CONTROL of STREET LIGHTS
by
SOLAR RADIATION.

A

Thesis

Presented

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of the

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by

Alvan Fisher

in

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Approved.

FOREWORD

This thesis was undertaken at the suggestion of Mr. C.A.B.Halvorson,Jr. - designing engineer of the Street Lighting Department of the General Electric Company. To him, the author is greatly indebted for the use of the facilities of his department and to the many courtesies and favors extended.

Great appreciation is also had for the kindly interest and hearty cooperation offered by Prof. W. J.Drisko of the Massachusetts Institute of Technology and by Mr. R.B.Hussey, physicist, of the General Electric Company.

STATEMENT OF PROBLEM

The purpose of this research into solar control of street lights was to experiment and attempt to develop some means or apparatus whereby an effective control of an electric circuit could be obtained by means of the varying light intensities from sunrise to sunset. This meant that some form or other of a sun valve must be developed which would operate to turn off the street lights at or before sunrise and to turn them on again at or after sunset. Naturally, ideal operation would cause the lights to be turned off or on just as twilight merges into daylight and vice versa. The other limit should be that the valve should not operate later than sunrise or earlier than sunset. Of course, the time before sunrise and after sunset at which the valve would operate, if that is possible, is dependent upon the season of the year- the time varying with the variation in twilight which, of course, is longer during the summer months. Though other methods of controlling street lights have been proposed and a few installations actually put into operation, they are, for the most part, based on some clockwork arrangement. However, this problem is concerned with solar control through some form of a sun valve and therefore no research or development has been undertaken along any but this one line.

ADVANTAGES OF EXACT CONTROL OF STREET LIGHTS.

Street lighting by electric lights, as it is now usually developed, is accomplished by means of a system of series circuits, with each individual circuit emanating from and controlled directly at the central station. This means that there will be many circuits coming into the power station, necessitating a large switchboard, additional transformers, extra circuit breakers, and all such apparatus required to adequately control the various systems. Then, each day at definite times, obtainable from a street lighting schedule, the switchboard is operated and all the lighting circuits are energized or de-energized as the case may be. The street lighting schedule is a table of times at which the street lights should be turned on or off- the time of operation averaging a half hour before sunrise and a half hour after sunset. Based on these times, street lighting contracts are usually made for four thousand operating hours a year. Street lighting circuits are most always series circuits, though this does not necessarily mean that the lamps themselves are also in series for they are generally considered to be in multiple through small transformers at each light. However, if the street lights, either singly or in small systems of twenty-five to fifty lamps--the number of lights in each system depending upon the size of the lamps- are connected to the multiple house lighting and power circuits and are regulated by some remote method of control, such as by a sun valve, a great elimination of apparatus will be noticeable at onee. There will no longer be a duplication and parallel stringing of wires due to the street lighting circuits being side by side with the multiple house circuits while the additional switchboard, transformers, circuit breakers,etc. formerly required can be discarded or used for other purposes. This means that there will be a decided saving in both the initial and maintenance cost of a street lighting system under these conditions. This would be especially true if the controlling device could be simple, inexpensive, accurate, and capable of longevity.

It is not necessary that street lights throughout a city should light at the same time. It is readily seen that residential and suburban districts of a city should take all possible advantage of any twilight before turning on the lights. However, business streets which are flanked by high buildings are not so able to take advantage of this twilight and become dark enough for lights at a definite time ahead of the residential and suburban streets. Therefore, to have an economical and efficient control, the lights in each section should be turned on only when that section really begins to need it. Naturally, this also applies to turning the lights off. Light being the controlling element of the time when the street lights should be operated, it necessarily means that some sort of a control switch operated by light intensities is exactly what is desired to accomplish the ends sought. This control will be called a sun valve and will be alluded to as such throughout this paper though it does not necessarily hold that it requires direct sunlight to make it function.

Such a sun valve would not only be applicable to controlling street lights alone but would be of inestimable value in controlling isolated light houses, traffic beacons, advertising signs, aircraft beacons, and all such types of apparatus. If an effective sun valve could be developed to control such apparatus, the economy of such operation is plainly apparent and makes the field of usage for an adequate sun valve very wide indeed.

