x5 to 6x6 inches. The original glass surface can be left in place.



SMALL CAMERA OBSCURA. The smallest practical camera obscura has a 5x5-in. drawing surface. To cover this field you need an 8 in. f.l. lens although some 6 and 7-inchers are satisfactory. In the typical homemade instrument shown in Fig. 8, focusing is done with a simple sliding box instead of the more convenient bellows with rack-and-pinion used for commercial cameras. The erecting mirror can be first or second surface. The construction should begin with the outer plywood box. The diagram shows the lens at infinity position, from which you can move about 7 in. forward to focus on an object at 17 inches. This is about $\frac{7}{8}x$ or 88%. If you care to make the lens a slide fit in its mounting block, you can gain the extra inch needed for picturing objects at 1x, 100% full-size.



⑨ **you can ENLARGE OR REDUCE IN SAME OVERALL LENGTH**

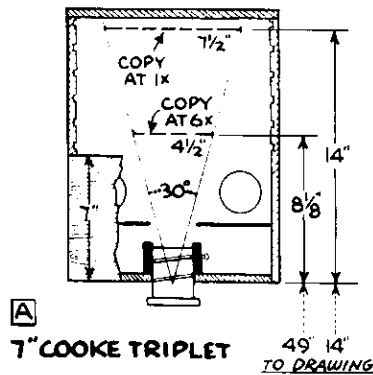
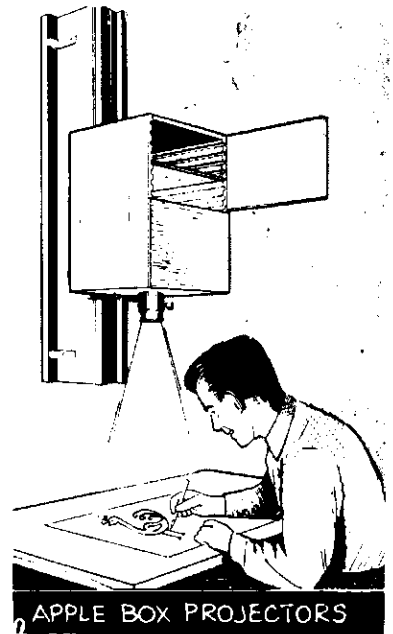
CAMERA FOR FLAT COPY. A camera obscura is sometimes used only for viewing flat copy. Such an instrument is often called a "visualizer" from its function of showing how artwork will look in reduced size as printed. Since any reducing camera will also enlarge in the same overall length, as shown in Fig. 9, commercial visualizers are usually combination instruments working both ways in a range from $\frac{1}{4}x$ to 4x. As shown in the diagrams, complete freedom of movement is required at the lens, with a shorter movement at the copyboard. The drawing surface remains in a fixed position. A homemade instrument of this kind is often made from a standard 8x10 view camera. You can add a homemade plywood back 8 or 10 in. deep, expanding the work surface to 11x14 inches.

DRAWING PROJECTORS

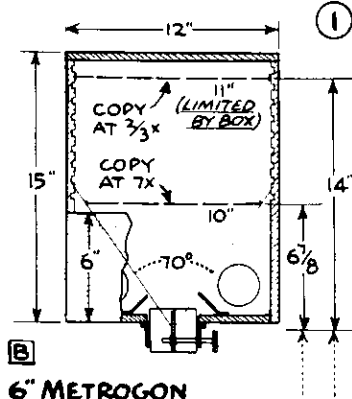
A DRAWING PROJECTOR is an opaque projector designed to enlarge opaque copy such as photographs or line drawings. The magnification range is usually low, being about 1x to 5x. The lens focal length ranges from about 6 to 12 inches. A 6-inch would be ideal except for the fact the short lens may not cover a large enough field. The Metrogon is an exception. In other lenses you usually have to go to 7 or 8 inches f.l. to get the needed field. The lens need not be fast since the usual line copy shows a bright image even at f/8. If you want to project photographs, a fast f/4.5 or wider aperture is desirable.

STRAIGHT-SHOT BOX. This is the simplest to build and is often satisfactory although it reverts the image left-to-right if you are using normal front projection. When rear projection is used, the image will be erect and normal left-right. Standard box dimensions for average lenses are about the size of an apple box, Fig. 1, and many builders actually use such a box. You take the box apart to dado or mould the slots in the side pieces which hold the copy board. The copy board itself should be soft pine or redwood or thicker composition board -- something that takes a thumbtack easily. The lighting is usually two 100-watt household lamps in porcelain or plastic sockets spaced no less than 8 in. center-to-center.

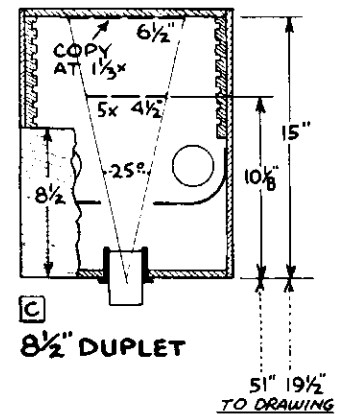
Your projector will be most satisfactory if wall-mounted over a table. Details of a simple mount are shown in Fig. 2. The counterweight



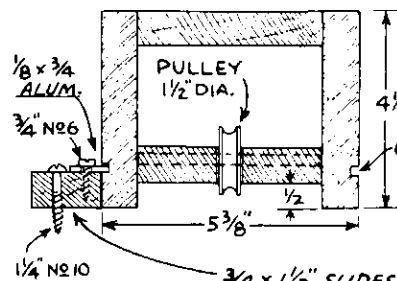
A 7\"/>



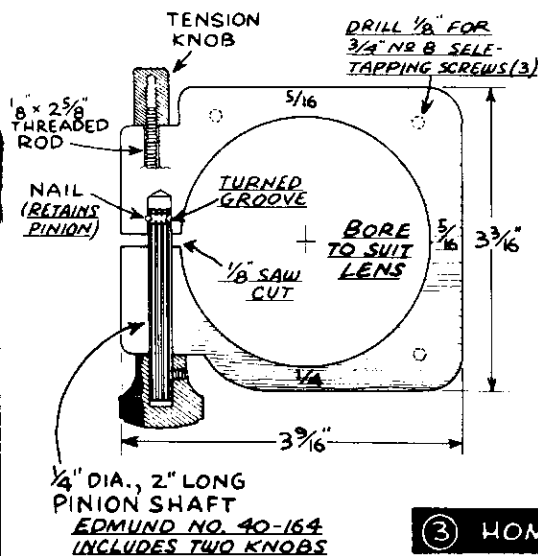
B 6\"/>



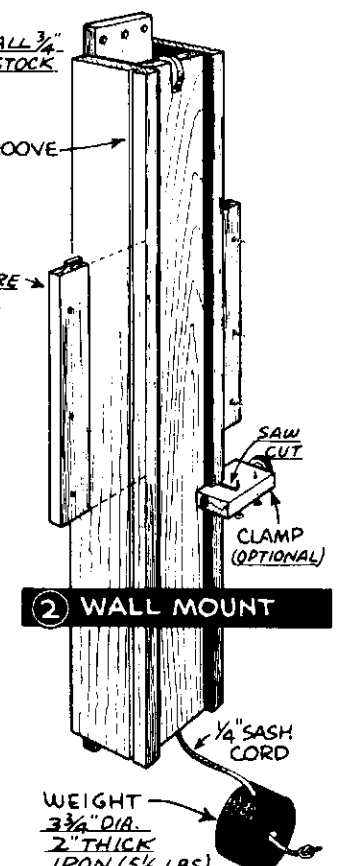
C 8 1/2\"/>



3/4 x 1 1/2\"/>



3 HOMEMADE RACK-and-PINION LENS MOUNT

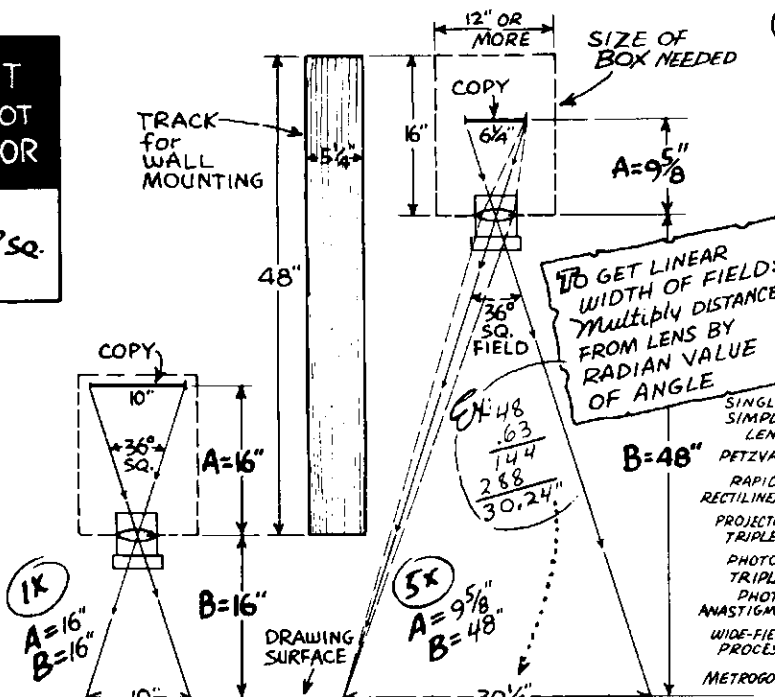
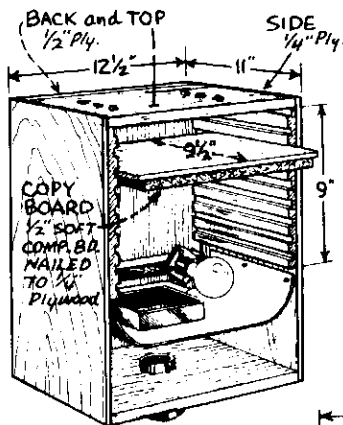


