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LIFE AND EFFICIENCY OF INCANDESCENT LAMPS.

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The intelligent selection and proper use of incandescent lamps largely determine the volume and growth of the electric lighting industry. Nothing produces such radical improvement in the lighting service as, first, the exclusive use of the best lamps and, second, the frequent and regular renewal of dim lamps. These principles are the precepts and practice of the leading central stations of the country, and should be law for every electric lighting company.

Central stations are in the business of making and selling light. They may sell by the Watt hour or by contract, but, regardless of the way it is measured, the customer is in reality buying and using light. Since the lamp transforms the electrical energy of the generators into light, the best lamp is an absolute necessity to obtain the best light. It is, then, almost a self-evident truth that the exclusive use of the best lamps is the only means of obtaining the best results.

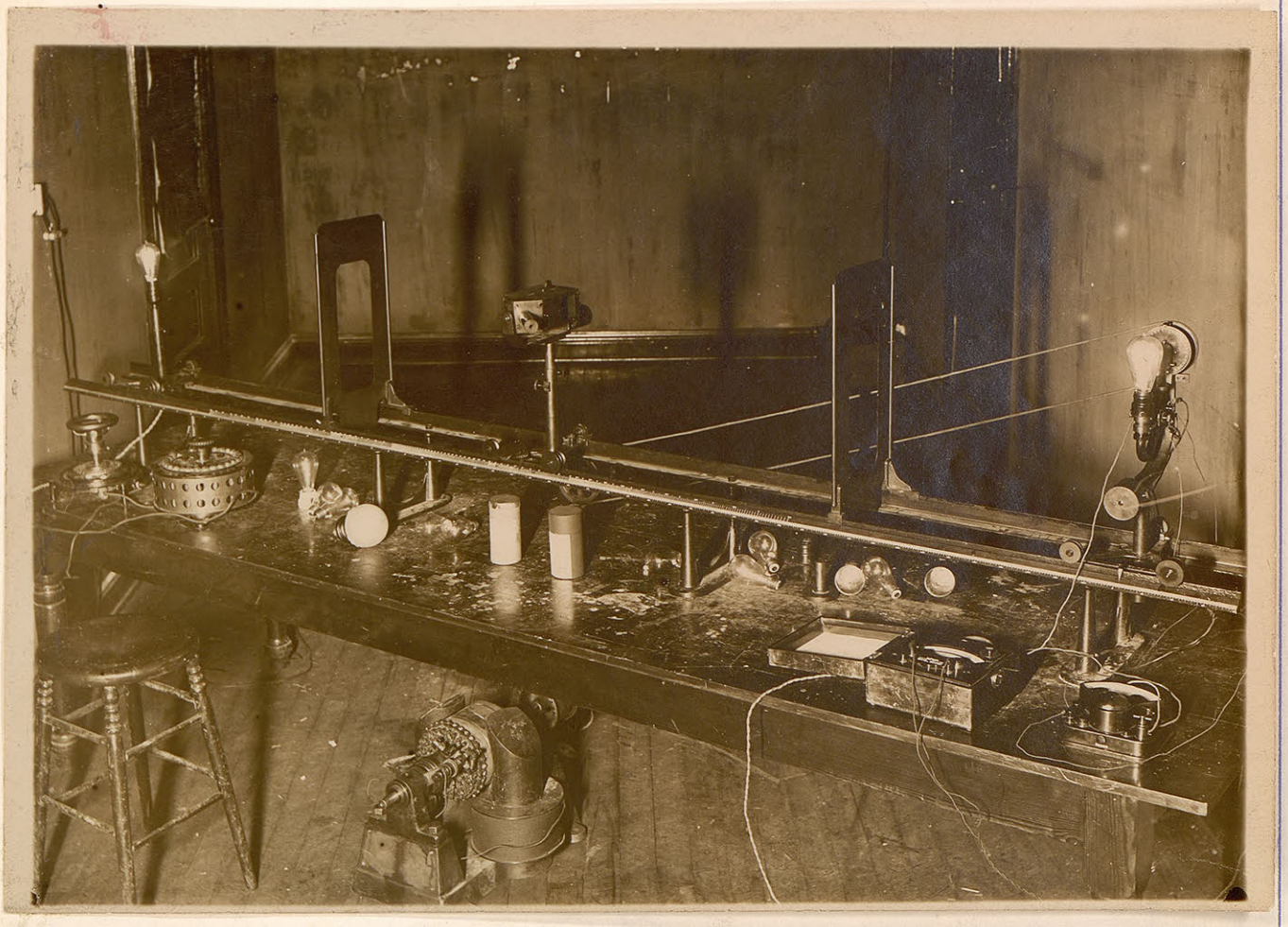
In order to investigate the relative merits and performance of lamps the following plan was carried out:

From nine prominent lamp manufacturers sample lamps were obtained. From another maker a lot of six lamps was secured. The makers of the different lamps claimed for them 16 candle power at 104 volts, with an efficiency of 3.5 watts per candle power. The lamps were all tested for initial candle power and wattage, and then were burned on a 104-volt alternating current circuit for 800 hours. At intervals of 100 hours all the lamps were tested for candle power and wattage.

The electrical measuring instruments used were as accurate as could be obtained and were as follows:

Weston Voltmeter (0-150) No. 13520,
" " (0-120) No. 3589,
" Wattmeter (0-1500) No. 2338,
Thomson " (0-300) No. 59089.

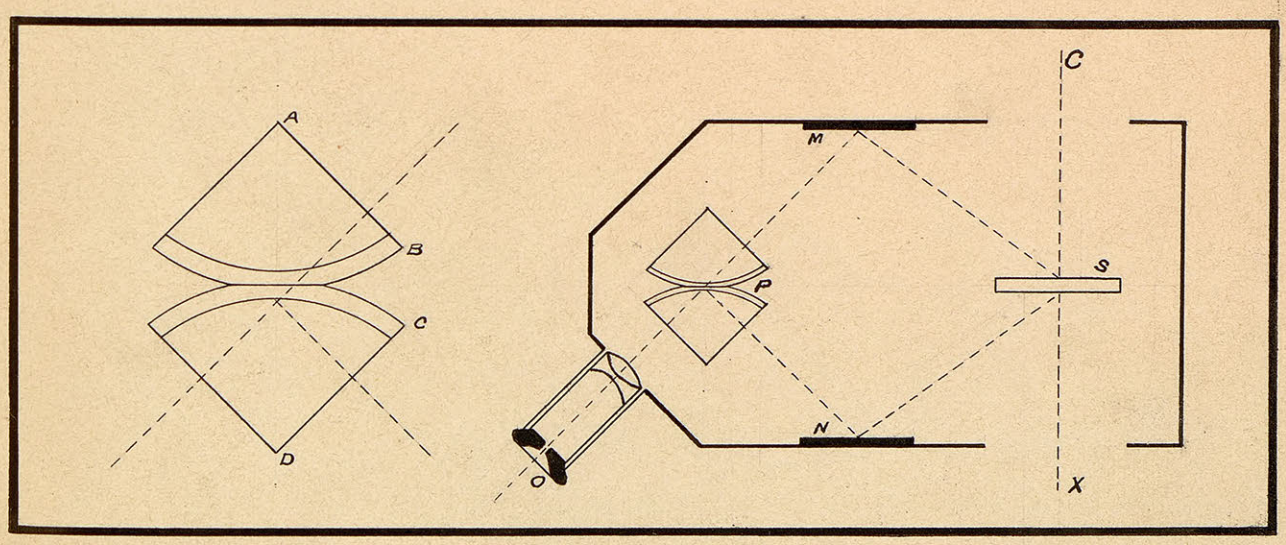
All the tests were made by means of a Queen Standard Photometer fitted with a Lummer-Brodhun screen and a rotating lamp stand. The following is a photograph of the complete photometer:



The scale extends the entire length of the photometer and is graduated both in centimeters and in candle power. The scale graduated in candle power is to be used only when the standard lamp is of 16 candle power.

The rotator holding the lamp to be tested was belt driven, at about 300 R. P. M., from a small electric motor. The lamp is supplied with current through brushes. Binding posts are provided for wires leading to the voltmeter and wattmeter.

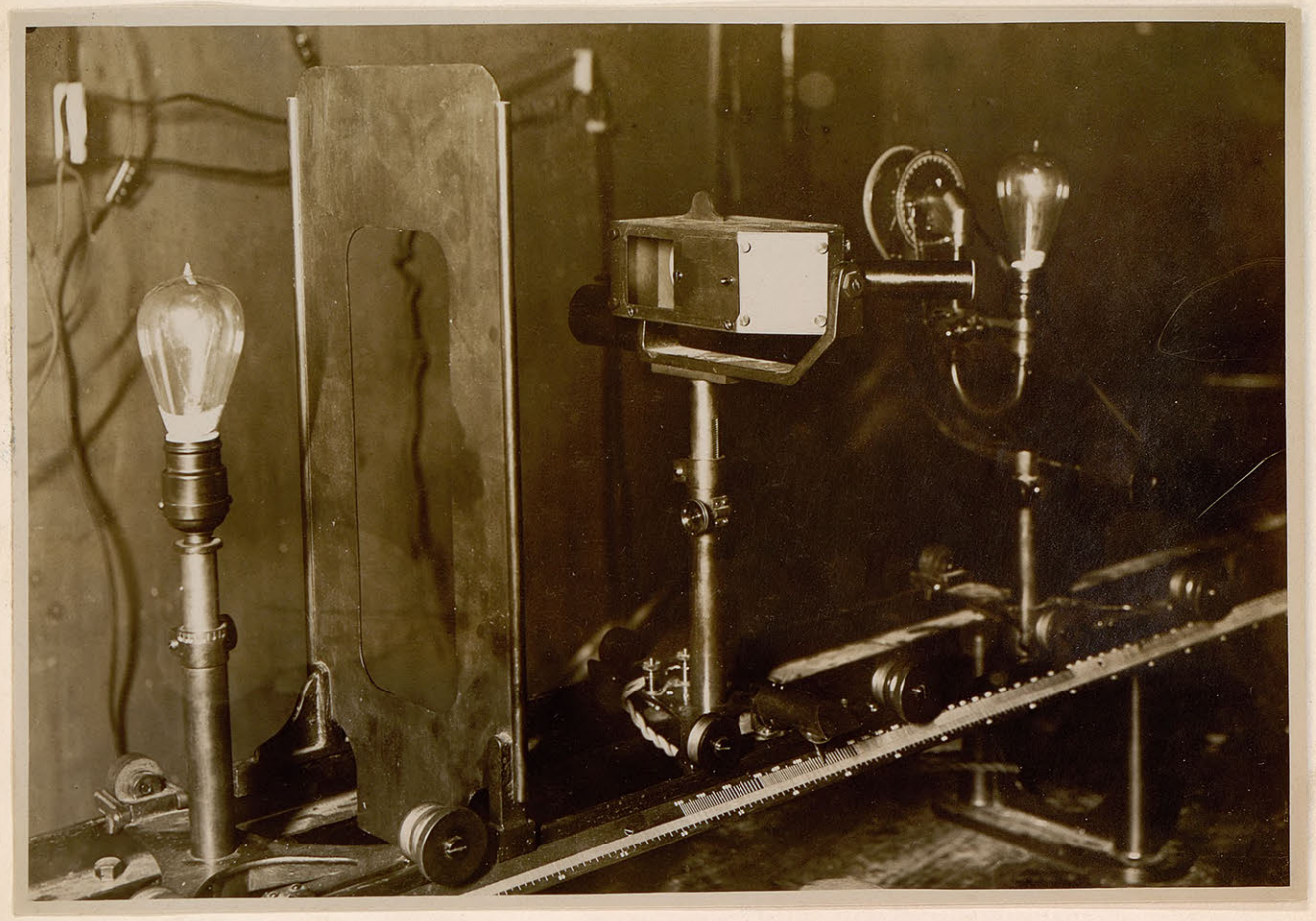
The Lummer-Brodhun photometer screen was devised by Drs. Lummer and Brodhun of the Reichsanstalt, and used in the photometric researches of that institution. In this instrument but one eye is used, thus eliminating any error due to the varying sensibility of the two eyes, and each of the two sources of light being compared illuminates its own field, these two fields being presented to the eye as a disc and a circle respectively, the latter surrounding the former and having a sharp line of separation from it. The following drawing shows the arrangement in diagram:



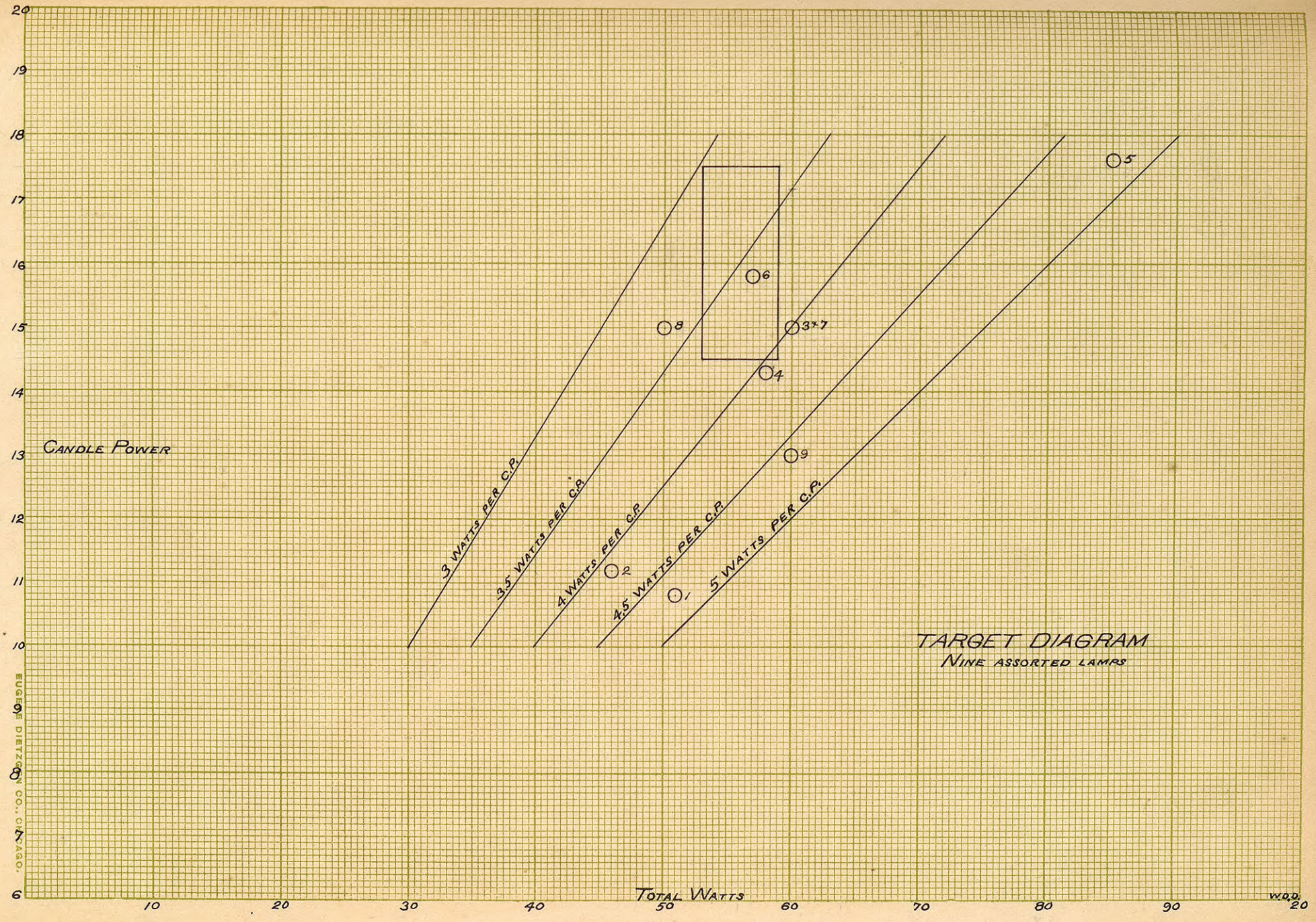
C and X are respectively the standard and the lamp being measured. S is an opaque white screen of plaster of Paris, receiving light on its two sides from C and X from which it is diffused to the mirrors M and N. P is composed of two right-angled prisms whose hypothenusal faces are spherical surfaces cut off by a plane, more of one being cut than of the other; when in contact, therefore, there is a disc of contact surrounded by a plane circle on C, which has not contact. Light from X normal to CD passes through both prisms where in contact, but suffers total internal reflection into O when it strikes the outer plane circle. Light from C, on the other hand, passes through both into O, where in contact, but is reflected back and out,(being absorbed by blackened surfaces), where it strikes the outer circle. An eye at O sees, therefore, a disc of light due to C, surrounded by a circle of light due to X. The observer moves the screen until the disc and the screen appear of the same brightness, when the intensity of the illumination on the two sides of the screen is the same; the relative powers of the two sources are then as the square of their distances from the screen. The distance between lamps was, in every case, 250 centimeters.

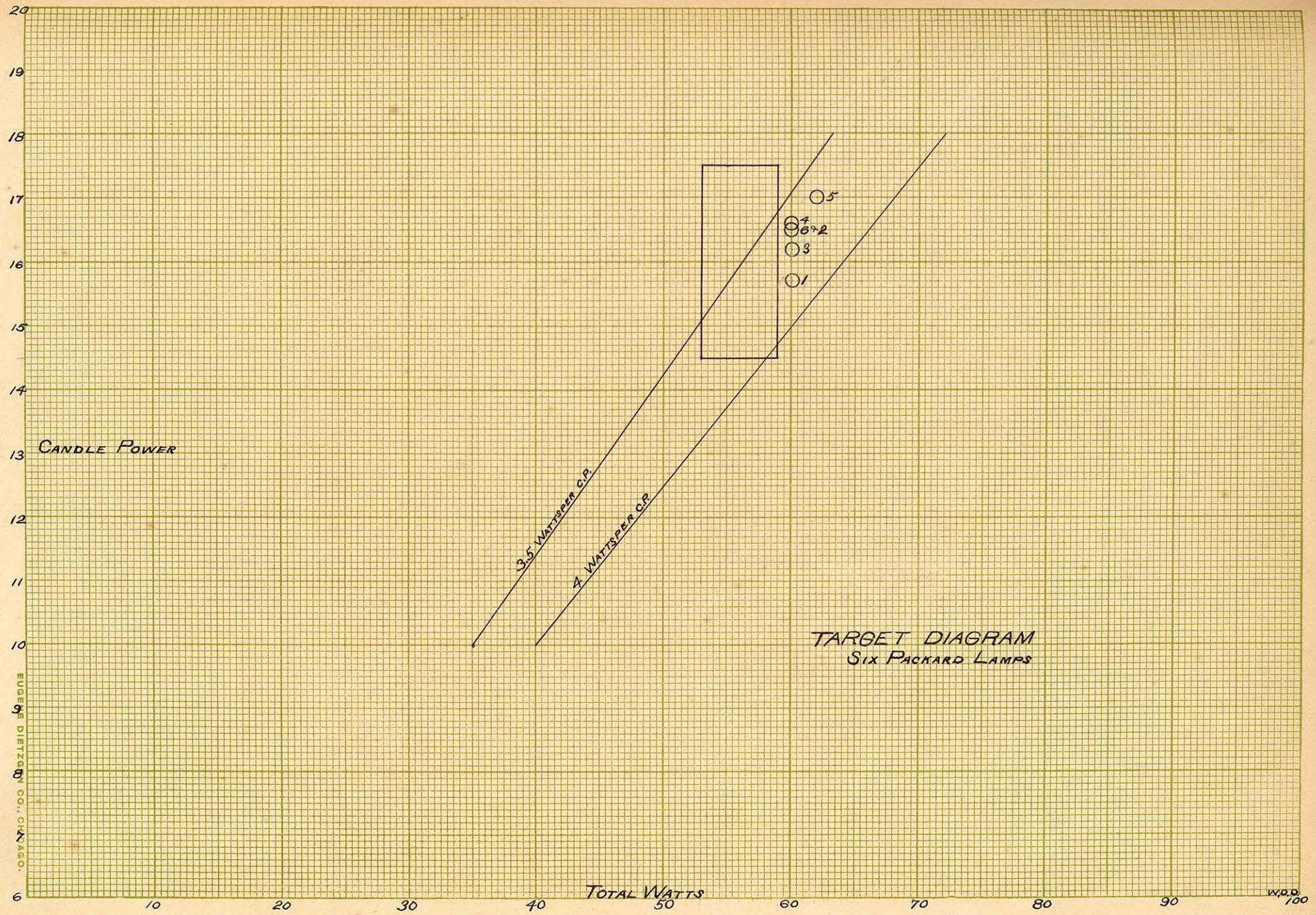
The standard lamp used in this test was of exactly 16 candle power at 104 volts. It was standardized by comparison with a lamp standardized in Queen and Company's laboratories. The standard lamp was allowed to burn no longer than absolutely necessary in o order to preserve full candle power. On the following page is a photograph showing the standard lamp, screen for cutting off reflected rays, Lummer-Brodhun screen and rotator.