The purpose of this research, then, is to develop some type of apparatus, affected by light intensities, which will be simple, rugged, accurate, practical, long-lived, inexpensive, and capable of operating without requiring frequent adjustments. Not only should the apparatus work but it must be so designed and constructed that it can be placed on the top of a pole and efficiently operate under all kinds of external conditions. this last requirement makes the problem even more complicated for though a laboratory set-up could undoubtedly be made to function, such an arrangement would be impossible under actual operating conditions.

PREVIOUS WORK

There has been very little known or published work along this line and the field of reference is exceedingly limited- so much so that no direct reference could be secured and even indirect references on the subject were very meager and consisted for the most part of the adaptation of photoelectric or selenium cells to photometric work. From this, it would appear that the subject is a decidedly novel one and that it is either a comparatively new thought or has been one not capable of an acceptable solution and thus is not generally known to the engineering profession.

The nearest approach of any device or apparatus to the control of an electric circuit by the intensity of light has been, with one exception, through several schemes for recording daylight. These daylight recorders have been developed and installed, for the most part, by several electric light companies for the purpose of keeping a record of the variations in the intensity of light. It was found that many complaints regarding the size of lighting bills could be easily settled by demonstrating graphically, by means of charts, the wide difference in the amount of daylight during monthly bill periods. Several of these devices will be briefly described. The exception is a sun valve or sun relay, manufactured by the American Gas Accumulator Company of Elizabeth, New Jersey, which actually is operated by the variations in light intensity.

One daylight recording outfit was developed by Mr.F.A.Swan of Boston for the Edison Electric Illuminating Company of Boston, Mr Swan had noticed, by accident, that the resistance of tungsten varied with, and apparently in a certain relation to, the amount of light falling upon it. This, of course, at once suggested a means, by use of the Wheatstone bridge principle, of measuring and recording variations in light flux with the result that he developed an apparatus which he called a Meteorograph.

The outfit consists of two principal parts, the receiver and the recorder. The receiver, which is located on the roof of the company's laboratory building, has the property of varying its resistance in proportion to the amount of light which falls upon it. The recorder, which is located within the building, records this variation on a moving chart. The device operates on the principle of a Wheatstone bridge. In the diagram,Fig.1,the resistances A and B, each having approximately 100 ohms, are

