

THESES.

ARTIFICIAL LIGHT DISTRIBUTION
IN A
KNOXVILLE PUBLIC BUILDING

J. H. Grainger.

'07.

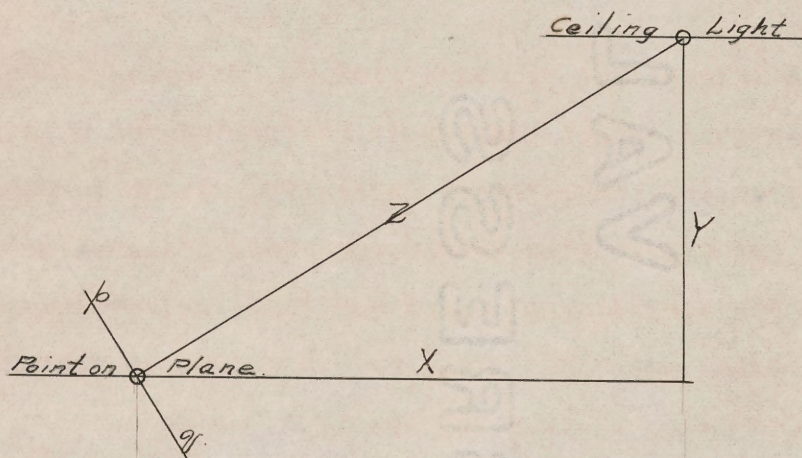
ARTIFICIAL LIGHT DISTRIBUTION
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It is impossible to calculate with anything like absolute accuracy the distribution of light in a room. Of course measurements of intensity might be taken at any number of points throughout the room, but after all, these measurements are compared to a standard and the standards themselves vary, owing to the fact that they are standardized by different people and no two see them alike. However, for engineering purposes there is an allowable margin, and it is possible to keep within this margin.

The subject selected for this paper is the general distribution of light throughout the auditorium of the new Second Presbyterian Church, at the corner of Church and Walnut Streets, Knoxville, Tenn. The idea is to take the lighting plans which they have and, using the curve of the lamp which the specifications calls for, calculate the intensity of light at a number of points on the plane where the light is most needed. The auditorium is about 65 feet square, with the pulpit in one corner, while the entrance hall occupies the corner opposite. The average height of the ceiling lights above the floor is thirty eight and a half feet. Taking the plane where it is required to find the intensity as two and a half feet above the floor, makes an elevation of 36 feet for the ceiling lights. The lamp to be used is the Columbia, 16 c.p. incandescent, and the reflector for which the calculations have been made is the Holophane, catalog number 7381, which gives greatest intensity at 45 degrees from the vertical.

It will be well, before going further, to define the unit of light intensity, the "foot-candle". Candle-power is a term which refers to the intensity of light at its source. To express degree of illumination, the distance must also be considered. A unit combining the candle-power and the distance is the foot-candle. One foot-candle is the intensity of illumination given by a standard candle at a distance of one foot, or by a 16 c.p. incandescent lamp at a distance of four feet. For general illumination, average intensities vary from $1/2$ to 2 or 3 foot-candles.

The general plan adopted for arriving at the intensity of illumination at various points throughout the auditorium is as follows;



Y is the vertical height from the plane upon which it is desired to find the intensity, to the plane of the light.

X is the horizontal distance for the point to a point directly under the light.

Z is the distance from the light to the point, or the hypotenuse of a right triangle whose legs are X and Y.

$$Z = \sqrt{X^2 + Y^2}.$$

Now, remembering that the intensity of light at a point varies in-

versely as the square of its distance from the source, the intensity of illumination on the normal plane^{p-q}₁ is found to be;

$$I_b = \frac{I_a}{X^2 + Y^2}, \text{ where } I_a \text{ is the intensity at one foot distant}$$

from the lamp. And to determine from this the intensity on a plane parallel to the floor, I_b must be multiplied by the cosine of the angle (θ), which the normal plane makes with the plane parallel to the floor. Since $\cosine(\theta) = \frac{Y}{\sqrt{X^2 + Y^2}}$, the amount of illumination in foot-candles is;

$$I_s = \frac{I_a}{(X^2 + Y^2)^{\frac{3}{2}}}. \quad I_a \text{ is taken from the distribution curve of}$$

the lamp, as shown on plate (C).

In order to avoid the necessity of calculating the effect of each separate light upon each point, thus involving an endless amount of work, arcs are drawn around the points for which the illumination is to be calculated, at intervals of one foot, as shown on plate (A), and it is assumed that the effect at (A), due to (x) lights included in the interval between two circles, would be practically the same as that due to one light of (x) times the candle-power, at a distance equal to that of the central point of the interval.

The intensity curves and plate (B) are self-explanatory, the plate showing a horizontal projection of the plane for which the calculations have been made and the points whose intensity have been determined.

In calculating the effect due to the chandelier lights, it has been assumed that 16 c.p. incandescent lights, the same as used for the ceiling - no reflectors - would be used; however, should the chandeliers be put in, the lamps will be surrounded with ground-glass balls, and this will somewhat increase the downward distribution. It has also been assumed that they will be dropped 10 feet from the ceiling, thus giving

an elevation of 25 feet from the plane for which the calculations are made.

