# ARC LIGHTING.

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and

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# OUTLINE.

## ARC LIGHTING.

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ARC LIGHTING.

In the opening years of the twentieth century, those taking a retrospective view of the nineteenth, predicted that marvelous indeed must be the advancement of the new century in electrical development if the high standard set by the old is to be maintained. But every improvement paves the way and makes easier the path of the next, and the new century had scarcely begun until there came to those connected with electric lighting the announcement of a new arc lamp, the magnetite arc, whose efficiency is twice that of the most modern carbon lamps which, in their turn, are more efficient than any other artificial light. Volta for the first time in 1800 observed the phenomenon of heat and light caused by a current of electricity bridging a short gap in a broken circuit. As the luminous stream flowed between horizontal points, it arced upward because of the influence of the heated air and is, therefore, known as the "Voltaic Arc". Soon after, Sir Humphrey Davy obtained a four inch arc between points made from gas carbon. From that the carbon arc lamp has developed during the nineteenth century to be improved upon by the metal arc in the very first years of the twentieth.

APPEARANCE.

Whether or not the new arc has all the advantages claimed for it, the carbon arc has yet a long period of usefulness before it, if for no other reason than that it already occupies the arc lighting field. The carbon arc is much shorter than the metal arc because of the refractory nature of carbon. The arc is composed of a conductive bridge of volatilized material which composes the electrodes. The intense heat vaporizes most metals much easier than it does carbon and so the vapor bridge, in the case of metal electrodes, has the lower resistance both because of the larger amount of metal vapor present and the conductive nature of the material itself.

The positive carbon is much the hotter and from it most of the light emanates. One experimenter credits 85% of the total light of the carbon arc to the positive carbon, 5% to the arc itself, and 10% to the negative carbon. The positive carbon always has a shallow pit in its center called the crater, and from that crater the light emanates. For that reason the positive is always placed above. The crater has a seething, boiling appearance probably caused by the actual boiling of the carbon. It has been determined that the light is constant per unit area of crater and that different current values only vary the size of the crater. The arc itself, though the least luminous portion, yet has a high candle power as compared with any other artifical source of light several times larger. The arc is from 1/8 to 1/4 inch long in lamps operating with a potential difference of eighty volts over the arc. The negative carbon has no crater and only becomes white hot when the current passes. The temperature of the positive carbon is from 3500°C to 4000°C, while the negative has a temperature of from 3000°C to 3500°C. In case the carbons contain metal impurities, the metals collect on the carbons in small beads only to disappear in the intense heat. The wattage in the different parts of the arc is proportional to the light given off, for a carbon pencil held in the arc shows, in a 45 volt 10 ampere arc, 40 volts between the positive carbon and arc stream, 2-1/2 volts between the ends of the stream, and 2-1/2 between the stream and the negative carbon.

The light given off, especially when viewed from a distance through clear air, has a cold, intense blue appearance which is the more appreciated if an incandescent electric or gas light is near. In color, the light from the carbon arc is nearest to sunlight. The composition of the light has been determined, using yellow lights as unity, to be, red and orange, 2.09; yellow, 1.00; green, .99; blue, .87; indigo, 1.03; violet 1.21. This varies somewhat with the hardness and composition of the carbons. It is seen from the proportions given that almost half of the light is of a bluish color. The effect on the eye is that of more blue than is most pleasant and various devices are used either for changing the color or absorbing the blue rays.

## OLD TYPES OF LAMPS.

The first electric lighting was outdoor work with open arc series lamps like the old Brush or Thompson-Houston types. These lamps took about fifty volts each with a current of ten amperes controlled by machines of the same name. The machines were series wound and worked on a falling characteristic, so that with special regulating devices which shifted the brushes or shunted the fields, the voltage over the series was so varied as to keep the current constant. The lamps themselves might have either a shunt or a differential winding. In the shunt lamp, the Thompson-Houston type, the carbons were held apart by a spring. A coil of fine wire connected across the arc gap first received a current, pulled down its amature, and released the upper carbon. This dropped down upon the lower one, completed the circuit, and a series coil of large wire then drew the carbons apart. As the carbons burned

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away, the resistance of the arc became greater and consequently the shunt coil strengthened until its armature was again pulled down and the tripping action repeated. The voltage was regulated by varying the spring tension. In one form of shunt lamp, the shunt coil was wound over the series coil so that the actions of the two opposed each other. The disadvantage of this form of lamp is the high voltage necessary to start it.

The differential lamp has two coils, a shunt and a series opposing each other mechanically instead of magnetically. The carbons are together on starting and, as before, the series coils draw the arc. The coils act upon amatures at opposite ends of a lever and as the shunt coil becomes stronger with the lengthening arc, they soon balance each other. As the carbons burn away, the tendence is to weaken the current in the series coil and strengthen that in the shunt coil so the carbons are slowly fed together. A gradual, continuous feed is the ideal one but in the best lamps the cut-out must finally operate, shunt the current around the lamp until the clutch can drop the carbon and get a new hold, when action is again resumed.

The incandescent lamp built to run on a constant potential circuit was the second development in electric lighting and with it came the constant potential arc lamp. These early lamps were made on the supposition that fifty volts each is the only pressure for arc lamps so the attempt was made to run two in series with a low resistance across 110 volt mains. The resistance, in some cases, was placed in the shank of the lamp, in which case the total resistance was divided between the two lamps, or placed external to both. The drop over the resistance was such that the voltage over the lamp terminals was from forty-five to fifty volts with ten amperes flowing; the drop over the arc was practically the same as over the terminals for the only other resistance besides the arc was the lifting solenoids.

These series lamps were very difficult to regulate and when placed on the line gave constant trouble by their uneven wattage. Any lamp could be run only with the particular resistance coil and mate with which it was regulated for the voltage here was adjusted by means of springs and shunt coils. The pairs were continually getting out of balance, one lamp burning brightly at ninety or one hundred volts while the carbons of the other were scarcely red. The lamps could have no cut-out device so both lamps must be on or off together.

All these old styles were direct current lamps burning with the arc exposed to the air. The constant current lamps were adopted and mostly used for street lighting, and in case it was desired that they burn all night, double carbon lamps were necessary. Twelve inches was the practical length limit of commercial carbons and these only burned eight or ten hours. During the winter months the all night lamps were trimmed with two carbons in parallel in lamps designed for that purpose. The lamp was so arranged that it required the shunt coil armature to be pulled down farther for the second carbon than for the first. For that reason, the one carbon burned entirely out before the second began to feed if the lamp was working properly, although both carbons would sometimes burn in parallel. With the lessened weight on the adjusting spring because of the removal of half its load, the second carbon always burned from five to ten volts higher than the first. When especially long life was desired, copper coated carbons were used. The copper coating prevented the air currents outside the arc from consuming carbon.

## MODERN LAMPS.

Modern arc lamp practice differs from that in vogue when arc lighting was first put upon a commercial basis in that the direct carbon feed is substituted for the rod feed and the enclosed arc for the open arc. Modern practice also has the addition of lamps connected singly in multiple on low tension circuits carrying either continuous or alternating currents, and lamps in series on high tension alternating current circuits.

The old style rod feed made necessary an unusually long lamp. The worst characteristic of the excessive length of rod and carbons was the liability of the carbons to cross when the guides became slightly worn. Cases were not infrequent in which the end of the upper carbon slipped entirely by the point of the lower. The rods were made of brass which demanded polishing whenever the lamp was trimmed in order that the brushes might make good contract. The polished rod then slipped easily through the clutch and so caused trouble. In modern lamps, good contact to the carbon is secured by slipping the carbon into a short holder which slides up and down in a tube. The holder makes electrical contact with the lamp circuit by a flexible conducting cord.

With the best carbons obtainable, the old style open arc lamps rarely burned with a single carbon more than eight to ten hours, or sixteen to twenty hours with two carbons as previously explained. In the enclosed arc type, the carbon is surrounded by a small globe which admits oxygen very slowly to the arc so that the lamp burns on each trimming about eighty hours if the current is alternating, and about one hundred twenty hours, if the current is direct. Usually the globe needs cleaning more often than the carbons need renewing if the service is to be the best. In the open arc, the current was usually ten amperes with fifty volts over the arc. Although the arc efficiency is greater as the current increases and the voltage decreases, enclosing the arc necessitates diminishing the current and increasing the voltage because of the danger of melting the globes or burning the deposit into the glass. The longer arc also diminishes the lower carbon shadow and lessens the globe deposit by giving time for more complete consumption of the carbon in the arc stream. Although the inner globe absorbs some of the light, it nearly compensates by preventing loss of heat by convection.

Series arc lighting with either continuous or alternating current is the standard American practice for street lighting. The lamps usually are distributed over a wide area but the drop over each lamp is the same if the adjustments are similar so that all lamps burn with equal brightness. Although there are many lamps upon the market, modern practice differs only in small details of construction; in general they are electrically and mechanically similar. The working parts are the same as the old style lamps with the exceptions previously mentioned. The functions of a series arc lamp mechanism are to strike the arc, maintain the proper distance between carbons, feed the carbons together as they are consumed, leave the lamp in such condition when the current is turned off that operation will begin when the current is again turned on, and to preserve the continuity of the circuit in case

