How to Build Opaque Projectors

NO. 9314

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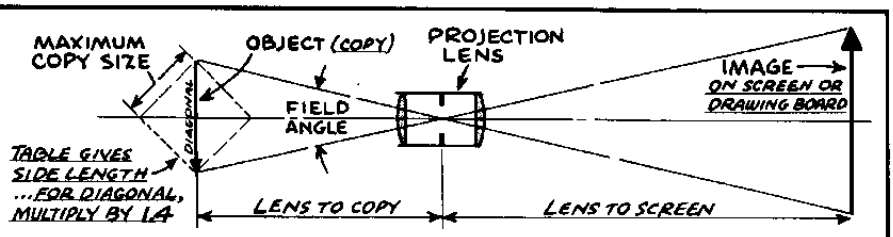
TABLE 1

OBJECT-IMAGE DISTANCES and SIZE OF COPY



LENS F.L.	FEATURE YOU WANT TO FIND	½×	1×	1½×	2×	3×	4×	5×	6×	7×	8×	9×	10×	15×	25×	50×
6"	TO COPY →	18"	12"	10"	9"	8"	7½"	7⅛"	7"	6⅞"	6¾"	6⅝	6⅝"	6⅜"	6¼"	6⅛"
	TO SCREEN →	9	12	15	18	24	30	36	42	48	54	60	66	96	13'-0	25'-6
	COPY SIZE 20°	4½	3	2½	2¼	2	1⅞	1¾	1¾	1¾	1¾	1⅝	1⅝	1⅝	1⅝	1½
	COPY SIZE 30°	7	4½	3¾	3⅜	3	2⅞	2¾	2⅝	2½	2½	2½	2½	2⅜	2⅜	2⅜
	COPY SIZE 53°	12¾	8½	7	6⅜	5⅛	5¼	5	4⅞	4⅞	4¾	4⅝	4⅝	4½	4⅜	4¼
6½"	TO COPY →	19½	13	10¾	9¾	8⅝	8⅛	7¾	7½	7⅜	7¼	7¼	7⅛	6⅞	6¾	6⅝
	TO SCREEN →	9¾	13	16¼	19½	26	32½	39	45½	52	58½	65	71½	8'-8	14'-1	27'-7
	COPY SIZE 20°	5	3¼	2¾	2½	2¼	2⅛	2	1⅞	1⅞	1¾	1¾	1¾	1¾	1¾	1⅝
	COPY SIZE 30°	7½	4⅜	4	3¾	3¼	3⅛	3	2⅞	2¾	2¾	2¾	2¾	2⅝	2½	2½
	COPY SIZE 53°	13¾	9⅛	7½	6⅞	6⅛	5¾	5½	5¼	5⅛	5⅛	5⅛	5	4⅞	4¾	4⅝
7"	TO COPY →	21	14	11¾	10½	9¼	8¾	8⅜	8⅛	8	7⅞	7¾	7¾	7½	7¼	7⅛
	TO SCREEN →	10½	14	17½	21	28	35	42	49	56	63	70	77	9'-4	15'-1	29'-9
	COPY SIZE 20°	5¼	3½	3	2⅝	2¼	2¼	2⅛	2	2	2	1⅞	1⅞	1⅞	1¾	1¾
	COPY SIZE 30°	8	5¼	4½	4	3½	3¼	3⅛	3⅛	3	3	2⅞	2⅞	2¾	2¾	2¾
	COPY SIZE 53°	14¾	9⅞	8¼	7⅜	6½	6¼	5⅞	5¾	5⅝	5⅝	5½	5½	5¼	5⅛	5
7½"	TO COPY →	22½	15	12½	11¼	10	9⅜	9	8¾	8½	8⅜	8¼	8¼	8	7¾	7⅝
	TO SCREEN →	11¼	15	18¾	22½	30	37½	45	52½	60	67½	75	82½	10'-0	16'-3	31'-10
	COPY SIZE 20°	5¾	3¾	3⅛	2⅞	2½	2⅜	2¼	2¼	2⅛	2⅛	2⅛	2⅛	2	2	1⅞
	COPY SIZE 30°	8½	5⅝	4¾	4¼	3¾	3½	3⅜	3¼	3¼	3⅛	3⅛	3⅛	3	3	2⅞
	COPY SIZE 53°	15¾	10½	8¾	7⅞	7	6⅝	6⅜	6¼	6	5⅞	5¾	5¾	5⅝	5½	5⅜
8"	TO COPY →	24	16	13¼	12	10⅝	10	9⅝	9¼	9⅛	9	8⅞	"8¾	8½	8¼	8⅛
	TO SCREEN →	12	16	20	24	32	40	48	56	64	72	80	88	10'-8	17'-4	34'-0
	COPY SIZE 20°	6	4	3¼	3	2⅝	2½	2⅜	2¼	2¼	2¼	2¼	2¼	2⅛	2⅛	2
	COPY SIZE 30°	9	6	5	4½	4	3¾	3⅝	3½	3½	3⅜	3⅜	3¼	3¼	3⅛	3⅛
	COPY SIZE 53°	17	11¼	9¼	8½	7½	7	6¾	6½	6½	6⅜	6¼	6¼	6	5¾	5¾
8½"	TO COPY →	25½	17	14¼	12¾	11¼	10⅝	10⅛	9⅞	9¾	9⅝	9½	9⅜	9	8⅞	8⅝
	TO SCREEN →	12¾	17	21¼	25½	34	42½	51	59½	68	76½	85	93½	11'-4	18'-5	36'-1
	COPY SIZE 20°	6¼	4¼	3½	3⅛	2⅞	2⅝	2½	2½	2½	2⅜	2⅜	2⅜	2¼	2¼	2¼
	COPY SIZE 30°	9½	6½	5⅜	4¾	4¼	4	3⅞	3¾	3¾	3⅝	3⅝	3½	3⅜	3⅜	3¼
	COPY SIZE 53°	18	12	10	9	7⅞	7½	7⅛	7	6⅞	6¾	6¾	6⅝	6⅜	6¼	6⅛
9"	TO COPY →	27	18	15	13½	12	11¼	10¾	10½	10¼	10⅛	10	9⅞	9⅝	9⅜	9⅛
	TO SCREEN →	13½	18	22½	27	36	45	54	63	72	81	90	99	12'-0	19'-6	38'-3
	COPY SIZE 20°	6¾	4½	3¾	3⅜	3	2⅞	2¾	2⅝	2½	2½	2½	2½	2⅜	2⅜	2¼
	COPY SIZE 30°	10¼	6¾	5⅝	5⅛	4½	4¼	4	4	3⅞	3⅞	3¾	3¾	3⅝	3½	3½
	COPY SIZE 53°	19	12¾	10½	9½	8½	7⅞	7½	7⅜	7¼	7⅛	7	7	6¾	6⅝	6½
10"	TO COPY →	30	20	16⅝	15	13⅜	12½	12	11⅝	11½	11¼	11⅛	11	10⅝	10⅜	10⅛
	TO SCREEN →	15	20	25	30	40	50	60	70	80	90	100	9'-2	13'-4	21'-8	42'-6
	COPY SIZE 20°	7½	5	4⅛	3¾	3⅜	3⅛	3	3	2⅞	2⅞	2¾	2¾	2⅝	2½	2½
	COPY SIZE 30°	11¼	7½	6¼	5⅝	5	4⅝	4½	4⅜	4⅜	4¼	4¼	4⅛	4	3⅞	3⅞
	COPY SIZE 53°	21	14	11¾	10½	9⅜	8¾	8½	8	8⅛	7⅞	7⅞	7¾	7½	7¼	7⅛
11"	TO COPY →	33	22	18¼	16½	14⅝	13¾	13⅛	12¾	12½	12⅜	12⅛	12⅛	11¾	11⅜	11¼
	TO SCREEN →	16½	22	27½	33	44	55	66	77	88	99	9'-2	10'-1	14'-8	23'-10	46'-9
	COPY SIZE 20°	8¼	5½	4½	4⅛	3⅝	3⅜	3¼	3⅛	3⅛	3	3	3	2⅞	2⅞	2⅞
	COPY SIZE 30°	12¼	8¼	7	6⅛	5½	5⅛	5	4¾	4⅝	4½	4½	4½	4⅜	4¼	4¼
	COPY SIZE 53°	23¼	15½	13	11⅝	10¼	9⅝	9¼	9	8¾	8⅝	8½	8½	8¼	8	7⅞
12"	TO COPY →	36	24	20	18	16	15	14⅜	14	13¾	13½	13¼	13⅛	12¾	12½	12¼
	TO SCREEN →	18	24	30	36	48	60	72	84	96	9'-0	10'-0	11'-0	16'-0	26'-0	51'-0
	COPY SIZE 20°	9	6	5	4½	4	3¾	3½	3½	3½	3⅜	3¼	3¼	3¼	3⅛	3
	COPY SIZE 30°	14	9	7½	6¾	6	5¾	5½	5¼	5¼	5⅛	5	5	4¾	4⅝	4⅝
	COPY SIZE 53°	25½	17	14	13	11¼	10½	10	9⅞	9¾	9½	9¼	9¼	9	8¾	8½
13"	TO COPY →	39	26	21⅝	19½	17¼	16¼	15½	15⅛	14⅞	14⅝	14⅜	14¼	13⅞	13⅝	13¼
	TO SCREEN →	19½	26	32½	39	52	65	78	91	8'-8	9'-9	10'-10	11'-11	17'-4	28'-2	55'-3
	COPY SIZE 20°	10	6½	5½	5	4½	4¼	4	3¾	3¾	3½	3½	3½	3½	3½	3¼
	COPY SIZE 30°	15	10	8	7½	6½	6¼	6	5¾	5½	5½	5½	5½	5¼	5⅛	5
	COPY SIZE 53°	28	18	15	14	12	11½	11	10½	10¼	10⅛	10⅛	10	9¾	9½	9¼

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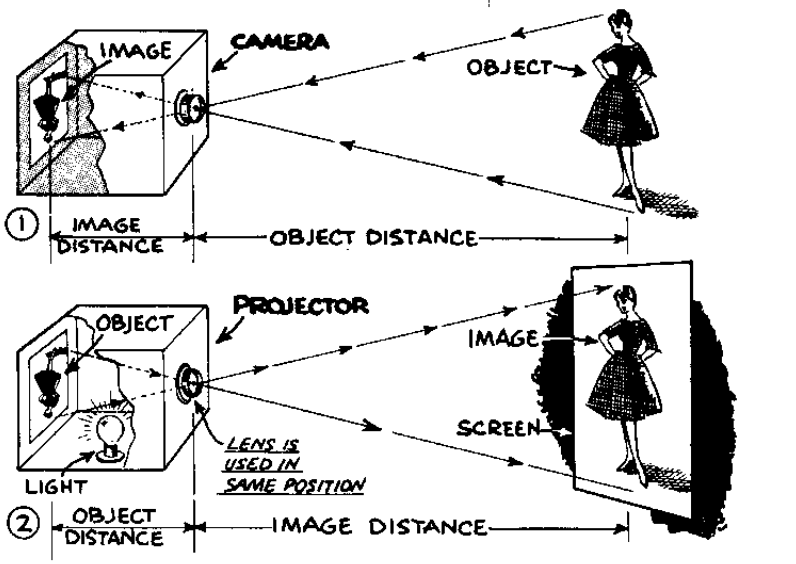


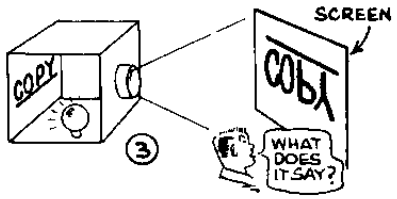
A PROJECTOR IS A CAMERA IN REVERSE

A PROJECTOR is simply a camera in reverse, as can be seen in Figs. 1 and 2. These diagrams also illustrate the fact that if you use any kind of camera lens as a projector lens, it should face out of the projector box in the same way as the camera. In both installations the lens faces the longer of the two conjugate distances.

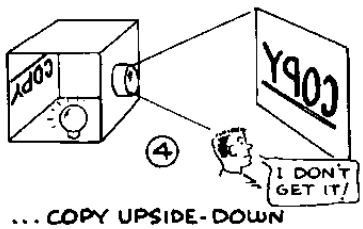
The opaque projector is used to project opaque copy, such as clippings or photos, and in this way is distinct from the transparency or slide projector which projects transparent copy. With any given amount of light, the screen image formed by light shining directly through transparent copy will be much brighter than an image formed by light reflected from opaque copy. A high-wattage slide projector can often compete with daylight, but the opaque projector invariably requires at least a semi-darkened room.

The simplest opaque projector is a "straight-shot" box, Fig. 3. Such an arrangement does not produce an erect image, and even if you turn the copy upside down, Fig. 4, the image remains reversed. If the image produced by a straight-shot box is formed on a translucent screen and viewed from a position opposite the projector, the image is seen erect and normal left-right, Fig. 5. Rear projection of this kind has many applications. However, the more common way of viewing the projected image is from the same side as the projector, and for this arrangement it is necessary to introduce a prism or mirror into the system to revert the image, Fig. 6.

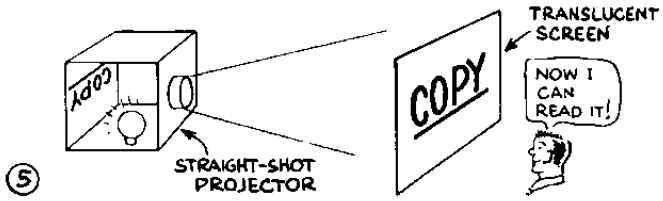
Usually you will want an opaque projector for one of two main applications: (1) as a picture projector for visual use only, (2) as a drawing projector. Brightness is the first requirement for a good picture projector, while the drawing projector can be dimmer but requires excellent definition and freedom from distortion.



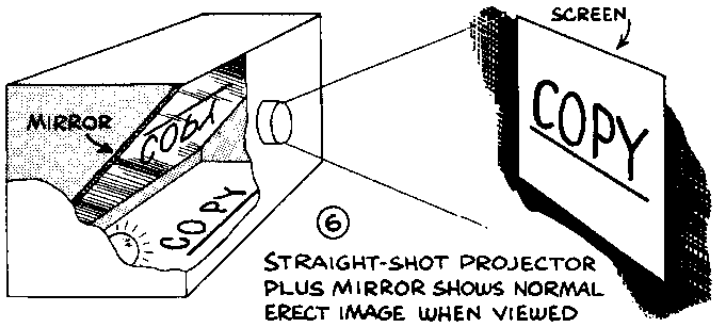
A STRAIGHT-SHOT PROJECTOR INVERTS AND REVERSES COPY



... COPY UPSIDE-DOWN STILL SHOWS REVERSED



VIEWED FROM THE FRONT (*REAR PROJECTION*), THE IMAGE IS SEEN ERECT AND NORMAL LEFT-RIGHT



STRAIGHT-SHOT PROJECTOR PLUS MIRROR SHOWS NORMAL ERECT IMAGE WHEN VIEWED FROM SAME SIDE AS PROJECTOR

Average Specifications

7

	LENS	COPY	MAG.	LIGHT
PICTURE PROJECTORS	7-24" F.L. f/6 OR FASTER	MIN. 4×4" BEST 7×7" OR MORE	5× TO 20×	200 TO 1500 WATTS
DRAWING PROJECTORS	6-10" F.L. f/8 OR FASTER	MIN. 4×4" BEST 6×6" OR MORE	1× TO 5×	100 TO 500 WATTS

projector OPTICS

LIKE MOST optical instruments, the construction of an opaque projector begins with the selection of a lens. The desirable features--good definition and illumination over a wide, flat field--are found in any f/4.5 or faster photographic objective of 6 inches or more focal length. Enlarger lenses are similar. The main thing against these anastigmatic aristocrats is that they cost real money. At the other end of the price scale is the single meniscus which can be made for about 50 cents and which does surprisingly well on small copy.