So far nothing has been said of the effect upon the general distribution due to the reflection from the walls and ceiling. The effect of the walls will be to raise the intensity near them, thus improving the general effect. The walls for the present will be a light cement grey, while the ceiling will be medium-dark oak finish, and this would probably add from 30 to 40 per cent.

The calculations show that the general illumination will be very good throughout the church. The chandeliers, if used, will somewhat disturb the distribution. They will also be in the line of vision of the minister, and some of the congregation in the rear of the church.

"Uniformity is the chief requisite of good illumination. It is a well known fact that if the illumination be uniform, the eye can work comfortably with a much less intense light than where the illumination is not uniform. This is due to the adaptability of the human eye to a wide range of light intensities. Where the illumination is not uniform the eye adjusts itself to the brighter illuminated spots by the pupil contracting and admitting less light, and the less illuminated areas appear very much darker than they would without the contrast of the intensely illuminated spots. Lack of uniformity of illumination, therefore, constitutes not only a waste of light in the strongly illuminated areas, but a still greater waste of light throughout, by the reduction of the sensibility of the eye for light. Most of the artificial illumination is deficient in this respect, and in very many cases the total amount of light, and therefore the power and cost of illumination, could be reduced to one half or even less, and still a much better illumination secured. It is especially objectionable to have the lamps in the line of vision, and the proper place for the lights is at or close to

the ceiling."

The present plan of the architect, in this case, is to use no reflectors on the ceiling lights. To quote from a letter received from the Holophane Glass Company, of New York, who make a specialty of such problems; "It would be almost a crime to use bare lamps here". As shown by the curves, in order to get sufficient illumination throughout the church with the bare lamps, all of them, with the exception of chandeliers, would be necessary; while by using the reflectors the illumination would be all that is required with about half the lamps, thus reducing the power consumption and light bill one-half. It is shown too that the distribution would be even more uniform.

To sum up in a few words the results of the work, it has been found;

1st. The general arrangement of ceiling lights is excellent for uniformity of light.

2nd. The light is sufficient in amount, ranging from about one to one and a half foot-candles without reflectors, and from two to three foot-candles with reflectors.

3rd. The arrangement is also excellent in excluding the lights from the range of vision.

4th. The addition of suitable reflectors would almost double the illumination, and at the same time somewhat increase the uniformity.

5th. The addition of chandeliers, while it might add to the brilliancy for special occasions, detracts from the uniformity of lighting and is especially objectionable because it will shine in the eyes of the audience and minister.

P O I N T A .

X	X ²	$\frac{Y}{(X^2 + Y^2)^{\frac{3}{2}}}$	No. of Lights.	Intensity Without Reflector. 1 ft. On Plane.		Intensity With Reflector. 1 ft. On Plane.	
				Ceiling Lights.			
1	1	.0008	4	10.75	.0337	16	.0493
2	4	.0008	4	10.75	.0330	16	.0492
3	9	.0008	4	10.75	.0328	16	.0491
4	16	.0008	4	10.75	.0326	16	.0488
5	25	.0008	4	10.75	.0322	16.5	.0495
6	36	.0007	4	11.00	.0326	17	.0504
7	49	.0007	4	11.00	.0321	17.5	.0511
8	64	.0007	4	11.25	.0322	18	.0516
9	81	.0007	4	11.25	.0317	18.5	.0521
10	100	.0007	4	11.50	.0317	19	.0524
11	121	.0007	4	11.50	.0311	20	.0540
12	144	.0007	4	11.50	.0303	21	.0554
13	169	.0006	4	11.75	.0302	22	.0565
14	196	.0006	4	11.75	.0294	22.5	.0563
15	225	.0006	32	11.75	.2282	23	.4468
16	256	.0006	24	12.00	.1696	24	.3393
17	289	.0006	16	12.00	.1096	25	.2284
18	324	.0006	8	12.00	.0532	26	.1148
19	361	.0005	16	12.25	.1045	27	.2303
20	400	.0005	16	12.25	.1009	28	.2307

Totals

1.2114

2.3160

Chandelier Lights.

27	729	.0005	48	14.00	.3373	.3373
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Totals

.3373

.3373

GRAND TOTALS

1.5487

2.6533

P O I N T B.

