Arch
378.2
Bartenstein

T H E   E L E C T R I C   L I G H T I N G   S Y S T E M

Of

L E X I N G T O N   V A.

Submitted as Part Fulfilment
for the Requirements
of the Degree of
Batchelor of Science
by

Frederick Bartenstein
and
Frederick F. Millsaps

McCORMICK LIBRARY
WASHINGTON AND LEE UNIV.
LEXINGTON, VIRGINIA 24450

JAN 13 1977

Part I.

The Lexington Power Station

The power house is situated on one of the old locks of the North river canal, about two miles below Lexington. The original dam of the canal is still used, two feet having been taken off the top so that the flour mill at East Lexington might have more power. The dam is of dry stone, no cement or mortar was used, a layer of plank sheeting was placed on the inside to prevent leaking. Both sides are vertical, and from ten to fifteen feet high. It is ten feet thick and three hundred feet long.

The plant is built over the old lock, which is used as a penstock. The water is taken from the dam by two gates which are closed only when it is necessary to inspect or repair the turbines, the enclosed water then being allowed to flow out through the wheels. There is no provision for stopping drift, and little need, as the gates are out of the main current, there are no pipes to become clogged, and the wheels are deep below the water surface. The penstock is 15ft. broad by 40ft. long. The sides are of stone, and the end is made of heavy oak boards wedged up stream. There are three turbines, one large and two small ones, spaced about 15ft. apart.

All three turbines are placed in the penstock. The water flows directly through them into the tail race below. This race is a continuation of the lock, and runs into the river 100ft. below the dam. The river has a steep fall here and there is not much danger of back flow during high water.

There are two houses to the power plant. They are covered with sheet iron, each 30 by 30ft. They are built partially over the penstock, 20ft. above the turbines, 8ft. above the water surface. The upper house contains two Westinghouse 75 KW generators at fixed speed of 1200 revolutions per minute for the arc light circuit, and 1300 revolutions per minute for the incandescent. There are also two direct current generators used as exciters, 1.5 K W capacity. These generators were found to be inadequate, and a new turbine and generator were installed in 1908. The new wheel is a 150 horse power Liffel Buckeye turbine and is supplied with an average head of 12ft. It's vertical shaft is geared by beveled wheels to a horizontal shaft. The teeth on the large horizontal wheel of the turbine shaft are defective. They are made of wood and have become worn. They do not fit the steel ones on the horizontal shaft well, so that the turbines cannot be run above a certian speed. These teeth should be replaced, as enough power cannot be obtained under the present conditions to light the town well. We found that at 75 amp. not more than 112 volts could be obtainedat the power house, and at 25 amp. not more than 104 volts. If the speed is increased the gearing vibrates very badly, and would soon tear itself to pieces if left alone. Mr. Snider said that he was trying to get this fault remedied. We have since learned that the teeth are here and will be put in as soon as possible. There is no governer on the turbine, A much more uniform current could be obtained if one were provided. Without one the current cannot be regulated by a rheostat. In order to reduce or raise the voltage the speed of the turbine must be changed by reducing or raising the amount of water that flows through it. Suppose that with a given amount of water and electric current the dynamo gives 112 volts. Now put on some resistance, the current will go down to say 106 volts , it will not remain here but will soon move back to 112 volts. The cause of this is easily shown from the followering equation given by Franklin and Esty, page 43:

$$E = \frac{p \Phi Z n}{p' \times 10^8} \text{ volts}$$

Where Φ = flux regulated by the rheostat, p = number of field poles, Z = number of conductors on outside of armature, n = speed of armature in revolutions per second, p' = No. of electrical paths in brushes, E = total electromotive force induced in armature. By increasing the resistance in the field coil with the rheostat, the flux Φ is lowered. Hence E is lowered and the turbine has less work to do.

Then without a governer as it has less work to do it's speed will increase, and thus bring the voltage up again. There is an arrangement on the horizontal shaft which allows the dynamo to be thrown out of gearing at any time. The generator is connected by a belt to the horizontal shaft so as to give 600 revolutions per minute. It is a General Electric alternating current generator, 1150 volts, 101, amp. The exciter is a direct current General Electric dynamo, 5.5 K W, 1252 v. 44 amperes, at 1800 revolutions per minute. The quantity of flow in the penstock cannot be regulated. The speed of the wheel is adjusted by a hand wheel in the generator room which controls the valves of the turbine.