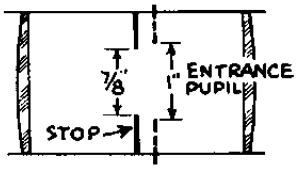
When two meniscus lenses are assembled symmetrically around a central stop, some of the faults or aberrations of the simple lens cancel out, but a few others--unfortunately--pile up, being worse for two lenses than for one. However, on the whole, the symmetrical duplet is an improvement over the single lens. In particular, it is completely free of distortion at unity (1X) magnification, and nearly so for all magnifications. Because of their ready availability, most simple lens duplets are made with plano-convex lenses. Comparing PCX vs meniscus: The meniscus has slightly softer definition but retains good imagery over fairly wide fields up to 40 degrees; the plano-convex is a little sharper down the center but is poorer at the edge of field.

An achromatized photographic duplet is better than the simple lens duplet. Although no longer manufactured, you may be able to locate in camera and secondhand stores such a "Rapid Rectilinear" in a suitable focal length. Usually the speed will be no more than f/8, but for projector use you can "open it up" to f/6 with entirely satisfactory results. Another old-timer is the Petzval, once the favorite lens for slide

① LENSES AND LENS TERMS

f/VALUE

DEFINITION: THE f/VALUE OF A LENS IS THE FOCAL LENGTH DIVIDED BY THE DIAMETER OF ENTRANCE PUPIL



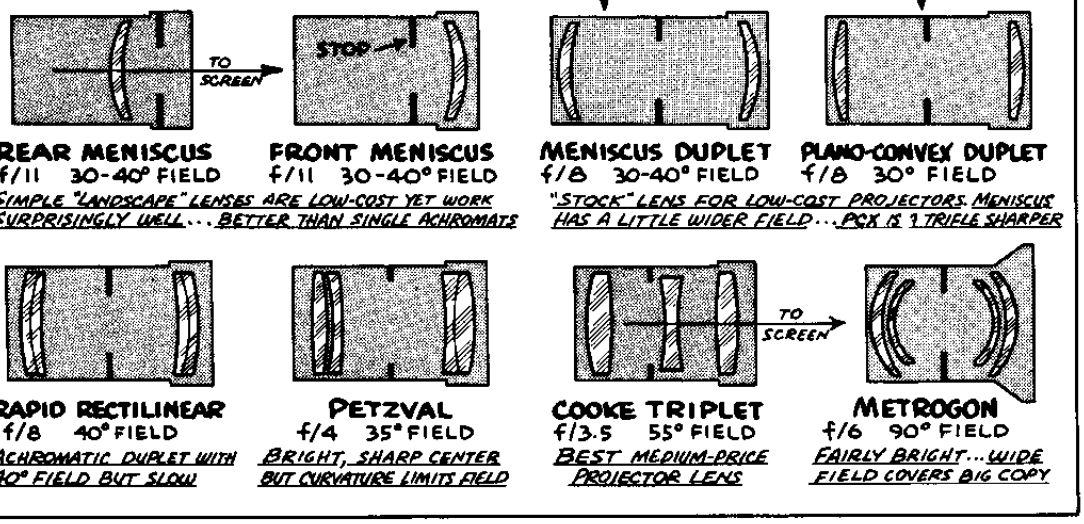
Example - 7" F.L. LENS

$f/ = \frac{7}{1} = 7$ (f/7)

FOR A NEAR APPROXIMATION, THE DIA. OF STOP MAY BE USED

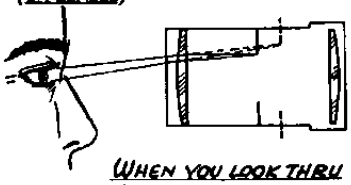
$.87 \overline{)700}\ 8$ (f/8)

696

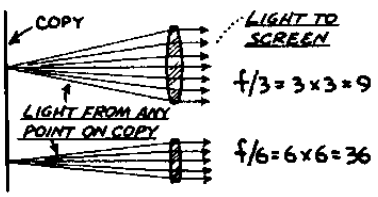


What is the ENTRANCE PUPIL?

DEFINITION: THE ENTRANCE PUPIL IS THE IMAGE OF THE STOP FORMED BY THE LENS PRECEDING IT (OR LENSES)



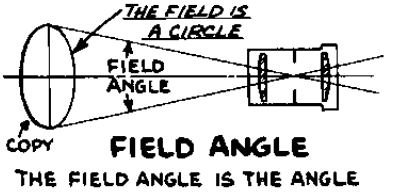
WHEN YOU LOOK THRU A LENS, YOU SEE THE ENTRANCE PUPIL



COMPARISON OF f/VALUES

RULE: THE RELATIVE SPEED OF A LENS IS PROPORTIONAL TO THE SQUARE OF THE f/NUMBER

Example (ABOVE) $4 \overline{)36}\ 9$ ..... *f/3 LENS IS 4 TIMES FASTER (BRIGHTER) THAN f/6 LENS*



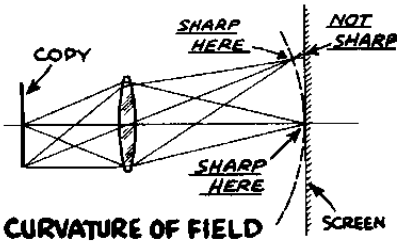
FIELD ANGLE

THE FIELD ANGLE IS THE ANGLE WHICH THE LENS CAN COVER WITH SATISFACTORY DEFINITION

COPY SIZE IS THE SQUARE WHICH CAN BE INSCRIBED IN CIRCLE

NOTE THAT SQUARE COPY EMBRACES SMALLER ANGLE THAN "FIELD ANGLE"

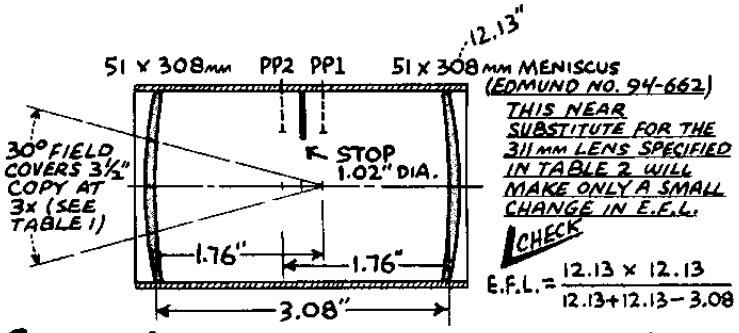
CIRCLE	SQUARE
20° =	14°
30° =	22°
40° =	29°
53° =	39°
90° =	70°



CURVATURE OF FIELD

THE NATURAL TENDENCY OF A LENS IS TO FORM A SHARP IMAGE ON A CURVED IMAGE PLANE BENT TOWARD THE LENS

RESULT: *CENTER OF SCREEN IMAGE IS SHARP BUT EDGES ARE OUT OF FOCUS*

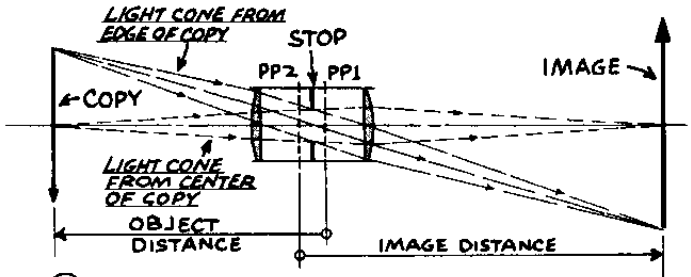


CHECK

$$E.F.L. = \frac{12.13 \times 12.13}{12.13 + 12.13 - 3.08}$$

Example 7" F.L, f/6

$$= \frac{147.14}{21.26} = 6.94"$$



② HOW LIGHT PASSES THRU A DUPLET

OVER A SPECIFIED FIELD ANGLE, THE SCREEN IMAGE IS EVENLY ILLUMINATED AT ALL POINTS

TABLE 2

Homemade Symmetrical DUPLETS

30° FIELD — SEE TABLE 1 FOR SIDE LENGTH OF FULLY-ILLUMINATED COPY

E.F.L.	F.L. of EACH LENS	*CLEAR APERTURE f/6	f/7	f/8	SPACE	STOP DIA. f/6	f/7	f/8	POSITION OF PP's
6"	10.50" 267mm	1.60" 41mm	1.50" 38mm	1.40" 36mm	2.64"	.88"	.75"	.66"	1.51"
6½"	11.37 289	1.73 44	1.62 41	1.51 38	2.86	.95	.81	.72	1.63
Example 7"	12.25 311	1.86 47	1.75 45	1.63 41	3.08	1.02	.87	.77	1.76
7¼"	12.69 322	1.93 49	1.81 46	1.69	3.19	1.06	.91	.80	1.82
7½"	13.12 333	2.00 51	1.87 48	1.75 44	3.30	1.09	.94	.83	1.88
7¾"	13.56 344	2.06 53	1.94 49	1.81 46	3.41	1.13	.92	.85	1.95
8"	14.00 356	2.13 54	2.00 51	1.86 47	3.52	1.17	1.00	.88	2.01
8¼"	14.44 367	2.19 56	2.06 53	1.92 49	3.63	1.20	1.03	.91	2.07
8½"	14.87 378	2.26 57	2.12 54	1.98 50	3.74	1.24	1.06	.94	2.13
8¾"	15.31 389	2.33 59	2.19 56	2.04 52	3.85	1.28	1.09	.96	2.20
9"	15.75 400	2.39 61	2.25 57	2.10 53	3.96	1.31	1.12	.99	2.26
9½"	16.62 422	2.53 64	2.37 60	2.21 56	4.18	1.39	1.19	1.04	2.36
10"	17.50 444	2.66 68	2.50 64	2.33 59	4.40	1.46	1.25	1.10	2.51
10½"	18.37 467	2.79 71	2.62 67	2.45 62	4.62	1.53	1.31	1.15	2.64
11"	19.25 489	2.93 75	2.75 70	2.56 65	4.84	1.61	1.37	1.21	2.76
12"	21.00 533	3.19 81	3.00 76	2.80 71	5.28	1.75	1.50	1.32	3.01
13"	22.75 578	3.46 88	3.25 83	3.03 77	5.72	1.90	1.62	1.43	3.26
14"	24.50 622	3.72 95	3.50 89	3.26 83	6.16	2.04	1.74	1.54	3.52
1"	1.75"	.266"	.250"	.233"	.44"	.146"	.125"	.110"	.251"
.57"	1"	.152"	.143"	.133"	.25"	.083"	.071"	.063"	.143"

* ADD ⅛" OR 3mm for MOUNTING

FOR E.F.L. NOT LISTED:
USE VALUES FOR 1" E.F.L. (Above) AND MULTIPLY BY E.F.L. YOU WANT

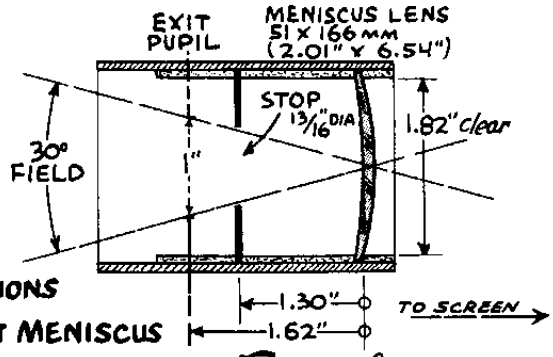
IF YOU HAVE A SET OF LENSES and WANT TO FIND E.F.L., Etc.
USE THE VALUES FOR 1" F.L. INDIVIDUAL LENS (below) AND MULTIPLY BY THE F.L. OF YOUR LENSES

Sample: YOUR LENSES ARE 10½" F.L. then: E.F.L. = 10.5 x .57 = 5.99" ETC.

projectors and even today a good lens although its heavy field curvature shows to disadvantage on large copy. Any lens described as a "4-element system" is usually a Petzval although some other types have the same general construction.

Currently tops for a medium-price projector lens is the Cooke Triplet. This construction can be corrected for curvature over a 55 degree field and can work as fast as f/2.5. Very few Cooke triplets will have both of these maximum specifications. The Cooke used as a projection lens will usually work at f/3.5, covering a 45 degree field. The field is flat and the definition excellent. Usually the lens has no iris stop, with the result it starts to vignette right from the center of field in the manner of all lens systems used without a stop. Happily the fadeout is rarely noticed unless you look for it.