X	X ²	Y (X ² + Y ²) ^{3/2}	No. of Lights.	Intensity Without Reflector.		Intensity With Reflector.	
				1 ft.	On Plane.	1 ft.	On Plane.
Ceiling Lights.							
1	1	.0008	3	10.75	.0249	16	.0370
2	4	.0008	3	10.75	.0248	16	.0369
3	9	.0008	3	10.75	.0247	16	.0368
4	16	.0008	3	10.75	.0245	16	.0364
5	25	.0008	3	10.75	.0242	16.5	.0370
6	36	.0007	3	11.00	.0244	17	.0378
7	49	.0007	3	11.00	.0241	17.5	.0387
8	64	.0007	3	11.25	.0242	18	.0387
9	81	.0007	3	11.25	.0238	18.5	.0390
10	100	.0007	3	11.50	.0238	19	.0393
11	121	.0007	3	11.50	.0233	20	.0405
12	144	.0007	3	11.50	.0227	21	.0415
13	169	.0006	3	11.75	.0226	22	.0424
14	196	.0006	3	11.75	.0220	22.5	.0425
15	225	.0006	16	11.75	.0636	24	.1272
16	256	.0006	9	12.00	.1141	23	.2234
17	289	.0006	13	12.00	.0891	25	.1856
18	324	.0006	5	12.00	.0331	26	.0718
19	361	.0005	9	12.25	.0588	27	.1311
20	400	.0005	5	12.25	.0315	28	.0721
21	441	.0005	5	12.50	.0311	28	.0696
22	484	.0005	3	12.50	.0180	28.5	.0410
23	529	.0005	5	12.75	.0295	28.5	.0658
24	576	.0004	3	12.75	.0170	28.5	.0380
25	625	.0004	3	13.00	.0167	29	.0371
26	676	.0004	3	13.00	.0160	29	.0358
27	729	.0004	5	13.00	.0257	29	.0344
28	784	.0004	3	13.25	.0151	29	.0330
29	841	.0004	3	13.25	.0145	29	.0317
30	900	.0004	12	13.25	.0560	28.5	.1204
31	961	.0003	10	13.50	.0454	28.5	.0958
32	1024	.0003	8	13.50	.0348	28.5	.0734
33	1089	.0003	6	13.50	.0249	28	.0517

Totals

1.0689

2.0834

Chandelier Lights

17	289	.0009	12	13.00	.1413		.1413
23	529	.0006	12	13.5	.1034		.1034
38	1444	.0003	12	14.5	.0463		.0463
41	1681	.0002	12	14.5	.0393		.0393

Totals

.3303

.3303

GRAND TOTALS

1.3992

2.4137

P O I N T C .

X	X ²	$\frac{Y}{(X^2 + Y^2)^{\frac{3}{2}}}$	No. of Lights.	Intensity Without Reflector. 1 ft. On Plane.		Intensity With Reflector 1 ft. On Plane.	
				Ceiling Lights.			
1	1	.0008	2	10.75	.0166	16	.0247
2	4	.0008	2	10.75	.0165	16	.0246
3	9	.0008	2	10.75	.0164	16	.0245
4	16	.0008	2	10.75	.0162	16	.0243
5	25	.0008	2	10.75	.0160	16.5	.0248
6	36	.0007	2	11.00	.0163	17	.0252
7	49	.0007	2	11.00	.0161	17.5	.0256
8	64	.0007	2	11.25	.0161	18	.0258
9	81	.0007	2	11.25	.0158	18.5	.0260
10	100	.0007	2	11.50	.0158	19	.0262
11	121	.0007	2	11.50	.0157	20	.0270
12	144	.0007	2	11.50	.0151	21	.0277
13	169	.0006	2	11.75	.0151	22	.0282
14	196	.0006	2	11.75	.0147	22.5	.0281
15	225	.0006	6	11.75	.0428	23	.0838
16	256	.0006	8	12.00	.0565	24	.1131
17	289	.0006	6	12.00	.0411	25	.0857
18	324	.0006	6	12.00	.0397	26	.0861
19	361	.0005	6	12.25	.0391	27	.0863
20	400	.0005	4	12.25	.0252	28	.0577
21	441	.0005	4	12.50	.0249	28	.0557
22	484	.0005	4	12.50	.0240	28.5	.0546
23	529	.0005	6	12.75	.0353	28.5	.0790
24	576	.0004	4	12.75	.0226	28.5	.0506
25	625	.0004	4	13.00	.0222	29	.0495
26	676	.0004	4	13.00	.0214	29	.0477
27	729	.0004	6	13.00	.0308	29	.0687
28	784	.0004	6	13.25	.0301	29	.0659
29	841	.0004	4	13.25	.0193	29	.0422
30	900	.0004	12	13.25	.0560	28.5	.1204
31	961	.0003	9	13.50	.0408	28.5	.0862
32	1024	.0003	7	13.50	.0304	28.5	.0642
33	1089	.0003	6	13.50	.0249	28	.0517
34	1156	.0003	4	13.75	.0163	28	.0332
35	1225	.0003	4	13.75	.0156	28	.0318
36	1296	.0003	2	13.75	.0075	28	.0152
37	1369	.0003	4	13.75	.0144	27	.0283
38	1444	.0003	4	14.00	.0139	27	.0271
39	1521	.0002	2	14.00	.0068	27	.0131
40	1600	.0002	4	14.00	.0129	27	.0249
41	1681	.0002	2	14.00	.0062	26.5	.0118
42	1764	.0002	2	14.00	.0060	26	.0111
Totals				.9492		1.9083	

P O I N T C .

X	X ²	$\frac{Y}{(X^2 + Y^2)^{\frac{3}{2}}}$	No. of Lights	Intensity Without Reflector 1 ft. On Plane.	Intensity With Reflector. 1 ft. On Plane.
Chandelier Lights.					
8	64	.0014	12	11.50	.0186
31	961	.0005	12	14.00	.0803
38	1444	.0003	12	14.5	.0463
48	2304	.0002	12	14.7	.0312
Total					.1764
GRAND TOTALS				1.1256	2.0847

P O I N T D .