The switch board is made of two marble slabs. One for the arc circuit, and one for the incandescent. It is equiped with a hand rheostat, three oil switches, voltmeter, ammeter, and ground detector. The voltmeter is put in shunt with the main circuit, and the current passes through a transformer before it reaches the meter. It is a Thomson meter, reading to 175 volts, with 2 volts per division. The ammeter is also of Thomson make, It reads to 200 amp. with 5 amp. per division. The fuses used at the power house are 1500 volts ——— for the incandescent circuit, and 2500 volts, 40 amp. for the arc light circuit. In regard to the dormitory fuses, we found that they were all of sufficient size. Those at the main switch are of 250 V.

80 amp. and have to carry a current of 55 amp. 100 volts. The fuse plugs in the wings are, 125 Volts, 10 amp. and have to carry a current of 5 amp. on each floor, or 15 amperes for each wing. The plugs in the center of the building are 125 v. 15 amp, and have a current of 7.5 amp. on each floor or 22.5 for this part of the building. The individual lamp fuses will cary safely 2.5A.

The incandescent light current is carried to Lexington at 1150 volts, and is stepped down to 100 volts by transformers at the separate houses. A maximum load of 4000 16-candle power incandescent lights is provided for. When the incandescent lights are used alone a line drop of 6 volts is allowed, when both arc and incandescent are in use a line drop of 8 volts is allowed. A larger drop than this should be allowed. We determined the drop by trial from the power house to a socket in Lexington, andfound that it was 15 V. with a current of 75 amp. on the mains. In determining this drop one person was stationed at the power house, and some one in Lexington, with a volt meter in connection. Our watches were set together, and we had arranged to read the voltages at certain intervals. We made three readings and took their mean as the correct drop. The Cardew volt meter was used in town; it had been previously calibrated with a Weston volt meter, and its readings were corrected by this calibration. The voltmeter at the power house was in circuit with a transformer, so that it read a low voltage, similar to the one in town. We did not calibrate it but even if it does not read correctly, still we know that in order to give 100 volts in Lexington it's reading should be 115 volts, at 75 amp. When the arc lights are being used the current divides at the power house The arc light current passes through a substation , situated across the river and nearer Lexington. Here the current is changed from a constant voltage to a constant current of 6.25 amperes. 6.25 This arrangement is worked by means of weights and electromagnets. When the arc lights are turned on the current must be lowered for a moment, for this transformer is not instantaneous and a full current would burn it out if it were put on suddenly.

To find the theoretic linedrop from the University power house to the dormitory we first measured the distance between them followering the wires. It was 700 ft. Then we found the size of the mains, No. 2 B & S gauge. We assumed a current of 55 ampares, or 110 lights. In the I. C. C. Mechanics Hand Book we found the formula $r = \frac{v}{n\ d}$ Where r is resistance of wire per ft. v is line drop, and n is number of lights, and d is the distance from the power to the load. We assumed that the load was concentrated at the dormitory, and took the distance to the end of the mains there. Substituting in this formula, taking r= 0.000156 ohms, We have: $v = .000156 \times 110 \times 700 = 12.018$ v

We have looked into this formula carefully and are sure that it is correct. From Franklin and Esty page 288 we have the formula $e = (10.8 \times 2L \times I)/d^2$ Where " d equals diameter in mills of copper wire required to carry a current of I amperes to a concentrated load distant L ft. from center of distribution, e equals drop in volts" : hence substituting

$$e = (10.8 \times 1400 \times 55)/66564 = 12.5 \text{ volts}$$

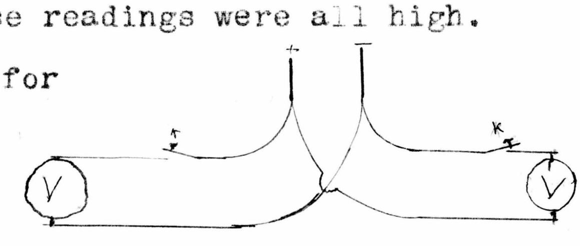
The difference in answers is due to the difference in constants used by the two books. The No 2 wire is able to carry the current safely but the drop is rather large. We have been unable to measure the actual drop from the power house to the dormitory, but as well as we have been able to estimate it seems to check with the theoretic drop. Allowing a drop of 5 volts we find that No. 000 B & S is the proper size. For: $r = v/n\ d = 5/\ 110 \times 700 = 0.000065$ ohms, Looking in the tables we find that No. 000 has a resistance of 0.068 ohms per 1000 ft. or a resistance of 0.000062 ohns per ft. This will give $v = .000062 \times 110 \times 700 = 4.8$ volts drop.