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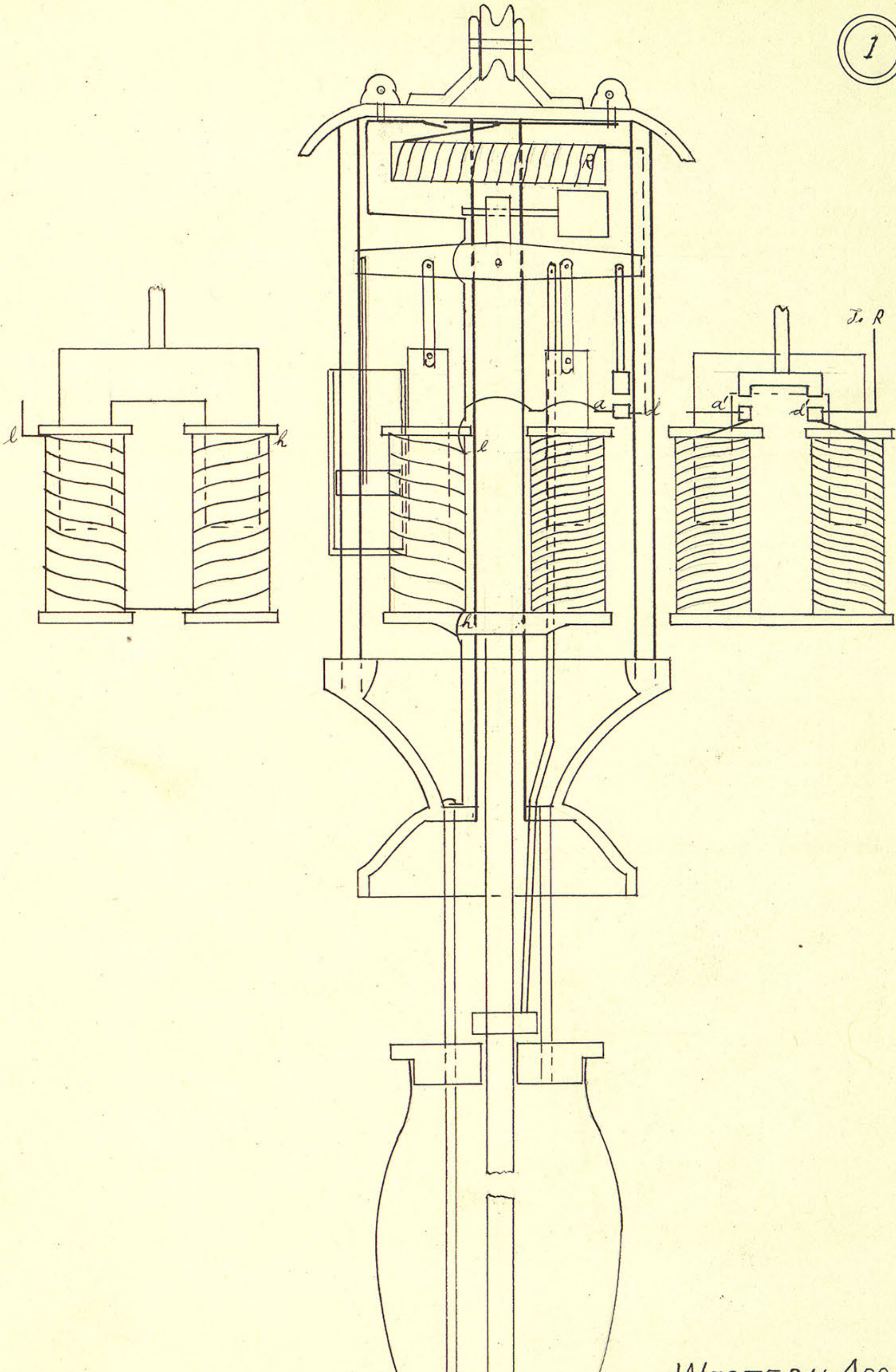
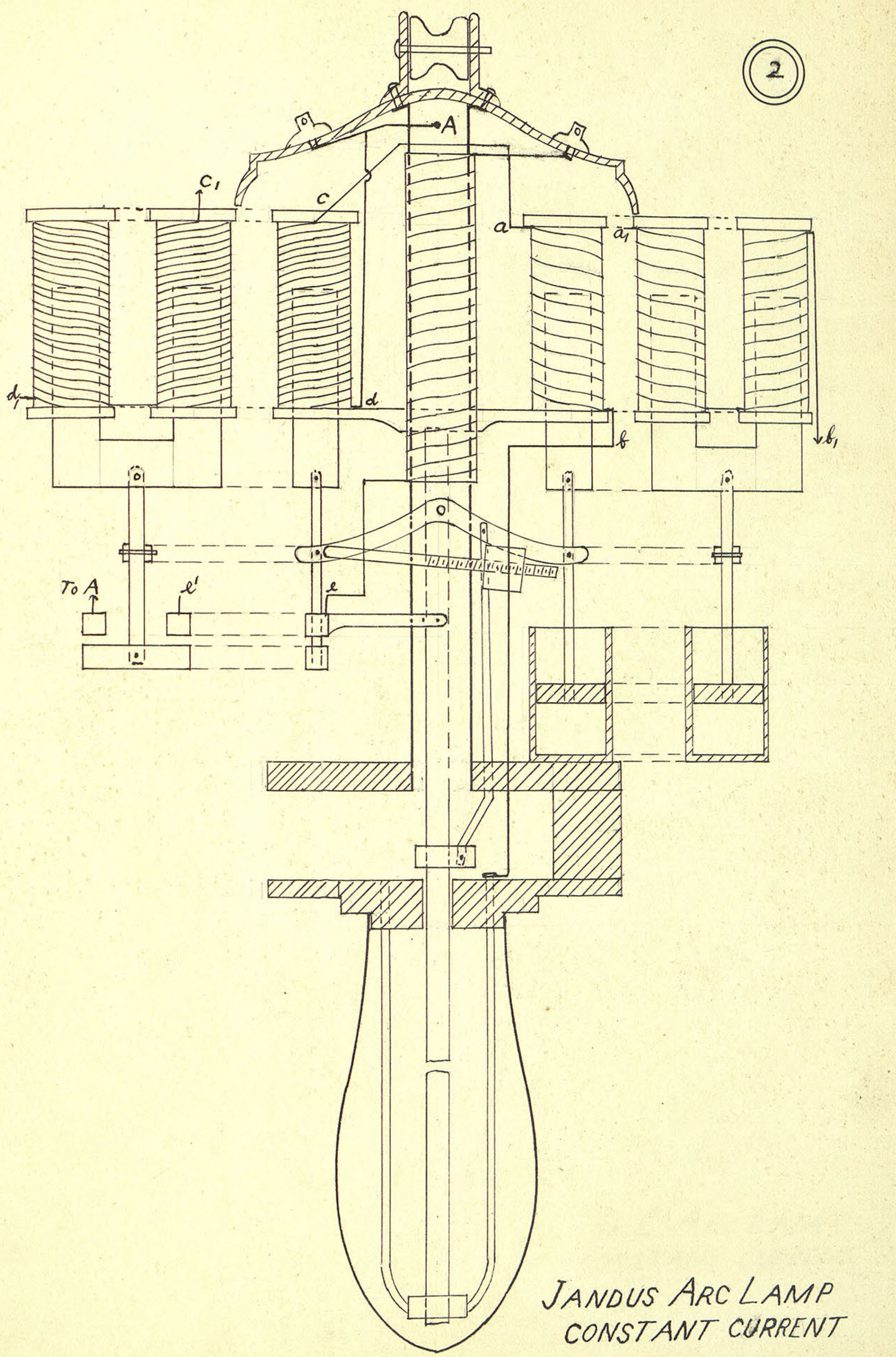