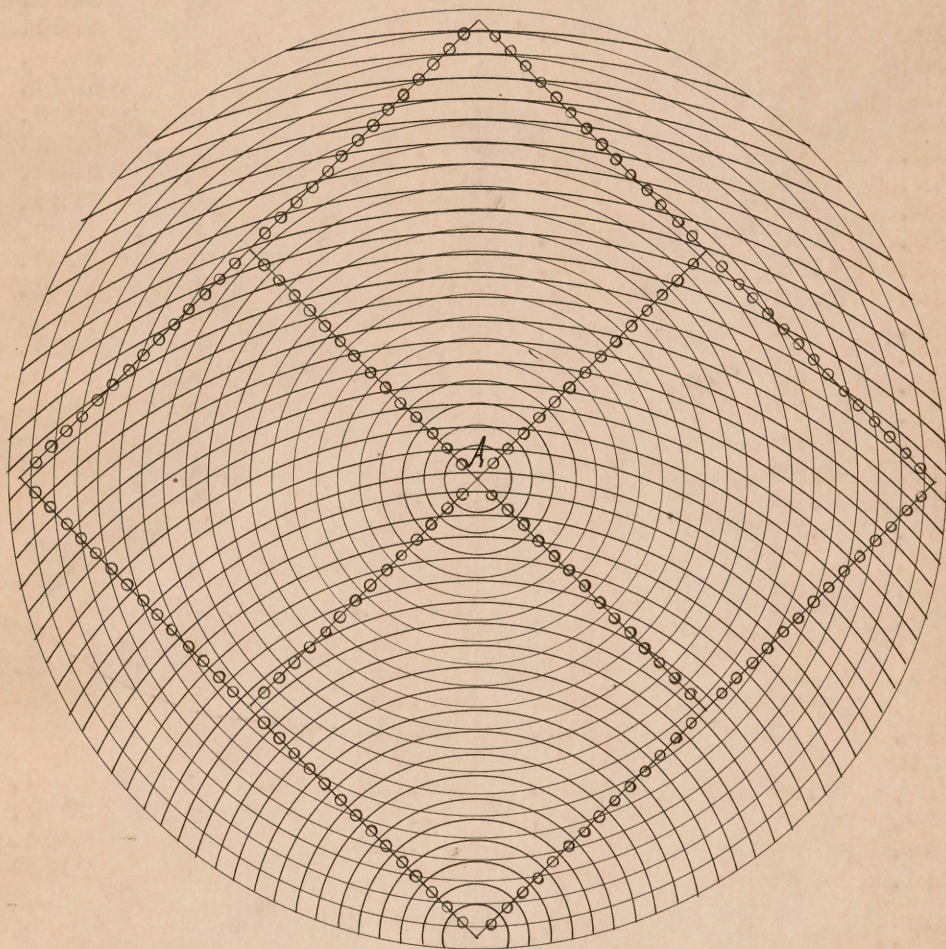
X	X ²	$\frac{Y}{(X^2 + Y^2)^{\frac{3}{2}}}$	No. of Lights	Intensity Without Reflector 1 ft. On Plane.		Intensity With Reflector. 1 ft. On Plane.	
				Ceiling Lights.			
12	144	.0007	6	11.50	.0455	21	.0830
13	169	.0006	7	11.75	.0528	22	.0989
14	196	.0006	5	11.75	.0367	22.5	.0703
15	225	.0006	5	11.75	.0357	23	.0699
16	256	.0006	3	12.00	.0212	24	.0424
17	289	.0006	5	12.00	.0343	25	.0714
18	324	.0006	3	12.00	.0199	26	.0431
19	361	.0005	1	12.25	.0065	27	.0144
20	400	.0005	5	12.25	.0315	28	.0721
21	441	.0005	3	12.50	.0186	28	.0417
22	484	.0005	3	12.50	.0180	28.5	.0410
23	529	.0005	5	12.75	.0295	28.5	.0658
24	576	.0004	3	12.75	.0170	28.5	.0380
25	624	.0004	3	13.00	.0167	29	.0371
26	676	.0004	3	13.00	.0160	29	.0358
27	729	.0004	14	13.00	.0719	29	.1604
28	784	.0004	12	13.25	.0603	29	.1319
29	841	.0004	8	13.25	.0386	29	.0844
30	900	.0004	7	13.25	.0326	28.5	.0702
31	961	.0003	1	13.50	.0045	28.5	.0096
32	1024	.0003	3	13.50	.0130	28.5	.0275
33	1089	.0003	5	13.50	.0208	28	.0431
34	1156	.0003	3	13.75	.0122	28	.0249
35	1225	.0003	3	13.75	.0117	28	.0239
36	1296	.0003	3	13.75	.0112	28	.0228
37	1369	.0003	3	13.75	.0107	27	.0212
38	1444	.0003	3	14.00	.0105	27	.0203
39	1521	.0002	3	14.00	.0101	27	.0196
40	1600	.0002	3	14.00	.0097	27	.0187
41	1681	.0002	3	14.00	.0093	26.5	.0176
42	1769	.0002	14	14.00	.0417	26	.0775
43	1849	.0002	12	14.00	.0343	26	.0636
44	1936	.0002	8	14.00	.0220	26	.0408
Totals				.8250		1.7029	

Chandelier Lights.