Part 2

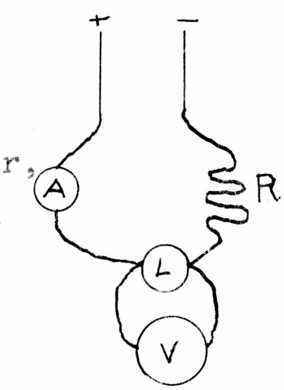
Experiments on the Efficiency of the Incandescent Lights, and of the Town and College Circuits.

These experiments were made to determine the efficiency of the lamps furnished by the Lexington power Co. under the average E. M. F. at which they are supplied. The instruments used were, the Kelvin balance, Weston voltmeter, and ammeter, Cardews voltmeter, and a Bunsen photometer. The Weston voltmeter and Kelvin balance were assumed as standard, and the other instruments calibrated from them. The Cardew voltmeter was calibrated by alternately connecting it and the Weston voltmeter to the same circuit of a direct current and recording the corresponding readings. They coincided at about 77 volts and varies at a maximum 2.25 volts. A curve is attached showing error of reading, these corrections were made use of throughout these experiments. We started with 30 volts taken from the storage battery, and increased it steadily to 50 volts; all these readings were low on the Cardew. Then we took readings from 90 to 117 volts taken from the College dynamo. These readings were all high.

This figure shows connections for calibration of Volt meter.



A standard 16 candle power lamp was obtained from the New York Testing bureau. It was necessary to determine a secondary standard from this, because continuous use of the primary standard would soon make it inaccurate. To do this we placed the standard lamp at one end of the photometer bar with the required voltage and amperage to give 16 candle power. The lamp to be standardized was placed at the other end of the bar. A resistance box and ammeter were placed in circuit with each lamp, and volt meters were put in parallel with each. The figure gives the connections of one lamp. The primary was carefully adjusted to required conditions. The Bunsen photometer was placed at the center of the bar, and the current was varied in the secondary standard until the photometer showed equal briliancy. The ammeter and voltmeter were read, and the conditions under which the lamp would give 16 candle power became known. Several readings were taken and from these an average was deduced, they were:



$$V = 49.4 \text{ volts}$$

$$I = 1.13 \text{ amp.}$$

The efficiencies of a few lamps in use were found. These could only be known when taken at the voltages supplied.

We have kept a record of the voltages given by the town lights, with alternating current and by the dormitory lights, furnished from our direct current dynamo Below are tables showing the average results of each. The records were kept from Feb. 25 to Mar. 10 '08.

Town Voltages

Hours	5	6	7	8	9	10	11	12
Volts	100	97	95	93	93	95	97	100

Dormitory Voltages

Hours	6	7	8	9	10	11	12
Volts	100.5	99.6	96.7	95.2	96.6	95.7	94.5

The average town voltage from 5 to 12 is 96.25 volts.
" " " " from 8 to 12 is 95.6 volts.
" " college " from 6 to 12 is 97 volts.
" " " " from 8 to 12 is 95.7 volts.

To determine the efficiency of the lamps, we wired tem i in the same manner tat we wired the lights to determin the secondary standard. We placed the secondary standard at one end of the photometer bar and the lamp whose efficiency we wished to find. The standard was put under the conditions necessary to give 16 candle power, and the candle power of the other light was found. At the same time we took the voltage, and amparage of the light under examination. We did this with two Edison, and two Shelby lamps. We found that the Edison lamps were more efficient.

In the table on this page A represents Ampares,

V	"	Difference in Potential
B	"	Candle Power
W	"	Watts
R	"	Ohms
E	"	Efficiency = B/W
K	"	B/W^3
1/K	"	W^3/B

Lamp Efficiency

Edison, and Shelby, 16 Candle Power

	A	V	B	W	R	E	K	1/K
Edison 1	.55	100	16.31	55	181.8	.296	.0000982	10833
"	.51	95	12.22	48.5	186.2	.252	.0001070	9346
Edison 2	.575	100	16.63	57.5	174.	.289	.0000874	11442
Shelby 1	.60	100	16.63	60	166.6	.270	.0000768	13021
Shelby 2	.60	100	15.30	60	166.6	.249	.0000709	14100
"	.64	105	19.4	67.2	164.	.289	.0000639	15600
"	.575	95	10.88	54.6	165.2	.200	.0000527	18900
"	.55	90	7.64	49.5	163.6	.154	.0000502	19900

Below we have drawn six curves. The data is taken from the above table on the Shelby lamp No. 2. Curve No. 1 shows the relation of candle power to volts, one division representing one volt and candle power each. From 96 to 103 volts the slope is slightly less than 45 degrees. This shows that a change of one volt will make a change of one candle power nearly. Outside of these limits the curve assums a smaller slope. This means that the change of candle power per volt is decreasing.