WESTERN ARC LAMP
CONSTANT CURRENT




JANDUS ARC LAMP
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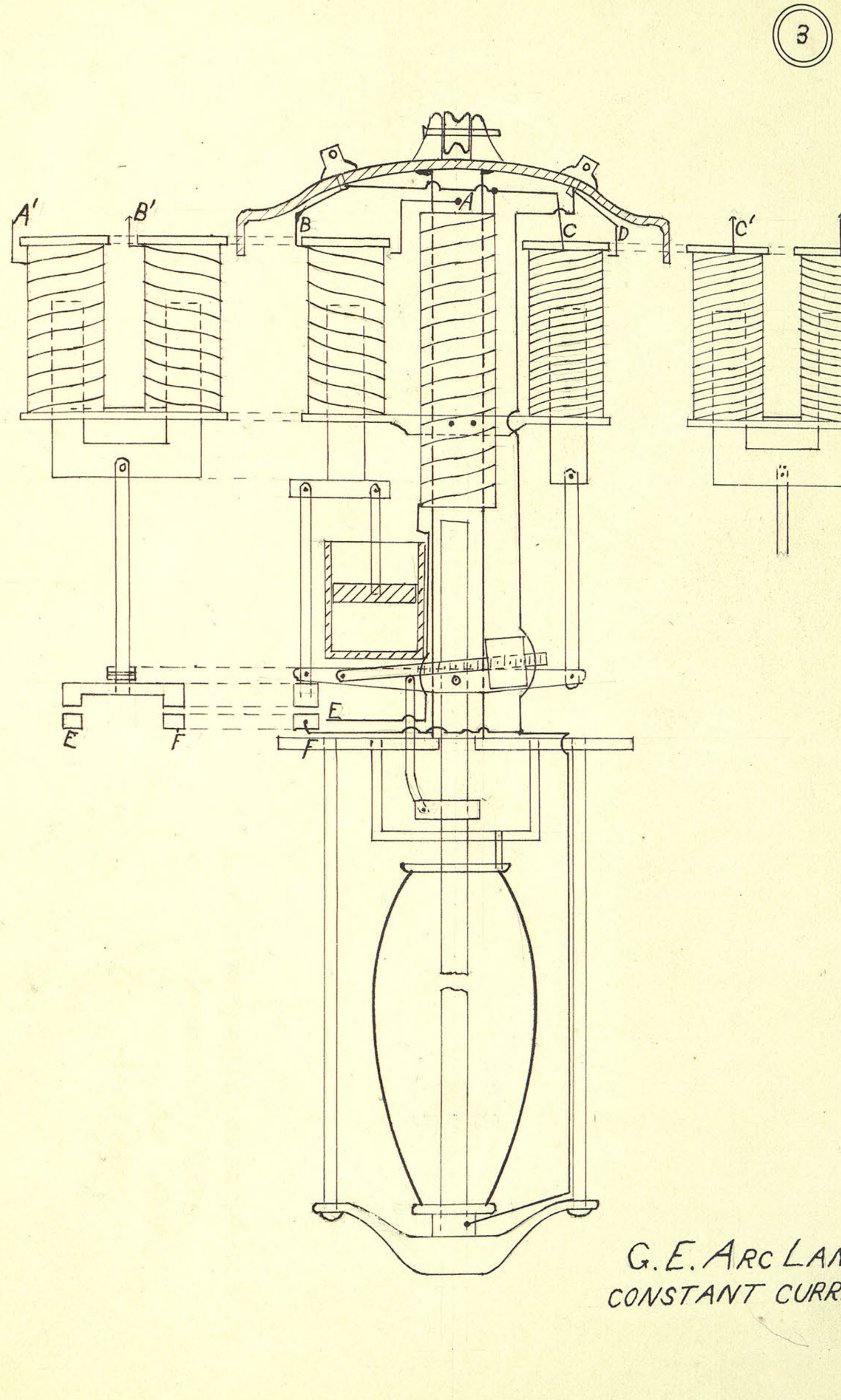
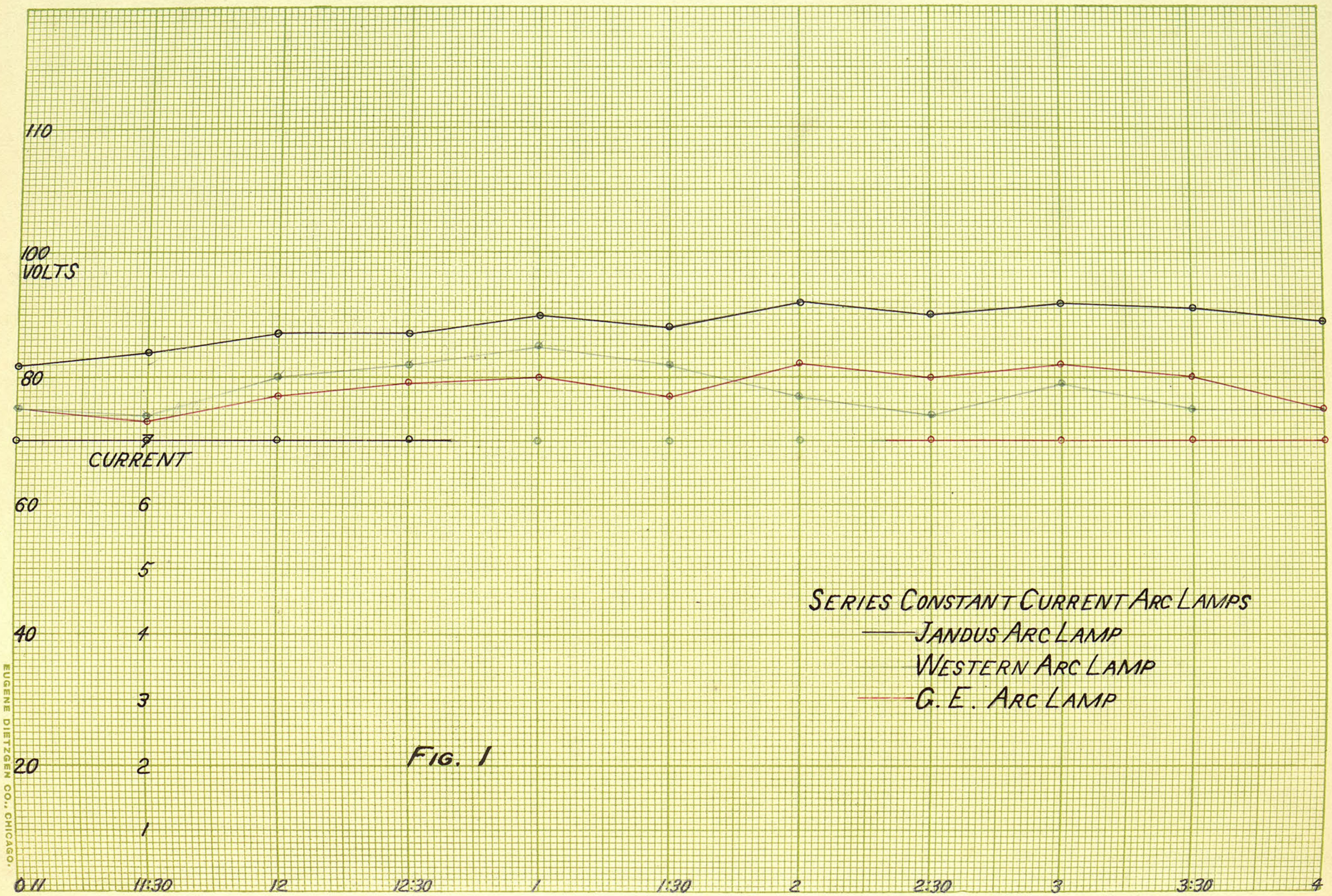



G. E. Arc Lamp
Constant Current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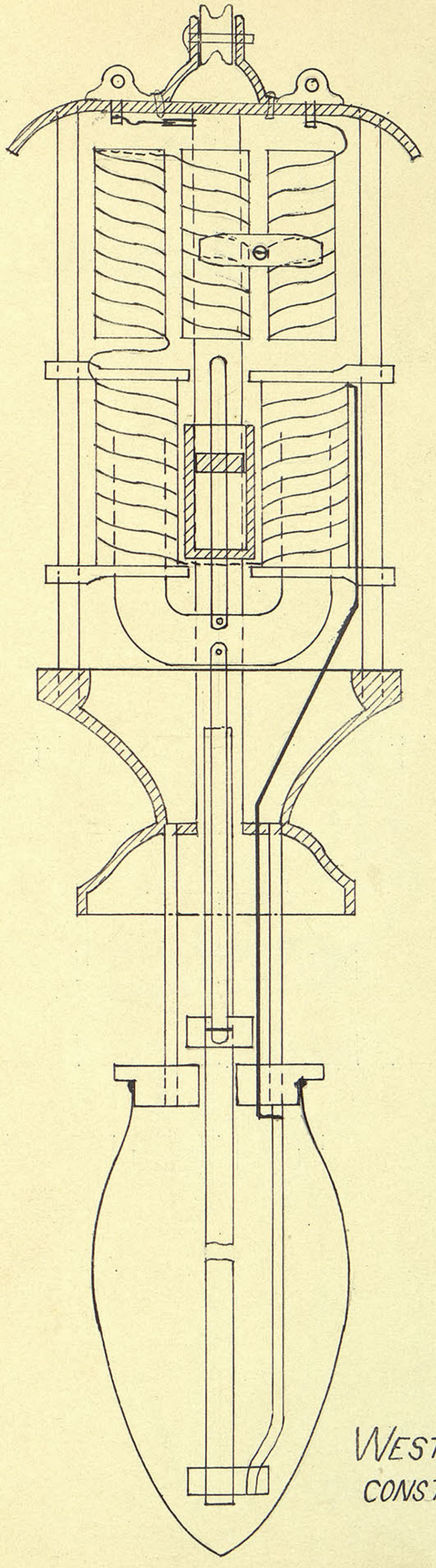
SERIES CONSTANT CURRENT ARC LAMPS
JANDUS ARC LAMP
WESTERN ARC LAMP
G. E. ARC LAMP
EUGENE DIETZGEN CO., CHICAGO.

FIG. 1

the carbons are not in working order. Plates 1, 2, and 3 show the general arrangements of the mechanisms of three standard makes of series arc lamps for alternating current. For direct current, the construction is practically the same except that the armatures and cores are not laminated as there can be very little loss with a direct current which is practically continuous. The current passes in turn through the lifting solenoid and the arc, a small portion being shunted around the arc through the fine wire coil which opposes the series solenoid. The shunt coil may become so strong as to operate the cut-out which throws the lamp almost entirely out of the circuit. When the cut-out operates, the entire current is thrown through a teasing coil of rather low resistance which is a shunt around the lifting solenoid and carbons. If the carbons come together, the resistance of the teasing coil throws enough current through the carbons to cause the cut-out to open and the arc to draw and burn as before. A hand operated switch cuts the lamp out entirely. Fig. 1 gives the regulation curves of the three arc lamps shown in the drawings. The lamps were run for five hours from a constant current transformer, readings being taken every half hour. The tests show the average power factors of the lamps, adjusted as they came from the factory, to be: General Electric, 83.5; Jandus, 83.8; Western Electric, 90.4. The average current was about seven amperes with an arc voltage of about seventy-five.

Multiple arc lamps are always operated with a resistance in series with the arc. About 30% of the lamp wattage is lost in this resistance, and, although it is certainly wasteful of power, it is necessary, nevertheless, because of a peculiarity of the



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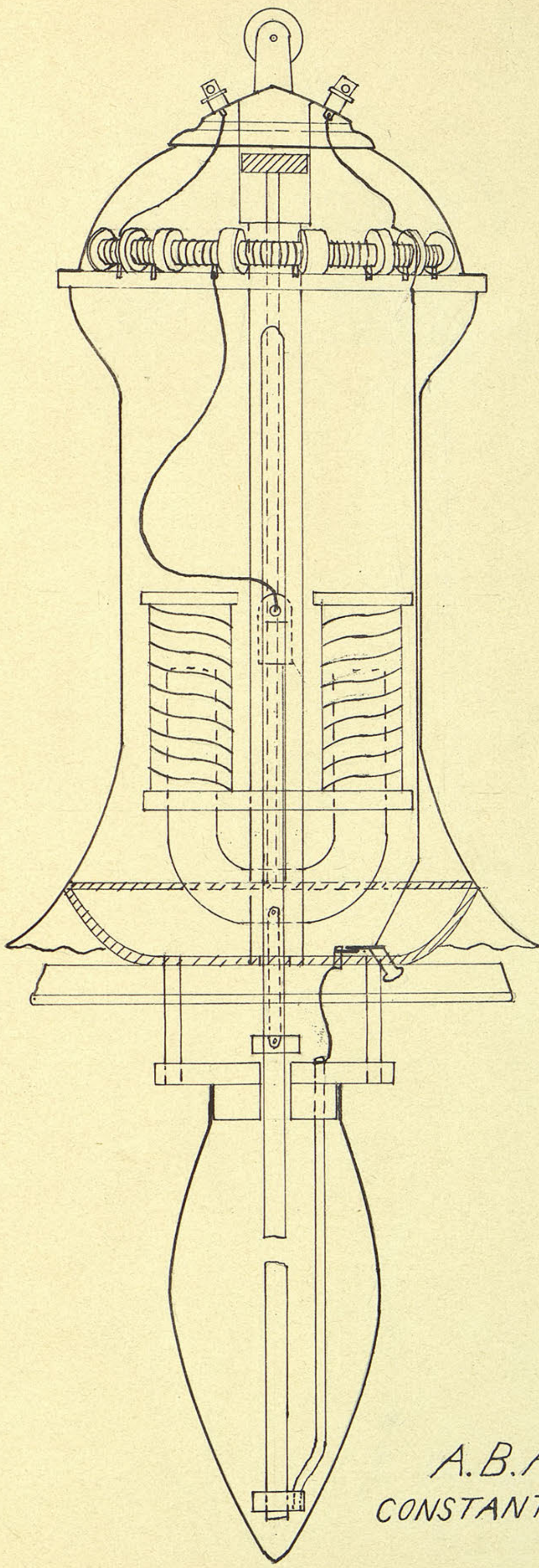
WESTERN ARC LAMP
CONSTANT POTENTIAL



