THESIS

ON

PHOTOMETRY OF KNOXVILLE STREET LIGHTS

Presented to the

ENGINEERING FACULTY OF THE UNIVERSITY OF TENNESSEE

For the degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

by

EDW. M. KIRKPATRICK- J. ELMER HOUSLEY.

1916

1916

THE PHOTOMETRY OF KNOXVILLE STREET LIGHTS.

The Photometry of Knoxville Street lights involves two subjects; the most desirable means of illuminating thoroughfares and the distribution of light by representative types of street illuminants. Our special task was the measurement of the actual illumination on the street surface under everyday conditions, as obtained from the three types of street lights now used in Knoxville, Tenn.

The three types are as follows: The alternating current series 500 watt arc lights; the nitrogen filled series 250 watt lamp, 250-C.P., and the series 40 watt mazda lamp of 32rated candle power. Each of the three types are operated on similar or, as required, the same circuit which carries on an A. C. Current of a constant value of 6.6 amperes. These circuits are fed from what is commonly called a "tub" transformer- this transformer automatically maintains a constant current, and when any lamp is "cut out" or "cut in" the transformer varies its terminal voltage to meet the changed conditions. In case of trouble or failure of the arc an automatic shunt operates and gives a by pass to the current. This is operated by means of an auxiliary apparatus operated by the potential drop across the arc, and either increases or diminishes the ampere-turns of the solenoid. This effect may also be accomplished by series transformers with a large no-load current, or by using choking coils with strongly saturated cores in parallel with the arcs.

*Owing to variation in permeability of the iron core and the self- induction of the windings the electrical regulation is not exact with the A. C. Series lamp.

LOCAL PRACTICE- There are in use locally 6 constant current transformers of 50 K.W. capacity feeding to two circuit each. The allowable number of arc on each curcuit we find to be 150 lamps. The impressed voltage may reach 6000 volts on any one series circuit. The nitrogen filled incandescent series lamp have only recently been installed, these being placed in Oakwood, a suburb of Knoxville, and the circuits are operated from a sub-station by means of clockwork. The small mazda lamps are used in the city arc circuits, and are commonly known as "bug"lamps, these are placed on side streets and alleys where there is only a small amount of vehicle traffic. There was no data available as regards the number of mazda incandescent lamps installed, there lamps have replaced a 108 watt carbon incandescent series lamp and are nearly twice as strong as the old lamps.

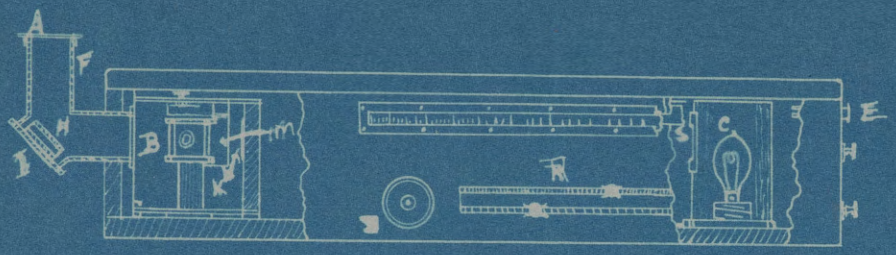
TYPE OF ARC LAMPS- The arc lights are of Adams-Bagnall Co., Cleveland, Ohio, manufacture and are of the clutch-feed, enclosed arc type operating on series A. C. circuit at a constant current of 6.6 amperes, the lamp being nominally rated at 500 watts. The inner enclosing globe of the arc is of clear glass as is the outer enclosing globe.

*ELECTRIC ARC LAMPS- ZEIDLER AND LUSTGARTNER

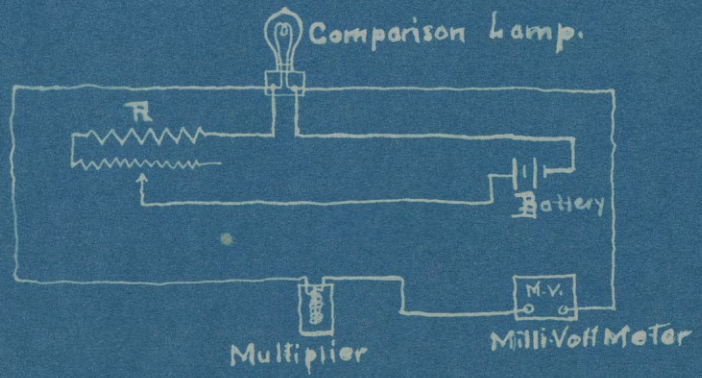
After burning a short time the inner globe becomes coated with a frost like deposit on the inside, and which would cut off from five to twenty per cent of the light if not cleaned regularly, however, all the lights examined seem to be well supervised and had clean globes. In some places other than Knoxville, opal globes are used which cut off about 20% of the light, yet give a more uniform distribution by diffusing the rays of the arc and the maximum distribution of light occurs usually at a somewhat smaller angle below the horizontal. We may readily see that with two enclosing globes we receive less light than by obtained from an open arc, yet the advantages, such as incressed life of carbons and greater steadiness of light makes the enclosed arc the more desirable. A solid carbon is ordinarily used for the lower electrode and a cored carbon for the upper in local practice.

THE REQUIREMENTS OF STREET LIGHTS:- Mr. Sweet has made an analysis of street illumination and I quote from him:

" There are two results to be achieved in adequate street illumination, which are both of such paramount importance that it is properly a matter for individual opinion as to which should be ranked first. These are the avoidance of glare effects and the obtaining of an approximately uniform degree of illumination at all points along the course of the street, with higher intensities at street corners. These two results can only be obtained, the one by the correct solution of the allied problems of intrinsic brilliancy, total light flux, and



Sharp-Miller Photometer



Wireing Diagram of Apparatus.