Last but not least of the lenses shown in Fig. 1 is the Metrogon. This is an extreme form of

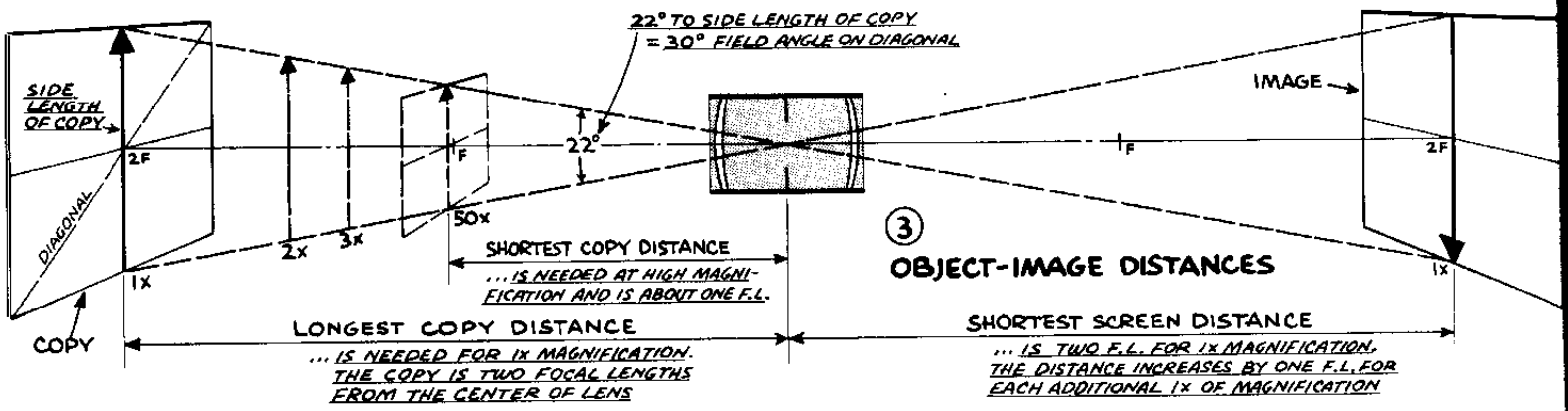


Suggested SPECIFICATIONS
f/6.5 FRONT MENISCUS

TABLE 3

	1" F.L.	Example 6.5" F.L.
CLEAR APERTURE	.28"	.28 x 6.5 = 1.82"
LENS TO STOP	.20"	.20 x 6.5 = 1.30"
STOP DIAMETER	.123"	.123 x 6.5 = .80"
LENS TO EXIT PUPIL	.25"	.25 x 6.5 = 1.62"
EXIT PUPIL DIA.	.154"	.154 x 6.5 = 1.00"

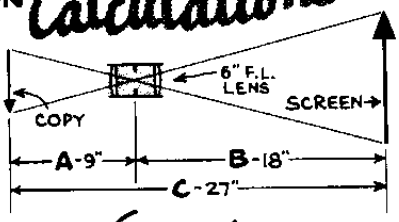
Check $f/\text{VALUE} = \frac{\text{F.L.}}{\text{EXIT PUPIL}} = \frac{6.5}{1} = 6.5$



③ OBJECT-IMAGE DISTANCES

④ PROJECTION Calculations

TABLE 1 WILL SOLVE MOST PROBLEMS. USE THESE CALCULATIONS FOR CASES NOT COVERED BY THE TABLE



Example-2x

1	$B = (M+1) \times F.L.$	$B = (2+1) \times 6 = 3 \times 6 = 18"$
2	$A = \frac{B}{M}$	$A = \frac{18}{2} = 9"$
3	$B = \frac{F.L. \times A}{A - F.L.}$	$B = \frac{6 \times 9}{9-6} = \frac{54}{3} = 18"$
4	$A = \frac{F.L.}{M} + F.L.$	$A = \frac{6}{2} + 6 = 3 + 6 = 9"$
5	$A = \frac{F.L. \times B}{B - F.L.}$	$A = \frac{6 \times 18}{18-6} = \frac{108}{12} = 9"$
6	$M = \frac{B}{A}$	$M = \frac{18}{9} = 2x$
7	$M = \frac{F.L.}{A - F.L.}$	$M = \frac{6}{9-6} = \frac{6}{3} = 2x$
8	$M = \frac{B - F.L.}{F.L.}$	$M = \frac{18-6}{6} = \frac{12}{6} = 2x$
9	$F.L. = \frac{B}{M+1}$	$F.L. = \frac{18}{2+1} = \frac{18}{3} = 6"$
10	$F.L. = \frac{A \times M}{M+1}$	$F.L. = \frac{9 \times 2}{2+1} = \frac{18}{3} = 6"$
11	$C = F.L.(2+M+\frac{1}{M})$	$C = 6(2+2+\frac{1}{2} = 6 \times 4.5 = 27"$

symmetrical construction with excellent correction for flatness of field over an amazing angle of 90 degrees. It is a hair less sharp at center of field than either a good Petzval or Cooke triplet, while its speed is rarely faster than f/6. The outstanding feature of the Metrogon is its wide field which is fairly sharp all over and free of distortion right out to the edge.

CURVATURE OF FIELD. This is the most annoying aberration in projector lenses, especially the homemade variety. Its detection is easy: if the center of your screen picture is sharp but the edges out of focus--and--if you can refocus to reverse this situation--you have a plain case of field curvature. This fault is not helped by "stopping down." When field curvature does not permit the desired linear size of copy, the common solution is to use a lens of increased focal length.

OBJECT-IMAGE DISTANCES. Simple object-image problems can be worked by the use of the formulas in Fig. 4 table. Nos. 1 and 2 are the ones commonly used, but you will find the others useful. Actually no arithmetic at all is needed

Worksheet

YOU HAVE A 7" F.L. LENS AND WANT A TOP M. OF 8x.
WHAT IS COPY DISTANCE?
WHAT LOW M. CAN YOU GET WITH 1½" LENS MOVEMENT?

By CALCULATION:

FOR 8x:

1. TO SCREEN (B) = 8+1 x F.L. = 9 x 7 = 63"
2. TO COPY = 63 ÷ 8 = 7⅞"

MAX. COPY DISTANCE = 7⅞ + 1½ = 9⅜"

3. M. = $\frac{7}{9.4-7} = \frac{7}{2.4} = 2.9x$ LOWEST M.

OK 3x TO 8x

7.88
8/63.
56
70
64
60

2.9x
2.4/70.
48
220
216

⑤

5" COPY 5x8=40" ON SCREEN

8x

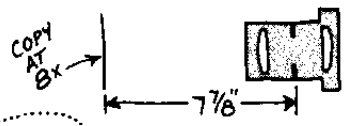
7" F.L. LENS

1½"

Can move LENS 1½" FORWARD

USING TABLE 1:

FOR 8x: COPY DISTANCE = 7⅞"



7⅞ + 1½ = 9⅜" MAX. COPY DISTANCE

9⅜"

TABLE SHOWS I CAN GET 3x(9¼") BUT NOT 2x (10½")

OK-3x TO 8x

since you can get object-image distances by merely referring to Table 1. This table also shows what size of square copy you can cover with good definition if your lens is capable of covering a 20, 30 or 53-degree field angle. For a 40 degree field (as for a projection Cooke triplet), twice the size of a 20 degree field is a near-approximation.

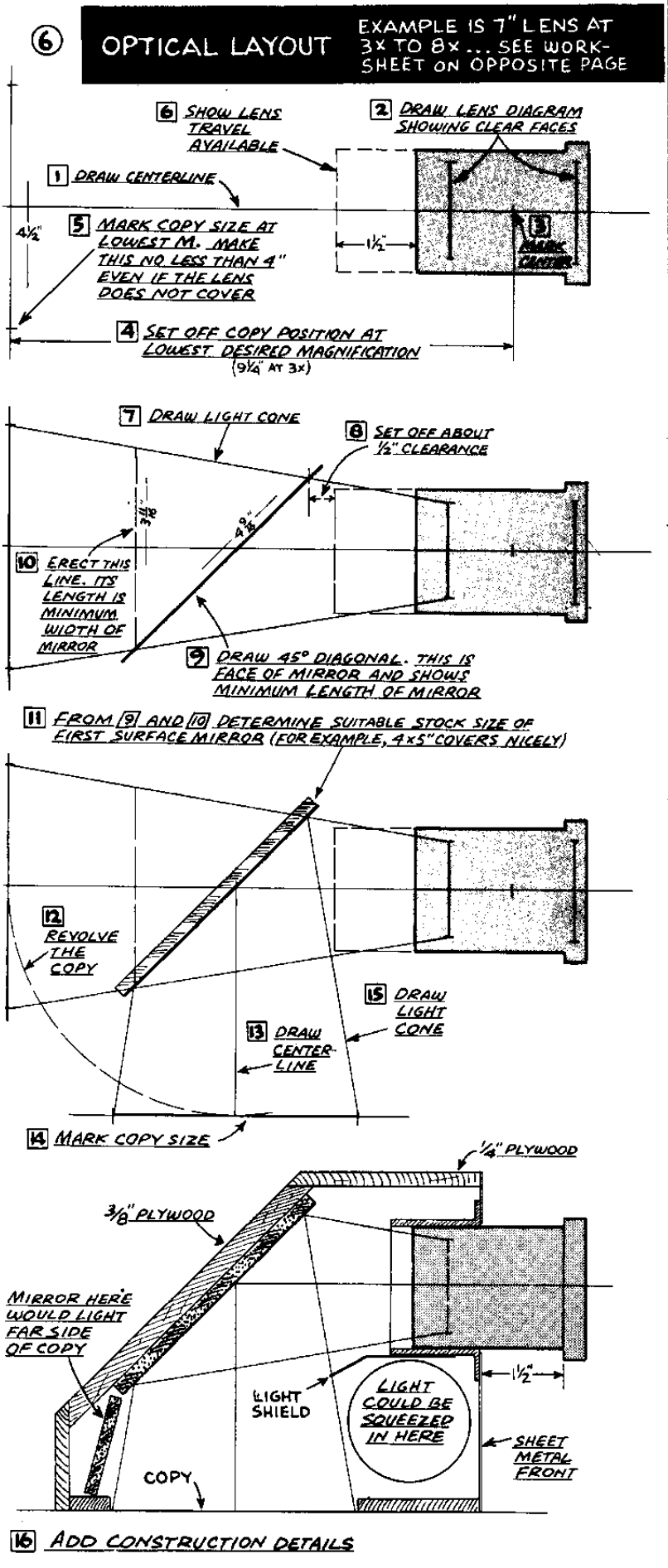
MAKING A SIMPLE LENS DUPLET. Either plano-convex or positive meniscus lenses can be used, and spectacle lens quality or better will work well to about 10x magnification. Table 2 gives suitable values. The most practical focal lengths are in the neighborhood of 8 inches. Incidentally, if you use a lens of 10 in. or more focal length and view the screen from the projector, the magnification is purely psychological. You have to believe a 20 ft. man on the screen is magnified, but since each unit of M. is obtained at the price of 10 in. or more greater viewing distance, there is no actual angular magnification nor will the big picture show additional detail. With a lens of less than 10 in. f.l., there is a real gain in angular magnification.

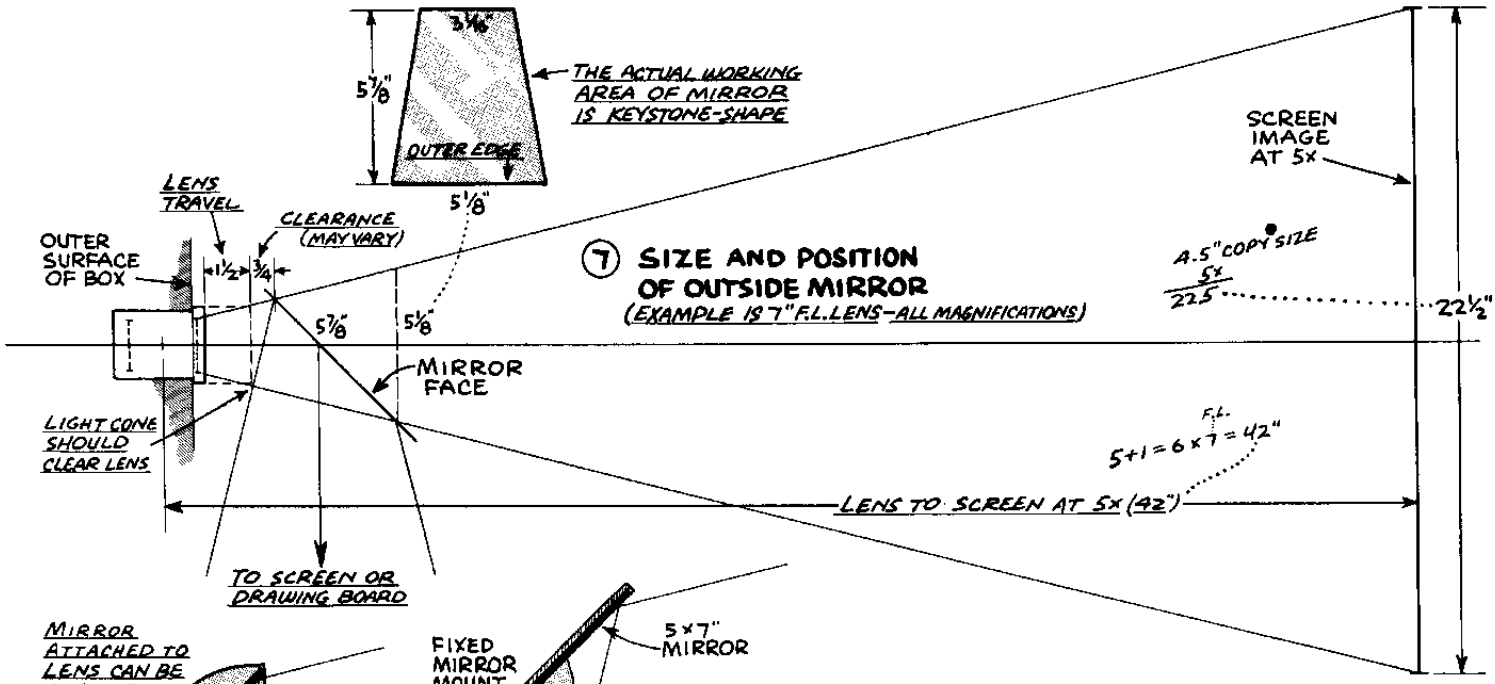
The space between lenses given in Table 2 is about average, and a little more or less will make no difference other than changing the f. l. of the combination. Closer spacing will make the combination a little shorter, while wide spacing will increase the f. l.

The stop is important. In addition to improving the performance of the lens, the stop also serves to equalize lighting over the whole field, as shown in Fig. 2. When the stop is eliminated the image sharpness suffers while the gain in brightness is confined solely to the center of the screen image. A small stop will make the screen image sharper but it will be dimmer. The inevitable compromise is somewhere around f/6.

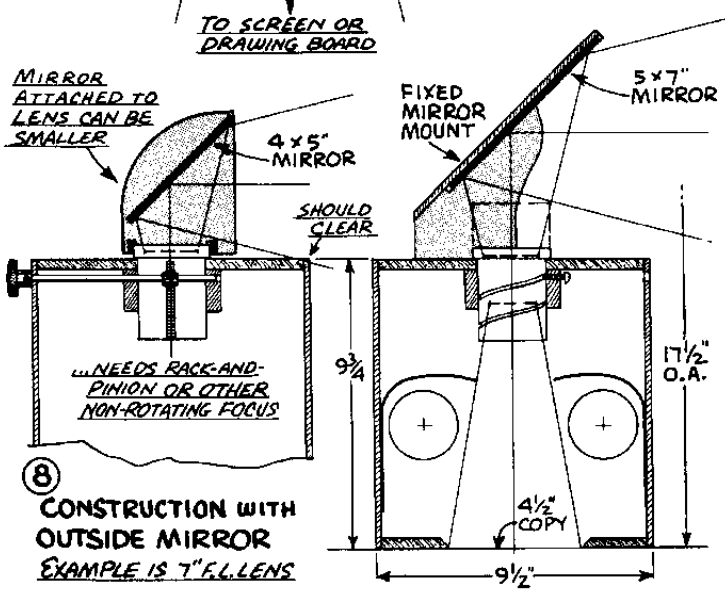
FRONT MENISCUS. Suitable specifications for this construction are given in Table 3. In general, the single lens is just half of a duplet. With controlled lens curves, the stop position is somewhat critical, but with spectacle meniscus, anything in the neighborhood of the value specified can be used with no visible change in the performance of the lens. The single lens with stop works surprisingly well considering its relative low cost.

OPTICAL LAYOUT. This is detailed in step-by-step fashion in Fig. 6 for a typical projector. After making such a layout you may find it necessary to make some revisions. In many cases you will have only a limited amount of lens





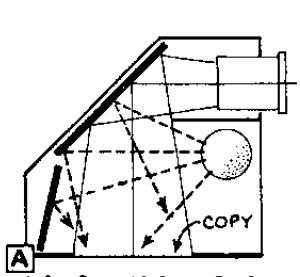
7 SIZE AND POSITION OF OUTSIDE MIRROR
(EXAMPLE IS 7" F.L. LENS—ALL MAGNIFICATIONS)



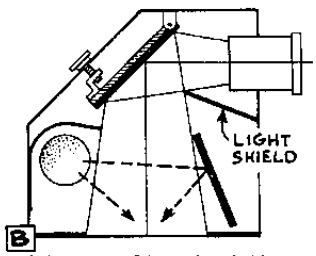
8 CONSTRUCTION WITH OUTSIDE MIRROR
EXAMPLE IS 7" F.L. LENS

movement and this must be used to best advantage to get the magnification range you want within the physical limits of the box. How this design finally works out (one solution) is shown on page 9.