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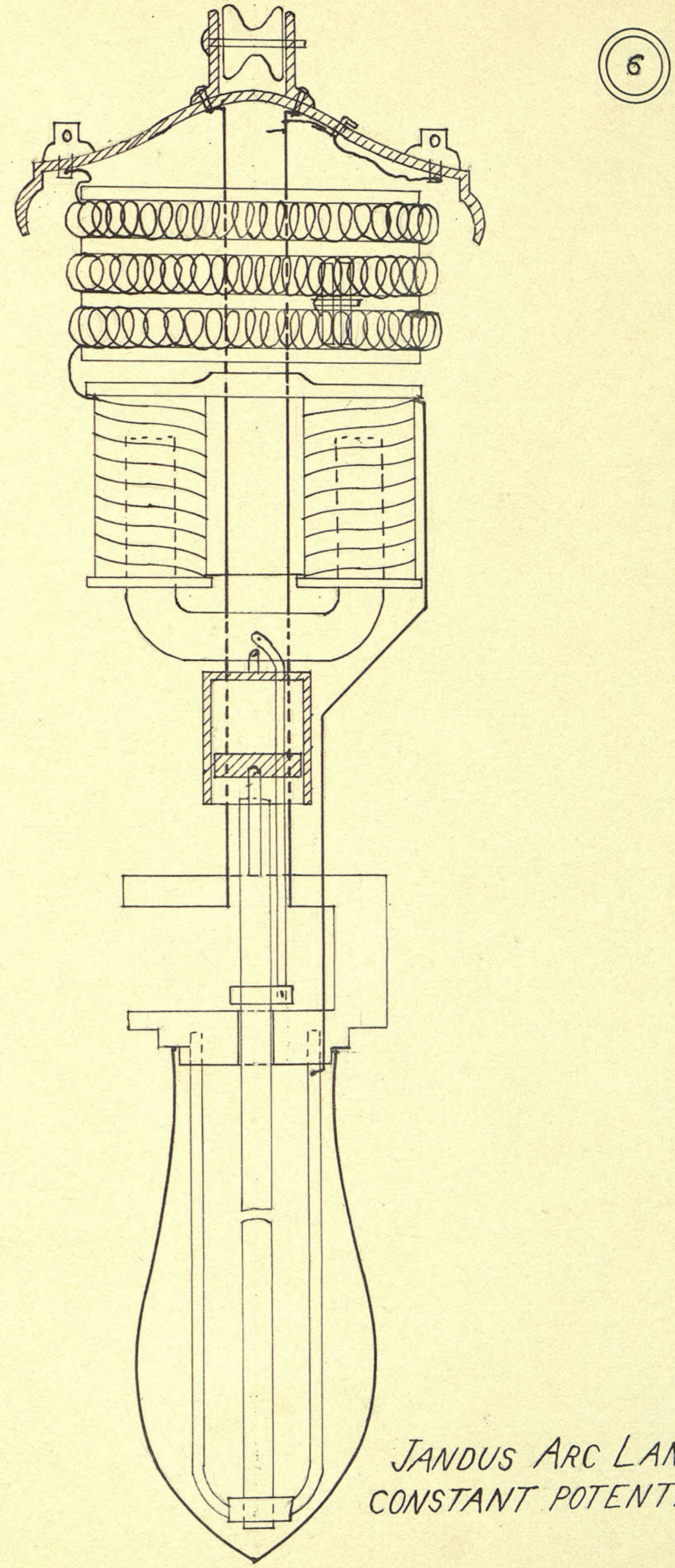
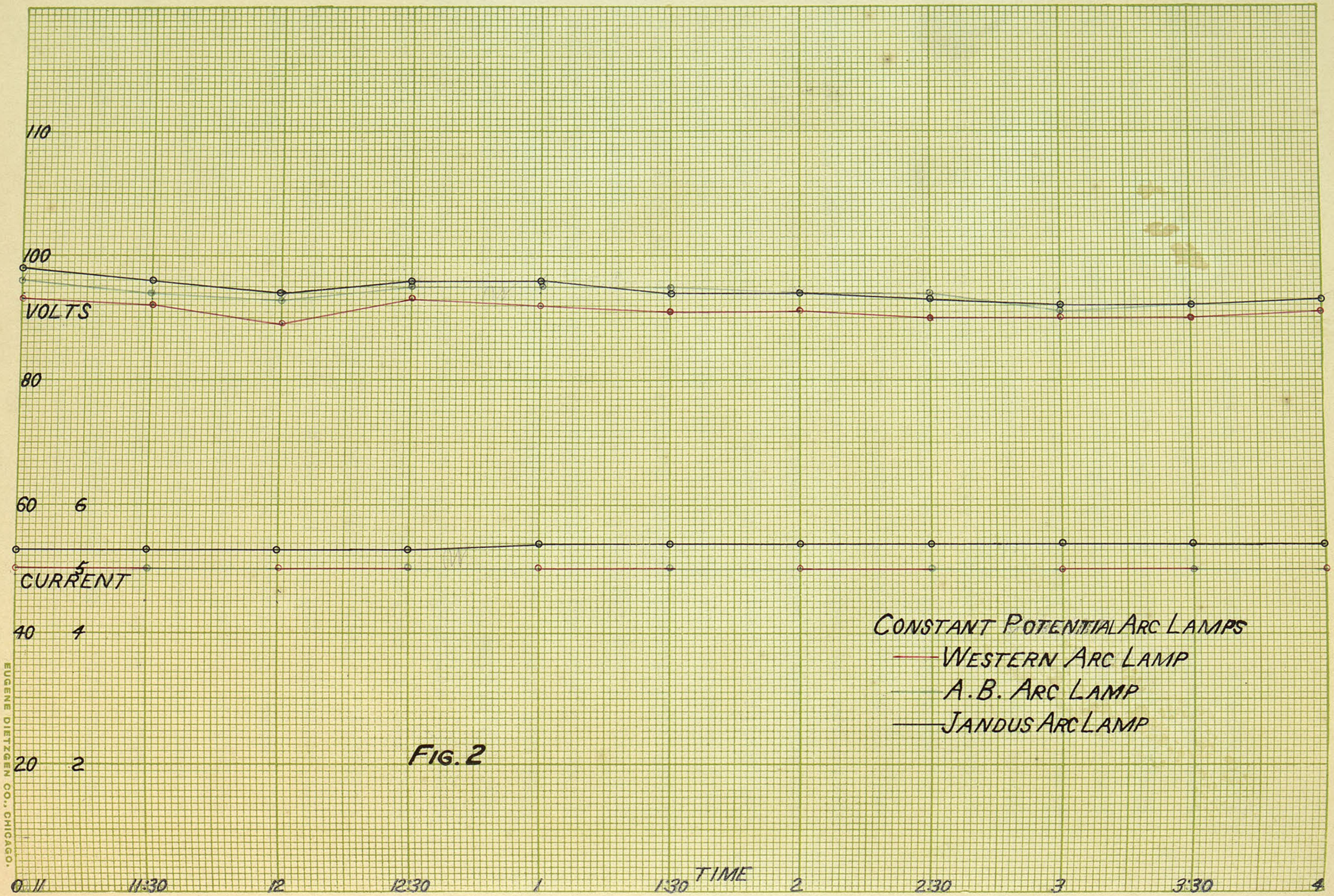
A. B. Arc Lamp
Constant Potential




JANDUS ARC LAMP
CONSTANT POTENTIAL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CONSTANT POTENTIAL ARC LAMPS
WESTERN ARC LAMP
A.B. ARC LAMP
JANDUS ARC LAMP
EUGENE DIETZGEN CO., CHICAGO.

FIG. 2

electric arc. The resistance of an arc depends upon its cross section. If no resistance were in series, the first effect would be that of a short circuit when the carbons are together and the current is turned on, but supposing the arc to be formed, if for any reason the current begins to increase, the resistance of the arc decreases and the tendency is for the current value to reach infinity. With a resistance in series, the fall of potential over the arc decreases as the current increases because the drop over the resistance varies as the current. The effect, then, of the resistance is that of an automatic electrical regulator which does not depend upon the inertia of moving mechanisms. Plates 4, 5, and 6 show the construction of three standard makes of lamps and Fig. 2 the regulation curves of the same lamps in multiple on a 110 volt direct current circuit. As in the case of standard series lamps, the general electrical and mechanical construction of multiple lamps is the same. The difference between alternating and direct current lamps is in the lamination of the iron cores and the substitution of a reactance coil for the resistance coil in the alternating current lamps.

An essential part of every arc lamp is the dashpot. The contact resistance of carbon is high but falls rapidly when the parts are heated. It is necessary, therefore, that the arc be drawn slowly in order that the drop over the carbons may not be greater than the lamp adjustment will allow. If the arc is drawn slowly, the carbons will heat so that the full arc voltage is soon operating. When the dashpot of a lamp is weak, the sudden jerk of the lifting solenoid breaks the circuit before the arc can be formed, the carbon then drops, is again jerked up, and the effect is a continual chatter of the carbons and clutch with no light. Dashpots are usually arranged so that the air cushion acts on the upward pull but is let out by a valve when the carbon is falling. Action is then so quick that the interruption of light is unnoticed. The barrels are usually placed so that the open end is down and so prevents dirt falling into and clogging the dashpot. Plungers are made either of brass or graphite. The graphite plunger has the advantage of self lubrication and is generally used. Brass plungers cannot be oiled for the heat from the arc would cause the oil to gum and the dashpot to stick.