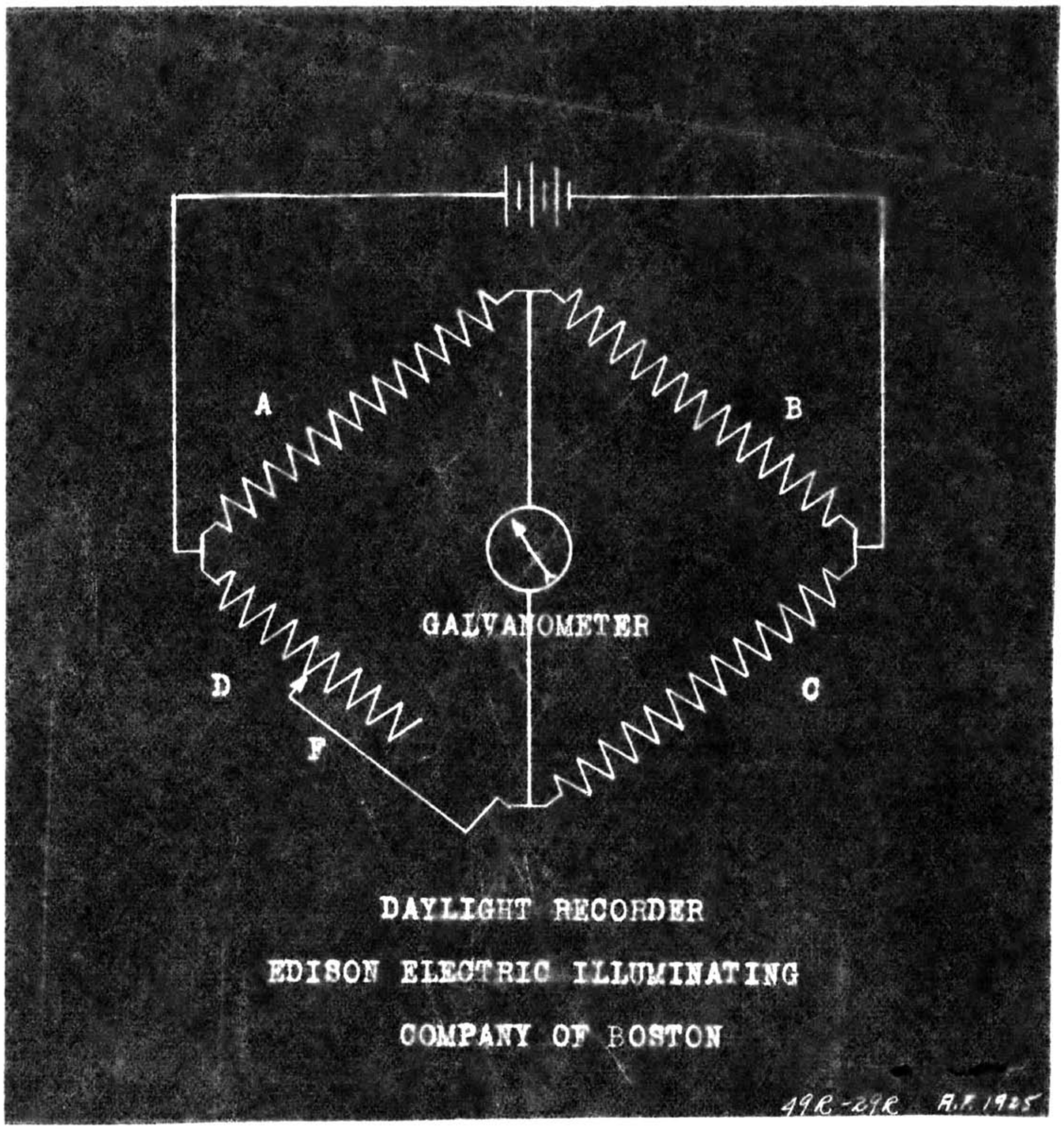

A
B
GALVANOMETER
D
C
F
DAYLIGHT RECORDER
EDISON ELECTRIC ILLUMINATING
COMPANY OF BOSTON
49R-29R
A.F. 1925

Fig. 1

mounted in the receiver. The resistances C and D of similar value are located in the recorder; D is adjustable by means of a sliding contact F. All four resistances are adjusted so as to be equal when no light falls upon the receiver. Under this condition, no current flows through the galvanometer and the bridge is in balance. The action of light on the receiver causes a change in the value of the resistance B. This throws the bridge out of balance and causes a deflection of the galvanometer G. The galvanometer is connected with a relay, and this relay causes the slider F to move along the resistance D until the bridge is again in the balance. The slider F carries with it a pen arm, and by this means a curve is drawn on the chart in accordance with every change of resistance in the arm B. As the change of resistance in B is caused by the action of daylight, it is obvious that the pen will make a record which will bear a certain relation to the variation in the intensity of daylight.

The resistance B in the receiver is composed of a bank of 40 watt, 220 volt, type B, Mazda lamps. In the operation of the bridge, it was found necessary to keep the current in each lamp below two milliamperes, to avoid changes in resistance due to the current in the filament. In order to obtain a sufficient amount of current to insure positive operation of the galvanometer, a bank of lamps in series-multiple was used. This arrangement permits a current of thirty-two milliamperes in the bridge arm. The resistance arm A is a coil of wire of the same resistance as the lamp bank, mounted in a lamp bulb which has been evacuated and sealed, and covered so as to exclude light, but to permit circulation of air. The resistance of this coil will be affected only by variations in air temperature and will serve to compensate for similar variations from the same cause in the lamp bank. This prevents errors in registration due to the effect on the lamp filaments of variable air temperatures.