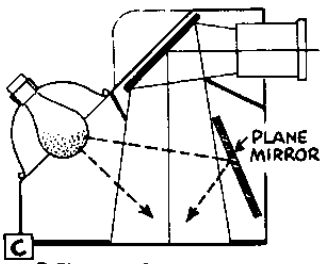
If you use an inside mirror, the size should be determined by the size of the light cone at lowest magnification, the low M. light cone being a little larger than high M. The layout for an outside mirror, Fig. 7, is preferably drawn for high magnification, being the reverse of the in-



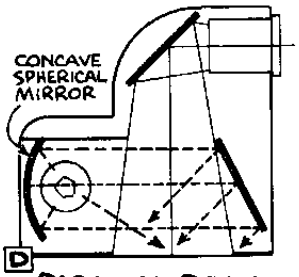
LAMP UNDER LENS
EFFICIENT SYSTEM USES ERECTING MIRROR AS REFLECTOR



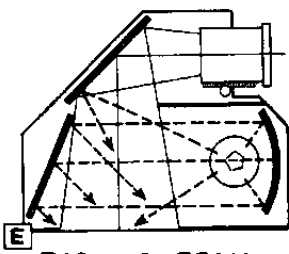
LAMP OPPOSITE LENS
NEEDS SHIELDING TO KEEP STRAY LIGHT OUT OF LENS



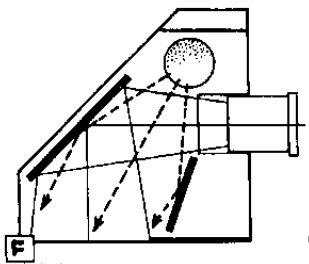
DETACHABLE LAMP
...PROVIDES ITS OWN WIRING AND REFLECTOR



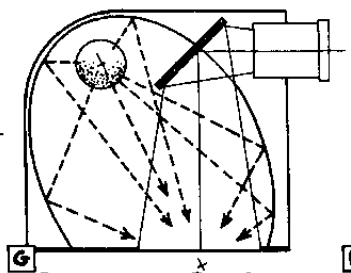
PARALLEL BEAM
AN EASY SYSTEM TO VENT AND KEEP COOL



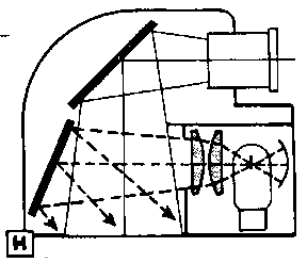
PARALLEL BEAM
LAMP UNDER LENS MAKE A COMPACT SETUP



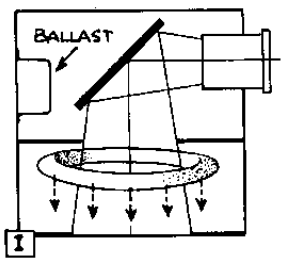
LAMP ABOVE LENS
FAIRLY EFFICIENT...EASY BOX TO VENT, KEEP COOL



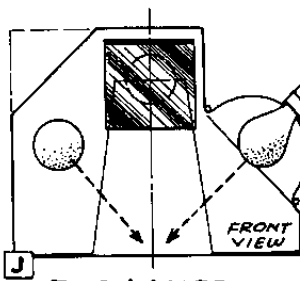
ELLIPSOIDAL REFLECTOR
GOOD SYSTEM BUT YOU HAVE TO MAKE REFLECTOR



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



LIGHT RING
CIRCULAR FLUORESCENT LAMP IS COOL LIGHT



TWO LAMPS
UNIFORM LIGHT...LAMPS CA BE OUTSIDE OR INSIDE BO

9 LIGHTING SYSTEMS

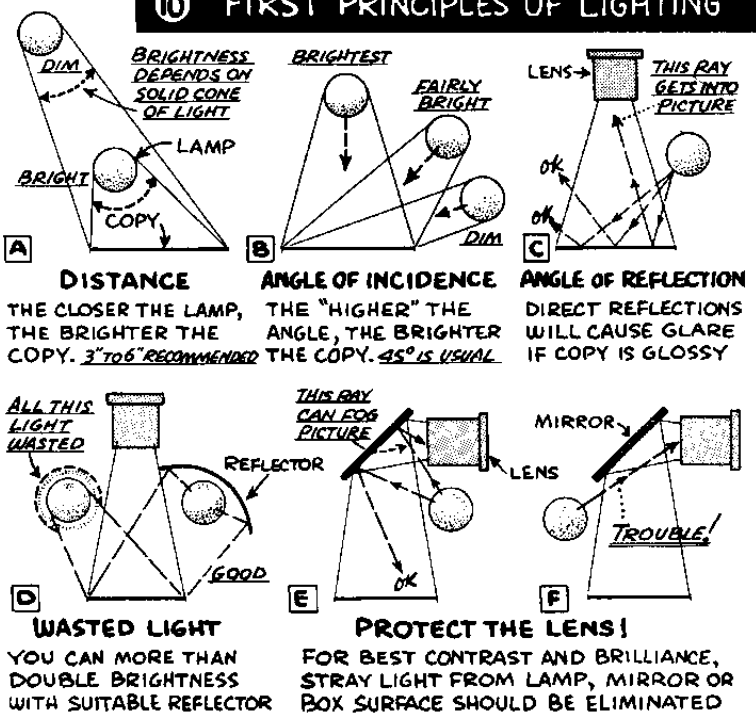
side mirror situation. This refinement in designing need not be pushed too much--2X is low enough for lowest M. and 4X or 5X does for high M. Notice that you must allow for the extension of the lens in locating the position of an outside mirror, Fig. 7, unless the mirror is attached directly to the lens mount, Fig. 8. In all cases an outside mirror will be larger than an inside mirror for the same projector.

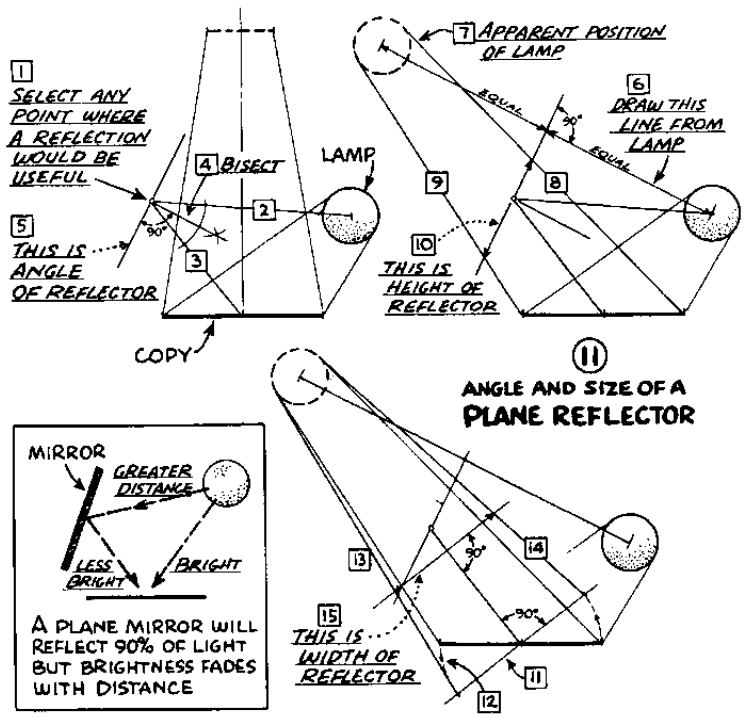
LIGHTING SYSTEMS. Many systems are used in projector lighting, Fig. 9. Most of the better commercial jobs are one-lamp designs with supplementary reflections from plane or concave mirrors. The familiar two-lamp system, J, Fig. 9, is popular because it is an easily understandable means of securing even illumination. Although not bright, fluorescent lighting (I) has the commendable feature of cool light which is especially desirable when delicate or valuable copy is being projected. The parallel beam systems, D, E, and H, are more expensive, more complicated, and are not often used in home-made projectors. The main advantage of the parallel beam is that it can be designed to give even illumination without glare spots. While most of the better commercial opaque projectors make use of high-wattage projection lamps, the amateur builder will find his best friend is the ordinary 100-watt household lamp in either inside frosted or soft white glass. The inside frosted lamp is a little brighter but the soft white shows less glare and can often be used to advantage when projecting glossy photos. Worth noting is the fact that if you use 100-watt household lamps, it is possible to substitute No. 1 photofloods for short-period use (not over 5 minutes) if you want to see a particular piece of copy real bright. If you want to use this type of lamp for regular use, it is necessary to use a blower.

Some of the basic principles of projector lighting are shown in Fig. 10. The strongest light is obtained by keeping the lamp close to the copy and beaming square-on as much as practical. The latter feature is somewhat complicated by the fact that the square-on beam will reflect into the lens, as shown at C. This is of no consequence if the copy is dull paper, but on glossy paper or glossy photos, any direct reflection will show as a bright flare spot in the projected image. The best compromise is 45-degree lighting.

Brightness can be greatly increased by using suitable reflectors. One common type of reflector is the plane mirror. The angle and size of

⑩ FIRST PRINCIPLES OF LIGHTING





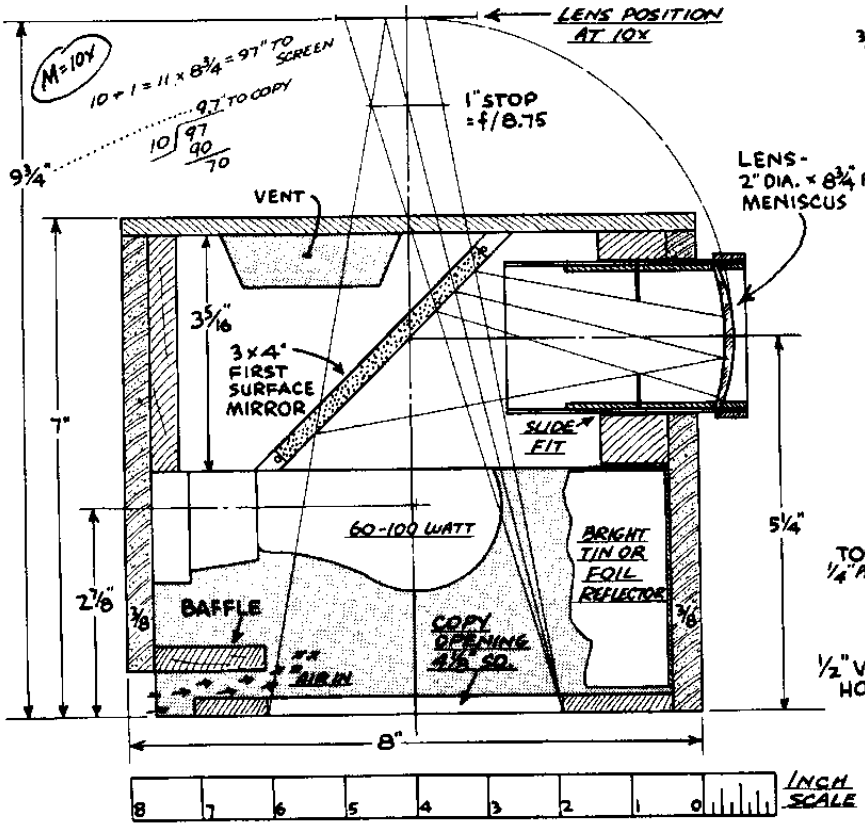
a plane mirror reflector can be determined by following the procedure shown in Fig. 11. Bright tin or chrome is nearly as effective as a glass mirror. One of the most practical reflecting materials is bright aluminum foil laminated with asbestos paper, making a combined reflector and insulator. If this product is not available locally, you can make your own by pasting aluminum foil on asbestos paper.

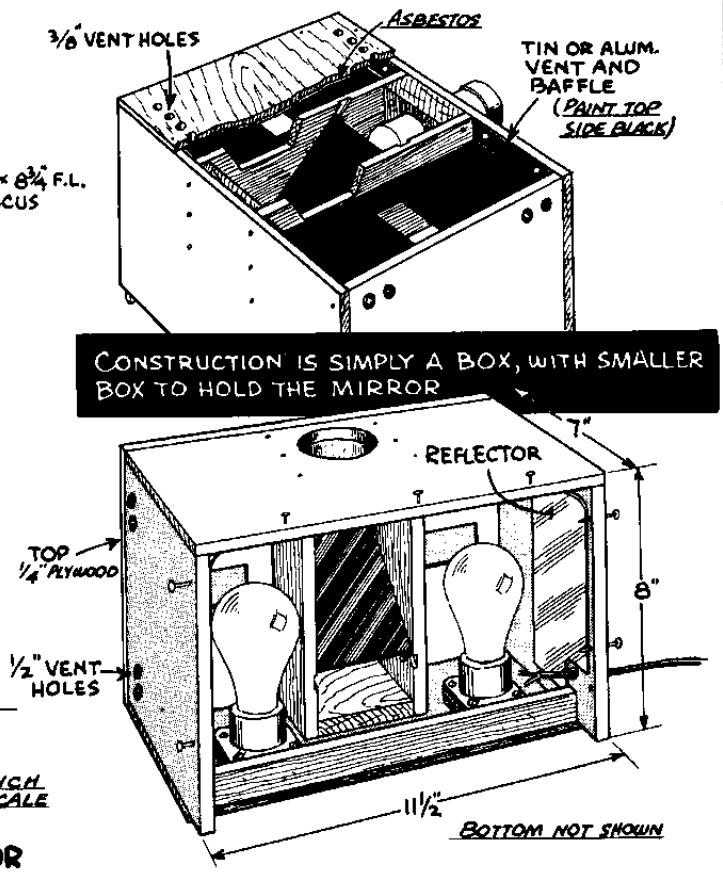
PICTURE projectors

OPAQUE PICTURE PROJECTORS intended for visual use only should show the screen image as bright as possible. One direct way of achieving this is to keep the projector close to the screen, which is to say you avoid high magnification. A top of about 12X is about the limit for most small projectors, with 7X or 8X the comfortable average for best brightness. The instruments described here are tested designs in all-wood construction, easy to build, and ideal for home or hobby use in showing photos or clippings.

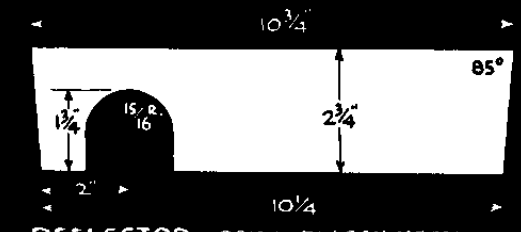
SIMPLE TWO-LAMP DESIGN. As shown in Fig. 1, the simple two-lamp design is an easy project which you should be able to hammer together in a few hours. This is a "table" model in the sense that the copy is placed flat on a table and the projector is placed over it. Handles may be added to the box if desired to aid in this manipulation. The lens shown is a single meniscus, a bit on the slow side at f/8.7 but nevertheless fairly bright because of the high transmission of the single lens. The same box can be used with a duplet of about 7-1/2 inches focal length. Reflective material should be fitted to three sides of the box, as can be seen in the bottom view drawing. The inside of the plywood bottom can be painted or stained black in order to put a dark frame around the projected picture.