Curve No. 2 gives the relation of efficiency with the voltage. From 90 to 101 volts the efficiency varies directly with the voltage. Above this the efficiency decreases per volt slightly.

No.3 gives the relation of watts to voltage. From 90 to 95 volts the slope of the curve is 45 degrees, showing that the watts increase directly with the volts. Above 95 volts the curve is concave upwards, showing that the watts increase faster than the volts.

Curve No. 4 gives the resistance as a function of candle power. We see from it that the resistance is not quite constant, it being greatest at 16 candle power. It increases rapidly at very low candlepower.

No. 5 shows the relation of candle power to efficiency. It resembles the hyperbola. Up to 16 candle power the efficiency increases at a greater rate than the candle power. Above this however the candle power increases faster than the efficiency.

No. 6 gives the relation of candlepower with watts cubed. The ordinates and abscissas are not drawn tot he same scale. For this reason the curve has a slope of about 45 degrees. In reality its slope is nearly 90 degrees, which shows that the watts cubed increase very much faster than the candle power.

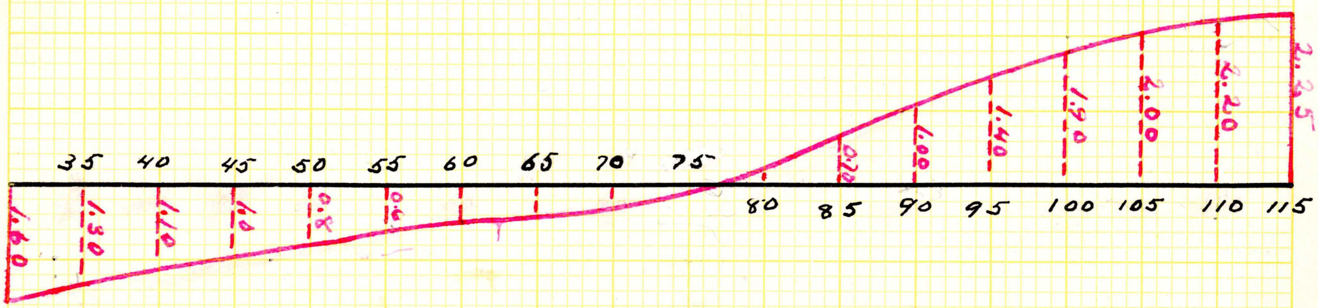
We see from the first curve that any voltage less than 100 will give very low candlepower. From the hours of 8 to 9 in town the voltage is about 93 and this gives only 8 candlepower. On the other hand any voltage much over 100 is very injurious to the lamps. They soon become blackened from the carbon shot off from the filament, and thus much of the light is absorbed. The resistance in each lamp is raised very much also and thus the watts per candlepower are raised. The illuminating surface is also lowered which lowers te candle power still more. Thus we see that it is more economical for the consumer to have a steady voltage of 100 volts. For a high voltage will ruin their lights, and a low voltage will give them poor lights. It is best for the company to give a steady voltage if they expect to give satisfactory service. If they give a voltage above 100, part of the night and less than 100 at other times things are never good. On acount of the fact that old lamps are more costly both for the consumer and producer and as the majority of consumers are too shortsighted to provide themselves with good lamps, it is usually more economical for the company to exchange new lamps for old ones, and to make sure that only good lamps are in use. No lamp should be used more than 800 hours.