16	256	.0010	12	13.00	.1484
26	676	.0005	12	14.00	.0884
52	2704	.0001	12	15.00	.0234
48	2304	.0002	12	14.70	.0312

Total .2914

GRAND TOTALS 1.1164 1.9943



PULPIT

FRONT ENTRANCE

PLATE A.

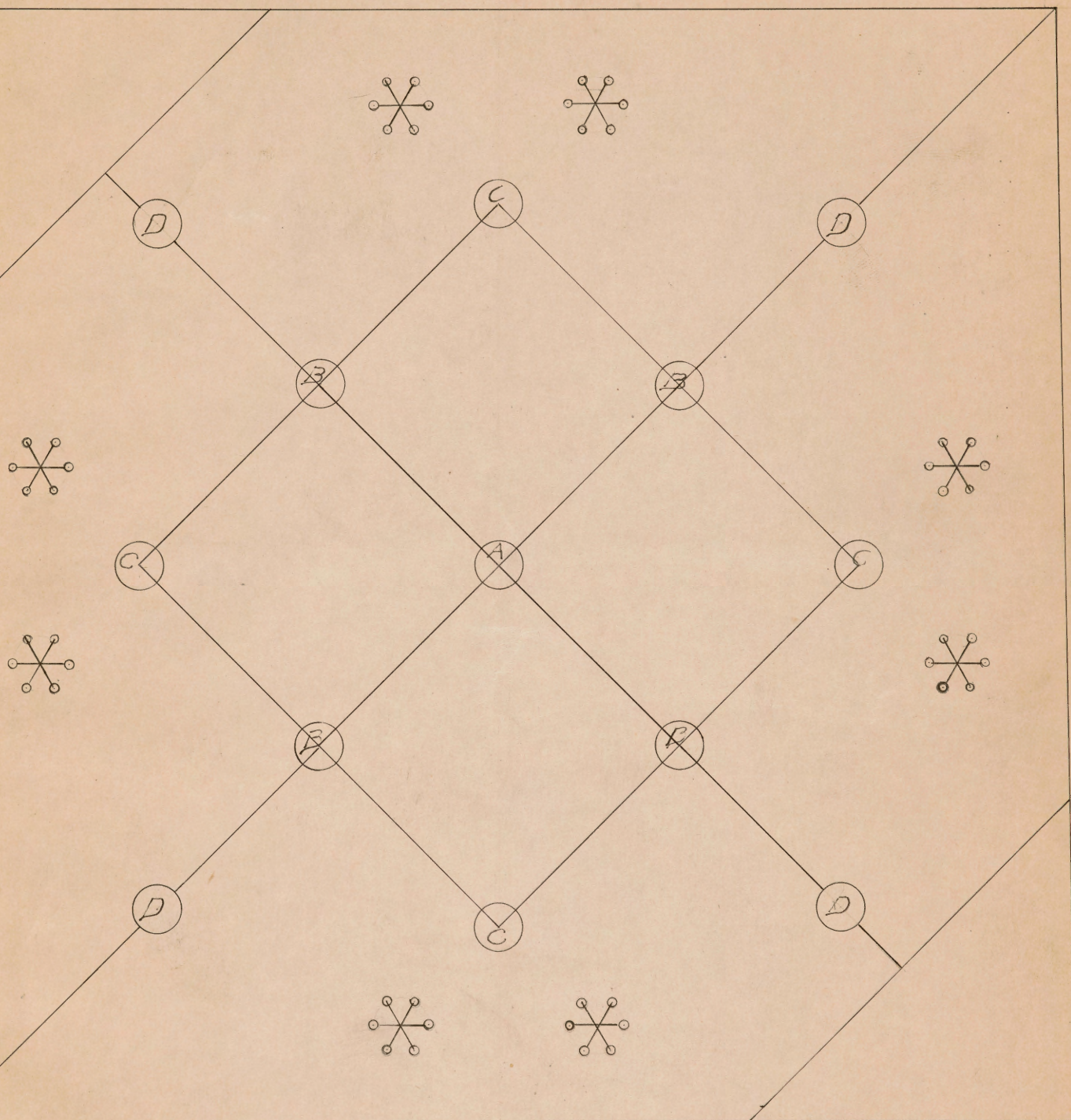
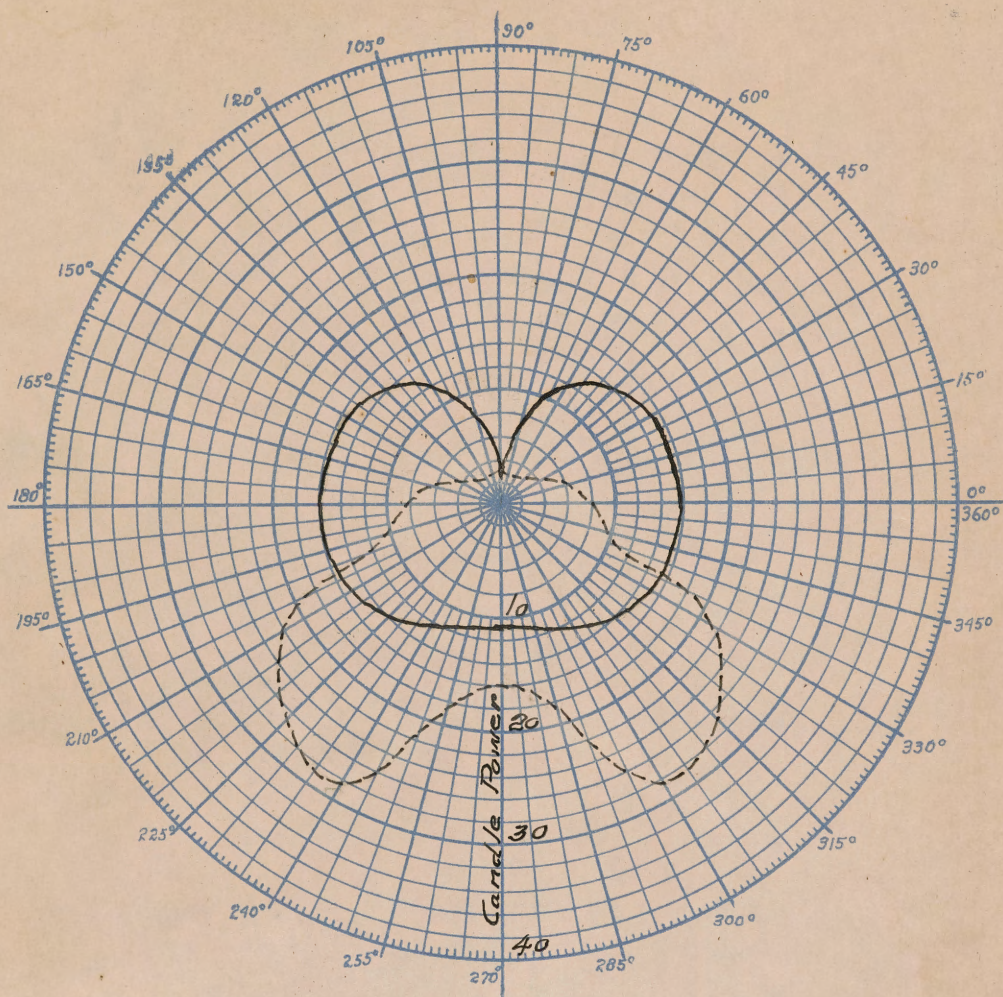