Photometry Knoxville Street Lights
HOUSLEY & KIRKPATRICK.

shadow contrasts, the other by the correct solution of the problem of distribution."

For street illumination that makes any pretense to be such, he points out, we should have a ratio of maximum to minimum intensity of four to one or a less ratio. Of,course, we see that this is only practicable for a large number of rather small lights placed close together. According to his definition other lights serve merely as street markers and the vast majority of American practice falls under this classification since he finds the ratio to "most frequently" fall between one hundred to one and five hundred to one.

MEASUREMENT OF STREET ILLUMINATION- It is an unsettled question concerning whether the illumination should be measured horizontally or perpendicular to the light ray. The commercial interests have fostered the latter method since it gives the minimum reading the largest possible value. However "the best single measure of how well the many diverse requirements are met is the intensity of illumination on the horizontal plane." In our street measurements we secured the horizongal and perpendicular illumination and also the candle power measurement.

THE METHOD OF PHOTOMETRY TESTS.- The photometer used was the "Sharp-Millar universal phomometer". This utilizes a modified o form of the LUMMER-BRODHUN prism for the comparison of brightness, located at B where it is viewed through a telescope eye piece in the side of the box. The photometrical balance is obtained by varying the distance between the comparison lamp and the screen. We used a battery lamp (standardized) with a voltage of 1.818 which valve

was held by the aid of a milli-voltmeter in series with a meltiplier. A side elevation is shown in an accompaning sketch. The comparison lamp is located at C and can be caused to slide along a track, running lengthwise of the box, by means of a cord which is attached to the supports of the lamp and passes through pulleys and around a drum which is operated by the knob D. The light from this lamp falls upon a milk glass plate at K. which is viewed through the optical device, the intensity of light upon this plate is made to vary inversely as the square of the distance from the comparison source by making the inner surface of the instrument a dull black and by interposing a series of moving screens, then permit only the direct rays from the lamp to pass unobstructed.

The scale upon which the indications of the photometer are read, is made of translucent celluloid, graduated with an inverse-square scale, and placed in a longitudinal opening in the side of the box. The scale is equipped with a shutter which may be raised or lowered to exclude external light from interior of the box. To facilitate taking readings in dark places, a slit is cut in the side of the housing containing the comparison lamp, so that the shadow of a pointer is thrown upon the brightly illuminated scale. The rear of the box carries four terminals, two for the supply line and two for the volt-meter.

The elbow tube at the end of the box has a number of important functions to perform. It fits friction-tight on a collar fastened in the end of the box, and hence may be turned about a

horizontal axis and set at any angle; which angle is indicated on a semi-circular scale on the end of the box. The use of a tube of this discription furnishes the simplest means of measuring illumination or light coming from any direction. In the elbow of the tube is fixed a reversible plate, one side being a diffusely reflecting surface used in the measurements of candle-power, and the other a mirror used in connection with a test plate on the end of the tube for measuring illumination. In measuring candle-power, the diffusely reflecting surface is turned toward the inside of the tube and the end of the elbow of the tube is open, the tube serving to screen off stray light from the plate. The distance between the plate and the source of light must be known.

To measure general illumination, the translucent illumination test plate is slipped on to the end of the tube and the plate at the elbow is reversed, making the mirrored side effective. The illumination on any required plane can then be measured.

The scale reads directly in foot candles, the same scale equally applicable to measurement of illumination and of candle-power. The range of scale is from four to twenty foot candles. Recourse may be had to absorbing screen on one side of the other when the light to be measured is too bright or too faint for direct comparison. By this means the range is made effective between .004 foot-candles up to 2000 foot-candles.

The foregoing description was abstracted from Light Photometry and Illumination by Barrows.

We calibrated the instrument by placing a standard 16 C.P. lamp 6 ft. 1-1/2 inches from the elbow of the tube, first setting the tube for candle-power measurement, the pointer on the scale was at 1.6 (since readings must be multiplied by 10 for candle-power) The proper voltage to produce a photometric balance was found by manipulating a slider rheostat on the side of the box and in the battery circuit. This value was always used afterwards (1.818 volts).

It was necessary to calibrate a volt-meter to use with the standard lamp, since there were no low reading voltmeters available, a 0-200 range milli-voltmeter was used with a series resistance of about 97 ohms so as to give a full scale deflection with 2 volts. The multiplier was adjusted until the milli-voltmeter checked exactly on a comparison, with the Weston laboratory standard volt-meter. Two cells of an Edison storage battery furnished the current for the lamp.

To familiarize ourselves with the apparatus, we took readings in laboratory on incandescent lamps and arc lights and an illumination survey was made of the Kuhlman and Chambliss Co., store No.1 which supplements this thesis.

For street work a box was made to contain the storage cells, the voltmeter, and multiplier with suitable leads. The photometer box was mounted on a tripod and stood about 2.5 feet from the ground. We took the illumination on a horizontal plane, on a plane perpendicular to the light rays, and also took the candle-power measurements, In making a survey we took a straight line between two lamps when two lamps were visible.

Readings were taken at intervals of about forty or fifty feet near the middle or dark portion of the street and as the intensity became greater and varied faster, readings were taken every twenty feet and were necessary, every ten feet. On an investigation of a city arc we took the terminal voltage, however, we could find no relation between the voltage and the street illumination since the arc wanders from side to side on the carbon and creates a much wider variation than a few volts could possibly give.

We found the Oakwood lights to be more satisfactory from the standpoint of glare than the arcs, the intrinsic brilliancy being low. The specially designed diffusing globe seemed to give a good distribution. The ratio of maximum to minimum intensity being 56 to 1. This type of light should be placed closer together in order to give a satisfactory lighting.