Respectfully submitted

Frederick Bartenstein

Frederick F. Millsaps

Correction Curve for Cardews Voltmeter



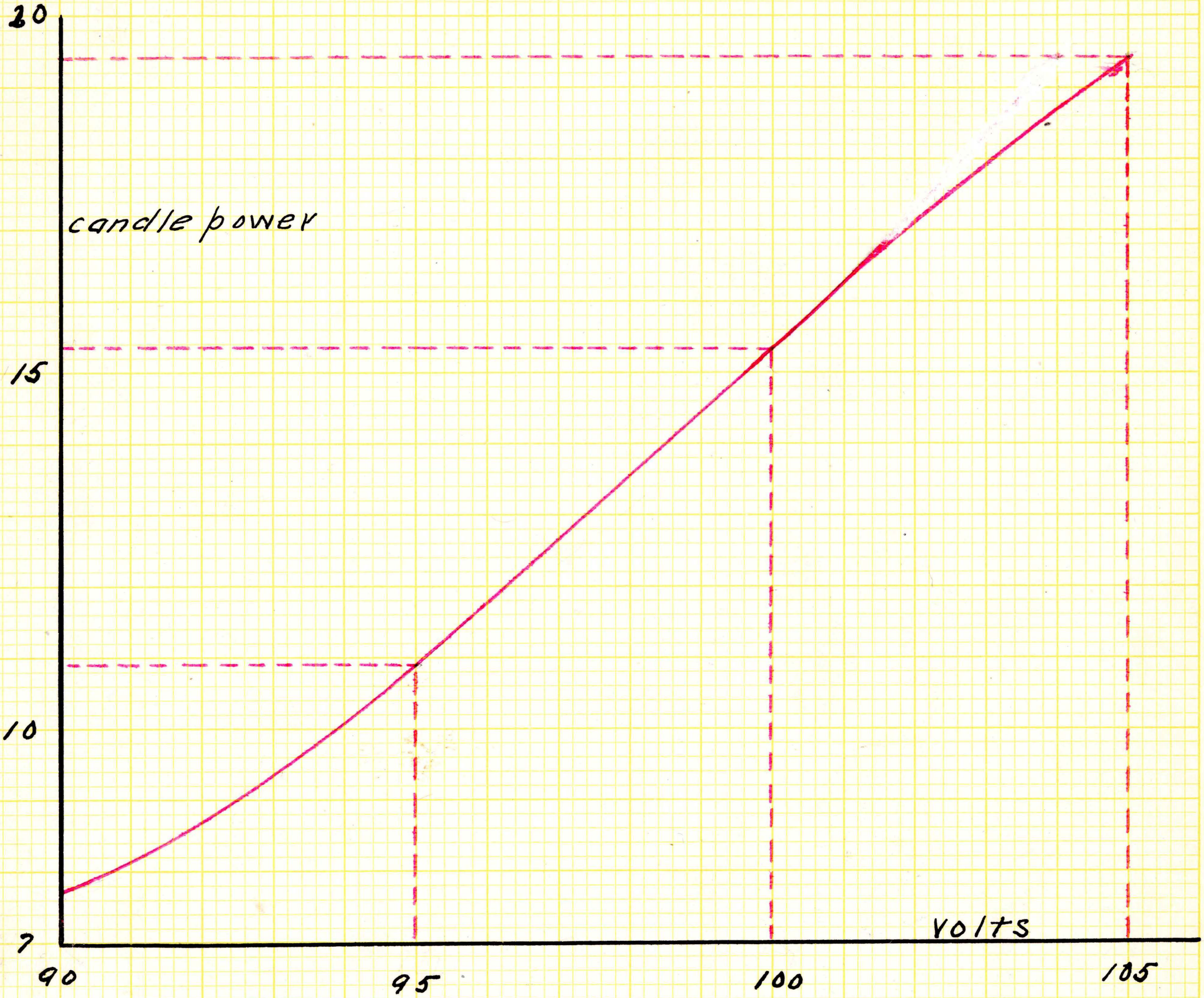
Black letters are correct readings when red letters are subtracted from observed reading

Red letters are corrections to be used with Cardew Voltmeter. the ordinates being the correction of the voltmeter redding, as shown by abscissas

x = reading in volts

y = correction for given x.