2 WALL MOUNT

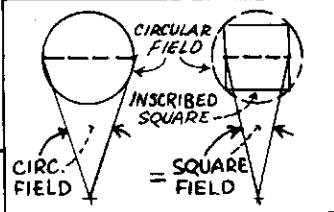
WEIGHT 3 3/4\"/>

④ OPTICAL LAYOUT for a STRAIGHT-SHOT DRAWING PROJECTOR

F.L. of LENS: 8"
FIELD: Est. 50° = 36° SQ.
M. to be: 1x to 5x

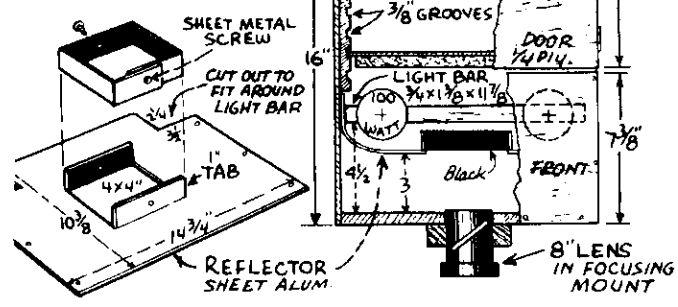


⑤ CIRCULAR FIELD to SQUARE FIELD

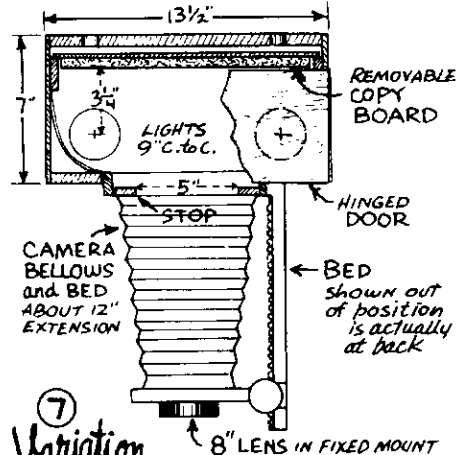


CIRC.	Radians	SQUARE	Radians
20°	.35	14°	.24
25°	.44	18°	.31
30°	.52	22°	.38
35°	.61	25°	.44
40°	.70	29°	.51
45°	.79	32°	.56
50°	.87	36°	.63
60°	1.05	43°	.75
70°	1.22	50°	.87
80°	1.40	58°	1.01

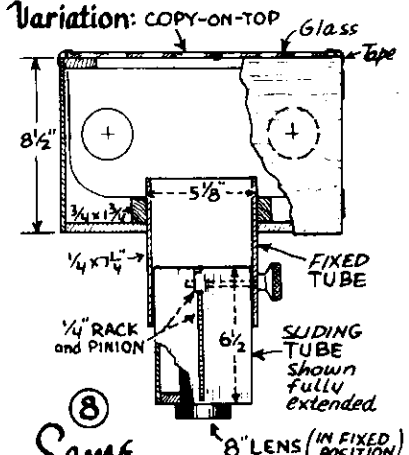
⑥ FINAL DESIGN and CONSTRUCTION



COARSE FOCUSING IS DONE BY MOVING THE COPY BOARD... FINE FOCUS IS AT LENS



⑦ Variation ALL FOCUSING IS DONE WITH CAMERA BELLOWS and BED



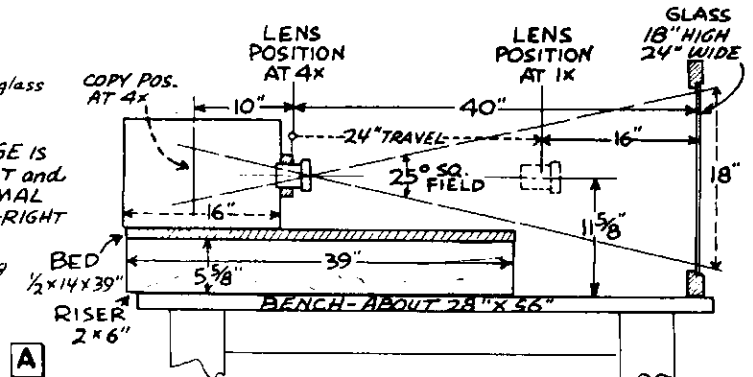
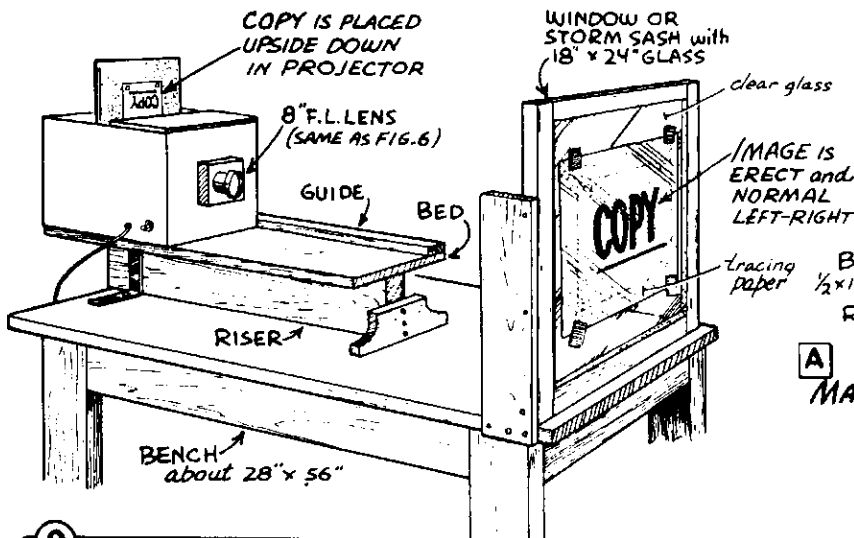
⑧ Same BUT FOCUSING WITH SLIDING PLYWOOD TUBE

shown is from an astronomical telescope. With any vertical box, simple slide focusing of the lens should be avoided since there is always the chance the lens might drop out of the box. Rack-and-pinion focusing is best, and it is not too much work to make a homemade unit of this kind, Fig. 3. One screw or rivet will hold the rack to the barrel, and you can usually mount this single fastening outside the glass and so avoid a disassembly of the lens.

OPTICAL LAYOUT. If you design your own projector, the optical layout is easily made, Fig. 4, using data from the object-image table on inside front cover. The field your lens will cover commonly applies to a circular field. In building a projector, it is simpler to work with a square-shape field, using the equivalent reduced angle, as given in Fig. 5.

Fig. 6 shows the final design and construction of a typical straight-shot projector with 8 in. Cooke Triplet. The lamps are 8 in. center-to-center and unavoidably will show two wide-spaced glare spots on the projected image. The glare spots are especially strong if you are working from a glossy piece of copy, such as a photograph; they are hardly seen at all if the copy is dull paper like newsprint. The square glare stop cut in the reflector will minimize general glare from the interior of the box.

ALL FOCUSING AT LENS. For 1x to 5x magnification with an 8 in. lens, you need only about 6 inches of focusing travel. All of this can be obtained with a bellows or a box to which the lens is attached, as shown in Figs. 7 and 8. When you have all of the focusing at the lens, you need only one permanent position for the copy board. This

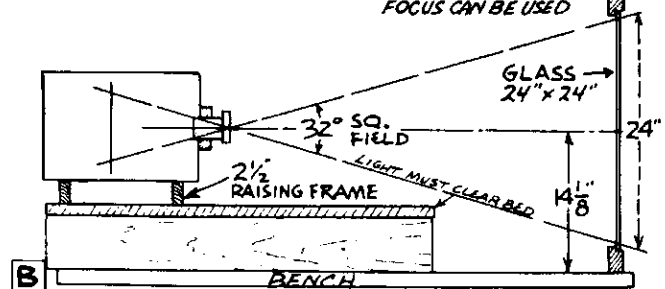


A MAIN DIMENSIONS - THE PROJECTOR ITSELF IS SAME AS FIG. 6, BUT SIMPLE SLIDE FOCUS CAN BE USED

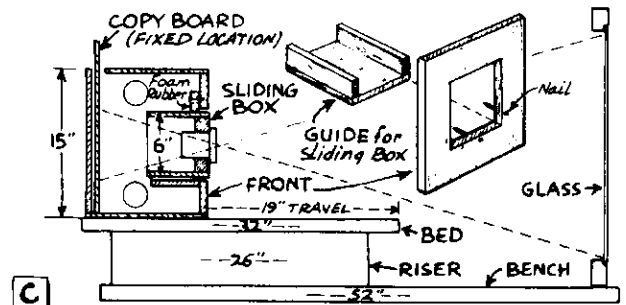
9 HORIZONTAL REAR PROJECTION - 1x to 4x with 8" LENS

in turn permits a fixed light-to-copy distance, as can be seen in the drawings. All of this makes the box a little more compact and a little easier to use. With one-position copy, it is possible to put the copy on top of the lighthouse over a pane of glass, as shown in Fig. 8. The advantage of this is that large copy or magazines can overhang the box. If you use a glass top it is necessary to have the lights at least 10 in. apart to get rid of the glare spots entirely.

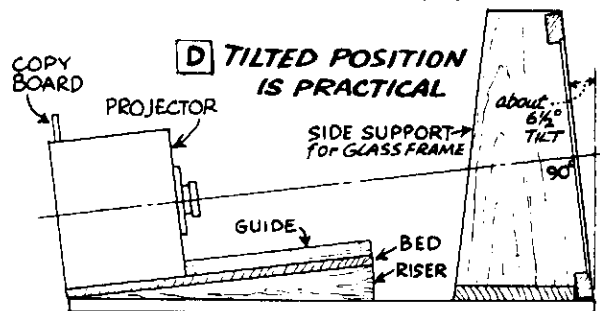
REAR PROJECTION. In rear projection you face the projector lens to view the image formed on a translucent screen. The actual image screen is usually tracing paper placed over a pane of clear glass, Fig. 9 shows a typical setup using a discarded storm sash for the image surface. The comparatively small field of 25 degrees can be covered with an inexpensive simple lens duplet of 8 in. focal length. It will be obvious that a larger field angle will require a larger glass, as shown at B. The projector is placed on the 1/2-in. plywood bed along which it can be set at any position needed for any magnification from 1x to 4x. You can focus and check the magnification from the projector side of the screen, using either tracing paper or a