On the arc light we found a very strong illumination under the light yet it fell to a very low value between lamps even when placed 300 feet apart. The ratio of maximum to minimum intensity was 100 to 1, which of course, is entirely too high. The glare effect was very noticeable owing to the high candle-power for the angles subtended by the eye. The greatest variation due to unsteadiness of the arc was one foot-candle.

The accompaning curves show the distribution of from each of the lights.

A survey of one of the small mazde series lamps was made. They are near the ground and only give a relatively good illumination in a small circle around the lamp as is shown by a horizontal illumination curve which we obtained.

Weston Standard Voltmeter	Voltmeter
Zero Readings	
- .2	+ .5
98	100
100.2	102.2
101.4	103.4
103.2	105.2
104.1	106.
105.3	107.4
105.8	108.2
107.2	109.5
107.8	110
109	111
109.3	111.4
1.2	1.1
1.16	1.2
1.28	1.3
1.4	1.4
1.5	1.5
1.6	1.6
1.7	1.7
1.81	1.8
1.92	1.9
2.1	2.0
21.4	2.1
2.26	2.2
2.36	2.3
2.48	2.4
2.59	2.5
2.7	2.6
2.79	2.7
2.92	2.8
3.02	3.9
3.16	3.0
3.24	3.1



— Oakwood —

N

Illumination on Springdale from Webster North

to

Houston St.

Series Nitrogen Lamps 25' from ground.

Thesis - Housley and KIRKPATRICK.

READING TAKEN IN OAKWOOD - SERIES NITROGEN LAMPS.

Horizontal illum. Readings	Perpendicular illum. Readings	Candle Power Reading	Dist. from Rt.Pt. Ft.	Horizontal illum. Ft.Candles	Perpendicular illum. Ft.candles	Angles	Dist. from Lamp
D .45	D 3.0		0	.0030		86	500
" .4	D 3.5		40	.0027		86	440
" .4	" 4.0		80	.0027		85	400
" .4	" 5.0		120	.0027		85	360
" .45	" 6.0		160	.0030		85	320
" .45	" 10.0	.65	200	.0030		85	280
" .6	" 10.0	.85	240	.0040		84	240
" 1.0	" 13.0	1.0	280	.0067		83°	200
" 3.0	" 24.0	1.2	320	.0207		80°	160
" 6.0	L .44	1.7	360	.0405		77°	120
" 7.5	" .58	2.3	400	.0506		70°	80
"20.0	" .85	L 4.0	440	.1350		55°	40
L .48	" .43	1.6	500	.1700		0°	0
D 5.0	D 8.0	D 3.	20	.0337			20
L 1.1	L 2.3	L 8.	20	.3894			20
L .4	L 2.	L 7.5	40	.0157			40
D10.	L .75	L 3.4	40	.0675			40
D 2.	L .48	L 1.4	40	.0135			40

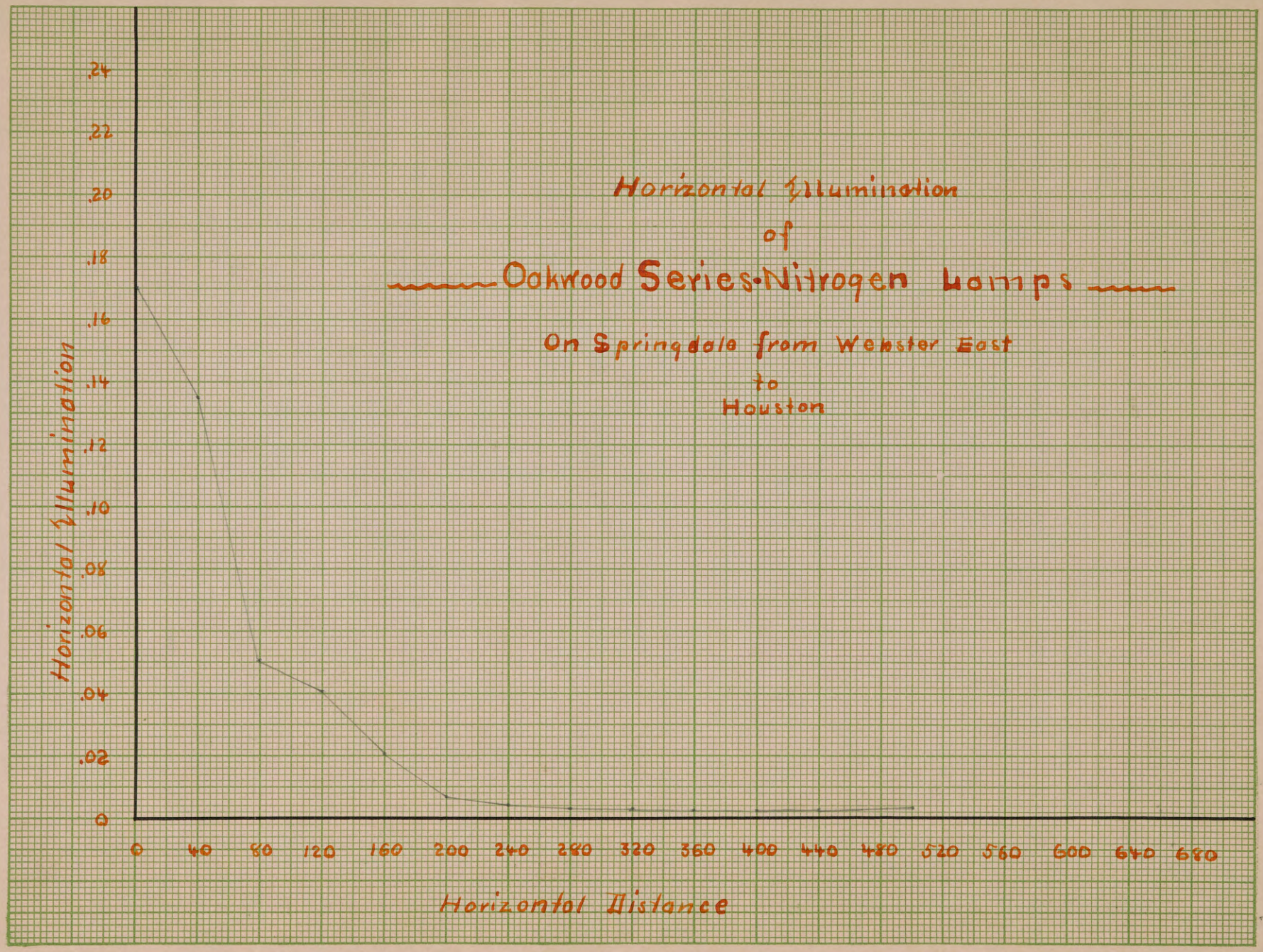
Symbols.