ONE LAMP DESIGN. Fig. 2 shows a neat, compact table model offering good screen brightness with a single 100-watt lamp. Lens equipment can be any lens of 7 to 8 inches focal length, the ideal being a fast Cooke triplet. With the lighting system shown, the edge of copy nearest the lamp is overly bright; this is corrected by cutting off some of the edge rays with a reflector, at the same time directing the light to the far side of copy. The plane mirror on the far side (opposite the lamp) also helps the illumination of this area. The net result is fairly even lighting, which

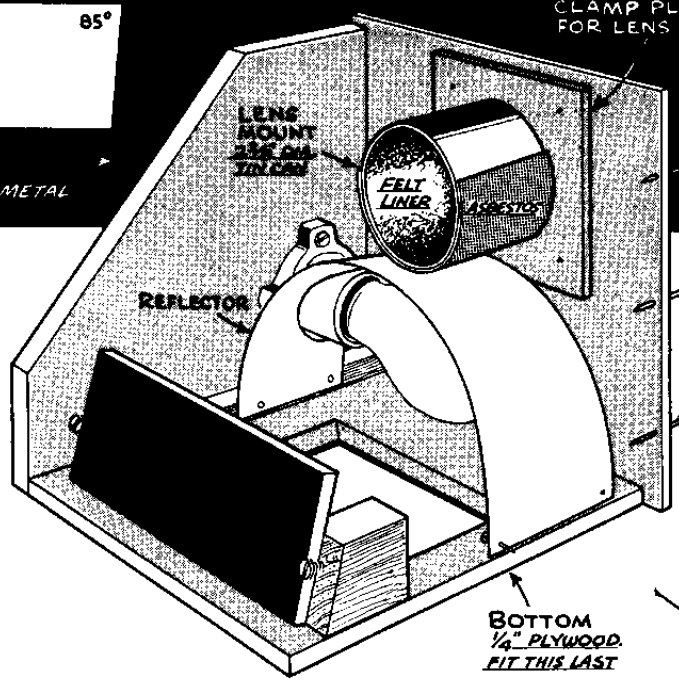




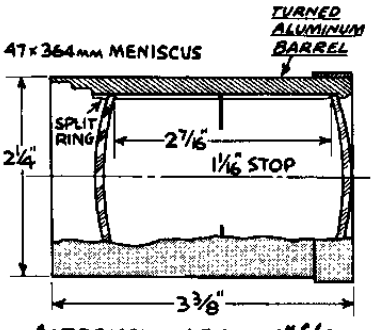
(1) 4x TO 10x TWO-LAMP OPAQUE PICTURE PROJECTOR



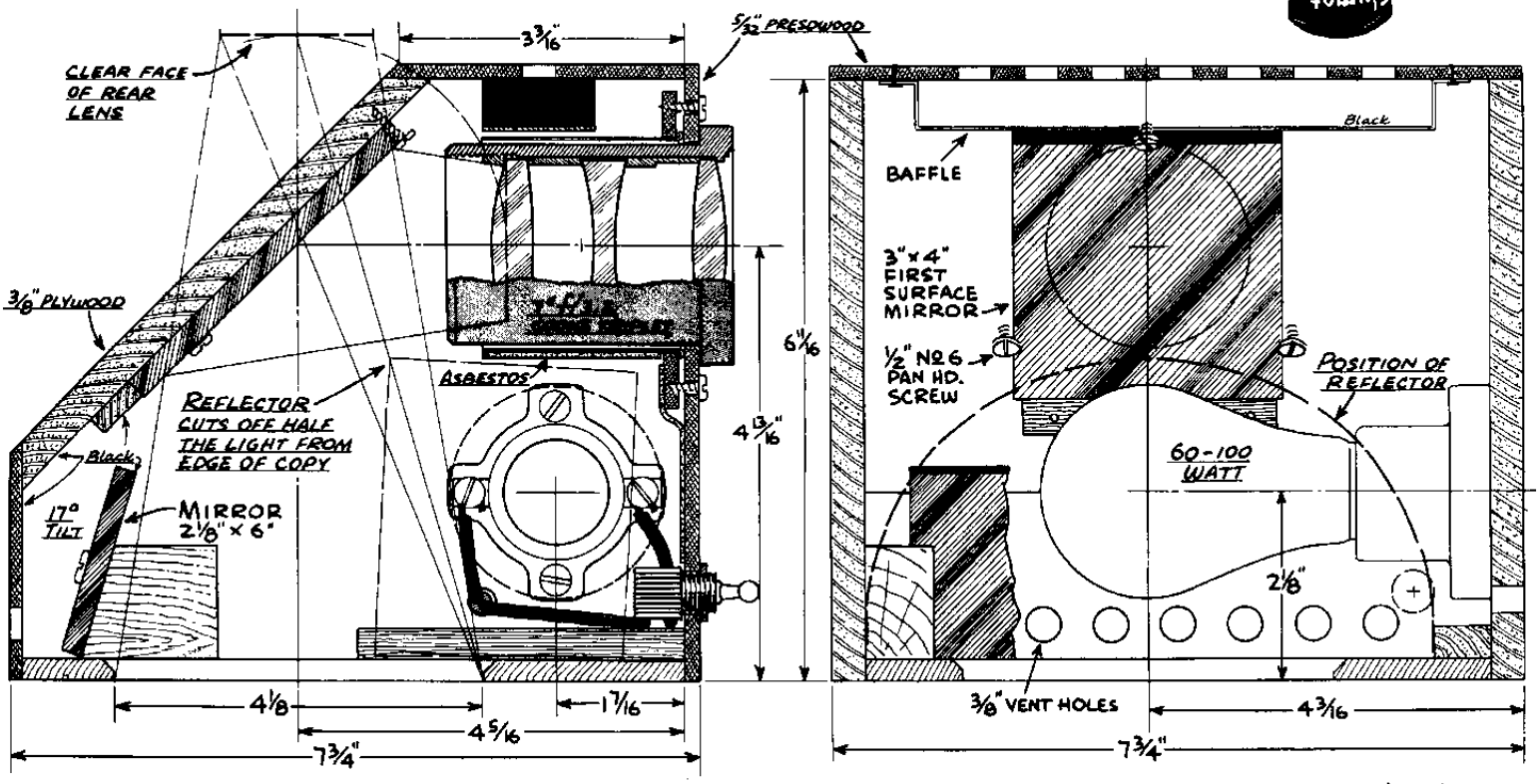
REFLECTOR - BRIGHT TIN CAN METAL



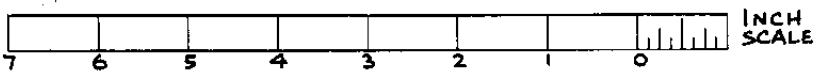
LENS MOUNT IS CUT FROM A TIN CAN. USE WHEEL-TYPE CAN OPENER



ALTERNATE LENS - 8" f/6.7
4x TO 15x



② 3x TO 7x OPAQUE PICTURE PROJECTOR



SAME BOX - different F.L.

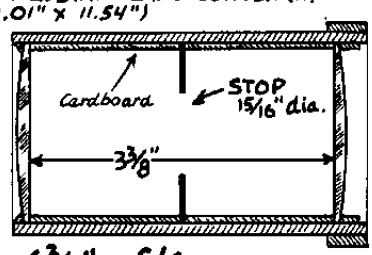
A SHORTER LENS WILL GIVE LOW POWER - LOWER THAN NORMAL - BUT YOU WILL NOT BE ABLE TO GET "IN" CLOSE TO COPY AS NEEDED FOR HIGH M.

A LONGER LENS ALLOWS HIGH MAGNIFICATION, BUT "OUT" FOCUSING MOVEMENT NEEDED FOR LOW M. MAY NOT BE AVAILABLE

for this box

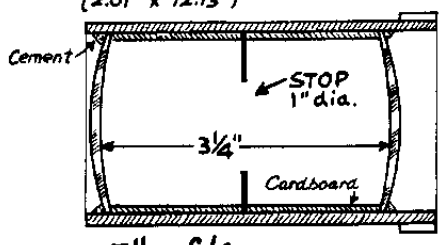
LENS F.L.	APPROX. M.
6"	2x to 3x
6½"	2x to 4x
7"	3x to 8x
7½"	4x to 15x
8"	5x to ∞

51 x 293mm PLANO-CONVEX (2)
(2.01" x 11.54")

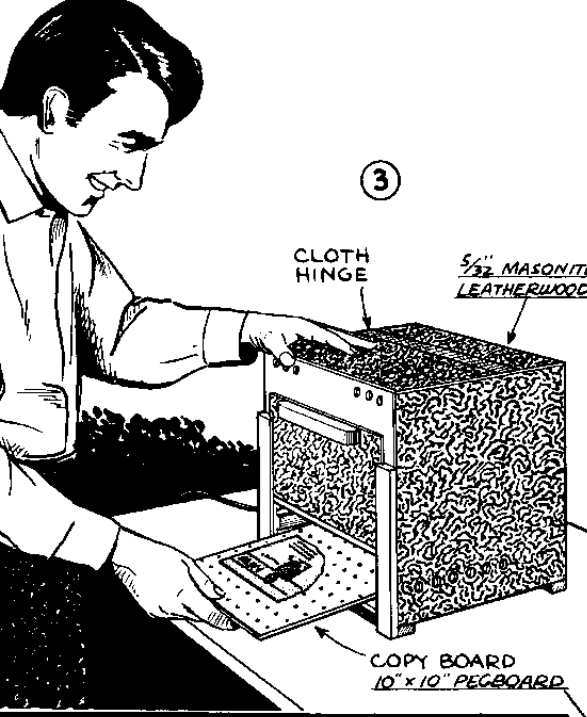


6¾" - f/6
2¼x TO 5x

51 x 308mm MENISCUS (2)
(2.01" x 12.13")