CARBONS.

The carbons usually used in direct current lamps are 1/2 inch solid forced carbons. Open arc work called for hard carbons so they were made by being pressed hydraulicly in molds before baking. Enclosed arc carbons can be much softer and yet last longer than the globes remain clean. Soft carbons give a much better quality of light, the light containing less of the blue and more of the yellow.

For alternating current work cored carbons must be used. This necessity lies in the fact that the alternating current is continually broken and the arc resistance must be made small in order that the arc may hold over for the reversed current. The carbons are accordingly filled with a 1/16 inch core of some earth salt whose composition is a secret of the manufacturer. The core is more easily volatilized and so makes alternating arc practice a success. One carbon, either upper or lower, must be cored and the other solid. When cored carbons are used in direct current lamps the resistance must be adjusted for a fall of about four volts in an 80 volt arc. In the photometer work with an upper cored carbon, the light was much steadier and the curve given under "Lamp Efficiencies" shows the light to have a better distribution. The use of cored carbons in the direct current arc would be expensive because the stub of the upper carbon could not be used for the lower carbon at the next trimming as is the practice when both carbons are solid.

Some experimenting was also done with 3/8 inch and 1/4 inch lower carbons with 1/2 inch upper carbon in the direct current multiple arc. The 3/8 inch lower carbon made little appreciable difference because of its being so nearly the size of the upper, but with the 1/4 inch lower carbon the change was noticeable. The lower carbon was so small that its shadow was correspondingly decreased. Most apparent, however, was the small amount of light thrown upwards, for the lower carbon was so small and kept the arc so well centered that the upper carbon burned with a well defined cup-shaped depression with sharp edges. When this carbon was burning in an opalescent inner globe, the upper carbon threw upon the globe a well defined shadow about on a level with the arc. Another effect, when the arc jumped to one side of the carbon, was to cause the crater to be directed at what would ordinarily have been the dark side of the lamp. The end of the small carbon burned into a well shaped hemisphere.

The ratio of carbon consumption in the direct current enclosed arc is practically 2 : 1. The upper carbon is wasted by electrolysis, oxidation, and mechanical disintegration due to the action of the air currents in the globe. The lower carbon wastes mostly by oxidation and at the same time receives a deposit from the positive carbon. In a ten hour run, the ratio with the small carbons seemed to remain nearly the same, though nothing could be definitely decided as the fraction burned could not be more than 1/15 of the whole. The long life is due mostly to the exclusion of oxygen. The contents of the globe surrounding a burning arc is probably carbon monoxide. If a globe be removed immediately after the arc has been extinguished, the entire contents will burst into a blue flame like that of burning carbon monoxide. Many times, if a lamp be turned on in two or three minutes after being turned off, a minature explosion of the mixture of carbon monoxide and oxygen will follow the first flash of the arc. In lamps with loose globe caps, the caps will be blown up, or if the inner globe is clamped tightly against the globe seat, the globe itself may be shattered. The carbon consumption in alternating current lamps has a ratio of about 7 : 5. The upper carbon burns somewhat faster because of the effect of air currents in the globe.

## ARC LAMP TROUBLES.

The most frequent cause of annoyance from arc lamps on multiple circuits is their jumping because of variable voltage on the line. For example, a motor load which keeps the line voltage down during the day when thrown off at night allows the voltage to rise and the lamps accordingly jump. The remedy is of course in the line and the regulating resistance of the lamp. The trouble next in importance is that from crooked carbons. After the lamps are properly regulated, almost all troubles may be traced directly to the carbons. The carbons if crooked may stick in the guides and so cause the lamp fuses to blow or the lifting solenoid to burn out. Again, crooked carbons may not align and the points then slip partly past each other thus causing the lamp to take excessive current yet give scarcely any light. Lamp fuses must be heavy enough to hold the heavy starting current so that the fuses do not often show the lamp to be taking excessive current. Some times a scab of impurities will form on the end of the carbon causing the arc to shorten and give out a sickly yellow light. In some cases, a nonconductive ash will form over the end of the carbon and prevent the starting of the lamp until the cause of the trouble is removed. Sometimes the jumping of a lamp may be traced to a globe cap which having been blown from its seat has allowed the carbons to burn quickly in the large supply of oxygen and thus necessitate frequent feeding. A continuous chatter of the carbons is due either to very low voltage or to dashpots which are too weak to steady the action of the lifting solenoids.

## PHOTOMETRY.

The general process of photometry is to balance an unknown light valve against a standard. The usual method is to so place a white screen that the intensity of the light of unknown value at that distance or angle is equal to the light intensity of the known which is an arbitrary standard. Even with the best apparatus and experienced operators, photometry is rather uncertain and writers make the point that results obtained by inexperienced operators are not reliable. When all conditions are the best possible, one source of error is the uncertainty of the light standard. Different lights have been tried all of which have a number of undesirable qualities. The best standard in use at present is the amylacetate lamp originated by Hefner, a German light expert in the government service. This standard is called the Hefner unit and its light intensity is about .91 of the standard English candle. The lamp itself is very simple in construction, having a wick resting in amylacetate with an adjusting screw for raising or lowering the wick and so keeping the flame at a constant height. Most of the light standards vary in intensity with air pressure, amount of water vapor present, and kindred conditions which are very difficult to control, and so make accurate photometry very complicated. However, the Hefner standard is by far the best because of the ease with which it can be reproduced. Hefner lamps, standardized, tested and certified, by the German experts, are used all over the world and are rapidly becoming standard.

The principal objection to the Hefner light is its color which is a redish orange and therefore entirely different in color from commercial lights. The flame, too, must be naked so that unless the photometer room is very quiet, the intensity of the standard light will vary. Even the movements of the operator set in motion air currents which seriously interfere with the work. For that reason, incandescent lamps, calibrated with the Hefner standard by experts, are being used as secondary standards in commercial work. The lamps are first aged by several hundred hours burning, then tested at a certain voltage which with the power in English candles or Hefner units is etched upon the bulb. Etchings also indicate the side of the filament which must be turned towards the photometer screen as the light intensity varies somewhat because of the amount of filament exposed.

A second source of error, even under the best conditions, is what is called the "personal equation". Into all experiments requiring fine distinctions the personal equation enters to a degree unsuspected by the uninitiated and it is particularly prominent in photometric work. The eyes of some persons are so constituted that they have no conception of color and a similar condition, though to a much less degree seems to hold in photometry. No two operators judge the lights exactly alike due perhaps to the different colors of the two lights under comparison as they are never exactly the same except in case of a coincidence. It was found that when a 25 candle power incandescent lamp for use as an arc lamp standard was being compared with a 16 candle power lamp from the U. S. Bureau of Standards that one of the two operators invariably read from one-half to one centimeter nearer the standard than the other on a two hundred fifty centimeter photometer bench. In this particular case the different readings caused a difference of 2% in the calculated candle power of the arc lamp standard.

THE PHOTOMETER.

At the present time, the Matthews integrating photometer is the best of the many in existence for arc light work. The principal feature is a vertical circle of mirrors with the electric arc in the center. These are set at such an angle as to center all the reflected light upon a single screen where the intensity is compared with the standard due allowance being made for the light absorbed by the mirrors.

The best instrument available for this work was the Lummer-Brodhun photometer. In the operation of this photometer, the standard light and the one which is to be calibrated are placed on opposite ends of a graduated photometer bench two hundred fifty centimeters long. A sliding screen on the bench between the two lights is so placed that the light intensities are equal on either side. The special feature of the Lummer-Bodhun photometer is the sight box for viewing the two sides of the screen simultaneously. The arrangement is shown in Fig. 3

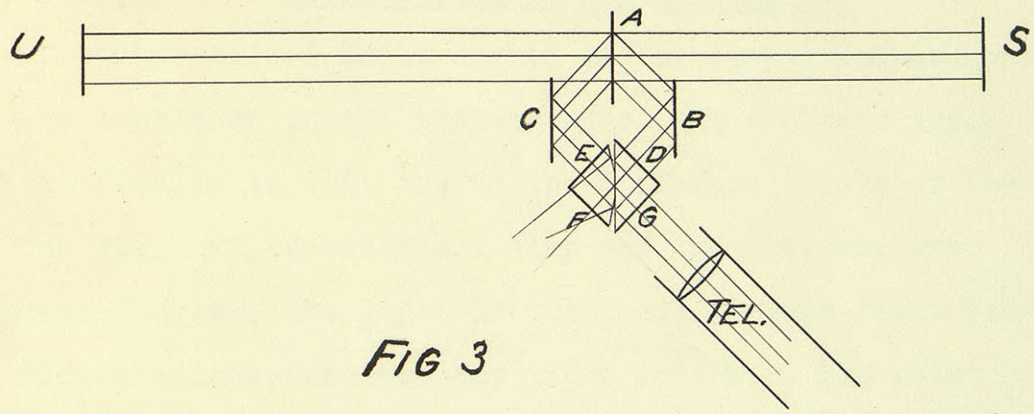



FIG 3

U is the light whose intensity is unknown and S the standard. The light from S is reflected from the screen A to the mirror B and from there to the glass prism D which is so arranged that the light strikes in a perpendicular direction and if any is reflected the amount will always be constant. The light travels in a straight line until it is incident on the inner face of the prism. That incident where the other prism makes contant with DG goes straight through and is absorbed by the black lining of the sight box. That incident where the prism is in contact with air is reflected into the sighting telescope. Light from the opposite side of A is reflected by means of C to, E, passes through, and as before is not reflected where the two prisms are in contact. Suppose the light incident upon A from S were of greater intensity than that from U. The view to one looking into the sighting telescope would be that of a rather dark spot circular in shape surround by an annular ring of greater intensity. The entire box is so arranged that the operator may turn it over and so reverse the whole arrangement by that revealing any error in the adjustment or unequal absorptive power of the mirrors or prisms. If that were done in this case, the center would be the bright area surrounded by a darker annular ring.