B LARGER FIELD REQUIRES A LARGER GLASS



C SLIDING FOCUSING BOX IS MORE COMPACT



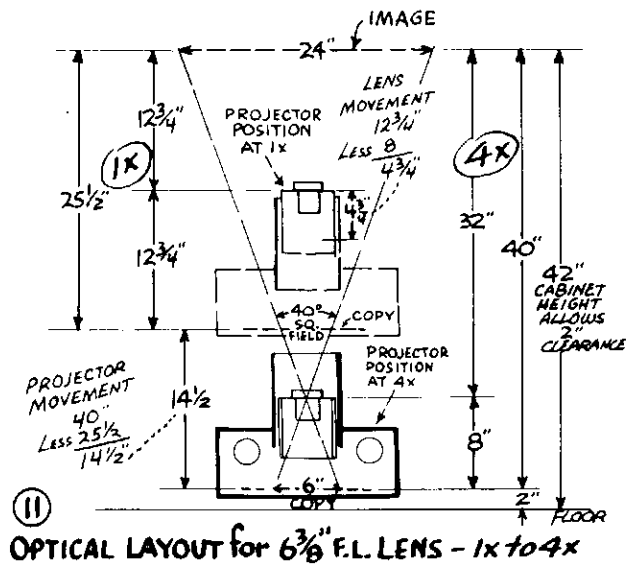
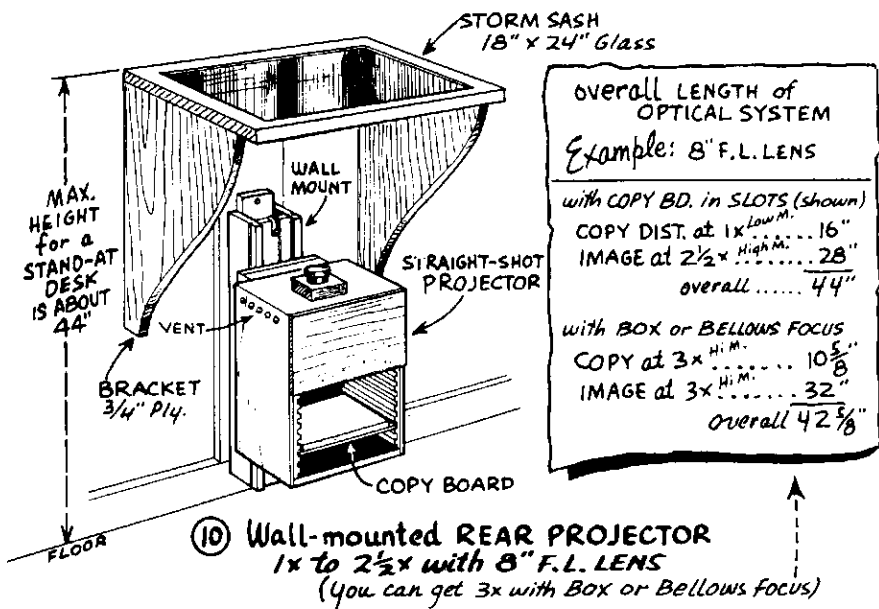
D TILTED POSITION IS PRACTICAL

Comparative BRIGHTNESS

Of course you know a fast f/3.5 lens transmits more light than a slow f/8, but the difference becomes more tangible when you use the table of comparative brightness at right. As listed, the fast f/3.5 gets a brightness rating of 82, while the f/8 scales only 16. A simple division of the two numbers (82/16) reveals that the f/3.5 gives an image five times brighter with the same lamp system.

BRIGHTNESS Based on f/Value of LENS

f/Value	BRIGHTNESS	f/Value	BRIGHTNESS	f/Value	BRIGHTNESS
f/3	110	f/6	28	f/9.5	11
f/3.16	100	f/6.5	24	f/10	10
f/3.5	82	f/7	20	f/10.5	9
f/4	63	f/7.5	18	f/11	8
f/4.5	50	f/8	16	f/16	4
f/5	40	f/8.5	14	f/22	2
f/5.5	33	f/9	12	f/32	1

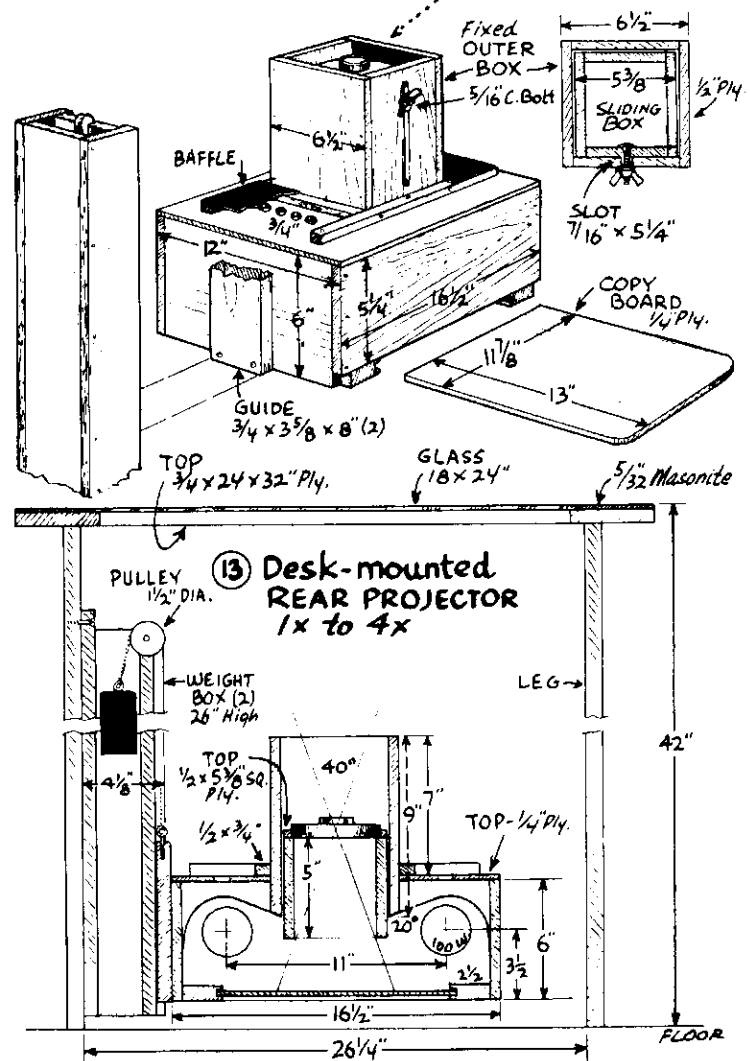
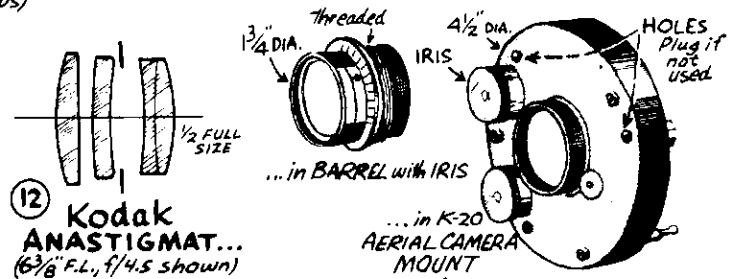


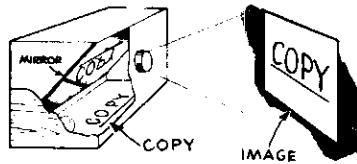
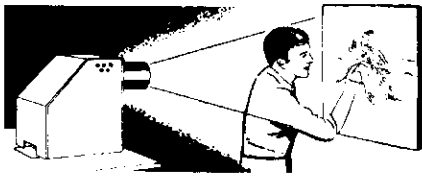
white card as the image screen, Fig. 9 at C shows the preferred construction using a box or bellows for the lens-to-copy adjustment; this reduces overall length by about 6 inches.

VERTICAL REAR PROJECTION. You use the same straight-shot box as before, except it is now pointing upward to the work surface, Fig. 10. It will be apparent that only a limited amount of vertical space is available, especially if you want a sit-down console. Fig. 10 is a stand-at desk, with the copy in slots. You can gain a little more M. in the same space by using box or bellows focus, as tabulated above.

For higher M. in the same or shorter space, you will need a shorter f.l. lens. If also you want a fair-size field of at least 6 x 6 inches, it means your lens must be a fairly expensive camera or enlarger objective. A typical choice would be a 6-3/8 in. Kodak anastigmat; the same lens is available at times in military surplus, being the objective of the K-20 Aerial Camera, Fig. 12. This lens and focal length is used for 4 x 5 inch or smaller cameras, but it will cover 6 x 6 in an opaque projector because you never use it at the infinity setting. For example, if your top M. is 4x, the copy distance will be 8 in., Fig. 11, and in this distance you get the needed spread of the light cone to cover 6 x 6 in. copy. At 2x, the lens will cover 9 in. copy.

Fig. 13 shows the construction of desk-mounted rear projector. Rough focusing is done by pushing the whole projector up or down, the instrument being counterbalanced to stay put at any position. The final focus is done with a sliding box carrying the K-20 aerial camera lens or similar. Focusing is a bit awkward in that you must squat down and look up at the





FRONT PROJECTION with a REFLECTING PROJECTOR SHOWS THE IMAGE ERECT and NORMAL LEFT-RIGHT. THE LINE OF PROJECTION CAN BE HORIZONTAL or VERTICAL

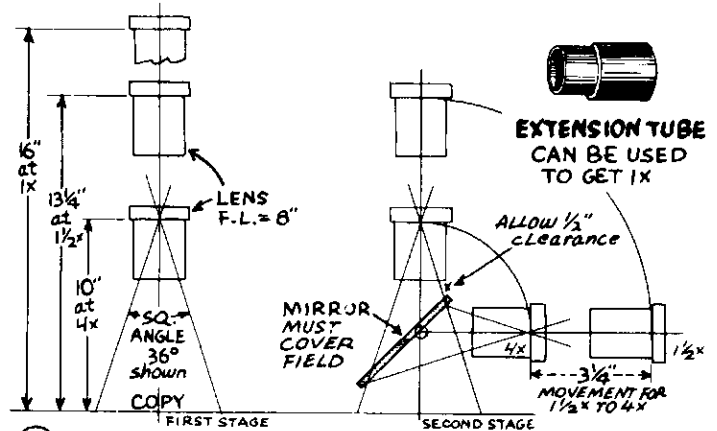


image; rack-and-pinion focusing with remote control by flexible shaft would be an improvement. Do not try to make the sliding box a snug slide fit in the outer box--a loose, free-sliding fit is all you need.