PLATE B



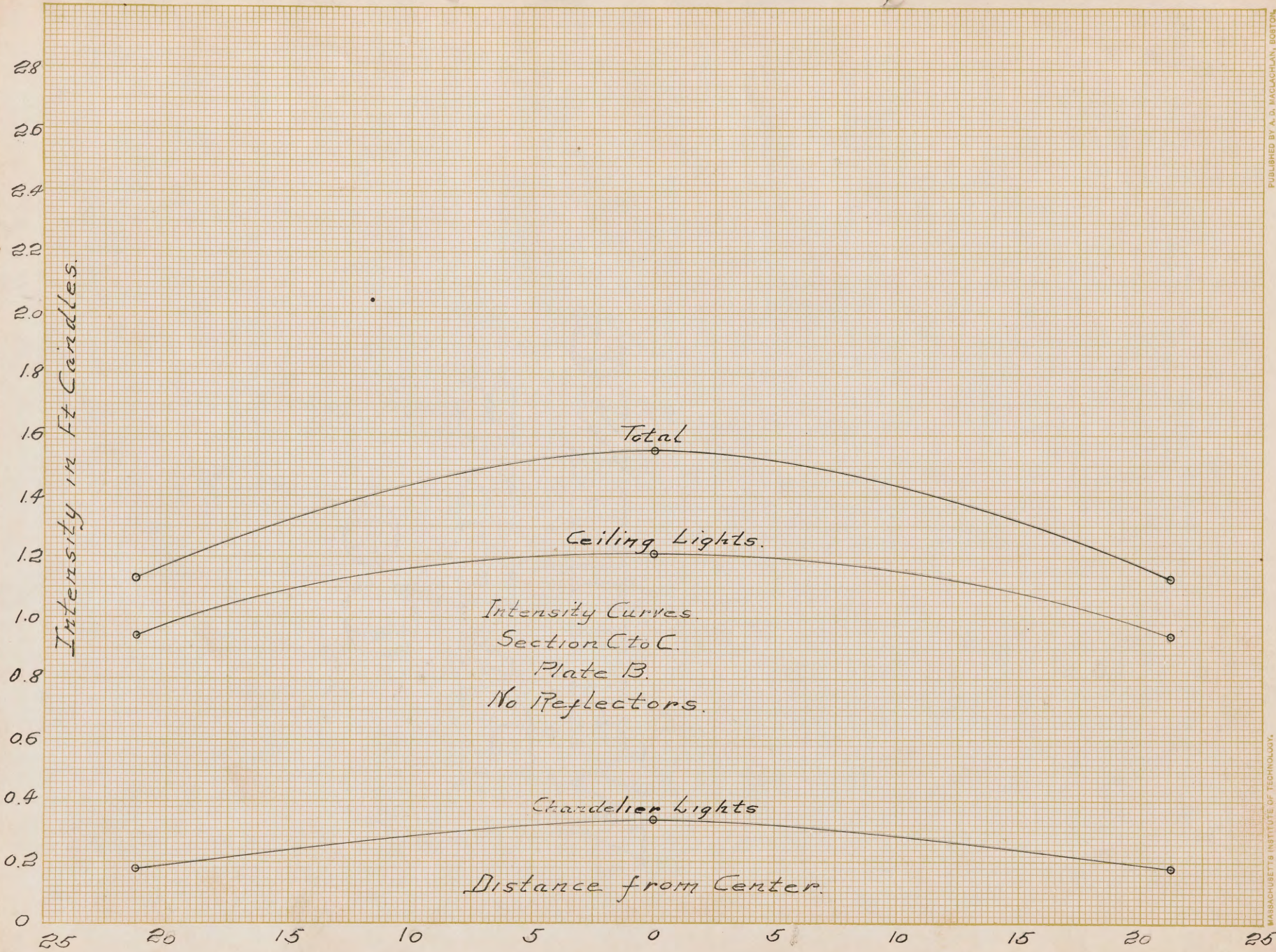
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— WITHOUT REFL'TR.
--- WITH REFL'TR.