Current for the lamps was furnished by a separate direct current machine in the dynamo laboratory and was regulated by placing the field rheostat in the photometer room.



The following diagrams were plotted from the data obtained during the test and show clearly the results. The target or "shot-gun" diagrams illustrate the variation in candle power and watt ratings of several makes of lamps. These diagrams afford a unique and interesting means of illustrating the accuracy and uniformity of lamp rating. Vertical distances from the bottom of the diagram represent candle powers, and horizontal distances from the left-hand side, the watts. The rectangle shown is the limiting target for well-made lamps. As the lamps tested were all rated at 16 candle power, 3.5 watts per candle, the intersection of the horizontal 16 candle power line and the vertical 56 watt line forms the center or "bull's-eye" of the target. The diagonal lines show the watts per candle power. The readings on each lamp in candle power and


20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
CANDLE POWER
3 WATTS PER C.P.
3.5 WATTS PER C.P.
4 WATTS PER C.P.
4.5 WATTS PER C.P.
5 WATTS PER C.P.
1
2
3
4
5
6
7
8
9
TARGET DIAGRAM
NINE ASSORTED LAMPS
10
20
30
40
50
60
70
80
90
20
TOTAL WATTS
W.O.D.
EUGENE DIETZGEN CO., CHICAGO.


20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
CANDLE POWER
5
4
6 & 2
3
1
3.5 WATTS PER C.P.
4 WATTS PER C.P.
TARGET DIAGRAM
SIX PACKARD LAMPS
10
20
30
40
50
60
70
80
90
100
TOTAL WATTS
W.O.D.
EUGENE DIETZGEN CO., CHICAGO.

watts at the marked voltage were noted and then plotted on the diagram by placing a circle at the intersection of the horizontal candle power line and the vertical watt line corresponding to the readings. Poor marksmanship in lamp manufacture is thus clearly brought out.

From the diagram of the nine assorted lamps it is seen that only one of the nine, No. 6, falls inside the limiting rectangle. Nos. 1 and 2 are extremely low in candle power, and Nos. 1, 9 and 5 take between 4.5 and 5 watts per candle power. This shows the remarkable lack of uniformity in the rating of lamps.

The diagram of the six Packard lamps is in striking contrast to the preceding diagram in the matter of uniformity, although all of the lamps fall outside of the rectangle. The variation in candle power is well within the limit, although the watt consumption is a trifle high, being between 3.5 and 4 watts per candle. As far as uniformity is concerned this is an exceptionally good lot of lamps.

It must be borne in mind, however, that the preliminary test, or initial rating, may not show the real value of a lamp. Any manufacturer may carefully select lamps so that they will be correct and uniform in rating. The test is of value,- therefore only with the average product, and not with specially selected lamps. Correct and uniform rating will not insure good candle power maintenance any more than a correctly measured piece of cloth insures good quality of material. At the same time this test serves to show at once the careless or incompetent manufacturer, when the average product is considered. It also records a lamp's true rating, in order that comparisons may be correctly made. Correct and uniform rating is desirable because it insures:

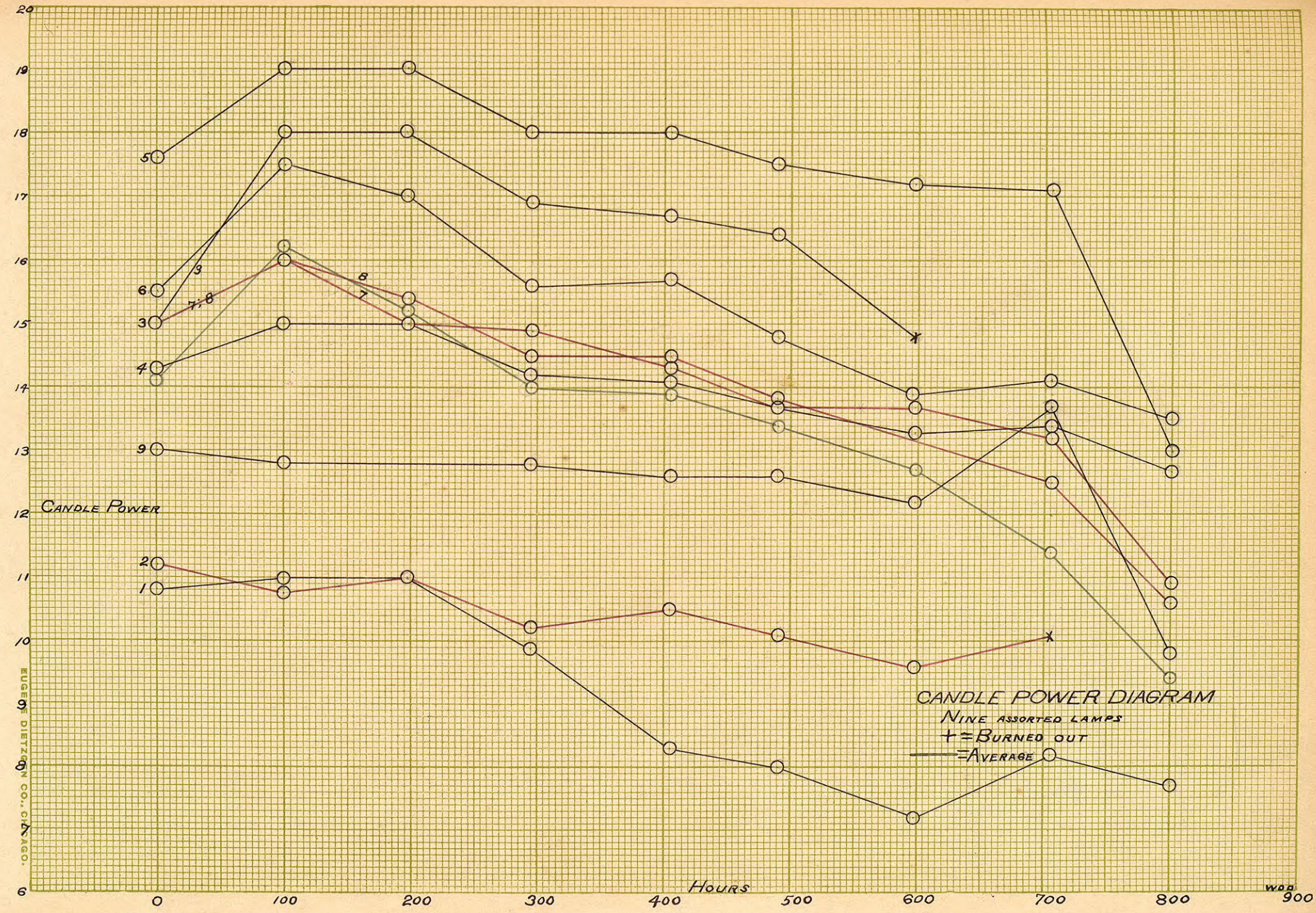
1. Full and uniform brilliancy, and avoids the marked contrasts which a wide range in candle power gives and which are so detrimental to good lighting effects.