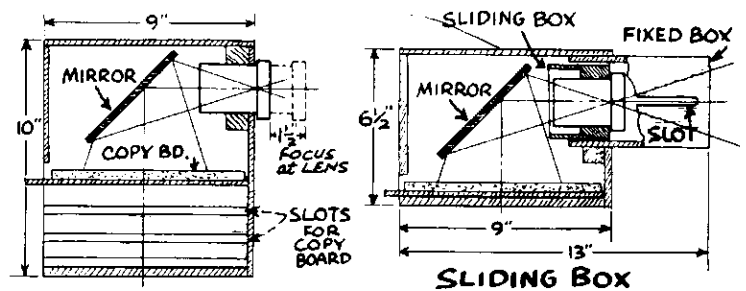
FRONT PROJECTION WITH A MIRROR. This is the usual type of projection where the image is seen on an opaque white screen or paper. The mirror is needed to erect the image. In designing a reflecting projector, you start by laying out the lens-to-copy distances in the same way as for a straight-shot box. The diagonal mirror is then drawn behind the lens and the lens is rotated to a horizontal plane, Fig. 14.

The simplest method of focusing is with copy board slots as already described. You also have available a short range of slide focus at the lens itself. All of the movement needed for a 1x to 4x projector can be obtained with a sliding box or bellows, Fig. 15.

LIGHTING SYSTEMS. A number of lighting systems are shown in Fig. 16, all being single lamp except J, which shows the familiar two-lamp system using a pair of 100-watt household lamps. Projection lamps are often used in



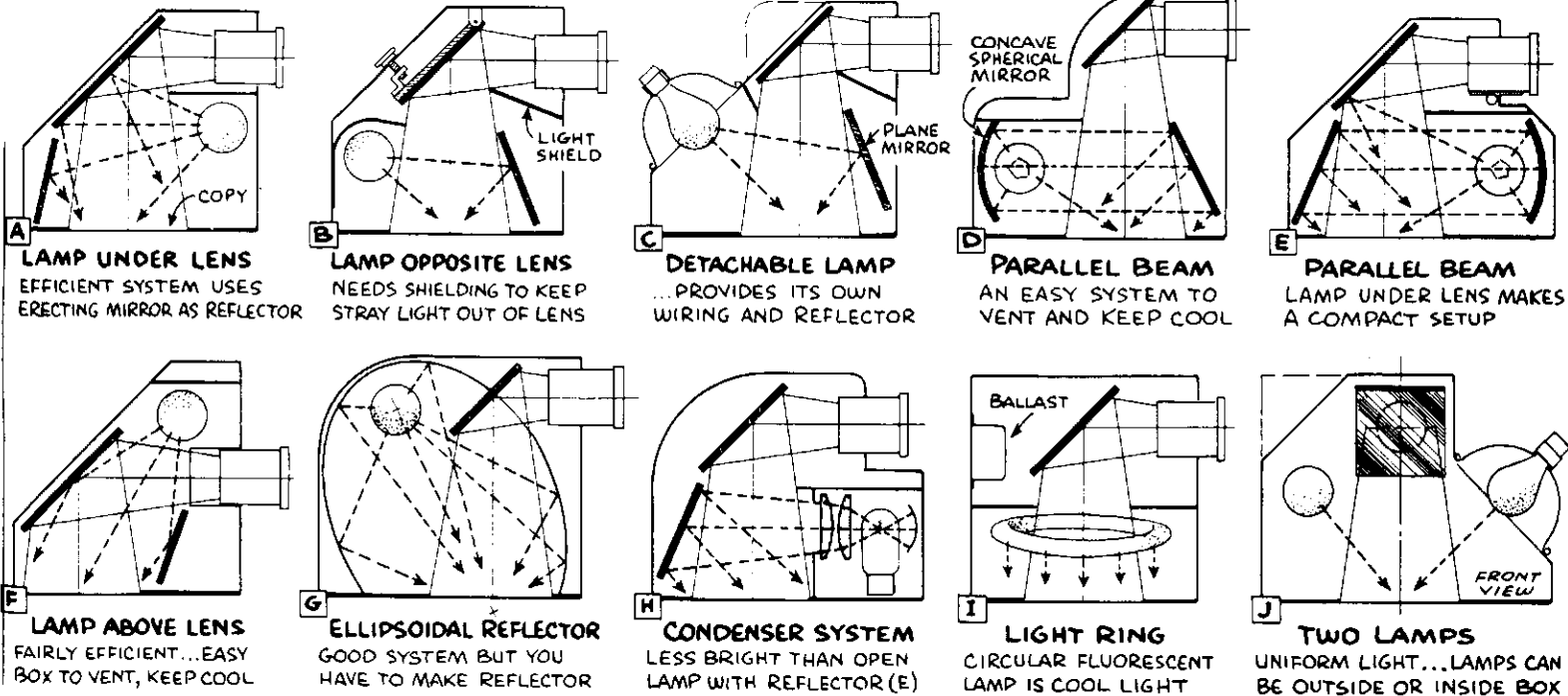
(14) OPTICAL LAYOUT BEGINS LIKE A STRAIGHT-SHOT PROJECTOR. THE TRAVEL NEEDED FOR FOCUSING CAN BE REDUCED BY SPECIFYING $1\frac{1}{2}x$ INSTEAD OF $1x$ FOR LOW M.



COPY BOARD IN SLOTS

(15) FOCUSING METHODS

(16) LIGHTING SYSTEMS



A LAMP UNDER LENS
EFFICIENT SYSTEM USES ERECTING MIRROR AS REFLECTOR

B LAMP OPPOSITE LENS
NEEDS SHIELDING TO KEEP STRAY LIGHT OUT OF LENS

C DETACHABLE LAMP
... PROVIDES ITS OWN WIRING AND REFLECTOR

D PARALLEL BEAM
AN EASY SYSTEM TO VENT AND KEEP COOL

E PARALLEL BEAM
LAMP UNDER LENS MAKES A COMPACT SETUP

F LAMP ABOVE LENS
FAIRLY EFFICIENT...EASY BOX TO VENT, KEEP COOL

G ELLIPSOIDAL REFLECTOR
GOOD SYSTEM BUT YOU HAVE TO MAKE REFLECTOR

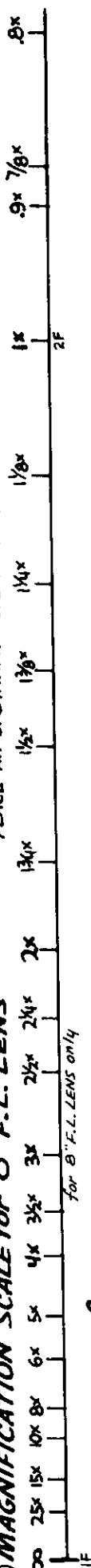
H CONDENSER SYSTEM
LESS BRIGHT THAN OPEN LAMP WITH REFLECTOR (E)

I LIGHT RING
CIRCULAR FLUORESCENT LAMP IS COOL LIGHT

J TWO LAMPS
UNIFORM LIGHT...LAMPS CAN BE OUTSIDE OR INSIDE BOX

PLACE AN ORDINARY RULER ANYWHERE ALONG THIS SCALE

①7 MAGNIFICATION SCALE for 8" F.L. LENS



Use this scale to find:

1. MAGNIFICATION RANGE YOU CAN GET WITH A SPECIFIED AMOUNT OF FOCUSING TRAVEL

Example: WITH 3" OF TRAVEL YOU CAN GET:

2x TO 8x

OR 1 3/4x TO 5x

OR 1x TO 1 1/2x

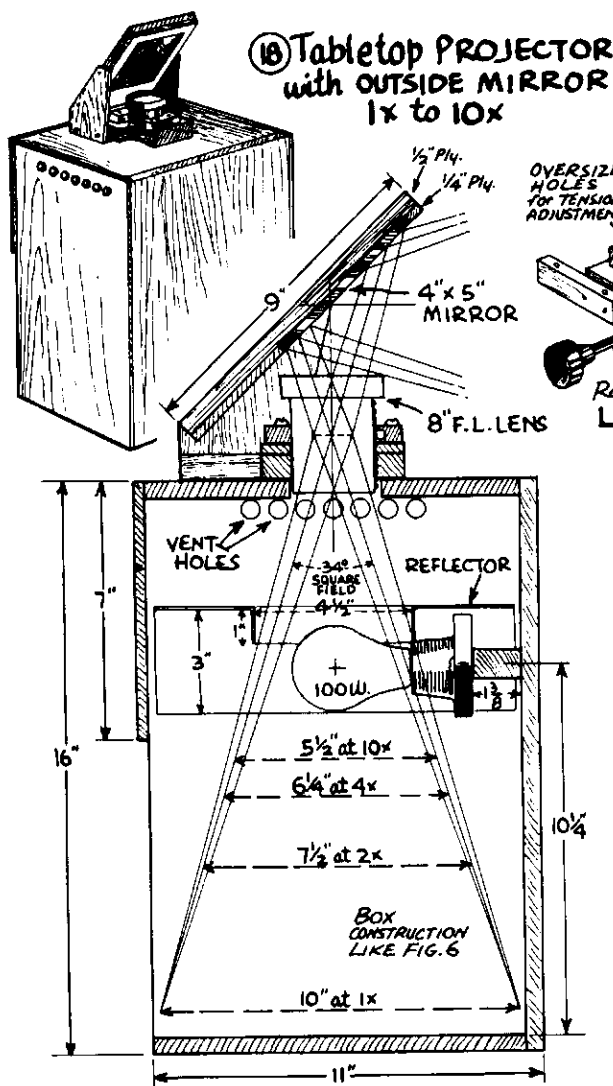
ETC. ETC.