2.8
2.6
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2.2
2.0
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1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
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Intensity in Ft Candles.

Total
Ceiling Lights.
Intensity Curves
Section D to D.
Plate B.
No Reflectors.
Chandelier Lights.
Distance from Center.

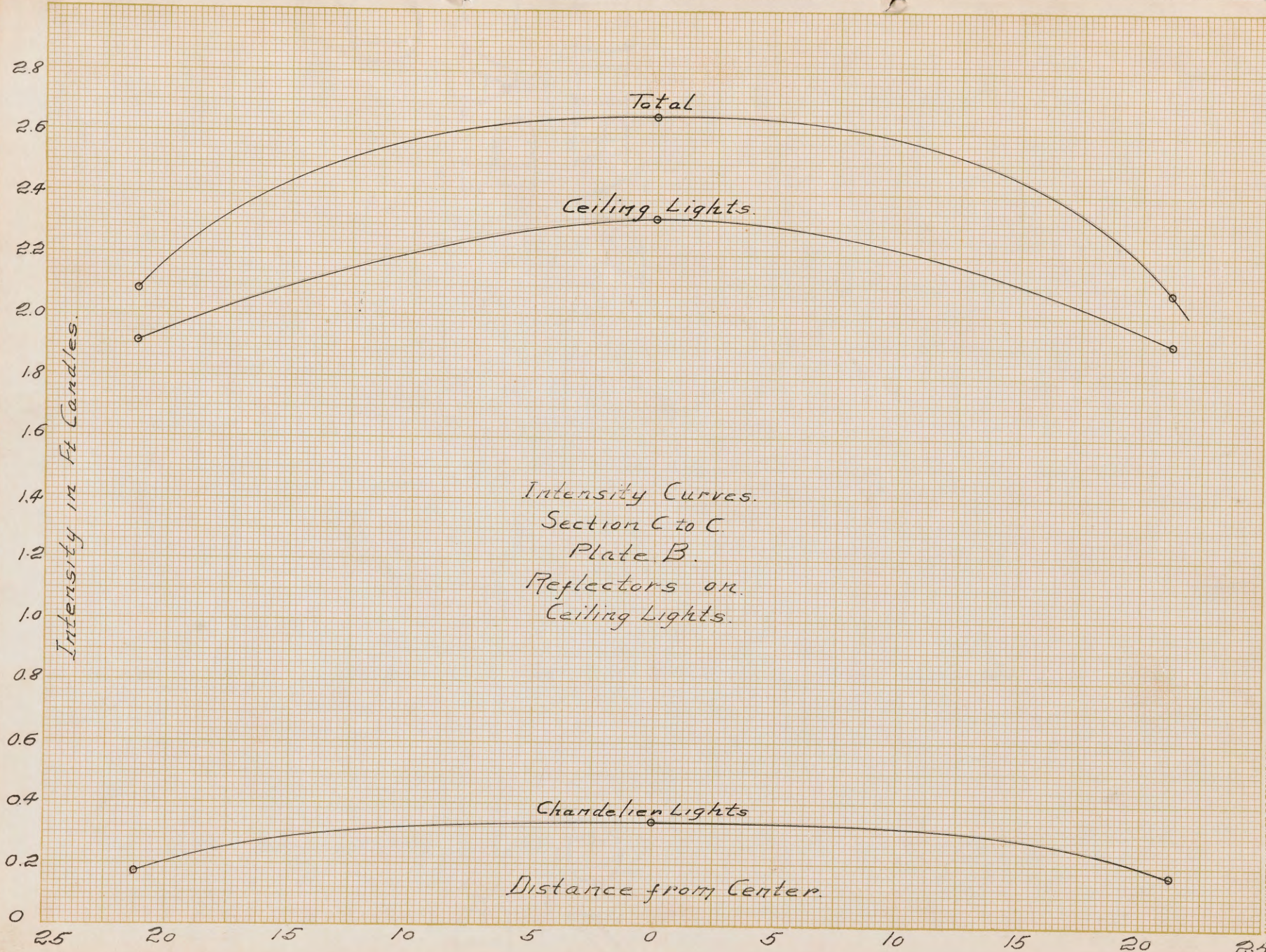