## DIFFICULTIES OF ARC PHOTOMETRY.

If photometrical measurements are at best somewhat uncertain, they are doubly so in the photometry of the electric arc. The first difficulty is that due to the different colors of the light from the standard incandescent lamp and the electric arc. On the photometer screen, the light from the arc appears light blue and that from the incandescent lamp light yellow. The point at which the illuminations become equal is very difficult to judge because of the difference in color. The best way of surmounting the difficulty is to view the image through colored glass held between the eye and the eye piece of the sight telescope. Pure green probably cuts out less light common to both than any other color and accordingly was used in the experiments. It is then a simple matter to find a balance as far as color is concerned yet the values ascertained must be uncertain.

An annoying feature of arc light photometry is the constant flicker and chase of the arc especially with arcs enclosed in clear globes. Enclosed carbons burn almost flat on the end and as a pit is burned at one place, the arc, following the path of least resistance jumps to the next promontory and so on until the carbon is burnt so that the lamp feeds. Many times in setting the screen the operator found a balance only to see one spot suddenly grow light while the other was dark,yet before the screen could even be moved the lights would reverse. The method taken to partially eliminate this difficulty was to take an average of ten readings which in so far as possible included the extreme settings. The second difficulty added to those of photometry is easily apparent.

A third difficulty in finding the mean candle power of an arc lamp is the difference in light intensitites at different angles, the light at one particular angle being in some cases ten times that at another angle. This not only makes difficult the calculation of the mean candle power of the lamp but also introduces a new difficulty in the mechanical part of the process of arc light photometry. One method is to have a photometer so arranged that one end can be raised or lowered to keep it in line with the lamp as it is raised or lowered and so take in the various angles. The disadvantage of this method is that everything on the photometer bench must be fixed so that it will not slide off. That would of course include the carriage and so make trouble in shifting the screen. The operation of raising or lowering the photometer would also be unsafe without a rather complicated mechanism. The simplest and easiest method in so far as the actual operation is concerned is that in which the lamp is shifted and a mirror on the end of the bench used to throw the light upon the screen. The objection to the mirror method is that the mirror must be perfectly plane so as not to disperse or converge the light. The best mirrors absorb at least 10% of the light incident upon them and also absorb different amounts at different angles. If mirrors are used the percent of light absorbed at the different angles must be predetermined and here again light colors would cause uncertainties; the mirrors would probably absorb more light of one color than of another. A third method and the one used in these experiments is that of leaving the photometer bench in its normal horizontal position and inclining the axis of the arc lamp to the various angles. Again difficulties and uncertainties present themselves. The chief source of uncertainty is abnormal regulation. With the lamp axis inclined, some of the weight of carbons and holder is taken off the lifting solenoids and thrown onto the guides where the friction destroys the natural regulation of the lamp. Recourse must be had to hand regulation which is slower and more uncertain than automatic regulation. Again in any other than a vertical position of the carbons, the action of the air currents even in a small enclosing globe is to cause the arc to stream upward and so partly prevent the usual flicker. Judging from experience with the third method, the first is the most reliable but the second combines reliability and simplicity to the greater degree in case the equipment necessary for the first is not obtainable.

The lamp used in most of these tests, that made by the Adams-Bagnall Company, is so constructed that the part enclosing the working solenoids obstructs the light at an angle greater than 30° above the horizontal. The lower angle limit is 60° below the horizontal. This lower limit was defined by the difficulty in lamp regulation at a greater angle. The limits, however, are extensive enough to give a comparative idea of the intensities plotted in the curves.

## GLOBES AND REFLECTORS.

If only lamp efficiencies were considered, globes would not be used, for experiments show that they absorb from 10% to as much as 65% of the light from the arc which they surround. However, other considerations such as appearance and dispersion enter so that globes are desirable. Inner globes are of course necessary in enclosed arc light practice but much is gained by the use of outer globes and reflectors which does not always show on the photometer. The greater part of the light from the electric arc comes from a small spot not more than 1/8 inch in diameter so that it is needless to say even to those who have never looked directly at an open arc that the light is too brilliant for the naked eye. The effect is to narrow the pupil of the eye so that only the objects directly in the rays seem light while those farther off seem to be in deeper shadow than if the light were not nearly so intense. The small area of the light source has also a marked tendency to throw a deep shadow from upper and lower carbons and the lower carbon supports. For these reasons, the best use of globes and reflectors varies with the conditions. For street lighting where the object is to throw the light as far as possible, clear inner globes with shades make up the necessary equipment except in cases where rain might be blown against the hot inner globes and cause them to break. Then outer globes must be used. For indoor lighting the case is entirely different. Here it is necessary to prevent all shadows so far as possible and also to soften and disperse the light. The best equipment for this is the indispensible inner globe of clear glass, an opalescent outer globe, and a shade. The shade is omitted in ordinary practice especially in direct current work because of the increased cost with little gain of efficiency. In some installations, shades are used and the opalescent outer globe omitted. This is bad practice for inside work even if the inner globe be opalescent. Experience shows that the shadows of the lower carbon and its support are a source of constant annoyance which is almost if not entirely prevented by the use of an opalescent outer globe. The opalescent globe because of its large diameter and its dispersing ability has an effect like that which causes the penumbra of a shadow and prevents a sharp shadow at any one spot. Curves 3 and 4 in Fig. 4 are comparative curves plotted from data taken from a lamp burning a cored upper and a solid lower carbon. Curve 3 was taken with a clear inner and an opalescent outer globe while curve 4 is with opalescent inner globe only. The outer globe doubled the light radiated at the more nearly horizontal angles and only slightly reduced that at 45°.

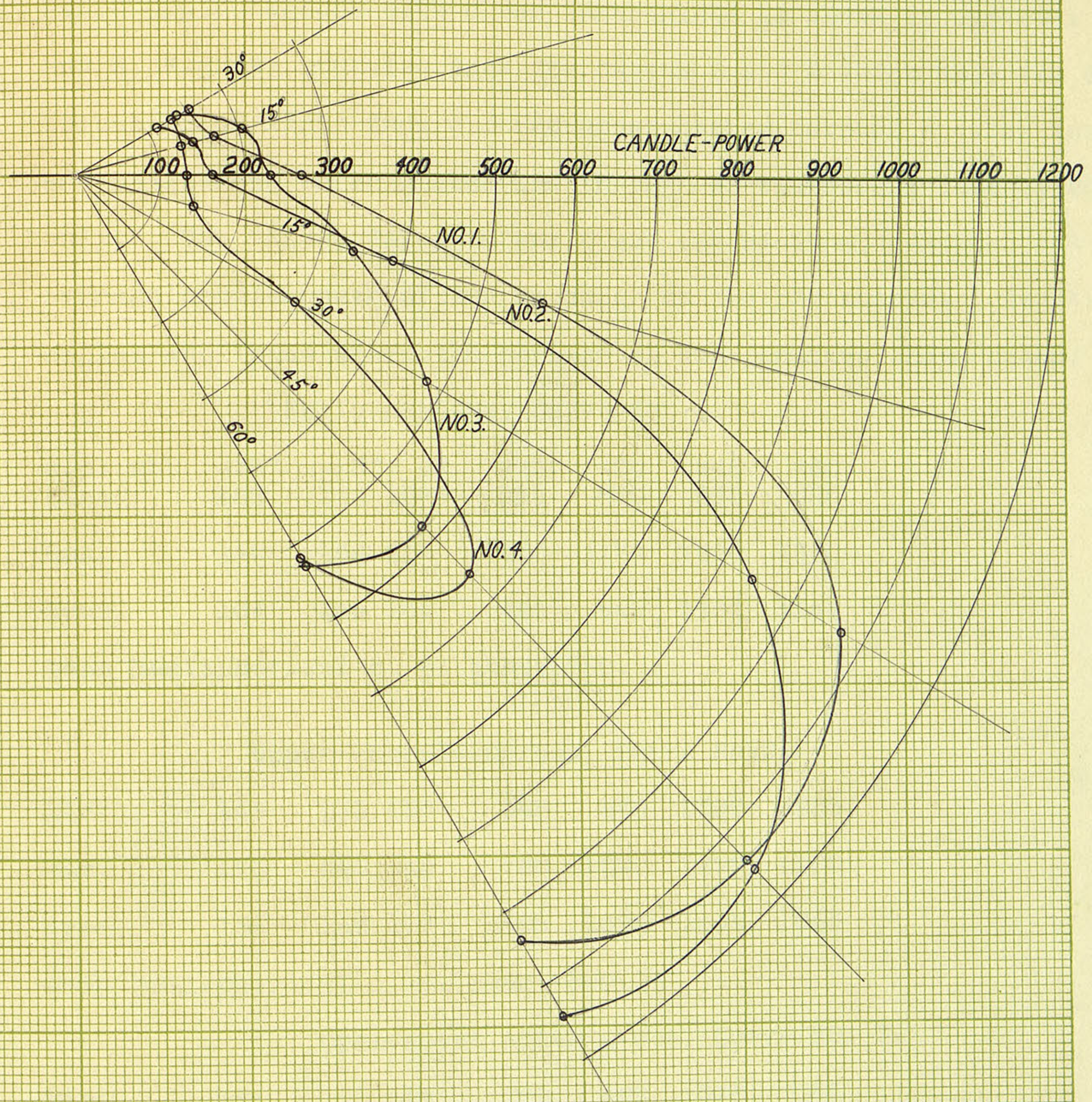
A peculiar practice noticeable in some installations is that of using an opalescent inner globe with that of a clear outer globe. Just where the advantage lies in this arrangement is difficult to perceive. Almost all the dispersing is done by the inner globe so that the outer globe is useless. An advantage of the reverse of this arrangement, clear inner and opalescent outer globe, is that not only is the light better dispersed and the shadows less sharp but the total light is radiated from a large area so that the pupil of the eye widens and the effect is that of more light. Another advantage is that the lower carbon and inner globe supports are hidden by the opalescent outer globe thus much improving the appearance of the lamp.

## ARC LAMP EFFICIENCIES.

The absolute light efficiency of different lights has been ascertained to be approximately as follows: Candle, 1.5%; gas flame, 1%; Welsback, 2.5%; magnesium, 12%; incandescent electric, 5%; and electric arc, 13%. These figures are uncertain but they are at least comparative. The absolute efficiency of a light in the per cent of the total enery going into the lamp which is given off as light. The makers of the new magnetic arc claim for it an efficiency twice that of the ordinary arc lamp so that its absolute efficiency at the lamp terminals may be as high as 20%.