2. FOCUSING TRAVEL NEEDED FOR A SPECIFIED RANGE OF M.

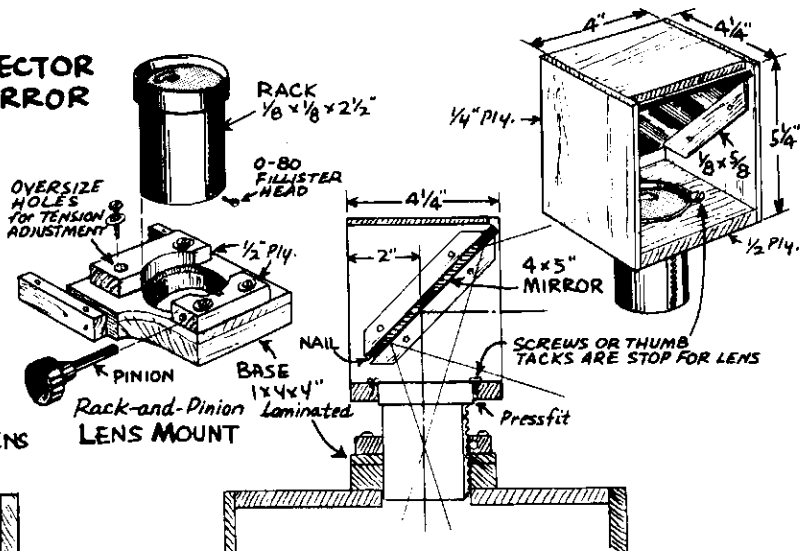
Example: YOU WANT 1x TO 4x. YOUR RULER READS 6" BETWEEN 1x AND 4x

ON THE SCALE, i.e., YOU NEED 6" OF TRAVEL

* RECOMMENDED, BUT 1/8" OR 1/4" IS USUALLY SATISFACTORY FOR THE LOW M.



①8 Tabletop PROJECTOR with OUTSIDE MIRROR 1x to 10x

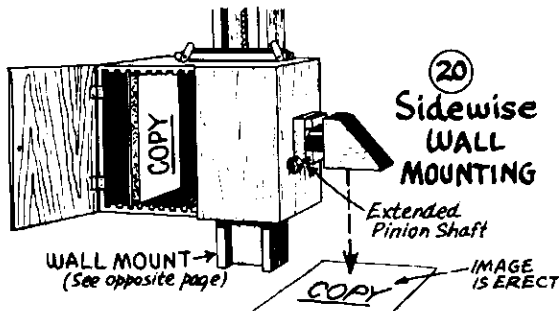


①9 ... Same... with MIRROR ATTACHED TO LENS

commercial projectors, but they are too hot for wood construction. An inexpensive circular fluorescent lamp can be used if you want an especially cool projector to protect delicate copy.

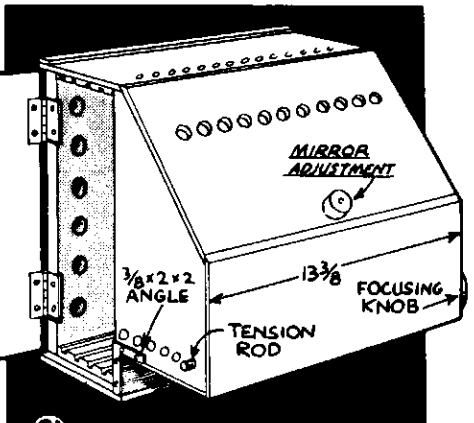
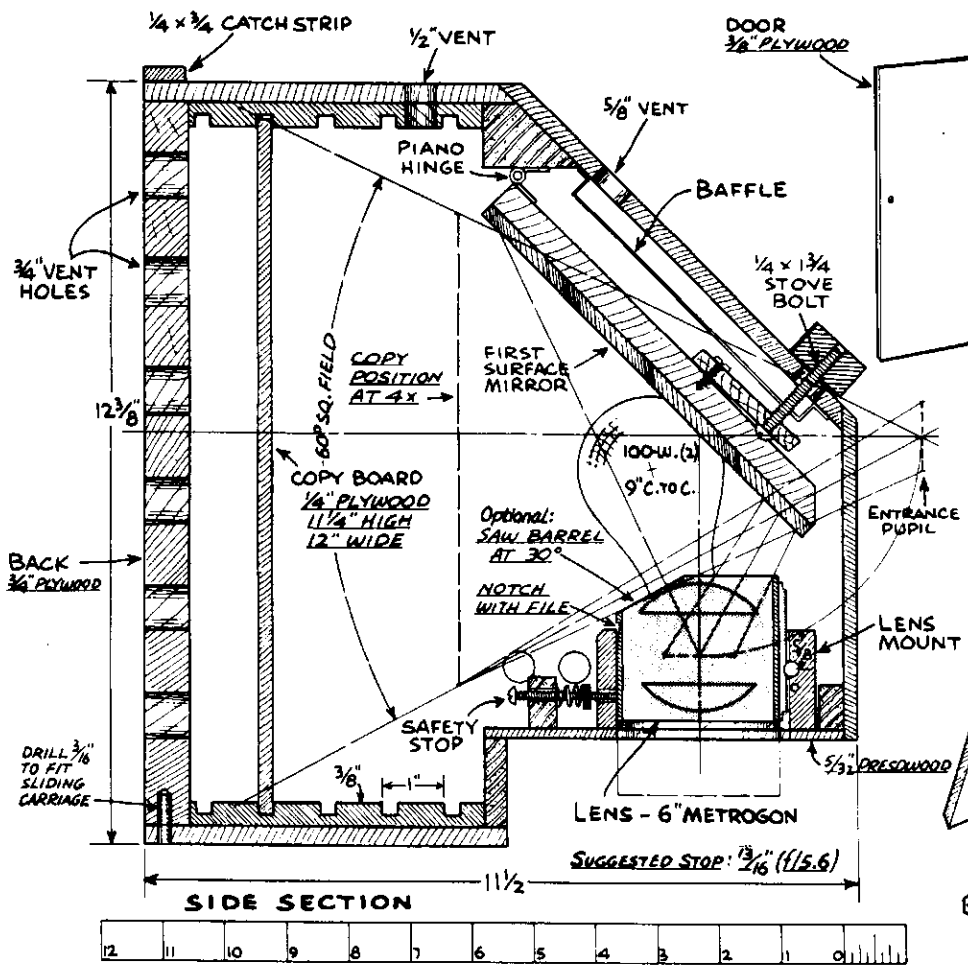
MAGNIFICATION SCALE. A full-size scale for any projection lens of 8 in. focal length is shown in Fig. 17. This solves the common problems of lens movement and magnification. It can be seen that low M. is expensive in terms of box size, while high M. is easily obtained with very little increase in physical size.

OUTSIDE MIRROR. The erecting mirror is often placed outside the light box. Fig. 18 shows the conversion of the plain box already described. The image is seen erect and normal on a white screen or drawing board. Sometimes the mirror is attached directly to the lens and moves with it, Fig. 19. In either case, rack-and-pinion focusing is desirable and can be obtained with the simple construction shown. A compact and practical wall mounting can be made in a "sidewise" position, Fig. 20. This shows an erect normal image as usual. The side position requires a change in lens orientation which must be rotated a quarter-turn. Also it will be apparent the mirror box need not be square--it can be sliced in half on a 45-deg. angle, as shown.

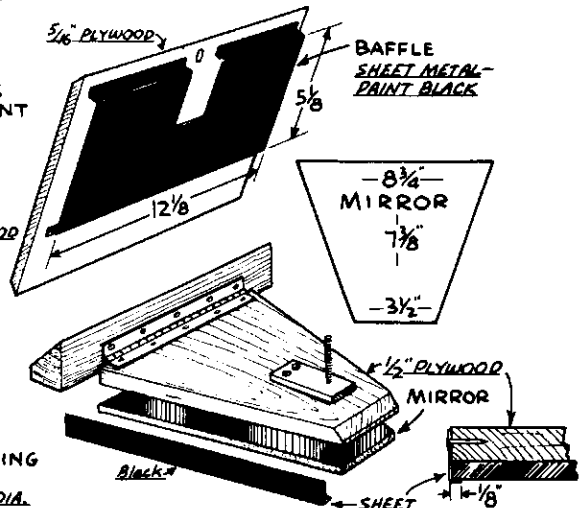


②0 Sidewise WALL MOUNTING

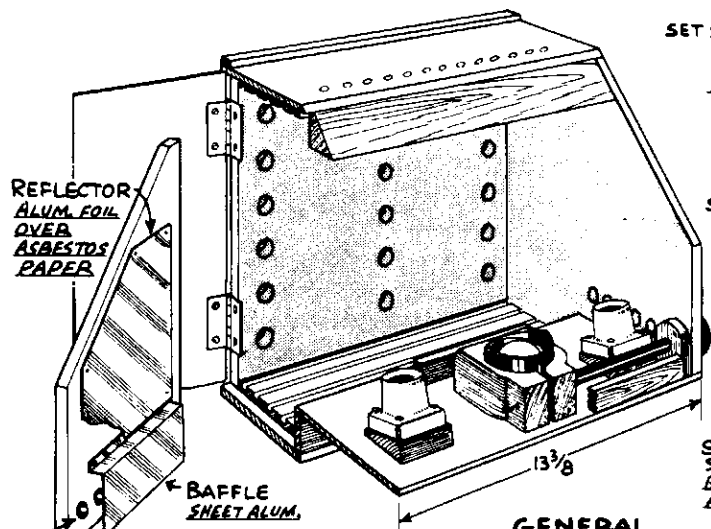
WIDE FIELD PROJECTOR. The Metrogon lens is well-known for its extremely wide field of 90 degrees. This lens is not fast, being about f/5.6 and so less than half as bright as an f/3.5 triplet. However, the projected image is flat and distortion-free from edge to edge. Fig. 21 shows a box for a 6-in. f.l. Metrogon. The lens



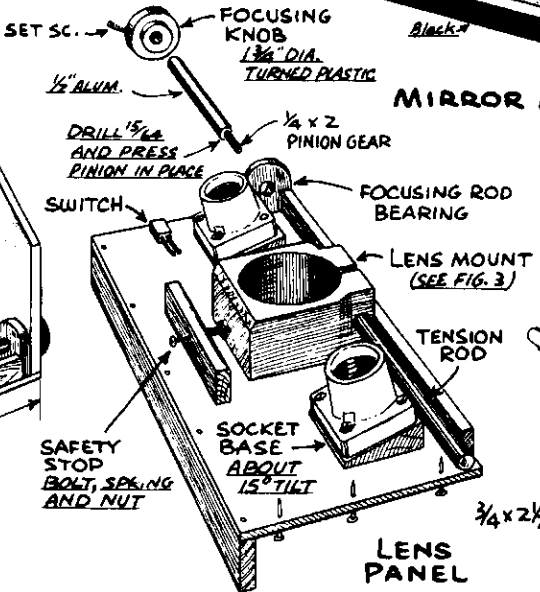
(21)
**1x to 4x Wide Field
 DRAWING PROJECTOR**
 COPY SIZE: 8" x 9" AT 4x