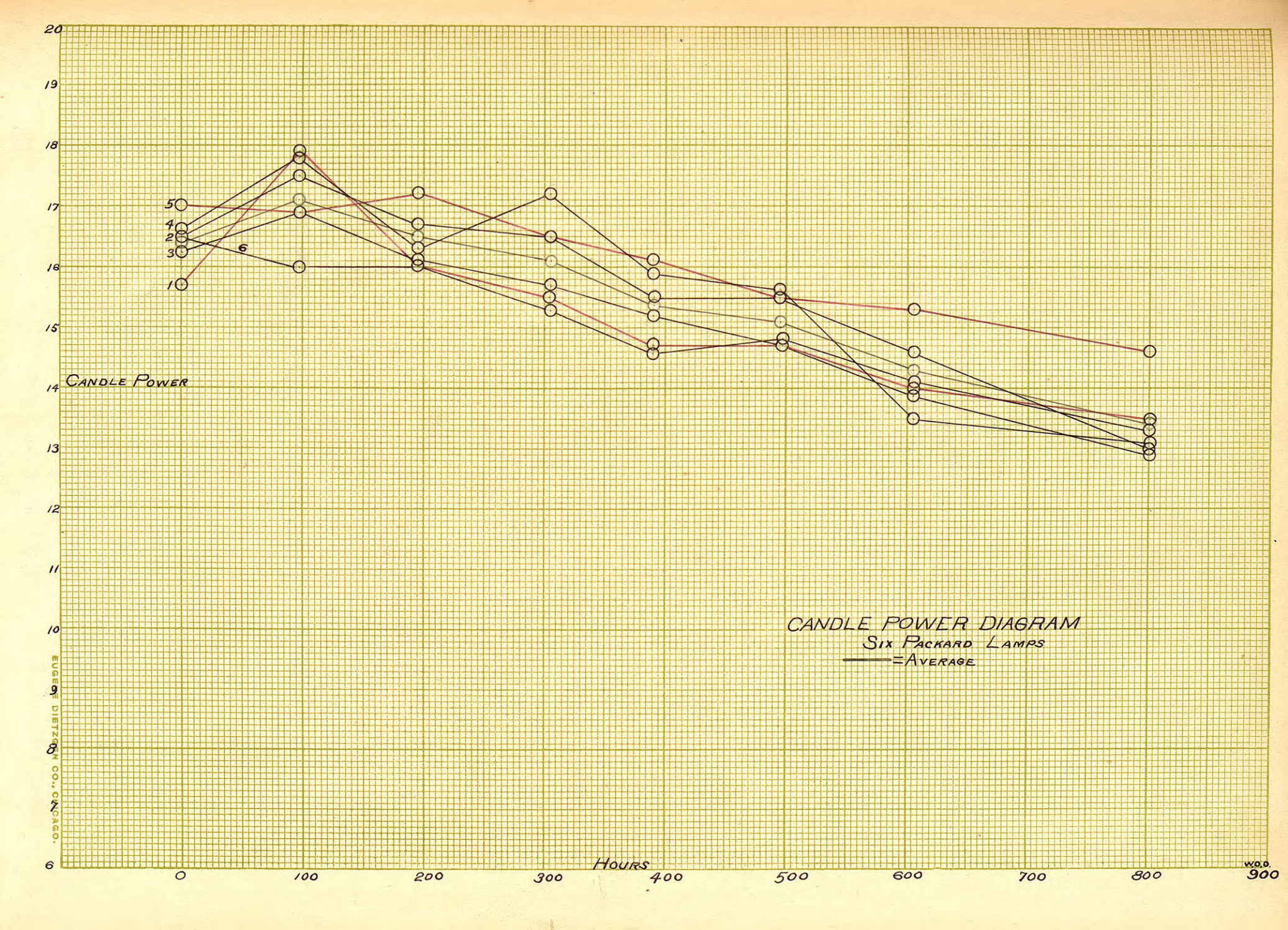
2. Uniform power consumption and definite meter bills and, therefore, satisfaction to customers.

The candle power diagrams illustrate the marked difference in maintenance of candle power of various makes of lamps and show the characteristic results given by a high-grade lamp. In candle power diagrams vertical distances from the bottom of the diagram represent candle power, and horizontal distances from the left-hand side, the duration of time in hours. The lamps were set up and burned, and readings taken every 100 hours and plotted on a diagram so as to form a series of points through which a curve for each lamp was drawn. The red lines were drawn so that the curves for each lamp might be more easily followed. The green line is the average for the lot.

In the candle power diagram of the assorted lamps it is seen that lamp No. 3 burned out after 600 hours and lamp No. 2 after 700 hours of burning. On account of the lack of uniformity shown for this lot by the target diagram, we would hardly expect a better candle power diagram than this. Lamp No.1 drops almost to 7 candle power after 600 hours of burning. The average curve crosses the 12.8 candle power line, which represents 80% of normal at about 600 hours.