The actual light efficiency of an arc lamp depends pretty nearly on the current flowing, for the size of the crater depends upon the current flow and the light is constant per unit area of crater. The arc wattage increases with the length of the arc and, since the light radiated depends upon the current flowing, with a constant current, an increased length of arc increases the load upon the generator without increasing the arc efficiency. A rather long arc is necessary, however, in order to decrease the carbon shadow and, in enclosed arcs, to give time for consumption of the volatilized carbon in the arc stream and so keep the globe deposit at a minimum. Enclosed arcs, then, are less efficient than the open arc because of the necessarily decreased current and the globe absorption. Yet, though the photometer shows enclosed arc lighting to be a backward step in so far as light intensities are concerned, the attendant advantages more than compensate for any loss of efficiency. It must also be remembered that to the human eye the enclosed arc <u>seems</u> more efficient than the open arc.

Because of the difficulties of arc light photometry and the calculation of the mean candle power of the electric arc it was the custom formerly to rate lamps consuming approximately 450 watts at the arc as 2000 c. p. and those using 320 at the arc as 1200 c. p., but now because of the decrease in current, the increase in arc voltage, and the use of dispersing globes and reflecting shades, it is usual practice to rate the lamps in current flow and watts over the arc. For the same reasons, the term efficiency is little used and then only for rough comparisons. In




CANDLE POWER CURVES

A. B. CONSTANT POTENTIAL ARC LAMP

NO.1 - UPPER CARBON CORED

NO.2 - SOLID CARBONS

NO.3 - OPALESCENT OUTER GLOBE

NO.4 - OPALESCENT INNER GLOBE

FIG. 4

the following table are the data of photometer tests for cored and solid upper carbons with clear inner globe as shown in Curves 1 and 2, Fig. 4; and also data for Curves 3 and 4 which show the distribution of light from a cored upper carbon through a clear inner and opalescent outer globes and through an opalescent inner globe only. The values for each angle are the minimum, maximum, and average candle power of ten readings on the photometer. Negative angles are those above the horizontal and positive those below:

Solid carbons, Curve No. 1.

| c.p. at | -30° | -15° | 0° | +15 | +30 | +45 | +60 |
|---|---|---|---|---|---|---|---|
| Min. | 182 | 122 | 137 | 315 | 710 | 920 | 980 |
| Max. | 147 | 164 | 214 | 460 | 1135 | 1290 | 1350 |
| Aver. | 104 | 145 | 162 | 400 | 940 | 1153 | 1144 |

Mean hemispherical c. p. about 760.

Upper--Cored--Carbon, Curve No.2.

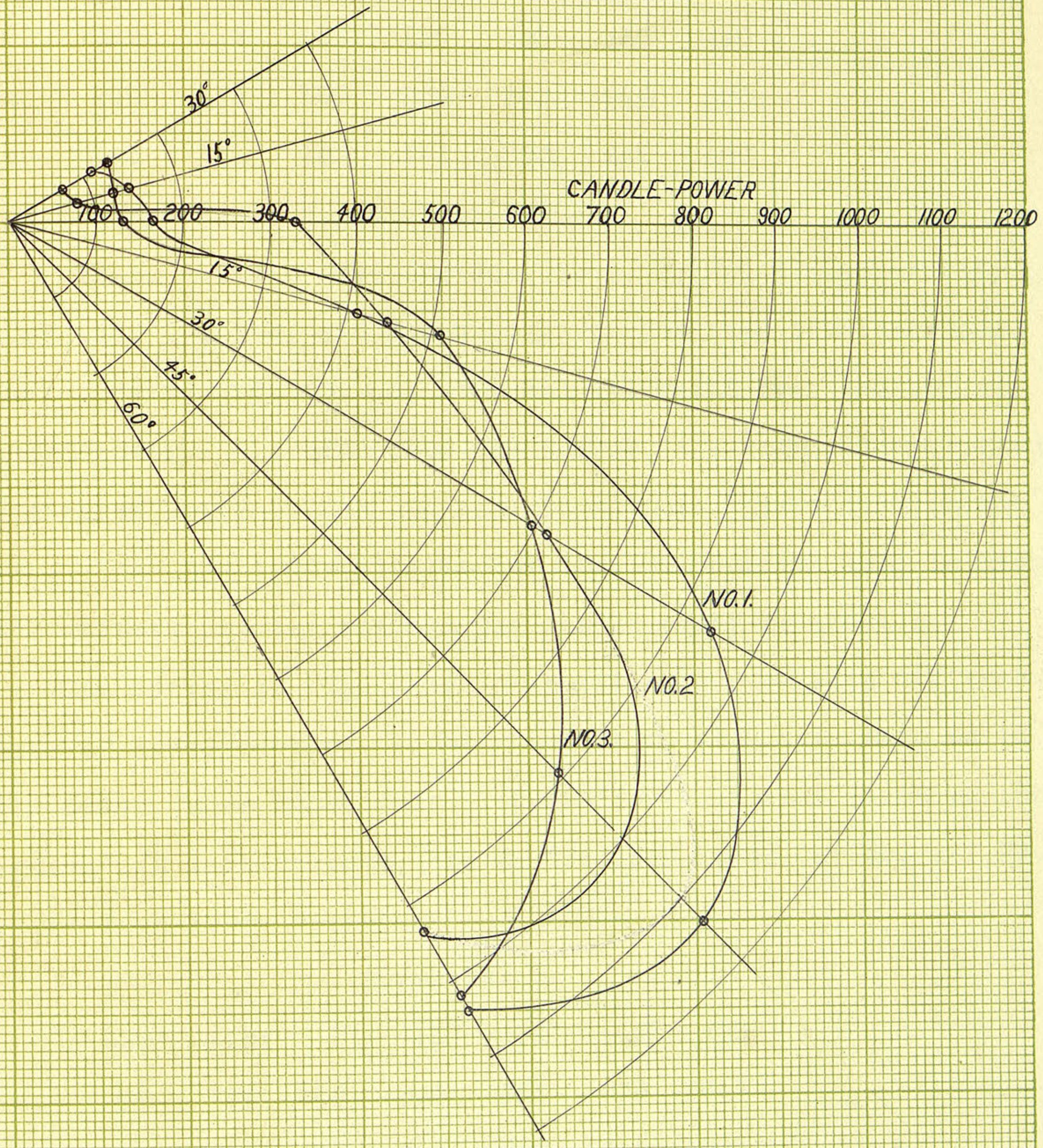
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Min. | 145 | 133 | 156 | 345 | 870 | 1030 | 930 |
| Max. | 170 | 240 | 440 | 780 | 1300 | 1290 | 1160 |
| Aver. | 156 | 168 | 277 | 568 | 1076 | 1142 | 1045 |

Mean hemispherical c. p. about 800.

Opalescent outer globe, Curve No. 3.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Min. | 121 | 193 | 215 | 280 | 400 | 378 | 365 |
| Max. | 164 | 225 | 235 | 390 | 550 | 770 | 740 |
| Aver. | 132 | 210 | 225 | 340 | 475 | 585 | 525 |

Mean hemispherical c. p. about 430.




CANDLE POWER CURVES
A.B. CONSTANT POTENTIAL ARC LAMP
NO.1. $\frac{1}{2}$" CARBON 78 VOLTS OVER ARC
NO.2. $\frac{1}{4}$" ,, ,, ,, ,, ,,
NO.3. $\frac{3}{8}$" ,, ,, ,, ,, ,,

FIG 5

Opalescent Inner Globe, Curve No. 4.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Min. | 127 | 119 | 137 | 130 | 208 | 550 | 440 |
| Max. | 190 | 155 | 163 | 158 | 365 | 790 | 670 |
| Aver. | 155 | 131 | 147 | 141 | 298 | 660 | 522 |

Mean hemispherical c. p. about 350.

These results give for Nos. 1, 2, 3, and 4 respectively about .74, .7, 1.3, and 1.6 watts over the lamp terminals per candle power, and .53, .5, .93, and 1.1 watts over the arc per candle power. Judging from the Curves, the light distribution with cored upper carbon and opalescent outer globe is much the best. The light distribution of the incandescent lamp is much more uniform but the wattage per candle power is about 3.

The curves in Fig. 5 are comparative curves with different sizes of lower carbons. Both carbons in each case were solid with clear inner globe only. Curve No. 1 is that given by the regular 1/2 inch carbons, No. 2, 3/8 inch lower carbon, and No. 3, 1/4 inch lower carbon.

Curve No. 2.

| | -30° | -15° | 0° | +15° | +30° | +45° | +60° |
|---|---|---|---|---|---|---|---|
| Min. | 66 | 73 | 265 | 390 | 625 | 920 | 1013 |
| Max. | 73 | 86 | 390 | 510 | 740 | 1054 | 1060 |
| Aver. | 71 | 79 | 330 | 448 | 710 | 995 | 1032 |