NO 1

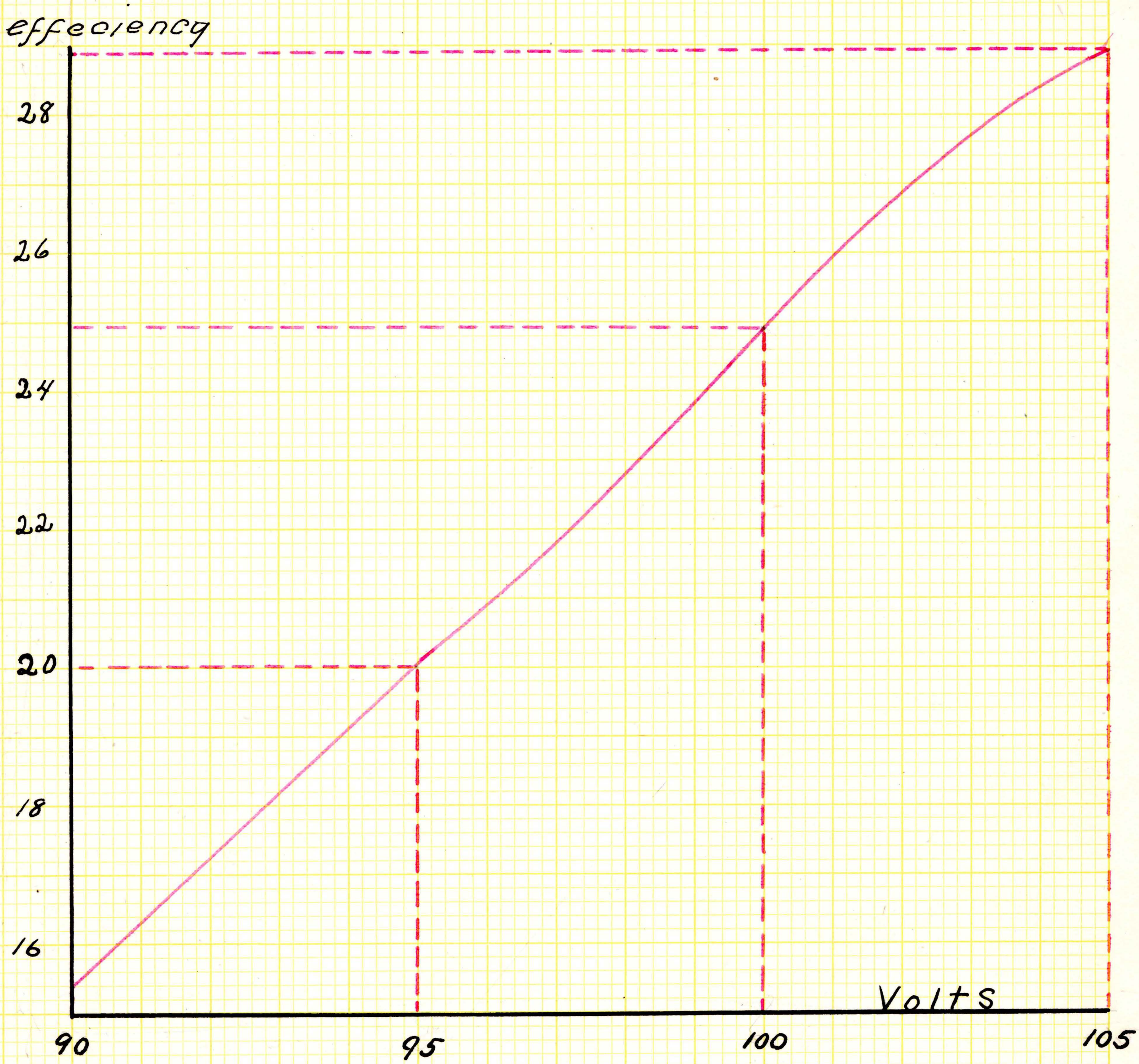


B = ordinates

ΔV = abscissas

Showing variation of candlepower with voltage.

NO 2



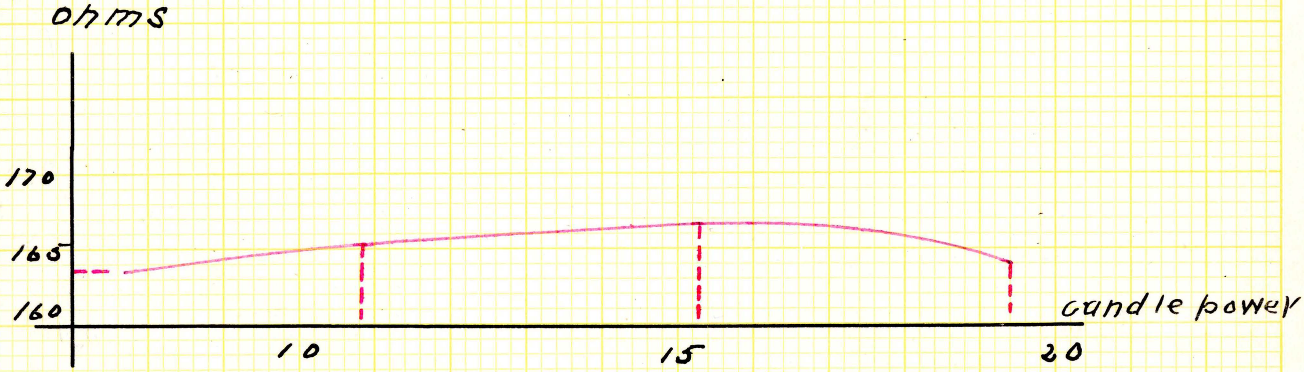
B/W = e = ordinates

ΔV = abscissas

Variation of effeciency and voltage.