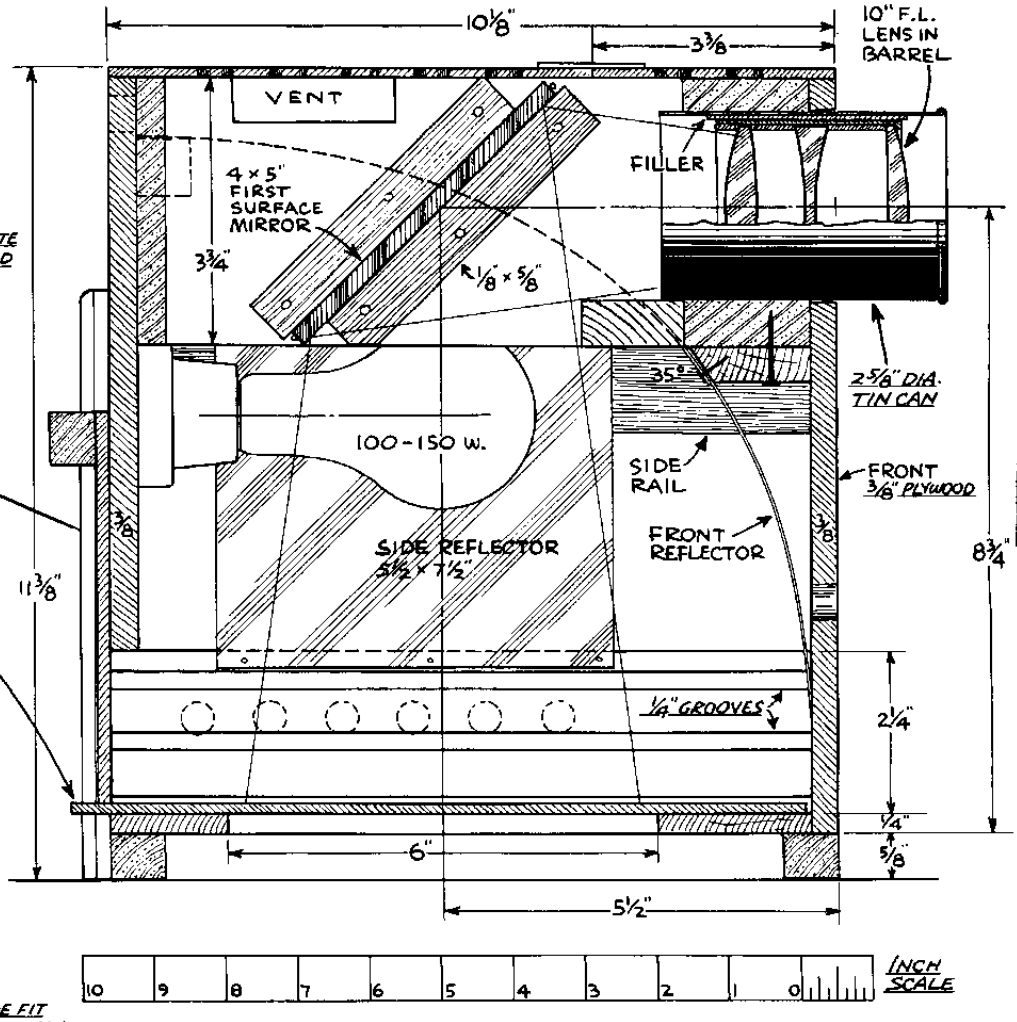


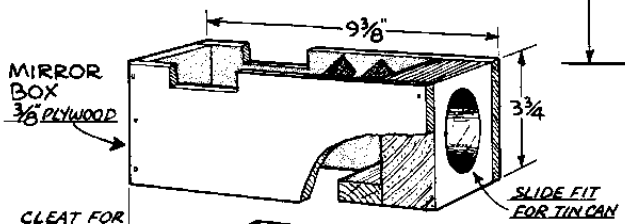
7" - f/6
3x TO 8x

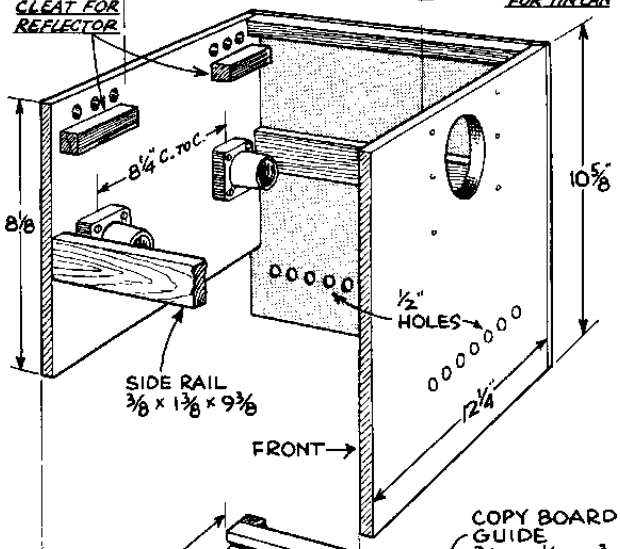


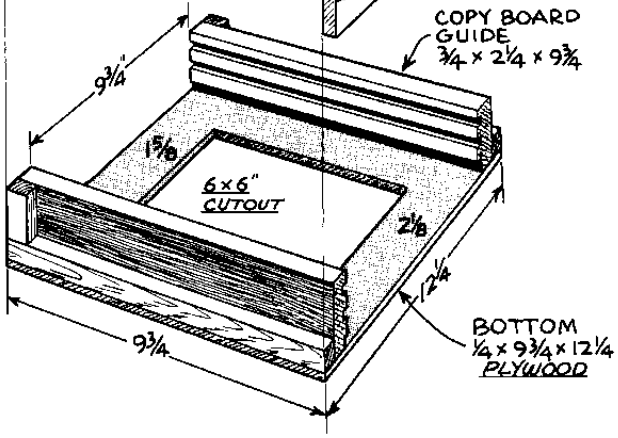
2× TO 10× OPAQUE PROJECTOR

BIG BOX HANDLES TWO 150-W. LAMPS WITHOUT OVERHEATING. COPY TO 6" SQUARE CAN BE COVERED WITH 10" LENS



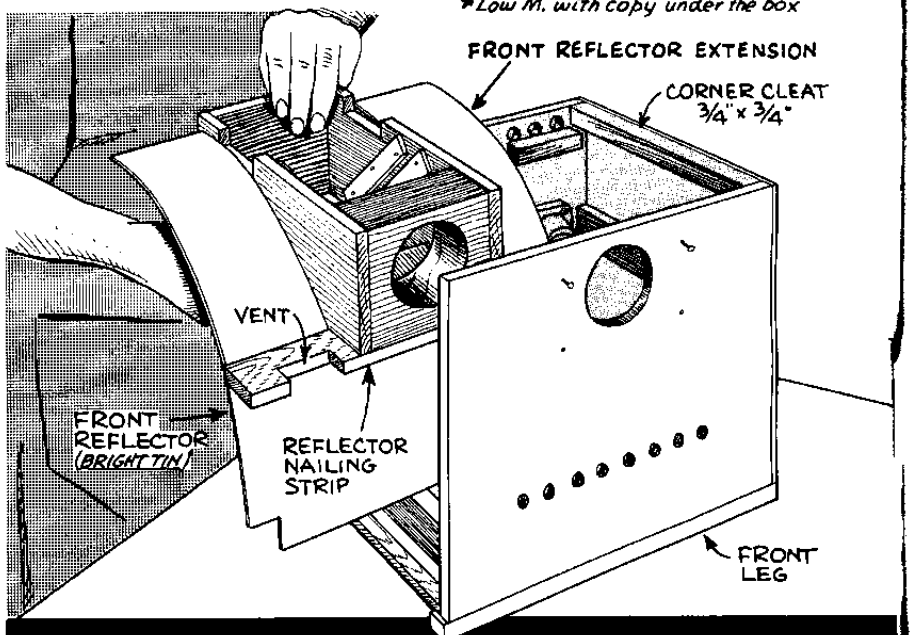




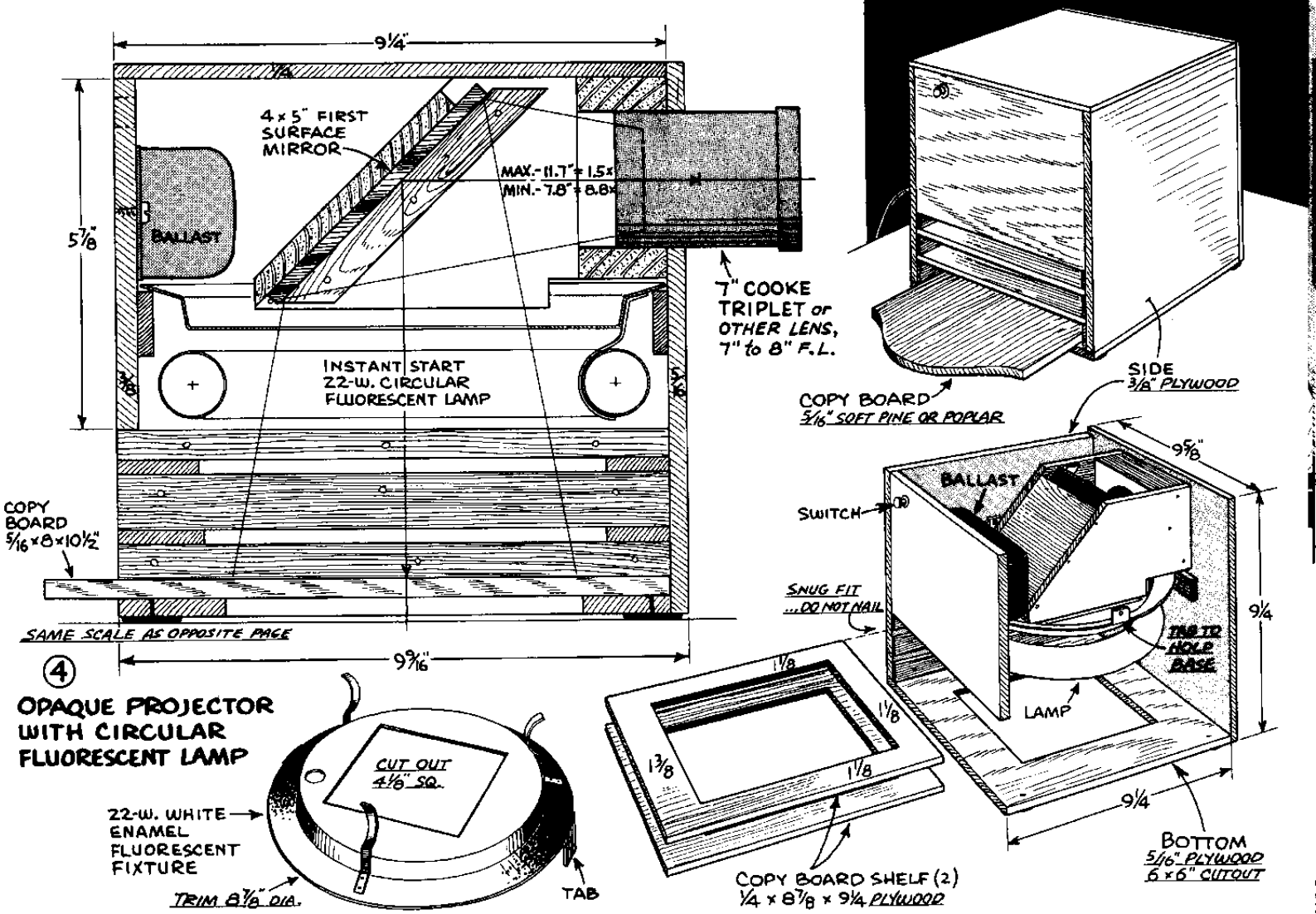


APPROXIMATE MAGNIFICATION RANGE with LENSES from 8" to 13" F.L. specified	F.L.	M.*	F.L.	M.*
	8"	1× to 3×	11"	3× to 50×
	9"	1½× to 6×	12"	4× to ∞
	10"	2× to 15×	13"	5× to ∞

*Low M. with copy under the box



REFLECTORS ARE FITTED LAST... PARTIAL DISASSEMBLY ALLOWS MIRROR BOX TO BE REFITTED WITH REFLECTOR ATTACHED



④

OPAQUE PROJECTOR WITH CIRCULAR FLUORESCENT LAMP

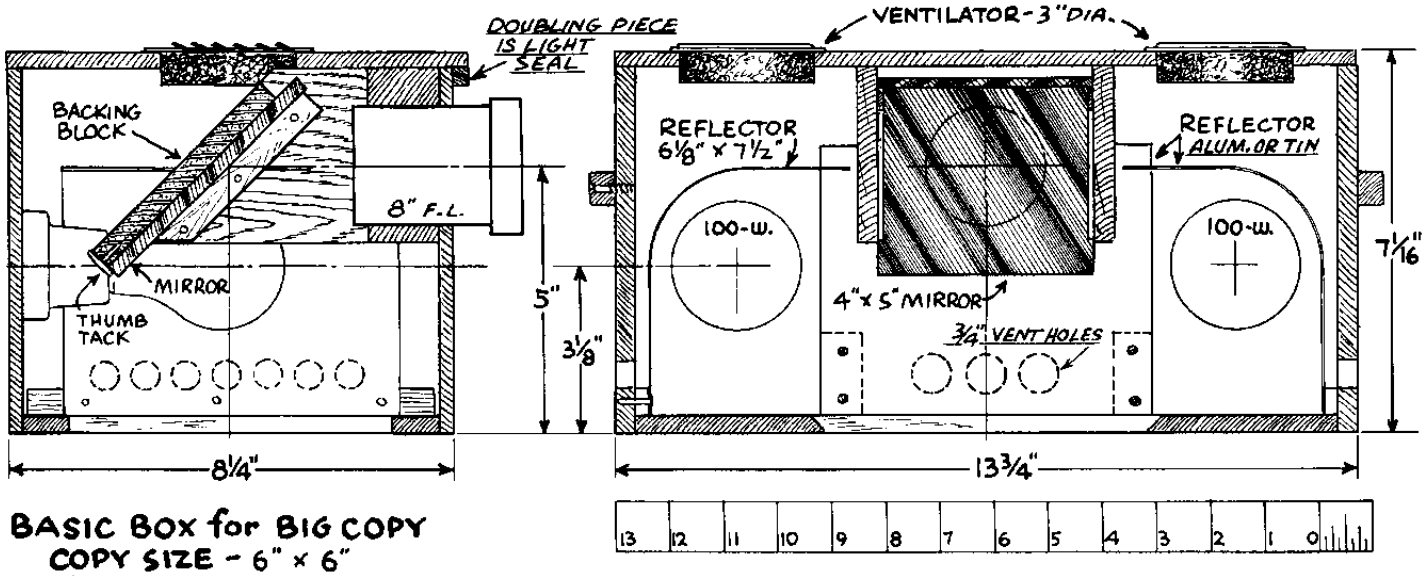
with a fast f/3.5 lens produces a bright and pleasing screen image. Slower lenses will also put on a good show. Like any projector, this box permits a modest variation in focal length, as shown at bottom of Fig. 2.

A 10-INCH BOX. When you want to cover big copy, one solution is a lens of longer focal length. A typical box with 10 in. lens is shown in Fig. 3. When you get into bigger boxes, it is not convenient to pick up the box and place it over the copy. Instead, the copy is placed on a copy board, which is pushed into the box, as can be seen in top drawing, Fig. 3. This construction also permits a greater range of lens-to-copy distances, making it possible to obtain low magnifications which are not possible with the average table model. Lenses other than 10-in. f.l. may be used if desired.

FLUORESCENT LIGHTING. Although only 22 watts, the 8-inch size circular fluorescent lamp packs a lot of light at short range and is practically as bright as a 100-watt filament lamp. The best way to obtain the lamp and parts for the projector shown in Fig. 4 is to buy a white enamel kitchen fixture (about $8). The base of this is trimmed down to fit inside the box and the center is cut out, as shown. The ballast is fitted to the back of the box and all of the original wiring can be used intact. The instant-start lamp specified is a convenience but uses a heavy ballast weighing nearly 3 lbs. Cheaper fixtures will usually have a conventional start lamp using a lightweight ballast of about 1 lb., which combination may be preferred for the weight-saving feature.

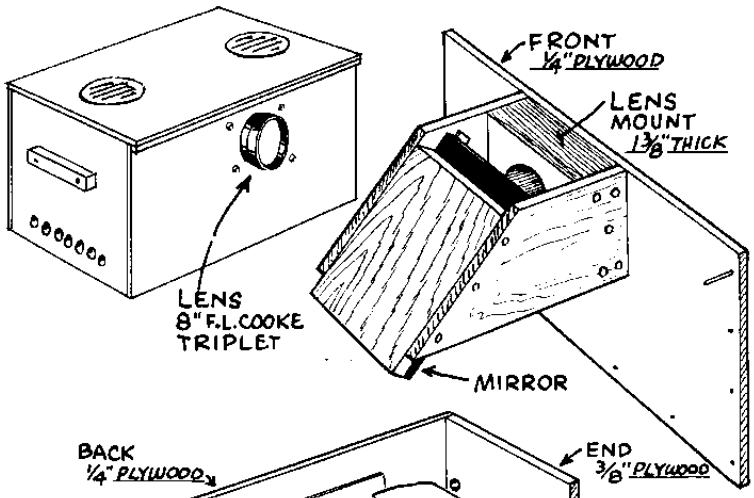
This box can use any lens of 7 to 8 inches focal length. Copy to about 5-1/2 in. square can be covered with a Cooke triplet. A simple lens duplet can show the same size field but the definition at edges will be poor. Cool fluorescent light permits this box to operate without vents of any kind although a few small holes in the top above the ballast would do no harm.

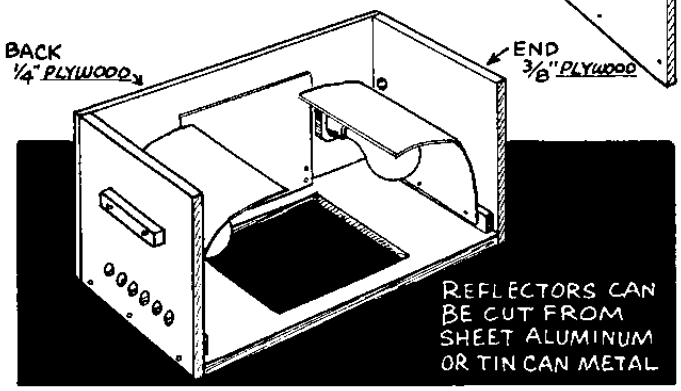
BASIC BOX FOR BIG COPY. Big copy in a picture projector starts at about 6 in. square. It



⑤ BASIC BOX for BIG COPY

COPY SIZE - 6" × 6"
MAGNIFICATION - 5x TO 15x
LENS - 8" COOKE TRIPLET





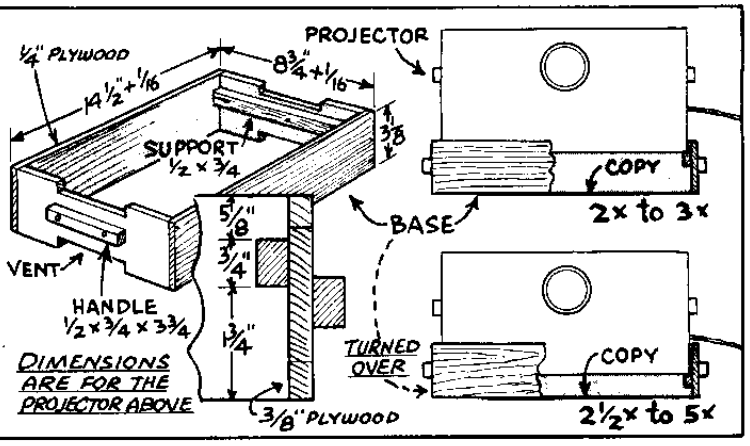
takes a lens of at least 8 in. focal length to cover this field unless you are using some extremely wide-angle type like the Metrogon. A popular choice is an 8 in. Cooke triplet, preferably in spiral-groove barrel for easy focusing.