The candle power diagram of the six Packard lamps shows that the uniformity displayed in the initial test has been maintained throughout the 800 hours of burning. The average curve shows 13.4 candle power, or nearly 84% of the normal, after 800 hours of con-


CANDLE POWER
HOURS
0
100
200
300
400
500
600
700
800
900
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
CANDLE POWER DIAGRAM
NINE ASSORTED LAMPS
+ = BURNED OUT
= AVERAGE
EUGENE DIETZGEN CO., CHICAGO.
WDB

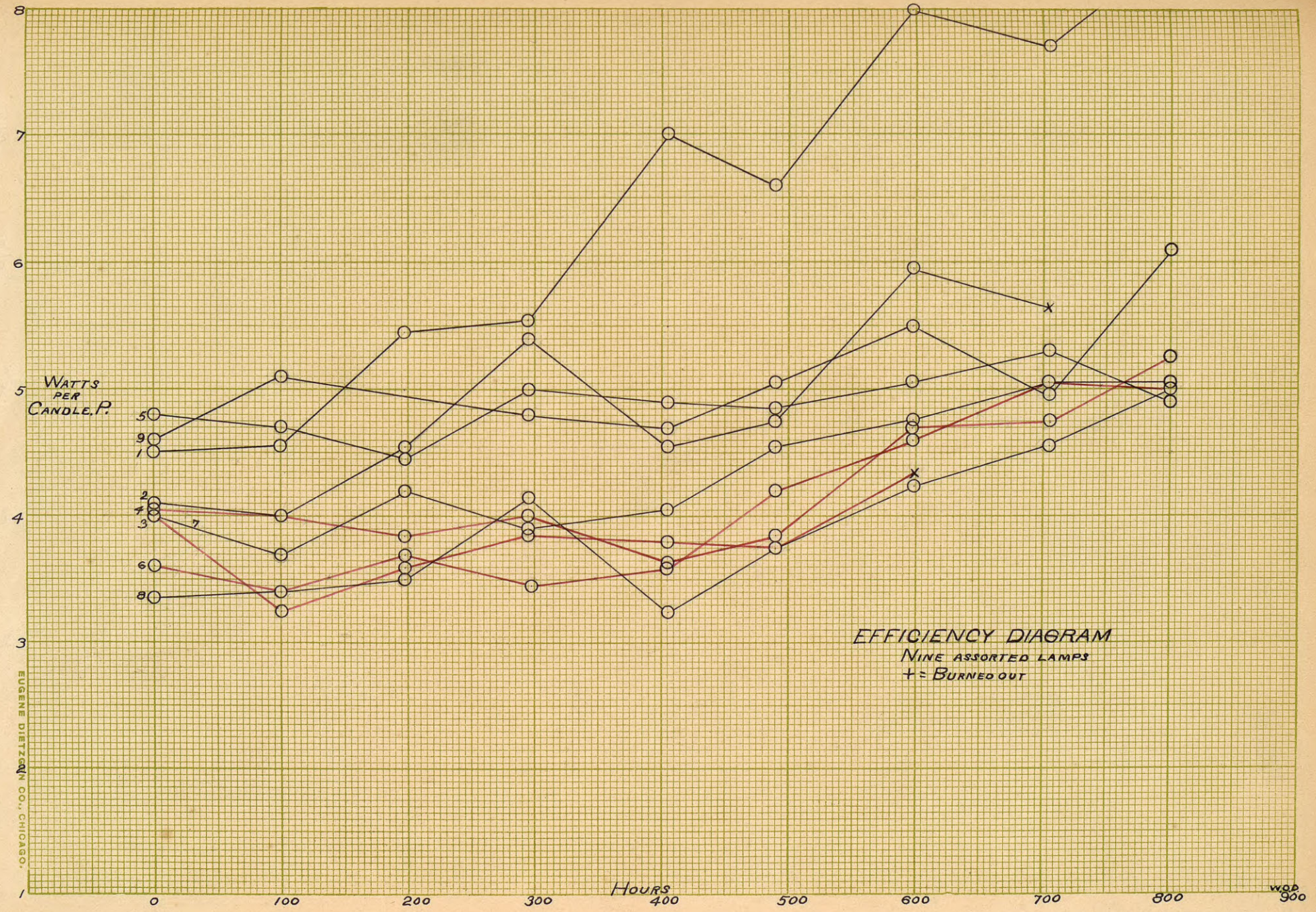

20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
CANDLE POWER
5
4
2
3
6
1
0
100
200
300
400
500
600
700
800
900
HOURS
CANDLE POWER DIAGRAM
SIX PACKARD LAMPS
——=AVERAGE
EUGENE DIETZGEN CO., CHICAGO.
W.O.D.

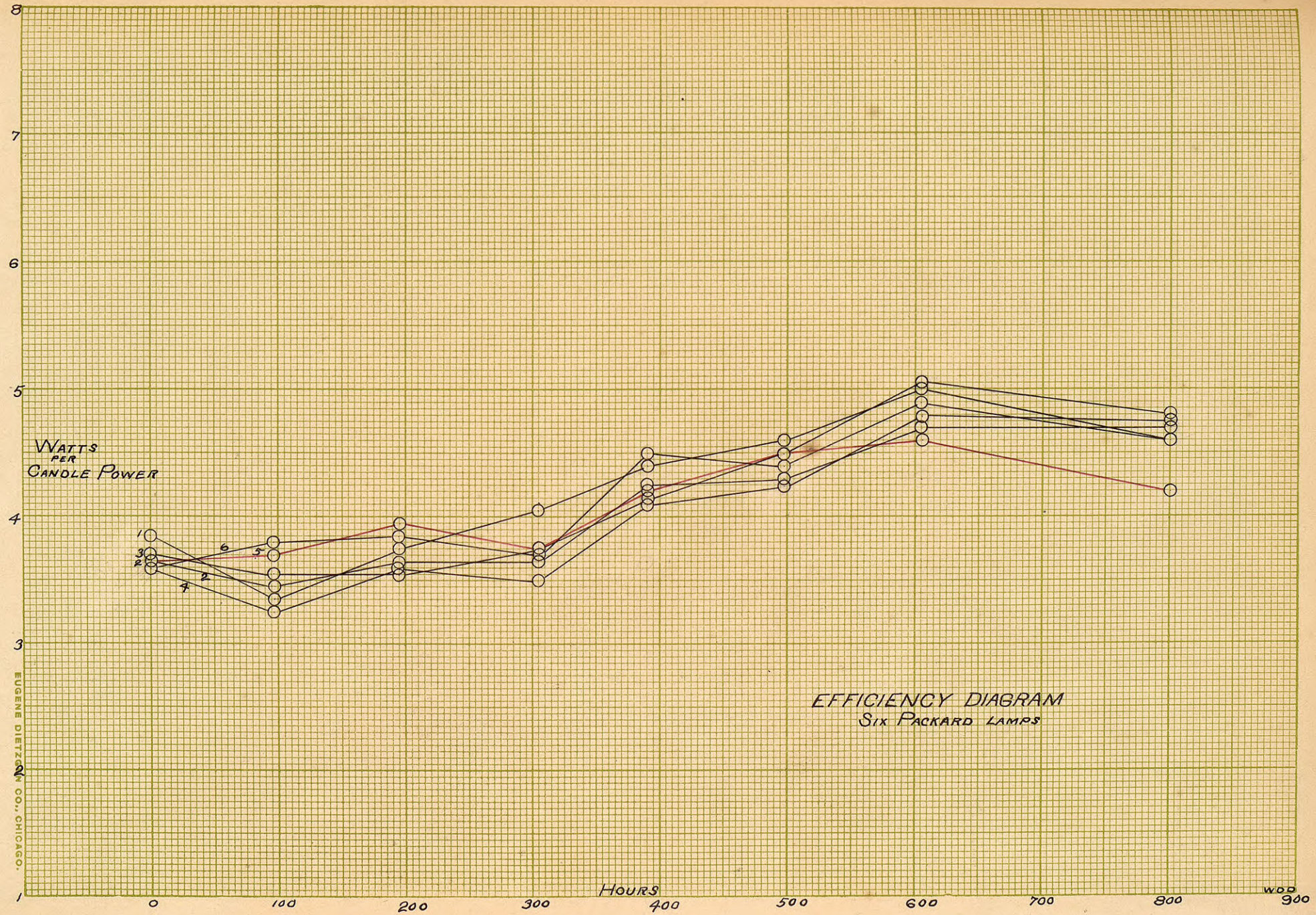
tinuous use. The superiority of this lamp over the preceding lot is clearly shown. Where the lamps are tested in lots it is better to plot each individual curve, as well as the average curve. By so doing the variation of the lot is shown as it is not in the curve of averages. Rapid drop in candle power indicates extremely poor manufacture, and it should be remembered that many lamps now on the market will give as poor results as some of these. A burning test of ten hours at normal or slightly excess voltage will promptly reveal the poorest lamps and thus enable one to quickly determine poor quality.