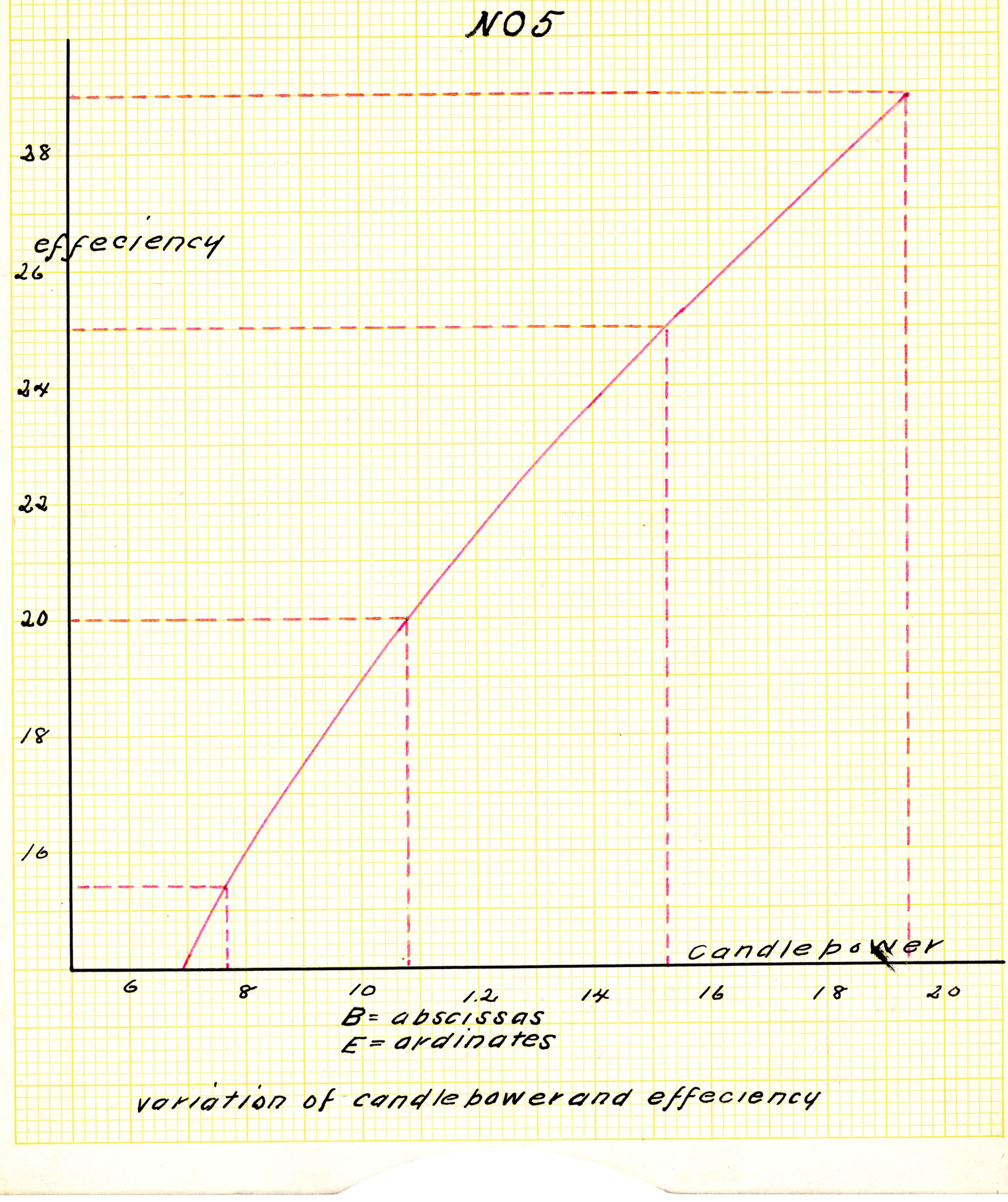
Variation of voltage and watts.