In a darkened room you can go to 15x on photo copy with good visibility and contrast on the screen.

The projector box itself can be any style, the one in Fig. 5 being conventional construction in plywood. The box is made a couple inches longer than is actually needed in order to space the lights wide to eliminate the glare spots at edges of glossy copy. It is very important to eliminate light leaks toward the screen, and to this end the front edge of the top is fitted with a doubling piece of wood, as shown. The box is dimensioned for high M., the lowest magnification being 5x. An auxiliary base (see below) can be used for low magnifications.

Auxiliary Base for Low M.

A shallow bottomless box with two cleats to support the projector will give you a range of low magnifications with any table top projector. The example shown is dimensioned for the projector above, but the general idea is easily applied to any other projector. The base can be made as deep as needed to obtain the low magnification you want. Note that the projector power cord should be high enough to clear the base.

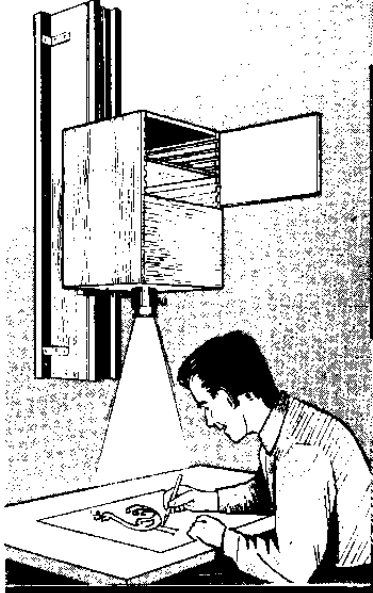


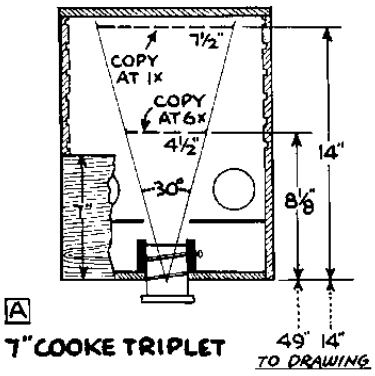
DRAWING PROJECTORS

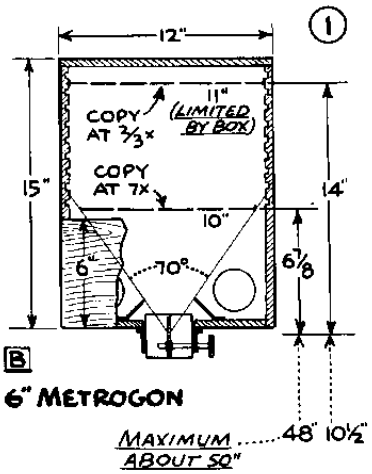
IF YOU find horizontal projection satisfactory, any of the boxes already described may be used as a drawing projector. Most artists prefer vertical projection. This involves a little extra work in making a wall or table mount, all of which is repaid tenfold in convenience of operation.

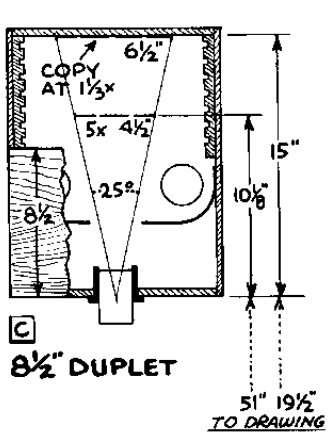
"APPLE BOX" PROJECTORS. Get an apple box and add slots for a copy board and a couple lamps and you have a simple yet practical straight-shot projector, Fig. 1. Working with such a box, the artist will usually trace the projected drawing on tracing paper, which is then "flipped" and retraced on the actual art work. In keeping with the simple construction, the lens is preferably a redi-mounted Petzval or Cooke Triplet with rack-and-pinion focusing mount. Spiral focusing (A, Fig. 1) is equally good. Simple slide-fit, push-pull focusing, C, is not practical if the lens is heavy but is satisfactory for a lightweight barrel if given a fair amount of tension to guard against the lens falling out of the mount.

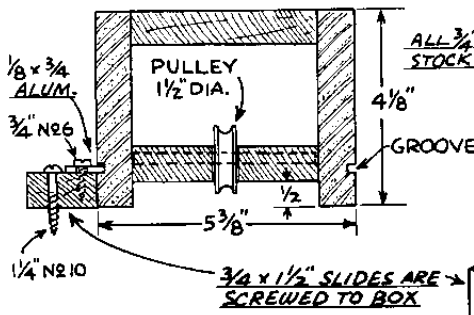
WALL MOUNT. If you are making a wall mount at all, go all the way and add a counterweight. The simple style shown in Fig. 2 can be used with any box although the cross-section may be varied to suit some particular weight you may have available, or to set the lens a greater or lesser distance from the wall. The average box will weigh 7 to 10 lbs. Since there is some friction drag, the counterweight can be a couple pounds

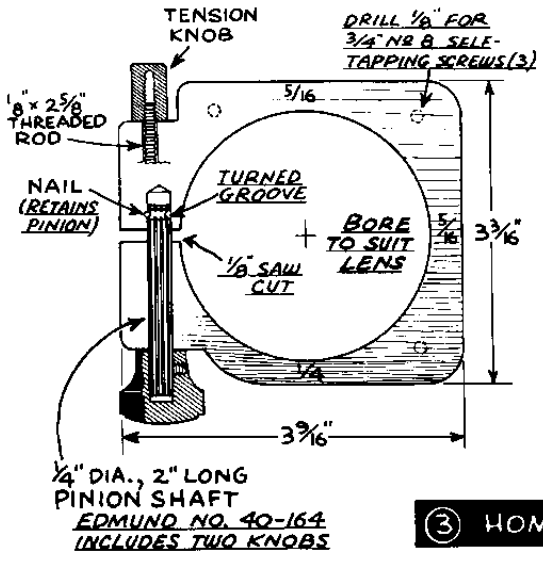


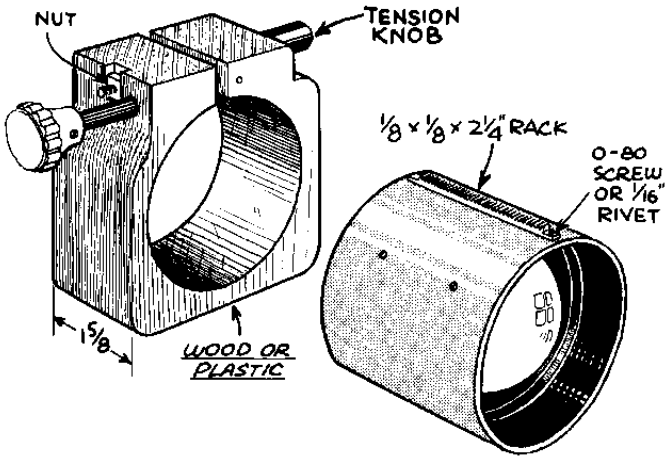




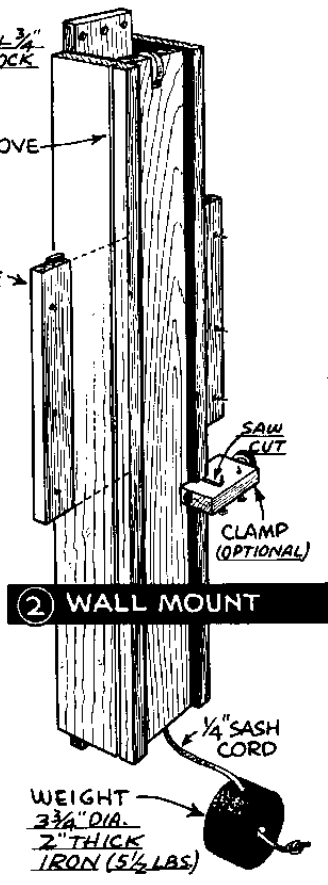


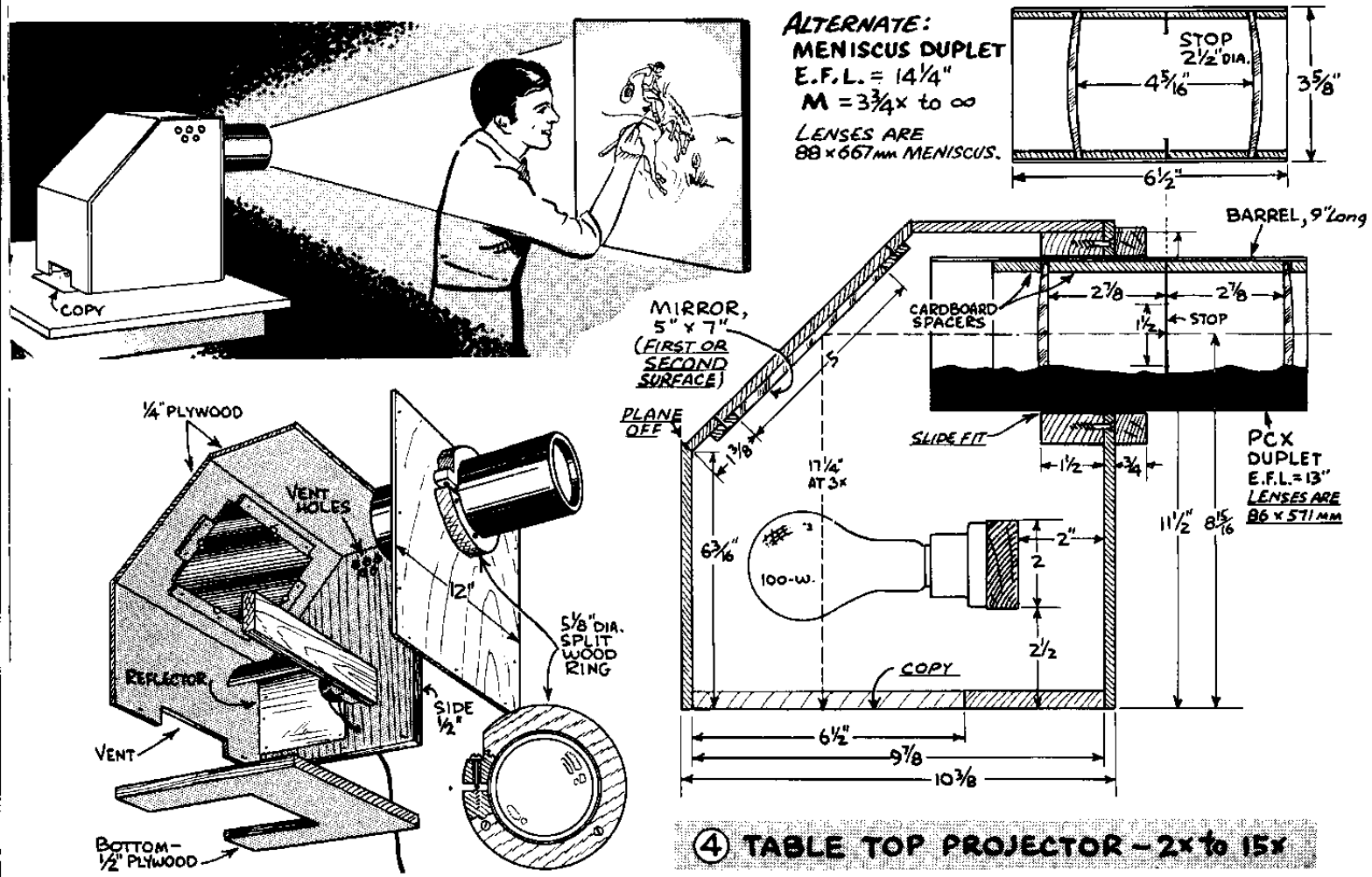






③ HOMEMADE RACK-and-PINION LENS MOUNT





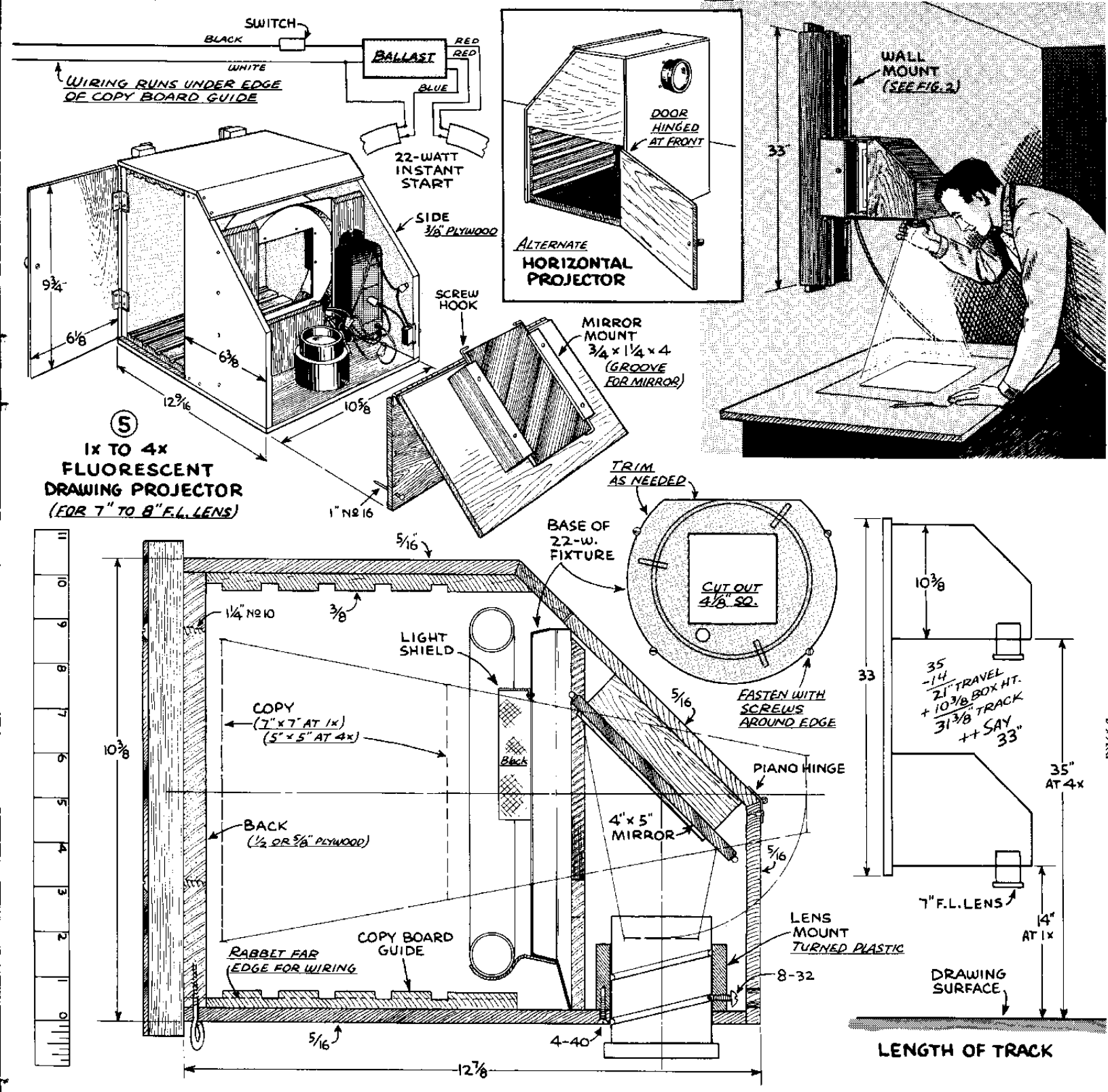
④ TABLE TOP PROJECTOR – 2× to 15×

lighter. If you use a positive clamp on the track, as shown, a 6 lb. weight will be satisfactory for boxes up to 12 lbs. The slides can be attached directly to the back of the projector box, although a neater and more useful arrangement is the sliding carriage which permits ready removal of the projector from the wall mounting. Fig. 6 shows this kind of mounting.