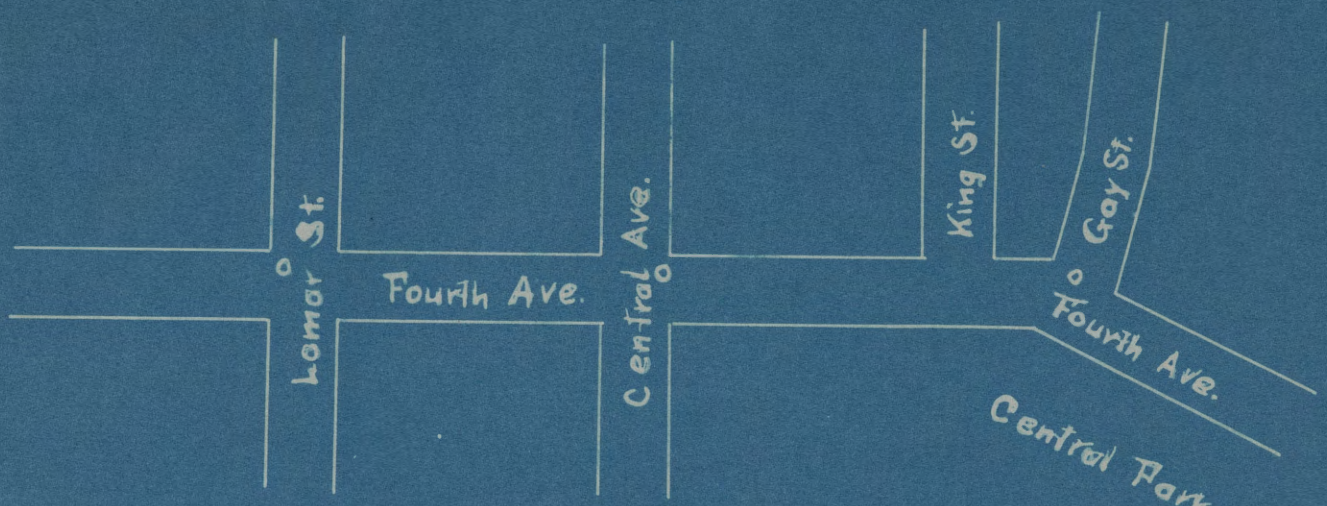
D - dark screen between std. lamp & prism
L - light screen " " " "

Street-start corner Springdale & Webster - E. to Houston on Springdale, for first twelve readings.

Corner Houston N. on Houston for remainder of readings.

No. 792. KOLESCH & CO., NEW YORK.





Horizontal Illumination taken on 4th Ave.

between

Central Ave and Gay Street.