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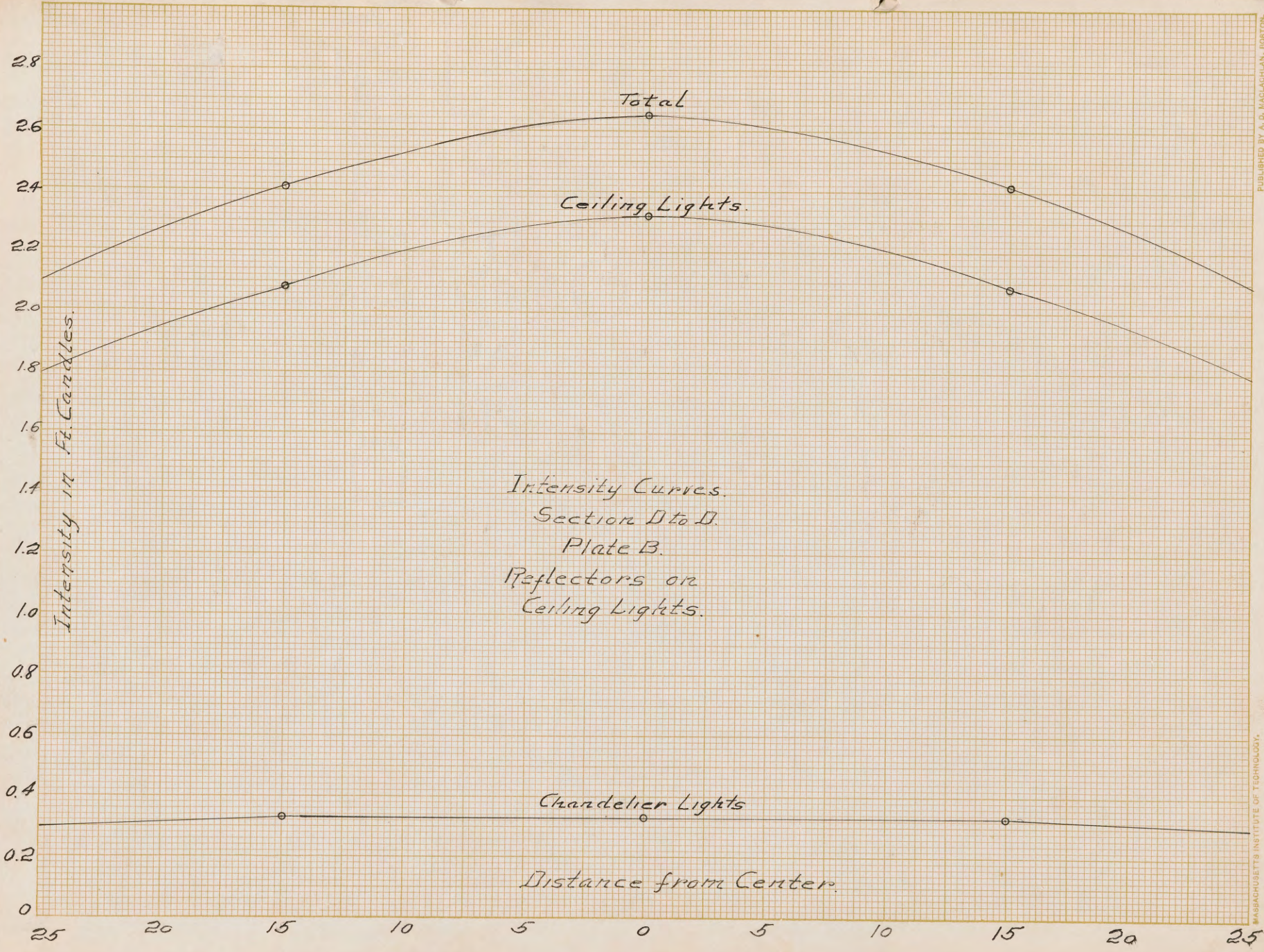


2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0

Intensity in Ft Candles.

Total
Ceiling Lights.
Intensity Curves.
Section C to C.
Plate B.
Reflectors on.
Ceiling Lights.
Chandelier Lights
Distance from Center.





Intensity Curves.
Section D to D.
Plate B.
Reflectors on
Ceiling Lights.