TABLE TOP PROJECTOR. The simple table top installation used for most picture projectors is also satisfactory for a drawing projector. The table model is almost a must when you get into projection lenses over 9 in. focal length, since the ceiling height of the average room limits the distance at which the projector can be placed from the drawing board. With a table top design, of course, the projection distance has no such limitation, making long lenses up to 14 or even 16 inches practical. The chief merit of the long lens is that it lets you cover big copy up to 6 inches square at a moderate field angle of less than 30 degrees. Simple plano-convex or meniscus duplets are commonly used, as shown in Fig. 4 design. The long barrel cuts off a little of the light, but the light loss is moderate; the idea of the non-symmetrical long barrel is that you can reverse it end-for-end as needed; the short end of barrel is faced toward copy when you want to get in close as needed for high magnification, while the long end faces the copy (as shown) when you want maximum lens to copy distance as needed for low magnification.

The alternate meniscus is shown in a short barrel, with central stop of maximum diameter. The big stop will make the screen image much brighter, but with some loss in sharpness which becomes rather poor on big copy at high magnification. A front stop of smaller aperture may be fitted and used as needed to increase sharpness. Simple slide focusing is used, an adjustable wood collar around the lens barrel providing the desired tension. If you want low (2x) magnification with the long meniscus duplet shown, the box should be made a couple inches taller. Alternately, an auxiliary base, as shown on another page, can be used for low magnifications.

FLUORESCENT LIGHTING. If 5 x 5-inch copy at 2x is big enough for your work, a fast 7 or 8-inch Cooke triplet in combination with a



circular fluorescent lamp adds up to a practical and attractive drawing projector, as shown in Fig. 5. The small 9-inch diameter lamp is used in this design; also available is a larger, 12 in. diameter lamp which could be used to make a larger projector. It will be noted that the lens must view the copy through the central opening of the circular fluorescent lamp, and it is this feature which limits the copy to about 5 inches square in the design shown.

The lighting components can be obtained by purchasing an inexpensive white enamel 22-watt fluorescent kitchen fixture. The center of the fixture base is cut out 4-1/8 inches square, and the base is trimmed down as needed to fit inside the box, as can be seen in the drawing. The slant top of the box is hinged in order to permit removal of the mirror for cleaning. The lens shown has a grooved barrel for spiral focusing. Lacking the spiral, a plain barrel

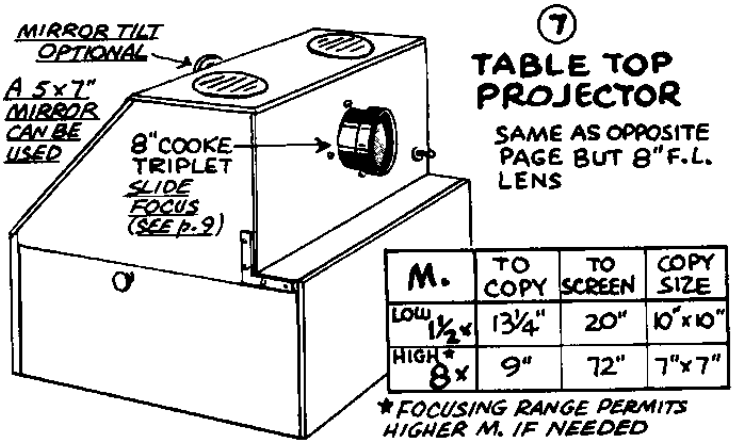
can be fitted with a 1/8 in. rack for rack-and-pinion focusing--a single screw at one end will hold the rack secure, and this can usually be fitted without removing the lenses from the barrel. Simple slide focusing can also be used, preferably with a flat spring or other tension device to make the lens stay put.

DRAWING PROJECTOR WITH METROGON LENS. A good design for a top-quality drawing projector is shown in Fig. 6. The lens is a 6-inch focal length Metrogon in barrel without a stop. Whether or not you care to add a central stop is a matter of choice. The situation is simply that without a stop, the image is bright but not too sharp; with a stop with central opening 7/8 in. diameter for f/5.3, the image is less bright but much sharper. Generally, for a drawing projector, where definition is more important than brightness, it is best to use a stop.

In a conventional light box with inside mirror, it is impossible to take full advantage of the wide 90-deg. field of the Metrogon lens. Using about two-thirds of the available field angle, you can cover 8 x 9-inch copy at 4x, and up to 11 x 12-inch copy at 2x. The whole projection range is from 1x to 4x. The mirror has a tilt adjustment to correct distortion which may be present in photo copy. For normal work, the mirror is adjusted until a grid of ruled 1-inch squares is seen to be perfectly square in the projected image. The grid should be pasted to the copy board to provide a constant check for squareness and magnification.

The lens is purchased in a barrel and needs to have a 1/8 inch rack attached, which can be done with one screw or rivet. The drawing shows one side of the barrel cut away at a 30-deg. angle to minimize light obstruction. However, this is not essential--try the box without cutting the barrel and decide for yourself if the lens cuts off too much of the picture. The big first surface mirror must be cut from the next larger stock size, which is 8 x 10. You can use a 5 x 7-inch mirror and get nearly full coverage. If you use a second surface mirror it should be no more than 1/8 inch thick to lessen the spread of the faint double image.

BEST LIGHT WITH TRIPLET. A good-quality triplet of 8 inches focal length will cover about the same copy as the 6-inch Metrogon, with the desirable feature of more light. This makes a good table projector and with lens in horizontal position, simple slide focusing becomes entirely practical. The light box itself is the same as before, Fig. 7, but with sheet metal ventilators installed on what is now the top of the box. Money-wise, this is a more practical project than the slower Metrogon; the Metrogon with shorter throw is more compact for wall mounting.



⑦

TABLE TOP PROJECTOR

SAME AS OPPOSITE PAGE BUT 8" F.L. LENS

M.	TO COPY	TO SCREEN	COPY SIZE
LOW 1½x	13¾"	20"	10"x10"
HIGH* 8x	9"	72"	7"x7"

*FOCUSING RANGE PERMITS HIGHER M. IF NEEDED

supplementary LENSES

A SIMPLE LENS CAN BE COMBINED WITH A PROJECTION LENS TO INCREASE OR DECREASE THE FOCAL LENGTH

A POSITIVE LENS IS USED TO DECREASE F.L.

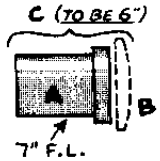
A NEGATIVE LENS IS USED TO INCREASE F.L.

IN FORMULAS AT RIGHT:

A IS F.L. OF PROJECTION LENS

B IS F.L. OF SUPP. LENS

C IS F.L. OF COMBINATION



7" F.L. PROJECTION LENS

Example 1

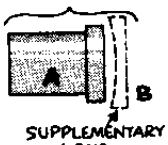
YOU HAVE A 7" F.L. PROJECTION LENS AND WANT TO DECREASE TO 6". WHAT POSITIVE SUPP. LENS IS NEEDED?

FORMULA:

$$B = \frac{A \times C}{A - C} \quad \frac{7 \times 6}{7 - 6} = \frac{42}{1} = 42\text{" F.L.}$$

TO CHECK F.L. OF COMBINATION, USE THIS FORMULA:

$$C = \frac{A \times B}{A + B} \quad \frac{7 \times 42}{7 + 42} = \frac{294}{49} = 6\text{"}$$



SUPPLEMENTARY LENS

Example 2

YOU HAVE A 7" F.L. PROJECTION LENS AND WANT TO INCREASE TO 9". WHAT NEGATIVE SUPP. LENS IS NEEDED?

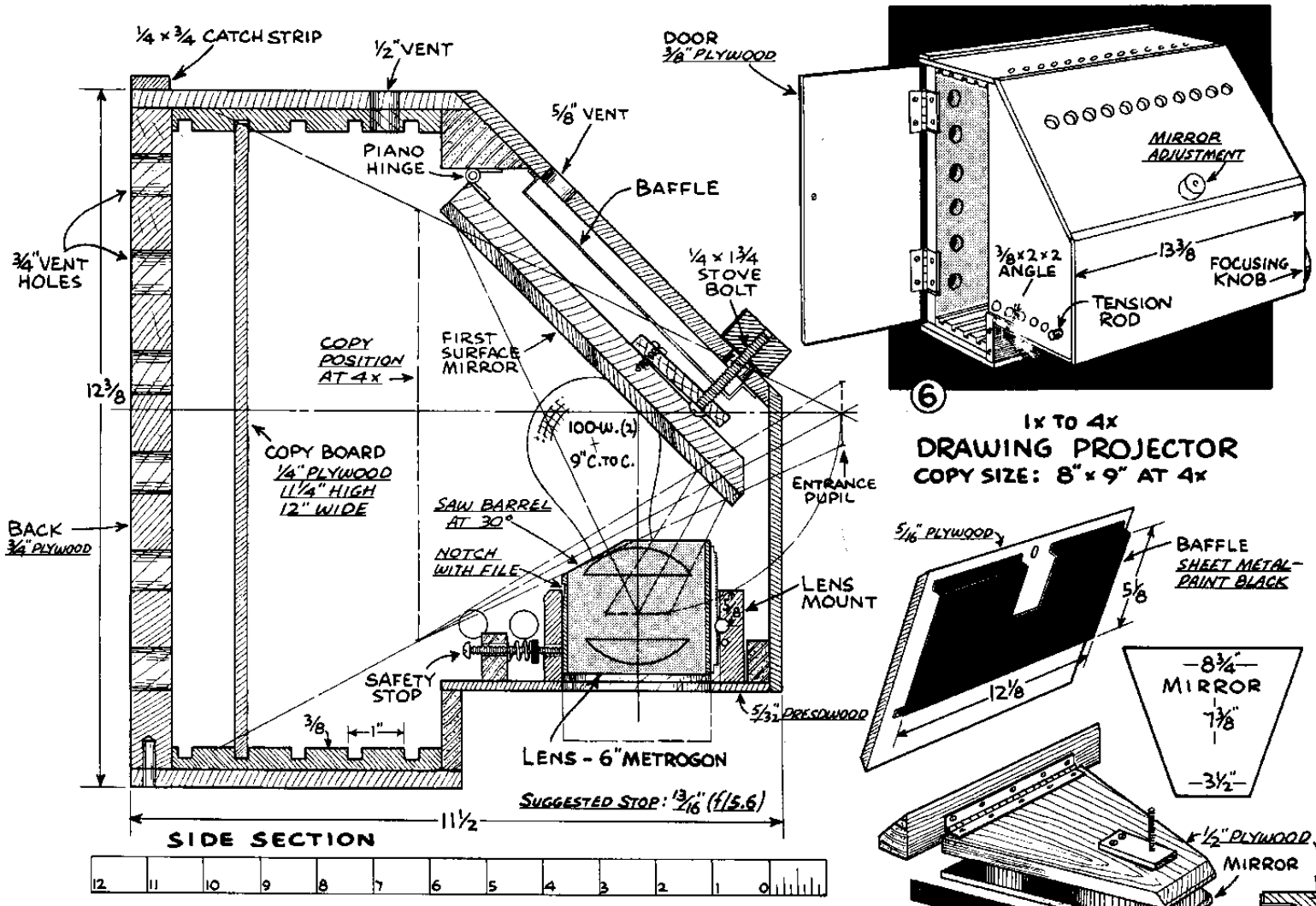
FORMULA:

$$B = \frac{A \times C}{C - A} \quad \frac{7 \times 9}{9 - 7} = \frac{63}{2} = 31\tfrac{1}{2}\text{" F.L.}$$

TO CHECK F.L. OF COMBINATION, USE THIS FORMULA:

$$C = \frac{A \times B}{B - A} \quad \frac{7 \times 31.5}{31.5 - 7} = \frac{220.5}{24.5} = 9\text{"}$$

THE FORMULAS DO NOT CONSIDER LENS SPACING AND HENCE ARE ONLY APPROXIMATE BUT CLOSE ENOUGH FOR PRACTICAL USE


¼ × ¾ CATCH STRIP
½" VENT
DOOR ⅜" PLYWOOD
⅝" VENT
PIANO HINGE
BAFFLE
¾" VENT HOLES
¼ × 1¾ STOVE BOLT
COPY POSITION AT 4×
FIRST SURFACE MIRROR
12⅜
100-W. (2) + 9" C. TO C.
COPY BOARD ¼" PLYWOOD 11¼" HIGH 12" WIDE
ENTRANCE PUPIL
BACK ¾" PLYWOOD
SAW BARREL AT 30°
NOTCH WITH FILE
LENS MOUNT
SAFETY STOP
⅜
1"
5/32" DRESDWOOD
LENS - 6" METROGON
SUGGESTED STOP: 13/16" (f/5.6)
11½
SIDE SECTION
12 11 10 9 8 7 6 5 4 3 2 1 0
MIRROR ADJUSTMENT
⅜×2×2 ANGLE
13⅜
FOCUSING KNOB
TENSION ROD
⑥
1× TO 4×
DRAWING PROJECTOR
COPY SIZE: 8" × 9" AT 4×
5/16" PLYWOOD
BAFFLE SHEET METAL PAINT BLACK
5⅛
12⅛
8¾"
MIRROR
7⅞"
3½"
½" PLYWOOD
MIRROR
Black
SHEET METAL
⅛
MIRROR MOUNTING
SET SC.
FOCUSING KNOB 1¾" DIA. TURNED PLASTIC
½" ALUM.
¼ × 2 PINION GEAR
DRILL 15/64 AND PRESS PINION IN PLACE
FOCUSING ROD BEARING
SWITCH
LENS MOUNT (SEE FIG. 3)
TENSION ROD
SOCKET BASE ABOUT 15° TILT
SAFETY STOP BOLT, SPRING AND NUT
REFLECTOR ALUM. FOIL OVER ASBESTOS PAPER
BAFFLE SHEET ALUM.
13⅜
GENERAL ASSEMBLY
LENS PANEL
3⅞"
4¼
33"
¾ × 2½
14⅛
10d NAIL
SLIDING CARRIAGE
SAW CUT
CLAMP SCREW TO CARRIAGE
½" VENT HOLES
6
LEFT SIDE
11¾
SIDE DIMENSIONS ½" PLYWOOD
1⁹/16
5½
5¾
11¼
VARIATIONS
10⅝
DOOR HINGED AT FRONT
WITHOUT BOTTOM STEP
TABLE MODEL

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