NO 4



R = ordinate
B = abscissas

Variation of Resistance and candle power



NO5
efficiency
28
26
24
22
20
18
16
candlepower
6
8
10
1.2
14
16
18
20
B= abscissas
E= ardinates
variation of candlepower and efficiency

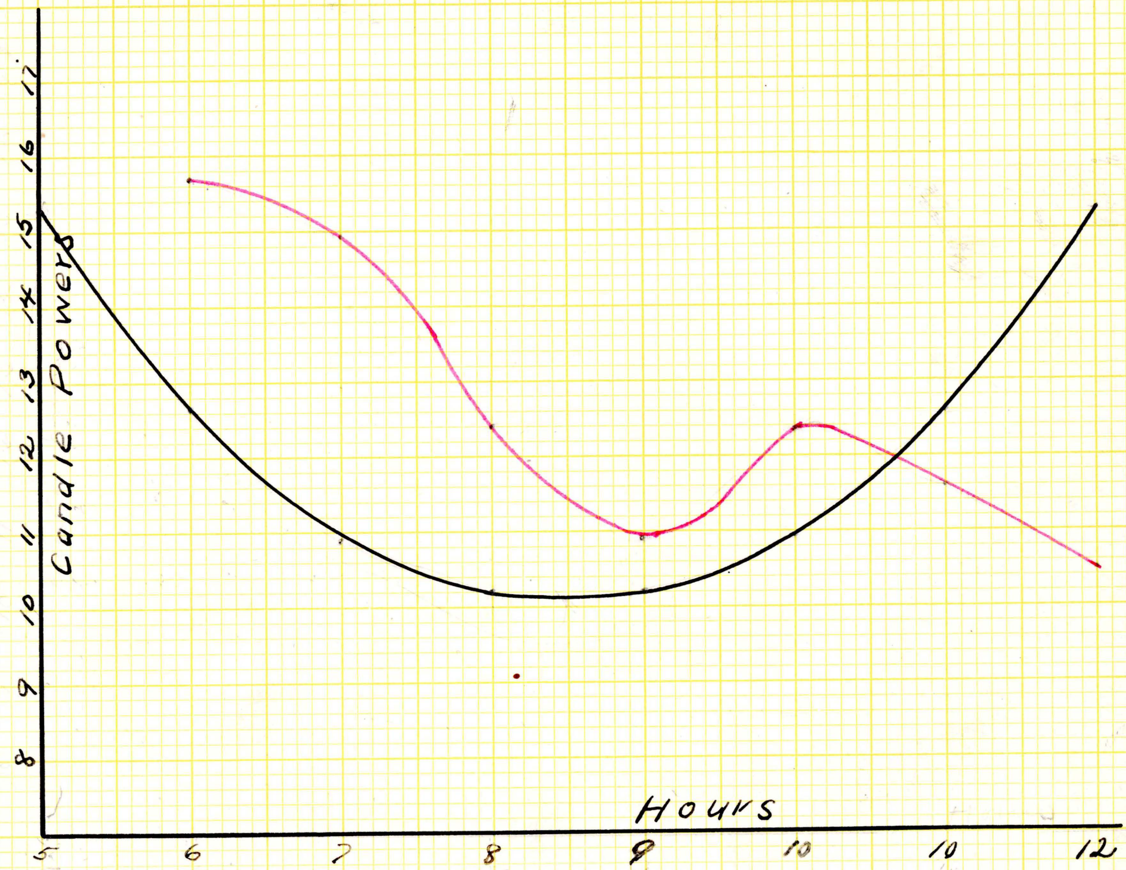
B = abscissas

W^3 - ordinate

Showing variation of candle power and watts cubed

Of the two curves given below the black one represents the candlepower furnished by the town alternating current from the hours 5 to 12 P. M. The red curve gives the candle power given by the direct current from the University dynamo, from the hours 6 to 12 P. M.

We see that neither gives the required candlepower. If a horizontal line be drawn at 16 candle power on the diagram, the area representing the candle power-hours which should be furnished will be the included rectangle. The actual candle power-hours given is shown by the area under the black curve, by the town current. We found the area of the rectangle to be 224 squares. The area under the curve is 164.4 squares. Thus only 73.4% of the required candle power-hours is furnished. At the local rate of 8 cents per kilowatt-hour we see that the consumer is actually paying 0.734/8 cents or 10.9 cents per kilowatt-hour for such light as he receives. Therefore he is paying 1.9 cents more than he agreed to pay. Assuming a light to be used 5 hours per day for 365 days he will loose , 0.019 X 5 X 365 = $34.67 per light.



The black line shows variation of candle powers with the hours at which the lamps are most used, for the town alternating current.

The red lines gives the candle powers from the college dynamo at the same time as for above curve.