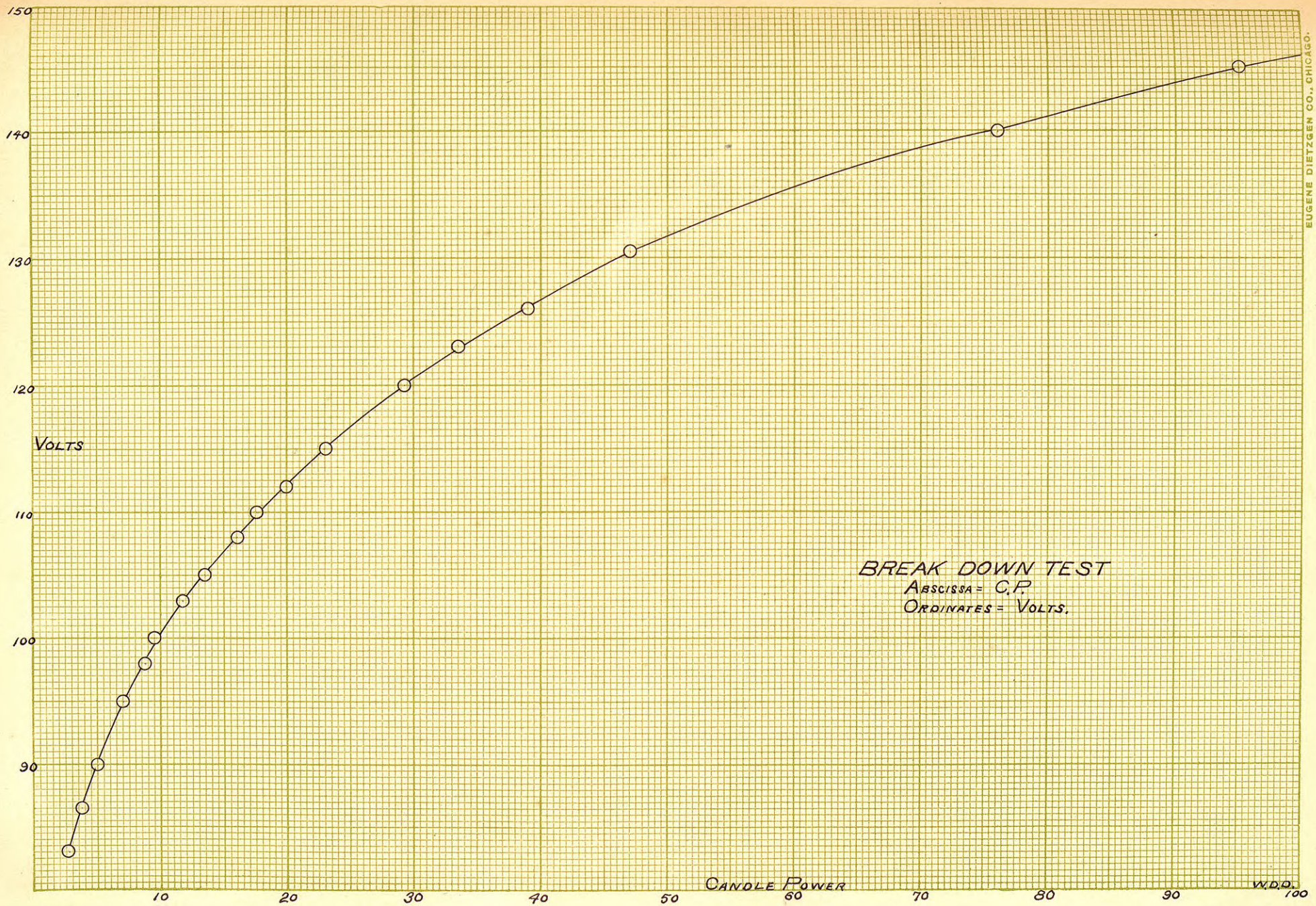
In the efficiency diagrams the curves have watts per candle plotted as vertical distances from the bottom, and duration of time in hours as horizontal distances from the left-hand side. The efficiency diagram of the nine assorted lamps shows the general tendency towards the increase in watts per candle as the lamps are burned. With the exception of the curve of lamp No. 1, the curves rise very gradually, but after 600 hours the average curve shows a consumption of nearly 5 watts per candle.

The efficiency diagram of the six Packard lamps shows a much more uniform performance, although the same tendency to rise in watts per candle with time is in evidence. These diagrams are the strongest arguments in favor of early lamp renewals.

The breakdown test was carried out in order to observe the variation of candle power with voltage, and, if possible, to find at what voltage the filament would be destroyed. The voltage is represented by the vertical distances from the bottom, and candle power as horizontal distances from the left-hand side. The lamp tested was a Peerless 110 volt lamp which gave 17.5 candle power at


WATTS PER CANDLE. P.
HOURS
0
100
200
300
400
500
600
700
800
900
1
2
3
4
5
6
7
8
EFFICIENCY DIAGRAM
NINE ASSORTED LAMPS
+ = BURNED OUT
EUGENE DIETZGEN CO., CHICAGO.
W.O.D.


8
7
6
5
4
3
2
1
WATTS PER CANDLE POWER
1
3
2
6
5
2
4
0
100
200
300
400
500
600
700
800
900
HOURS
WOD
EFFICIENCY DIAGRAM
SIX PACKARD LAMPS
EUGENE DIETZGEN CO., CHICAGO.