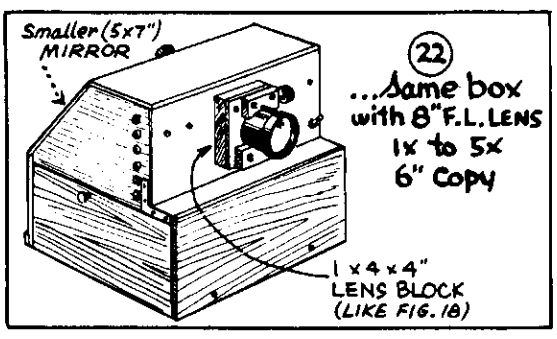
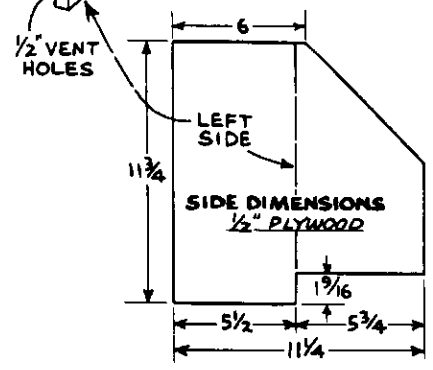
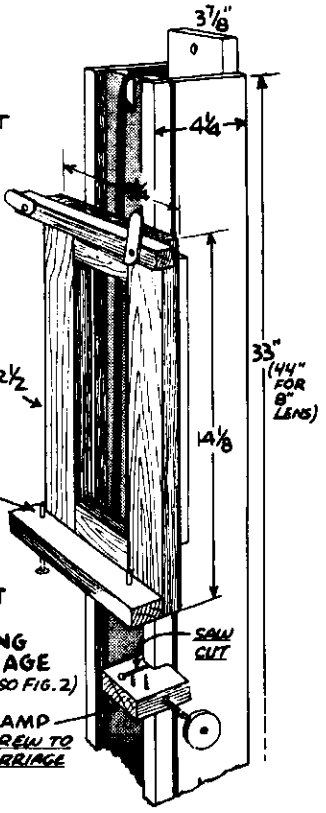
MIRROR MOUNTING

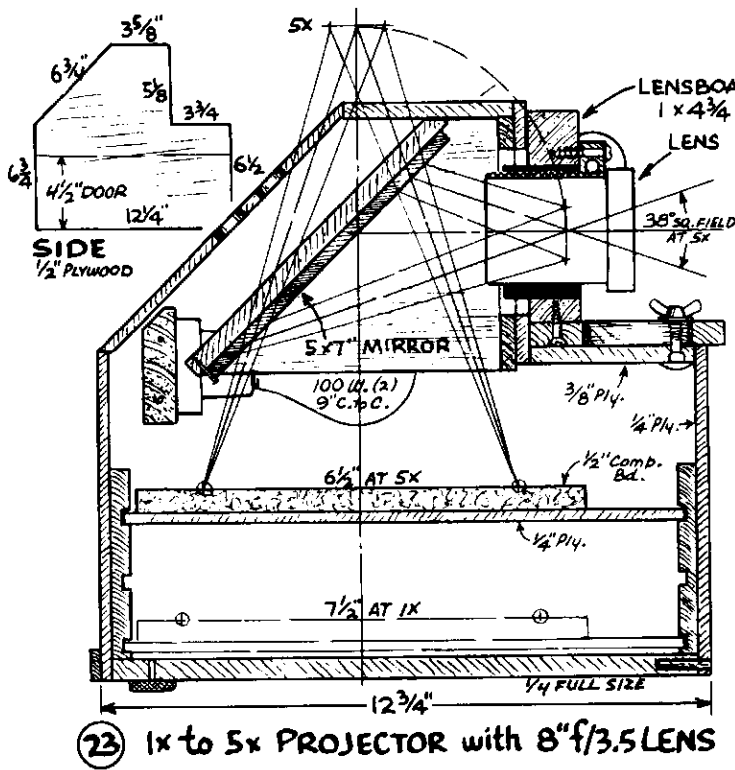


GENERAL ASSEMBLY



LENS PANEL



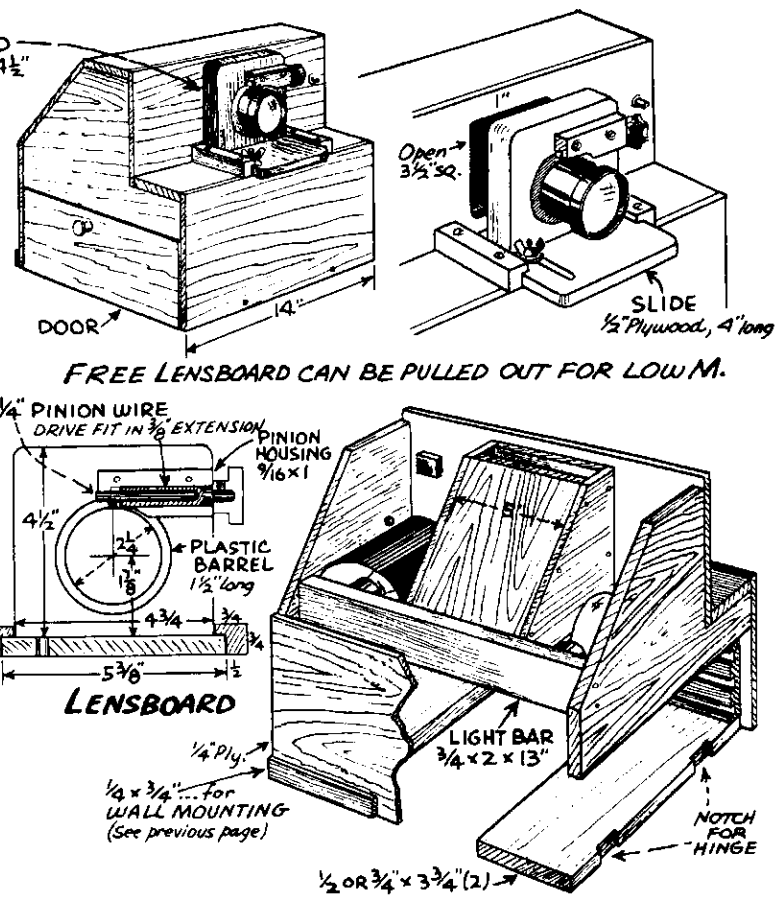


22 1x to 5x PROJECTOR with 8" f/3.5 LENS

is purchased in a barrel and needs to have a rack attached. The sliding carriage type of wall mount permits easy detachment of the projector for table use.

STANDARD PROJECTOR. A lens of 8 in. focal length is a common standard for opaque projectors. Fig. 22 shows the Metrogonbox slightly altered for this focal length. Fig. 23 shows a similar box designed specifically for an 8 in. lens. Both designs use a standard 5x7-inch first surface mirror; box on this page has the mirror held in place with 1/8 in. thick hold-in strips, plus a brad at either end to keep the mirror from sliding out.

Start building this box by making two sides of 1/2 in. plywood; one of these can be sawed in two later to make a door. Rack-and-pinion focusing is conventional but you will need an extension to the standard 2-in. length of pinion wire commonly sold. The lens rides in a turned plastic sleeve cemented to the lensboard; this will eliminate the jamming often encountered with a plain hole in a block of wood. An extra



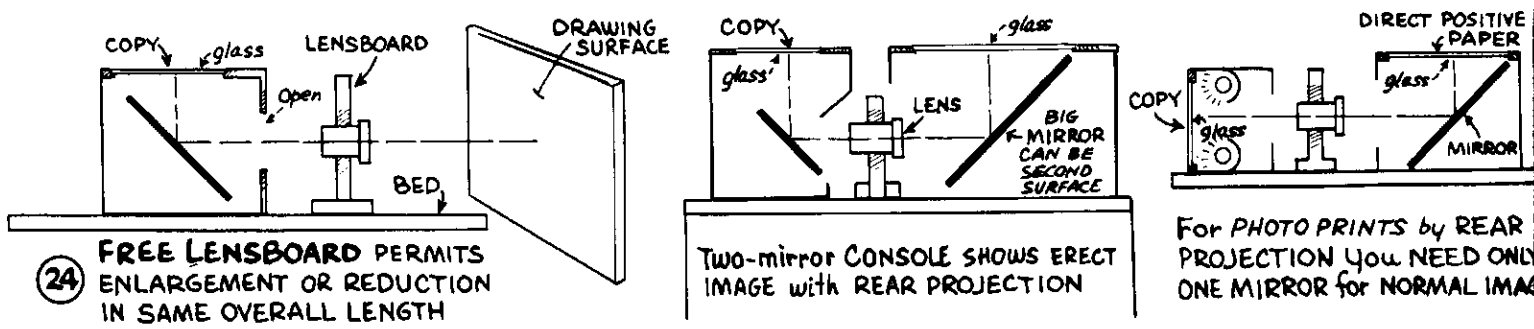
FREE LENSBOARD CAN BE PULLED OUT FOR LOW M.

LENSBOARD

1/4" PINION WIRE DRIVE FIT IN 3/8" EXTENSION
PINION HOUSING 9/16 x 1
PLASTIC BARREL 1 1/2" long
4 3/4
5 3/8
1/2
1/4" PLY.
1/2 x 3/4" for WALL MOUNTING (See previous page)
1/2 OR 3/4 x 3 3/4 (2)

measure of extension is provided by a sliding lensboard, which is pulled out for low (1x) magnification. The open bottom of the box permits projection of small flat objects. Vent holes or metal ventilators should be fitted as needed to allow cool air to pass through the box.

FREE LENS. The general idea of a free lens can be expanded to allow both reduction and enlargement with the same projector in the same overall length. Fig. 24 shows three typical setups. The moderate light spill will not usually degrade the image contrast, but some shielding may be necessary. Reduction is seldom used for drawing--the way you use it is with photographic paper such as Kodak Direct Positive to make photo prints.