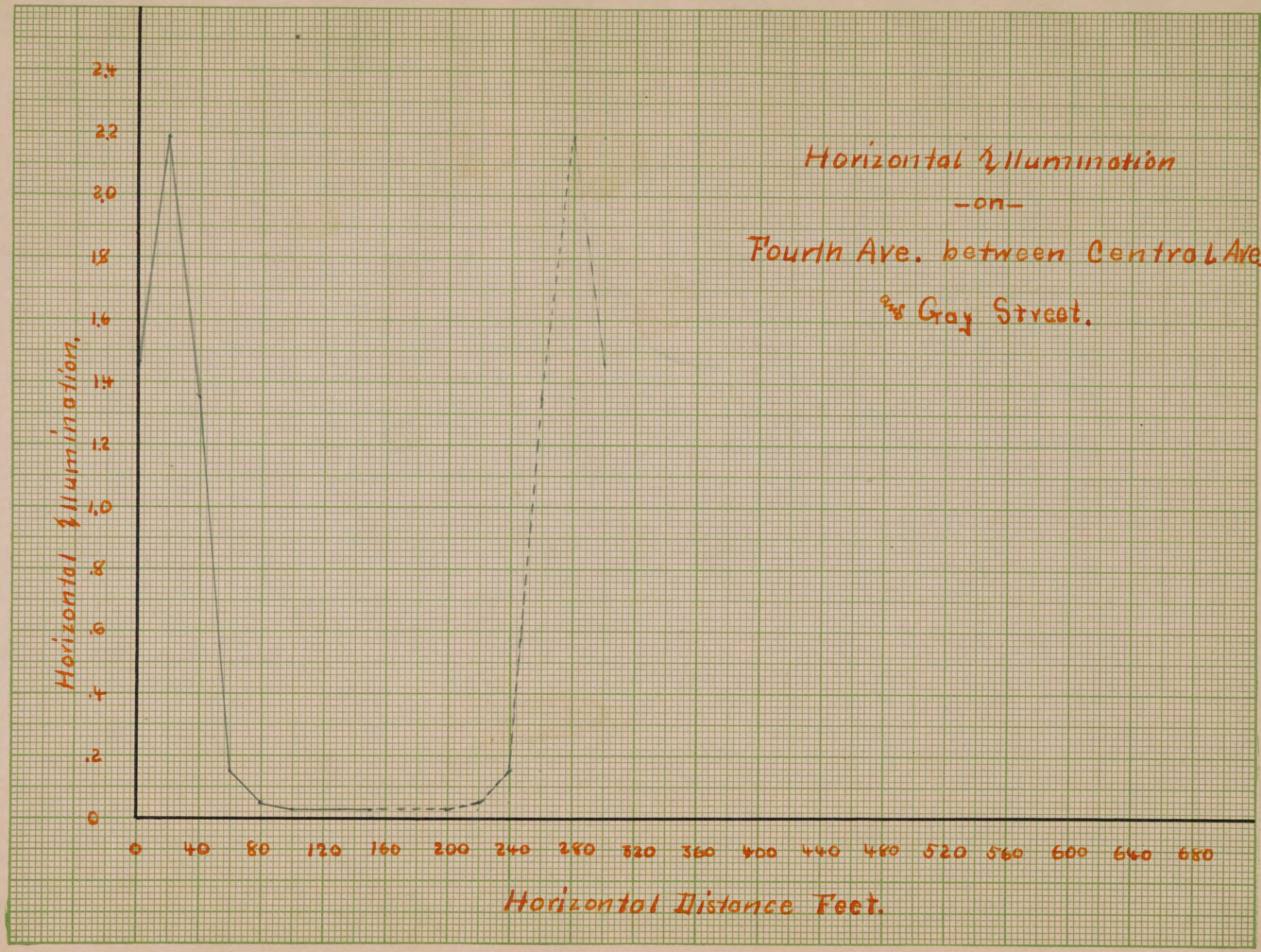
Thesis – Housley et Kirkpatrick

N

DATA FOR ARCS ON FOURTH AVE. CORNER CENTRAL.

Volts	Horizontal Illumination	Distance	Volts	Candle Power	Degrees
90	6.4 L	20	86	2.90 No.	38°
84	6.6 "		80	2.80 "	
85	4.0 "		83	2.80 "	
91	5.2 "		92	1.56 "	
85	7.2 "		89	1.84 "	
77	6.8 "		92	1.34 "	
77	5.2 "		85	1.35 "	
78	7.8 "		84	1.56 "	
79	6.8 "		91	2.2 "	
	6.20			2.19	Average
80	2.2	40	80	1.17 "	55°
80	0.7 "		86	.48 "	
84	.87 "		83	.5 "	
87	1.18 "		83	.5 "	
85	1.18 "		85	.44 "	
86	0.9 "		83	.46 "	
87	1.75 "		89	7.2 L	
85	2.1 "		93	9.0 "	
89	1.5 "		90	7.0 "	
	1.35 - .48			.48	Average
85	.9 L	60	84	3. "	64°
90	.42 L		80	8. "	
84	7.4 D		84	15. "	
84	5.5 D		82	5.2 "	
90	10.0 "		86	3.2 "	
91	7.0 "		82	6.5 "	
86	8.8 "		83	4.4 "	
92	13. "		89	15.0 "	
89	15. "		84	3.9 "	
83	15. "		90	4.7 "	
	10.2 - .151			.151	Average
88	6.2 D	80	83	4. L	69°
94	5.4 "		79	2.9 "	
85	6.2 "		88	1.9 "	
92	9.0 "		85	1.6 "	
90	7.0 "		85	1.9 "	
91	10.0 "		85	2.7 "	
84	7.0 "		84	2.1 "	
86	5.2 "		94	2.6 "	
	7.0 - .047			.047	
88	3.0 D	100	83	1.0 "	74°
92	3.8 "		89	1.4 "	
62	2.4 "		88	2.1 "	
92	3.5 "		83	1.7 "	
85	3.9 "		83	1.6 "	
85	2.6		85	1.35 "	
	3.2 - .0216			.0216	
85	3.4 D	150	85	1.2 "	80°
89	3.0 "		87	.83 "	
87	6.0 "		90	1.85 "	
85	3.7 "		87	.8 "	
83	2.8		88	.75 "	
92	2.5 "		90	1.07 "	
91	3.5 "		90	.87 "	
	3.54 - .024			.024	

No. 792. KOLESCH & CO., NEW YORK.



32 C.P. V Filament Mazda Lamp.

King St. between Fifth Ave. and Park Ave.

Horizontal Illumination	Distance	Candle Power Readings	Candle Power
.68 L	0	3.0 L	
.78 L	10	5.5 L	
16	20	2.8 L	
4.5 D	30	1.5 L	