150
140
130
120
110
100
90
VOLTS
10
20
30
40
50
60
70
80
90
100
CANDLE POWER
W.D.D.
BREAK DOWN TEST
ABSCISSA = C.P.
ORDINATES = VOLTS.
EUGENE DIETZGEN CO., CHICAGO.

normal voltage. By decreasing the voltage to 108 the candle power drops to 16, that is, a 1.8% drop in voltage is accompanied by an 8.5% loss in candle power. This illustrates clearly the necessity for good regulation. By raising the voltage the candle power is increased and the consumption in watts per candle is decreased, but the loss in life makes this uneconomical. Although the voltage was raised to 146 volts the lamp did not burn out at once, but undoubtedly would have done so in a short time.

To determine the relative values of various makes of lamps a correct basis of comparison must be established. No comparison should be made solely on the life of a lamp, since the candle power may diminish rapidly. The proper basis of comparison considers both life and candle power, and is the average life of the lamps measured to a certain limit of candle power. This period is called the useful life of the lamp, and the best lamp is that which, under certain conditions, gives the longest period of useful life. Using the 80% limit for comparison we can at once determine the relative values of lamps. For example, the curve of lamp No. 8 crosses the 80% limit line at 500 hours, while the curve of lamp No. 5 reaches the same limit at about 800 hours. Lamp No. 8 would therefore require renewing 1.6 times as often as lamp No. 5, and the value of lamp No. 5 would consequently be 1.6 times as much as the value of lamp No. 8. In reality the cost of attendance for the much more frequest renewals of lamp No. 8 would still further reduce its relative value. It should be borne in mind that for this method of comparison uniform conditions are essential.

A high-grade incandescent lamp has three distinguishing characteristics: First, the absence of all defects in the mechanical

construction of the lamp; Second, accuracy and uniformity in candle power and watt rating, and Third, good maintenance of candle power in service and uniformity of performance in this respect.

Physical defects, such as loose caps or bases, poor or bad vacuum, spotted or discolored filaments, weak joints between filament and leading-in wires, etc., may be found in the average lamp to a greater extent than is generally known. These defects positively condemn a lamp, rendering it not only useless, but troublesome. A casual inspection of lamps will reveal the prominent physical defects. Loose caps or bases are detected by twisting the cap and bulb; bad vacuums, in many instances, by causing the filament to vibrate,-vibration will cease quickly in a poor vacuum. The filaments, when examined in the light, should reveal a clear, smooth, solid, dark gray surface. At a dull red heat they should appear perfectly uniform and free from any bright or dark spots.

Remarkably few makes of lamps are rated correctly and uniformly in candle power. The National Electric Light Association made extensive tests on various makes of lamps in 1898 and drew the following conclusions:

"From this investigation the fact stands out that the incandescent lamp sold for 16 candle power is, on the whole, a lamp which is often giving considerably less than its rated candle power, even when new."

Lamps should measure well within 10% above or below rated wattage, and 10% above or below rated candle power.

To secure the exclusion of low-grade lamps central stations must control the supply of lamps used on their circuits. Complete control is practicable only by the adoption of a system of free renewals, the stations supplying all the lamps used. Free renewals

involve but a slight expenditure that will be more than returned by the increased meter income and the increased business resulting from the improved lighting service. At the present low price of lamps, free renewals can be profitably adopted by every central station selling current by the meter.

The preceding curves clearly emphasize the importance of the frequent and regular renewal of old or dim lamps. All lamps lose in candle power as they burn,- some to a greater degree than others. This depreciation of light must be repaired, and the only effective way is to replace the old lamps with new ones. A consideration of the loss of candle power in lamps, as shown by the diagrams, shows plainly the necessity of adopting some system of lamp renewals that does not depend upon the customers and will limit the average life of the lamps to a period when they give from 12 to 16 candle power. The limit of useful life on which the renewal systems of leading central stations are based is at present 80% of the normal, that is, 12.8 candle power for a 16 candle power lamp. The point to be noted is that there should be some fixed limit at which the old lamps should be replaced by new ones. Lamps should not be allowed to burn through a dim and useless old age until burned out. The cleaning out of dim lamps cannot be left to the customer; it must be under the control of the central station.

Of late years there have been many attempts made to increase the efficiency of the incandescent lamp. No doubt the greatest success in this line has been achieved by Dr. Walther Nernst, a German scientist.

In the Nernst lamp instead of a carbon filament in a vacuum, the light is produced by the current passing through a glower, com-

posed of metallic oxides of the rare earths and which operates in the open air. The glower is not a conductor when cold, and a heater is provided to give it a temperature sufficient to make it conductive after a certain temperature is reached. When the current flows in the glower, sufficient heat is generated to keep the glower conductive and the heater is automatically cut out. A one-glower lamp tested on the photometer showed 85 candle power without the globe, and 51 candle power with a frosted globe. The wattmeter showed a power consumption of 90 watts or an efficiency of 1.76 watts per candle. This is just half the power required by the best incandescent lamps for the same light. No tests were made on the life of the glower, but 800 hours is claimed by the manufacturers. The lamp emits a soft white light free from shadow or flicker, and bids fair to come into very general use.

Within the past year the Cooper-Hewitt mercury arc has been placed on the market with a fair degree of success. Although not an incandescent lamp it is closely related and may well be discussed here. The lamp consists of a glass tube having a bulb on each end into which is led a platinum wire. The lower bulb is filled with mercury, and the upper is the condensing chamber. When the current is turned on the arc between the two terminals will not start except at a very high voltage, but since this is not easily obtained, and also undesirable, the tube is tipped until the mercury in the lower bulb flows into the condensing chamber, thus completing the circuit. The tube may now be allowed to return to its normal position, but the current has so heated the mercury that a vapor of mercury fills the tube. This acts as a conductor for the current and gives off a soft light which is practically free from red rays. The light is very rich in actinic rays and photographs taken by it can hardly be

detected from those taken by sunlight. The photographs on the preceding pages were made by this light with a 60 second exposure. For blue printing and portrait printing the exposure required is extremely short. No accurate readings of candle power could be obtained on the photometer because of the difference in the color of the lights, but 300 candle power is approximately correct. The lamp consumes 365 watts at 110 volts, giving an efficiency of 1.22 watts per candle.

For general illumination where it is important to get the cheapest possible light, and where the true ratio of color values is not important, the lamp will find its greatest field of usefulness. It is said that the light is very restful to the eye on account of the absence of red rays and, therefore, will make a splendid illumination for places where fine mechanical work, reading, writing and drafting is done.

The incandescent lamp is in too general use to be replaced by new types of lamps in a short time. Through all the past years of progress the incandescent lamp has held its own and has grown in relative popularity. The same virtues that gave it its start in life have kept its fortunes in the ascendant. With all its failings in points of efficiency, it is now, as it was in the beginning, the best illuminant in point of quality and general usefulness. At the present time there are nearly twenty million incandescents in lighting service from central stations in this country alone. The incandescent lamp is then today, as it has been all through its history, the mainstay of modern illumination as far as interior lighting is concerned. It may in due season be supplanted by something better, but that something will have to be equally good in color, steady, simple and convenient.