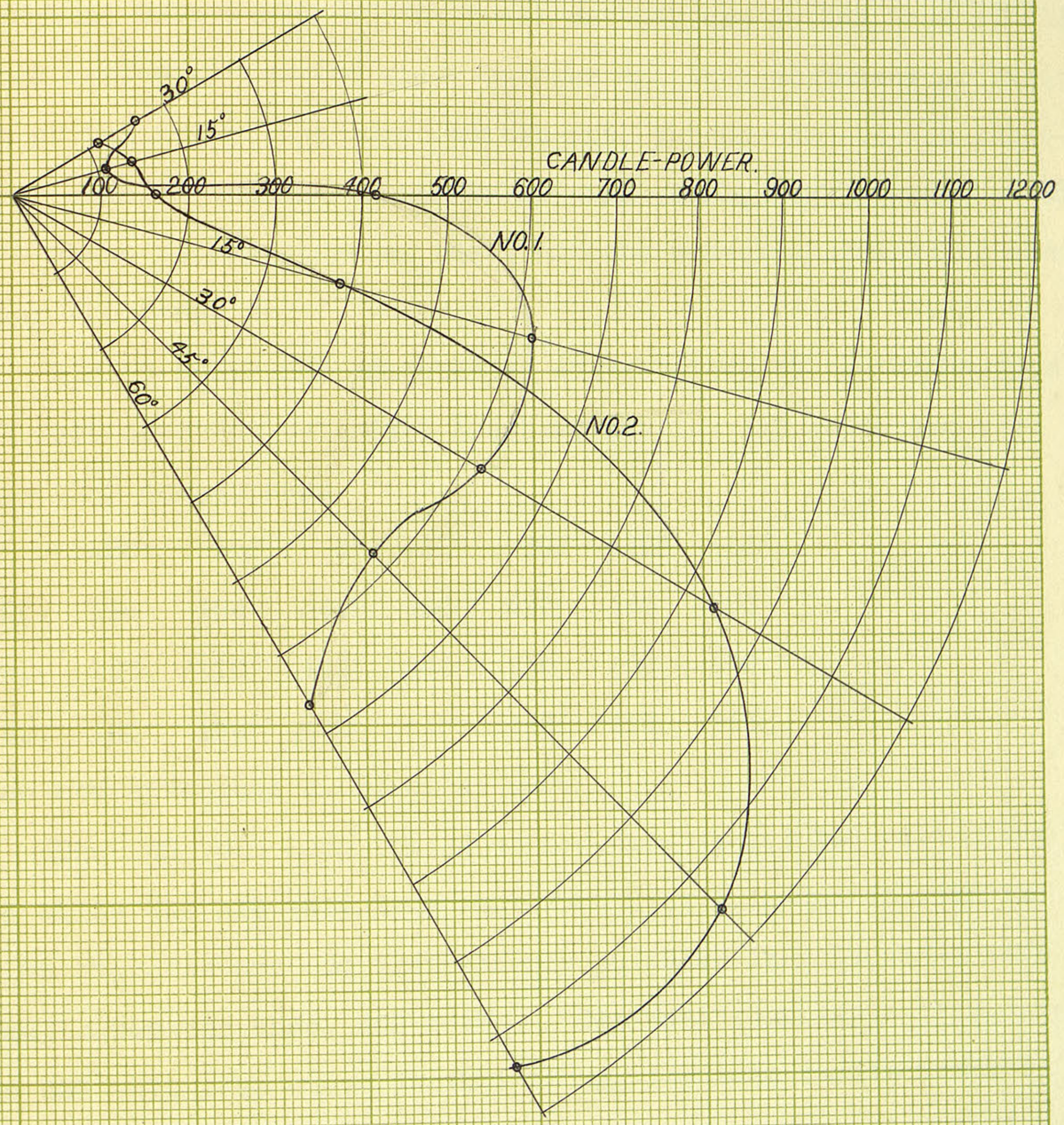
Mean hemispherical c. p. about 700.

Curve No. 3.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Min. | 70 | 103 | 103 | 320 | 600 | 750 | 960 |
| Max. | 180 | 164 | 144 | 700 | 815 | 1000 | 1068 |
| Aver. | 140 | 129 | 128 | 510 | 690 | 891 | 1020 |

Mean hemispherical c. p. about 650.

It is unlikely that the true candle powers given by the




CANDLE POWER CURVES
CONSTANT POTENTIAL ARC LAMPS
NO.1. WESTERN LAMP 220 VOLTS
NO.2. A.B. LAMP 110 VOLTS.

FIG. 6

three carbons are so different as the curves seem to indicate though as both curves of the small carbons are inside that of the large carbon either the small carbons are less efficient or during the photometry of the large carbon arc, the arc was on the photometer side of the arc enough to give an unduly high average. This test shows no advantage of small carbons except a diminished shadow under the lamp.

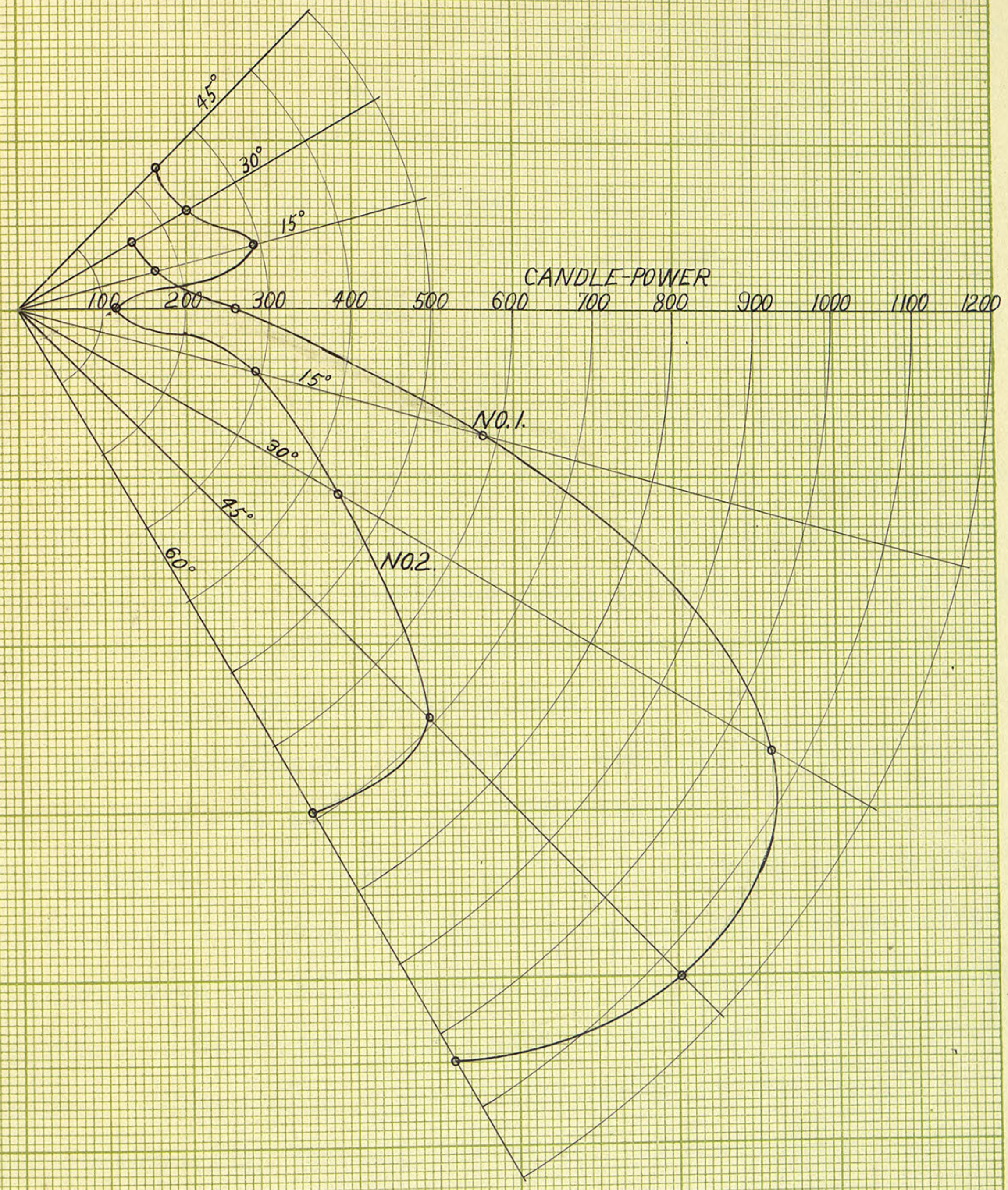
Fig. 6 shows the comparative distribution of the light from a 220 volt constant potential arc lamp and the 110 volt lamp used in the other comparisons.

| | -30° | -15° | 0° | +15° | +30° | +45° | +60° |
|---|---|---|---|---|---|---|---|
| Min. | 164 | 104 | 365 | 530 | 530 | 485 | 530 |
| Max. | 167 | 110 | 465 | 760 | 670 | 660 | 800 |
| Aver. | 165 | 105 | 420 | 617 | 613 | 574 | 666 |

Mean hemispherical c. p. about 580.

The 220 volt lamp burned with 3 amperes and 138 volts over the arc while the 110 volt lamp as before drew 5.1 amperes with 78 volts over the arc, so that the arc wattages in both cases were practically the same, 400 watts. The most remarkable thing about the 220 volt lamp curve is that though the mean candle power is low the distribution is almost ideal, the candle power being much greater on the horizontal and less at 45° degrees so that the curve closely approaches a quadrant of a circle. Another noticeable thing is the small variation of candle power due no doubt to the long arc.

The curves of Fig. 7 show the comparative efficiencies of the alternating and direct current arcs. The wattage of the alternating current arc averaged 450 as against 400 in the direct current arc.




CANDLE POWER CURVES OF
NO.1. A. B. CONSTANT POTENTIAL ARC LAMP
UPPER CARBON CORED.
NO.2. JANDUS CONSTANT CURRENT A.C. ARC LAMP
UPPER CARBON CORED.

FIG. 7

Curve No. 2.

| | -45° | -30° | -15° | 0° | +15° | +30° | +45° | +60° |
|---|---|---|---|---|---|---|---|---|
| Min. | 200 | 180 | 153 | 76 | 189 | 225 | 610 | 610 |
| Max. | 270 | 275 | 236 | 152 | 420 | 510 | 840 | 870 |
| Aver. | 233 | 230 | 195 | 116 | 295 | 430 | 698 | 694 |

Mean hemispherical c. p. about 450.

This shows the hemispherical efficiency of the alternating current arc to be one-half that of the direct current arc though the efficiency could be much increased by the use of a good reflector. This curve is the most uncertain curve of all. The voltage over the arc was constantly varying between wide limits and so made large variations in the candle powers.

Notwithstanding all its defects, arc lighting is far ahead of other systems both because of the light color and the flexibility of the system. The electric arc lamp is probably the most inefficient electric machine in commercial use,yet again it compares most favorably with any of its competitors. If one were to calculate the absolute efficiency of the electric arc from its beginning in the coal bunkers of an electric lighting plant, the result would be most discouraging, yet only one century of knowledge of the electric arc has placed it above other lights except in cases where natural resources enable some other system to be much more cheaply operated. With the steady increase of electrically operated industries, electric lighting will continue to grow in importance because the power for the lights may be cheaply produced in connection with that for the main system. If one may judge from the growing importance of electricity, the electric arc lamp has an assured place in commercial work.