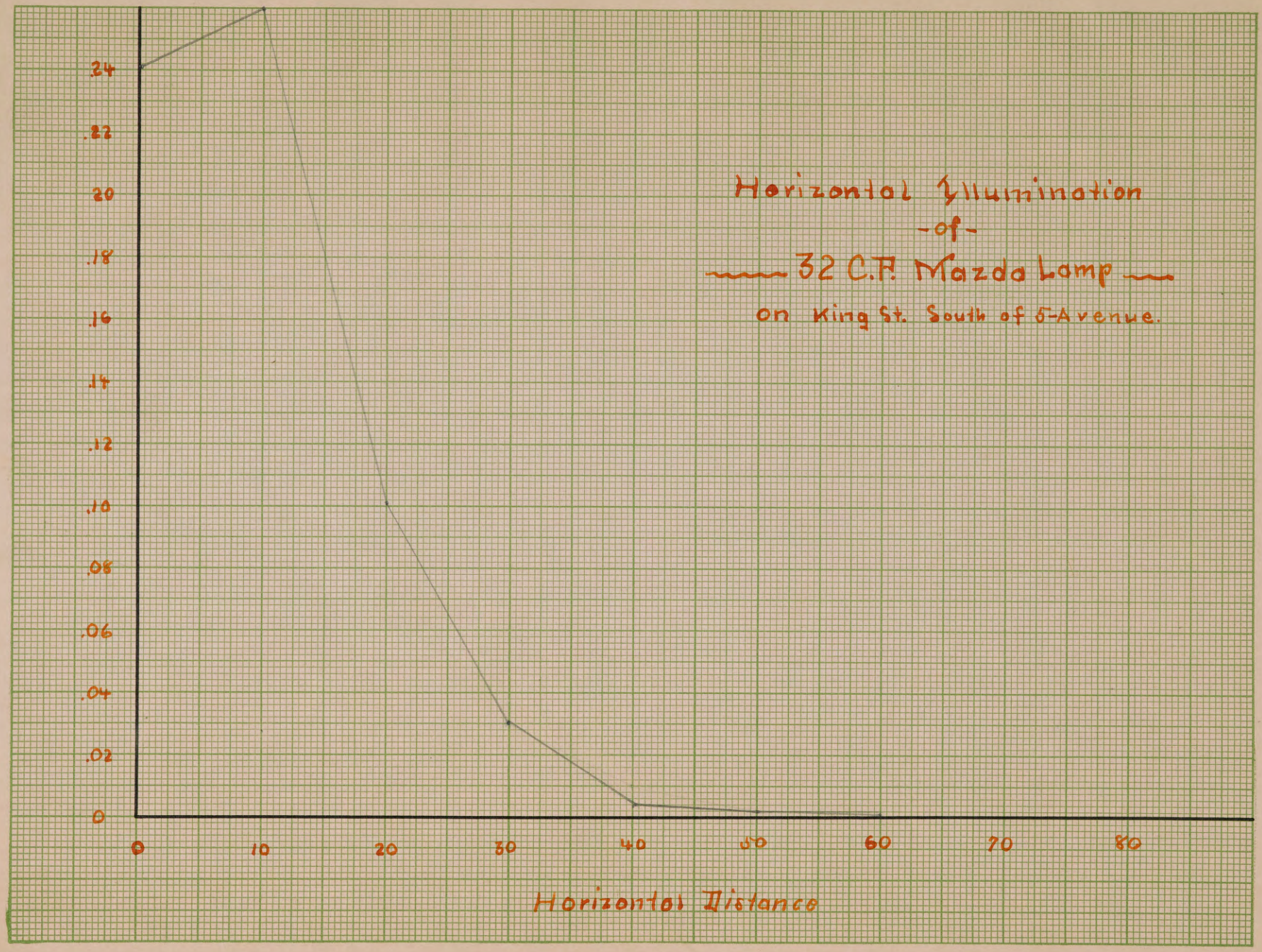
Watts of Above Lamp.

$E = 5.9$ (LABORATORY)

$I = 6.6$

$\text{Watts} = R I^2 = 40$

No. 792. KOLESCH & CO., NEW YORK.