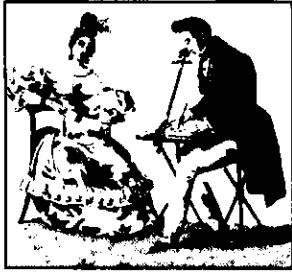


24 FREE LENSBOARD PERMITS ENLARGEMENT OR REDUCTION IN SAME OVERALL LENGTH

TWO-MIRROR CONSOLE SHOWS ERECT IMAGE with REAR PROJECTION

For PHOTO PRINTS by REAR PROJECTION you NEED ONLY ONE MIRROR for NORMAL IMAGE

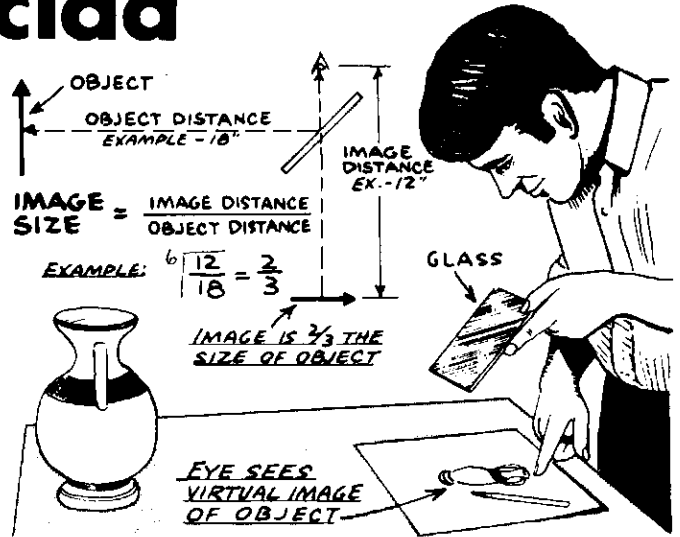
The Camera Lucida



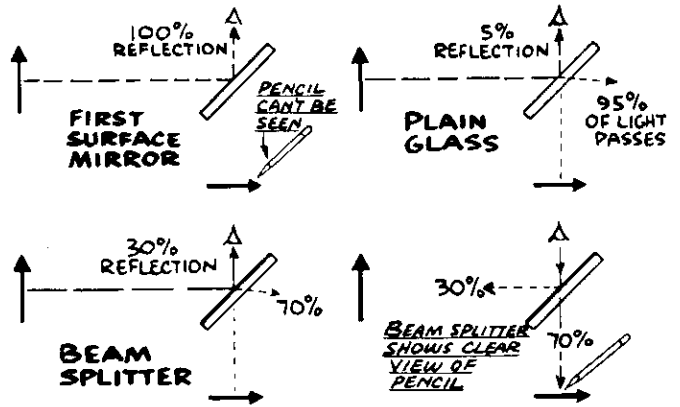
CREDIT for the original camera lucida goes to W. H. Wollaston, English physicist, who invented it about 1804. Fig. 3H shows Wollaston's design, a "split-vision" type with a quadrilateral prism.

A number of variations have been made and sold throughout the years and the "lucy" is today as popular as ever. What the lucy does is to project a virtual image of any object onto the drawing board surface, where it can be traced with a pencil. The general idea of the whole thing is right in front of your eyes every time you look out of a window--with a china-marking pencil you could draw what you see on the window glass.

IMAGE SIZE. The simplest lucy is a plain piece of glass, Fig. 1. Looking at the glass, you can see the object by reflection, and your eye will form a virtual image on any surface below the glass. You are also able to look directly through the glass at the drawing board and pencil. The image size is in direct ratio to image distance-object distance, as shown in Fig. 1 example.

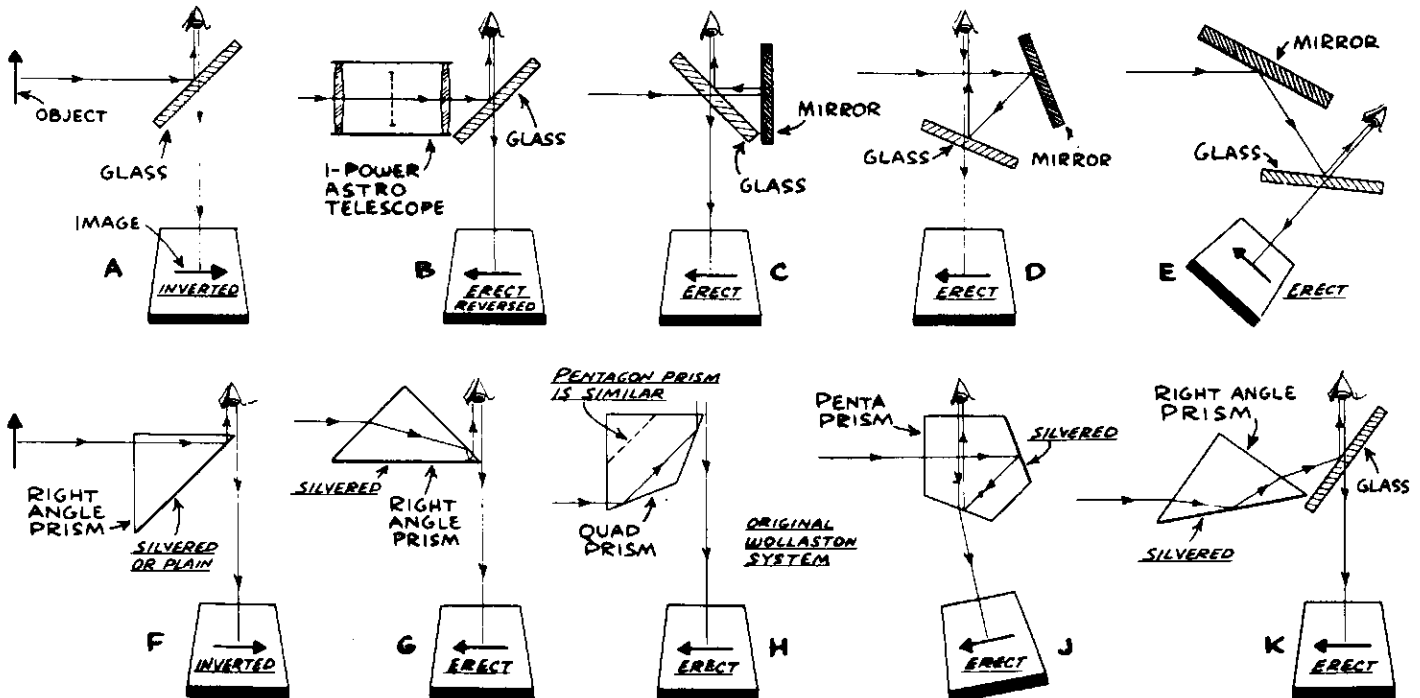


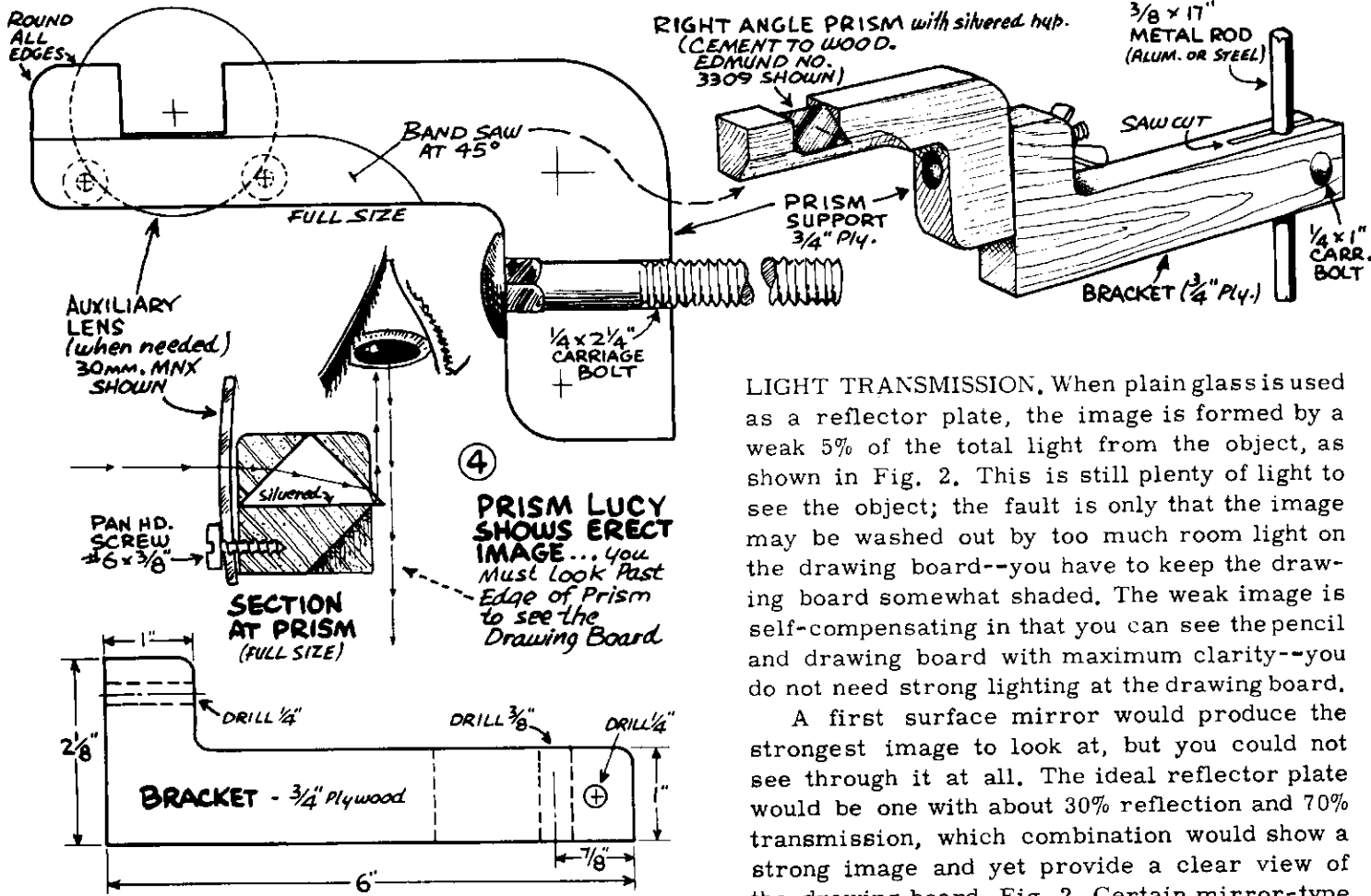
① SIMPLE EXPERIMENT SHOWS HOW THE REFLECTING "LUCY" WORKS



② LIGHT TRANSMISSION

③ OPTICAL SYSTEMS





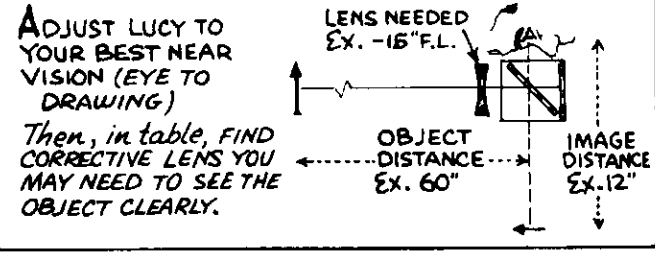
LIGHT TRANSMISSION. When plain glass is used as a reflector plate, the image is formed by a weak 5% of the total light from the object, as shown in Fig. 2. This is still plenty of light to see the object; the fault is only that the image may be washed out by too much room light on the drawing board--you have to keep the drawing board somewhat shaded. The weak image is self-compensating in that you can see the pencil and drawing board with maximum clarity--you do not need strong lighting at the drawing board.