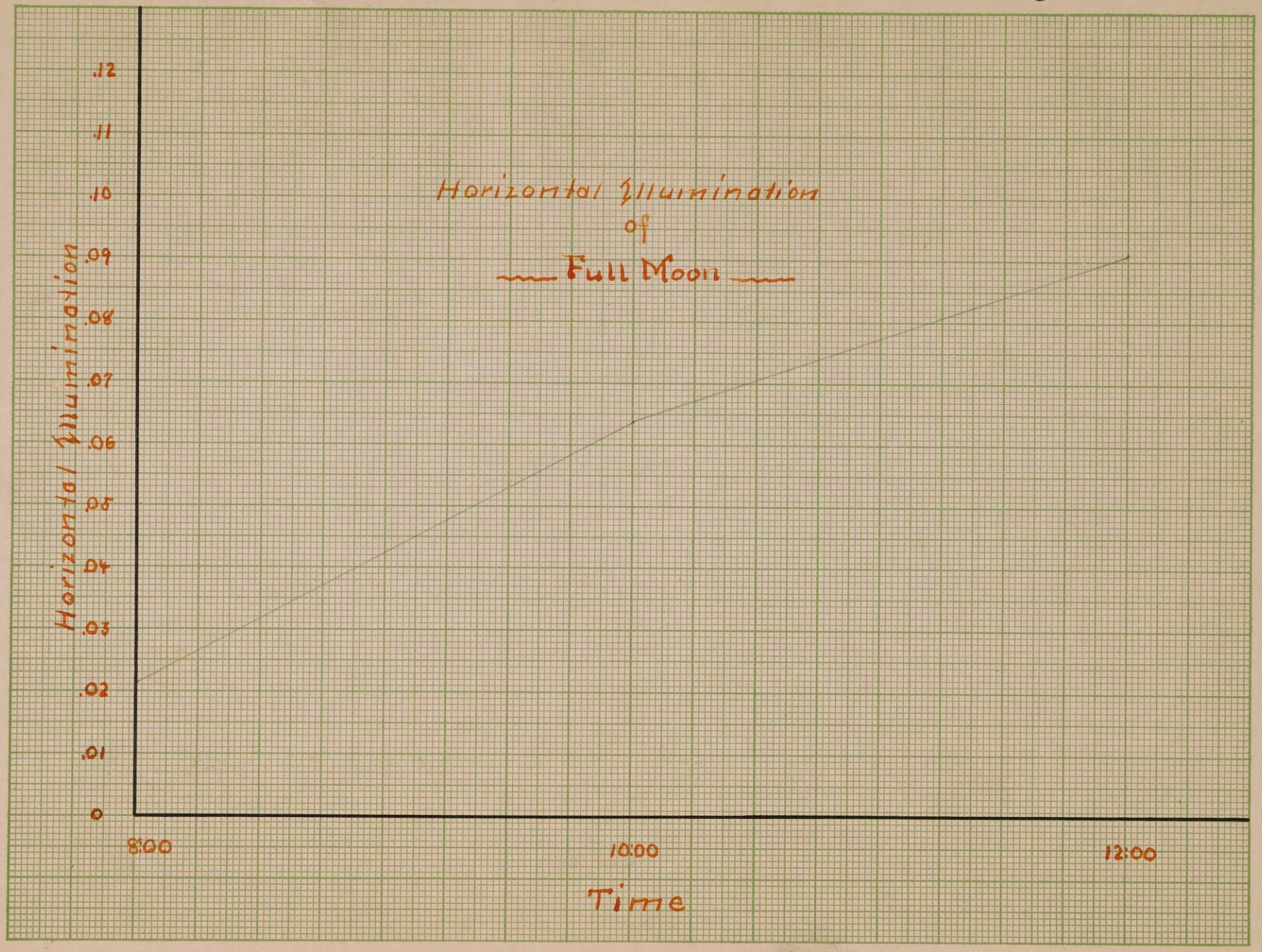


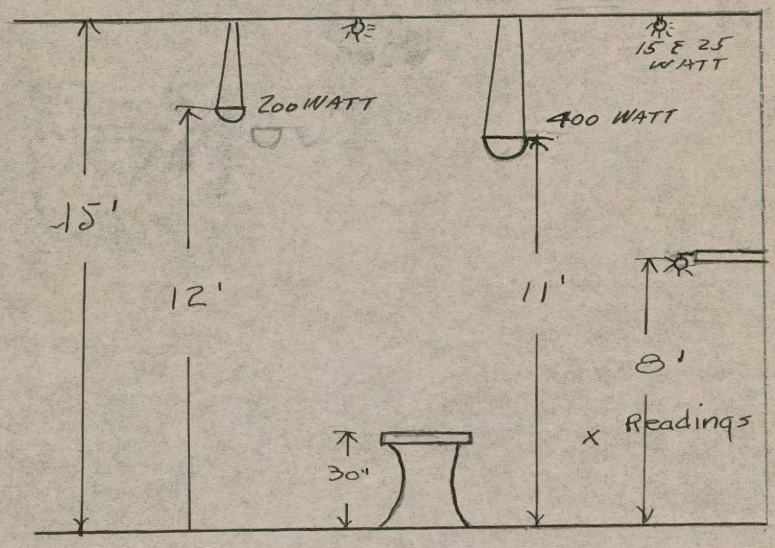
FULL MOON.

Time	Horizontal Illumination	Perpendicular Illumination	Perpendicular Candle Power	Horizontal Candle Power	
8:00	3.4 D	4.8 D	19.0 D	.42 D	
"	3.2 "	4.0 "	19.8 "	.40 "	
"	3.0 "	4.5 "	19.5 "	.40 "	
	3.2 "	4.45 "	19.45 "	.41 "	Av.
10:00	9.2 "	19.0 "	.95 L		
	9.0 "	20.0 "	.90 "		
	10.0 "	21.0 "	.90 "		
	9.4 D	20.0 "	.9x1 "		Av.
12:00	12 D	.4 L	1.1 L		
"	13 D	.41 L	1.1 L		
"	14 D	.44 L	1.4 L		
"	12 D	.42 L			
"	14 D	.42 L			
"	16 D	24. D			
"		26. D			
		22. D			
	13.5 D	24 D	1.2 L		Av.
		.42 L			