A first surface mirror would produce the strongest image to look at, but you could not see through it at all. The ideal reflector plate would be one with about 30% reflection and 70% transmission, which combination would show a strong image and yet provide a clear view of the drawing board, Fig. 2. Certain mirror-type beam splitters have the desired characteristics, such as Edmund No. 578. The interference coating is practically invisible; the coated side is the side which shows a single reflection when touched lightly with the tip of your fingernail.

OPTICAL SYSTEMS. There are two general optical systems for the camera lucida. Examples A to E in Fig. 3 are reflecting lucys. The other --and original--system makes use of a prism. The simplest example of this is shown at F in Fig. 3. Like the reflector plate, the object is seen by reflection. However, the drawing must be viewed by looking past the edge of the prism. This splitting of the vision requires the eye to be fairly close to the prism to prevent loss of field. Wollaston's original system was a quad prism, as shown at H, Fig. 3; present-day instruments are usually made with a simple right angle prism, as at G. The prism itself need be no larger than 1/4 to 3/8 inch clear face; larger prisms contribute nothing. Most of the better-quality manufactured lucys use the right angle prism, arranged on a pivot so that both inverted and upright views can be obtained. Several small auxiliary lenses are supplied with most instruments to provide for larger-than-life drawings, and also to correct the accommodation of the eye if needed. No lens is needed if drawing is same size as object.

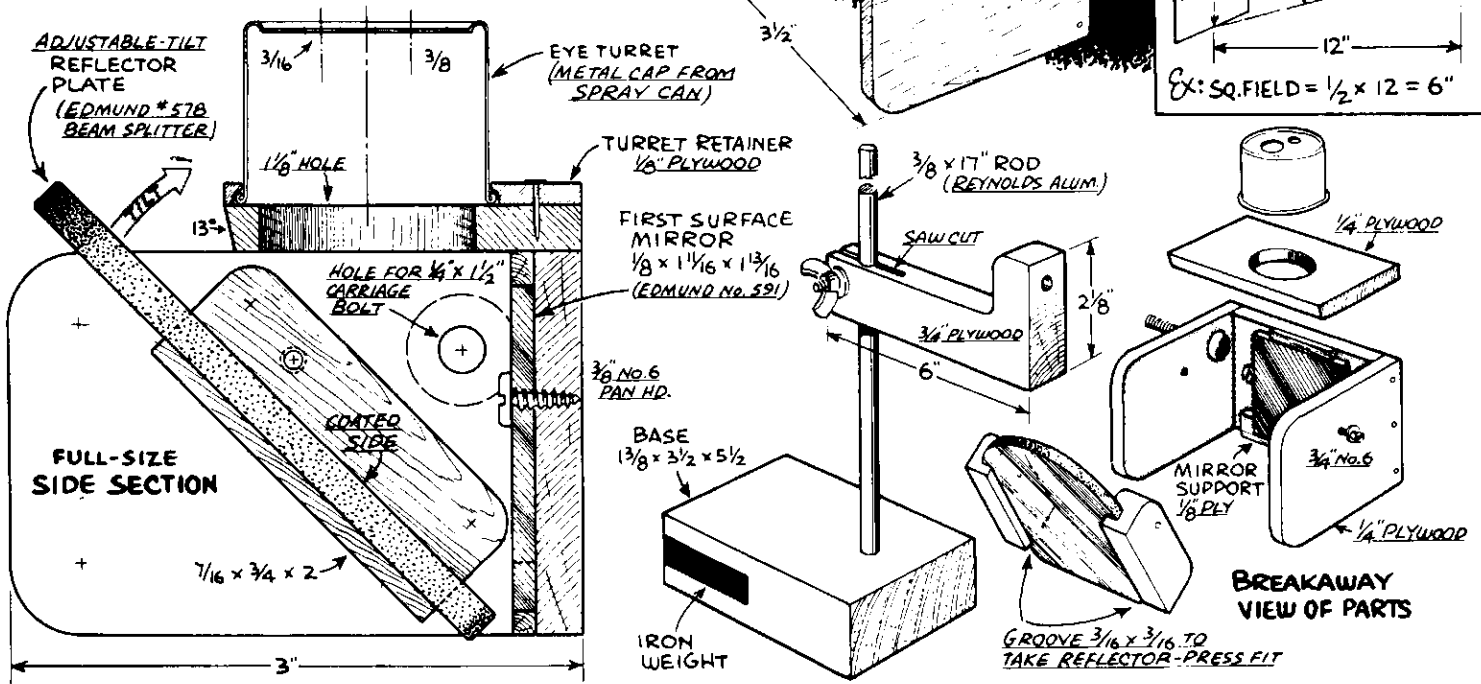
5 AUXILIARY LENSES

OBJECT DISTANCE	IMAGE DISTANCE (EYE TO DRAWING)				
	8"	10"	12"	16"	20"
4"	+8" 203mm	+7" 178mm	+6" 152mm	+5" 127mm	+5" 127mm
6"	+24" 610	+15" 381	+12" 305	+10" 254	+8" 203
8"	NO LENS	+40" 1016	+24" 610	+16" 406	+13" 330
10"	-40" 1016	NO LENS	+60" 1524	+26" 660	+20" 508
12"	-24" 610	-60" 1524	NO LENS	+48" 1219	+30" 762
14"	-18" 457	-35" 889	-84" 2134	+112" 2845	+47" 1194
16"	-16" 406	-27" 686	-48" 1219	NO LENS	+80" 2032
20"	-13" 330	-20" 508	-30" 762	-80" 2032	NO LENS
25"	-12" 305	-17" 432	-23" 584	-44" 1118	-100" 2540
40"	-10" 254	-13" 330	-17" 432	-27" 686	-40" 1016
60"	-9" 229	-12" 305	-15" 381	-22" 559	-30" 762
10 FT.	-8" 203	-11" 279	-13" 330	-18" 457	-24" 610
20 FT. OR MORE	-8" 203	-10" 254	-13" 330	-17" 432	-22" 559

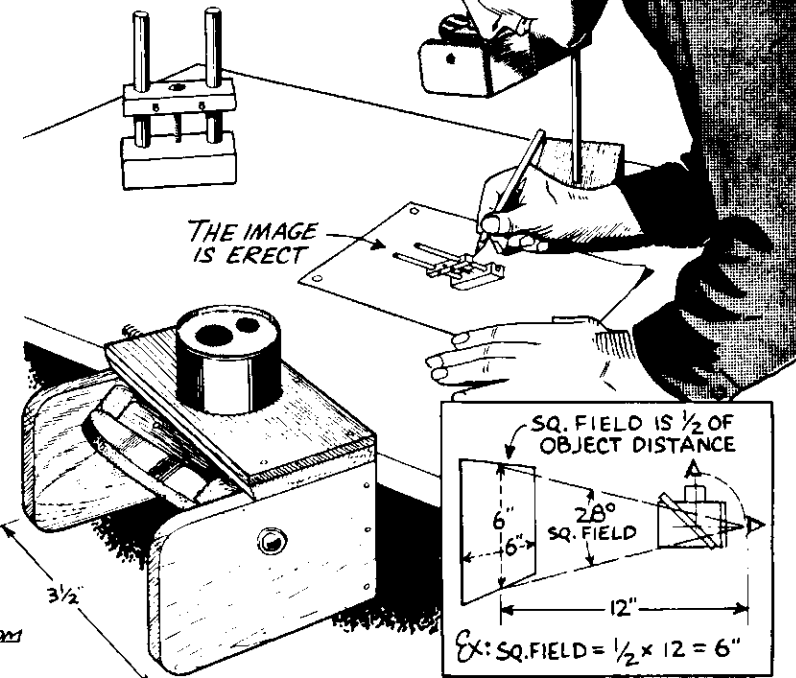


HOMEMADE PRISM LUCY. The homemade prism lacy is a very simple project in plywood construction, as shown in Fig. 4. The prism must have a sharp edge since it is this area you use to see the object. The prism overhangs the wood support by about 1/8 in. to eliminate any possible interference of your sight line past the edge of the prism. In use, you must anchor your eye in a fixed position, because the image will move if you move your head. This is the main reason a small prism is used--it confines your eye. The prism specified is a bit large, which fault can be corrected with 1/8 in. strips of masking tape applied to either side of the prism surface facing your eye. Two screws in the front of the prism support provide a mounting for 30mm diameter auxiliary lenses.

AUXILIARY LENSES. Short focal length lenses



⑥
REFLECTING LUCY SHOWS ERECT IMAGE



are used as magnifiers, allowing you to draw objects larger than life size. The long f.l. positive lenses and all of the negative lenses are used mainly for spectacle correction, which may or may not be needed. In general, if you are a young person with normal eyes, your ability to focus your eyes near or far (accommodation) will be excellent and you will be able to work at various object distances without discomfort. Most persons over 45 will do best with a corrective lens. The exact f.l. of this is non-critical; anything within 25% of the calculated values in Fig. 5 will do the trick. The whole idea is simply that you can see the drawing okay at some near

distance, say 16 inches. The specified corrective lens will then bring the object into the same range.

REFLECTING LUCY. This construction is popular because it eliminates the slight annoyance of split-vision. A poor feature is that auxiliary lenses must be 2-1/2 or 3-in. diameter to maintain the field. Fig. 6 design has the reflector plate supported by wooden sidepieces, the whole pivoted on screws to provide a tilt adjustment which is useful when you want a view looking down on an object. The revolving eye turret has two holes, the smaller being best to anchor your eye and so prevent image movement.