TIME	FT.CANDLES
8:00	.0216
10:00	.0635
12:00	.0911

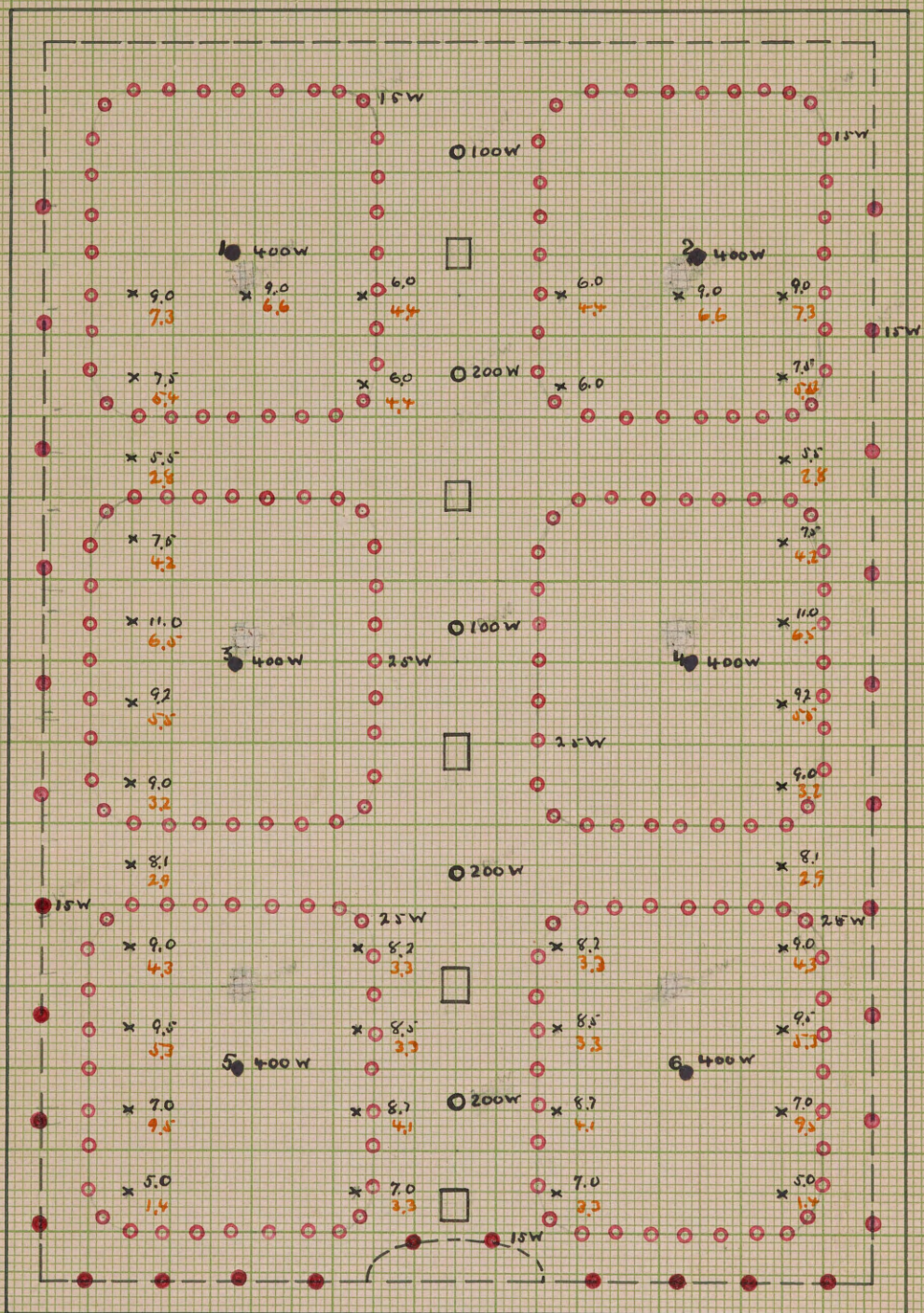
No. 792. KOLESCH & CO., NEW YORK.





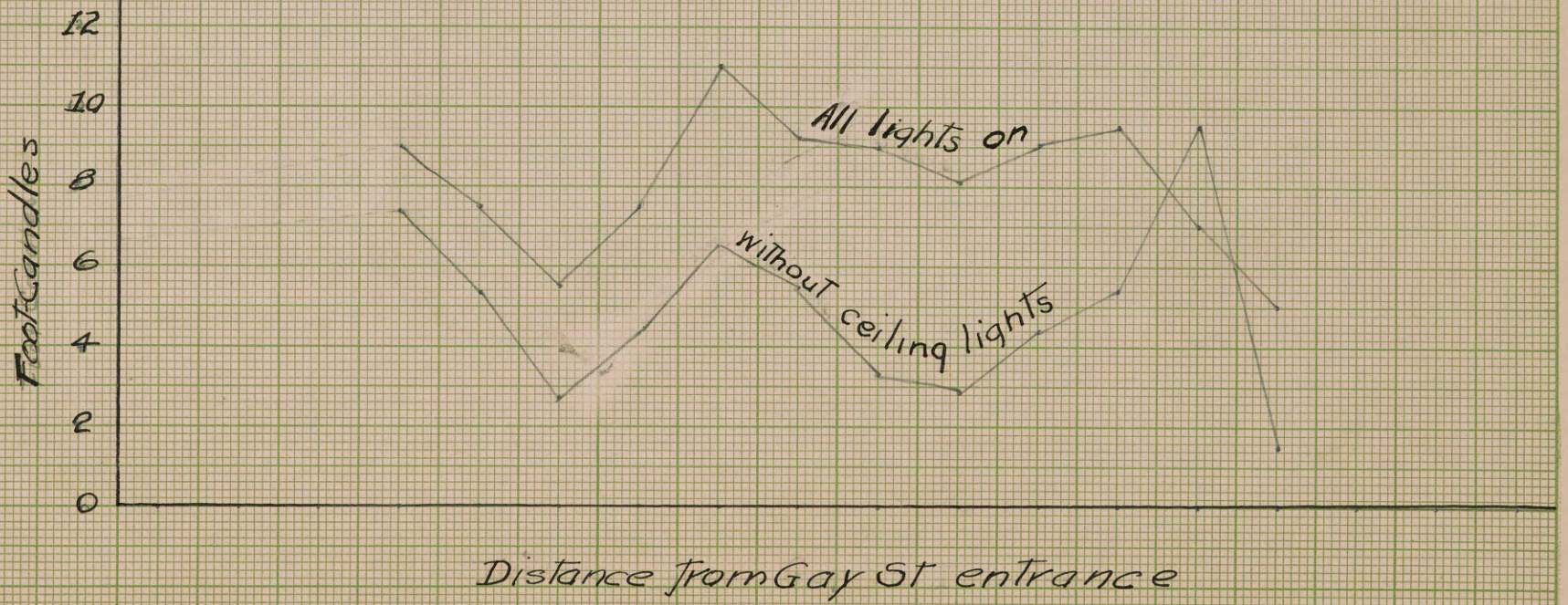
FRONT ELEVATION VIEW
LIGHTS
Kuhlmans Store No 1.

Kuhlman's Drug Store No. 1.



No. 792. KOLESCH & CO., NEW YORK.

Illumination Curve
of
Kuhlman's Store No. 1.



Scale. 1" = 10 FT.

Housley.