Another type was the daylight recorder used by the New York Edison Company and very similar to that just described and shown in Fig.2. The receiver erected on the roof of a building, consisted of fifty-six 40 watt, 220 volt Mazda lamps, connected in series-multiple, seven in series. These groups of series lamps likewise were connected in multiple. The lamps were inverted under a housing and mounted about nine feet above the roof in order that they might receive the reflected rays of light from the

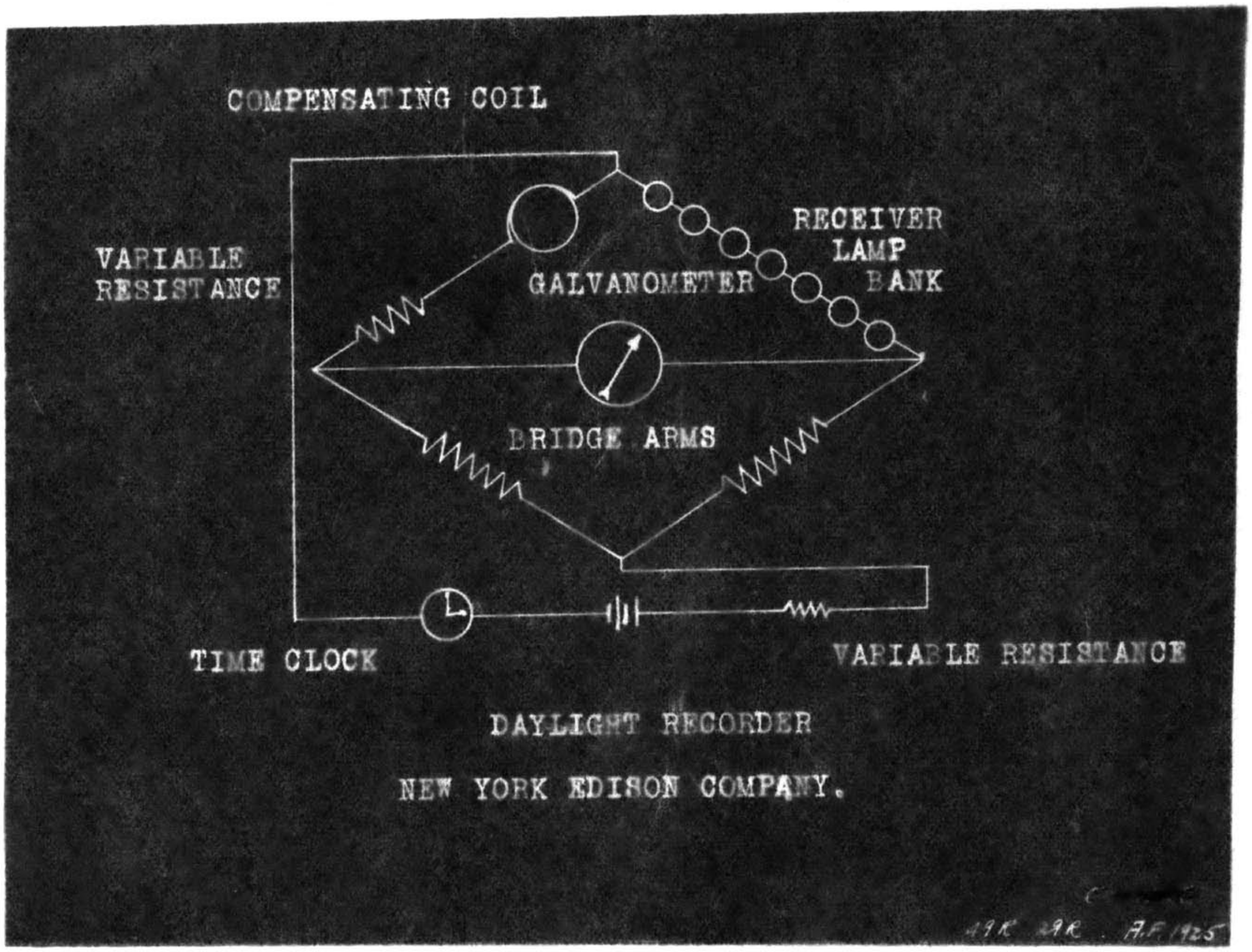
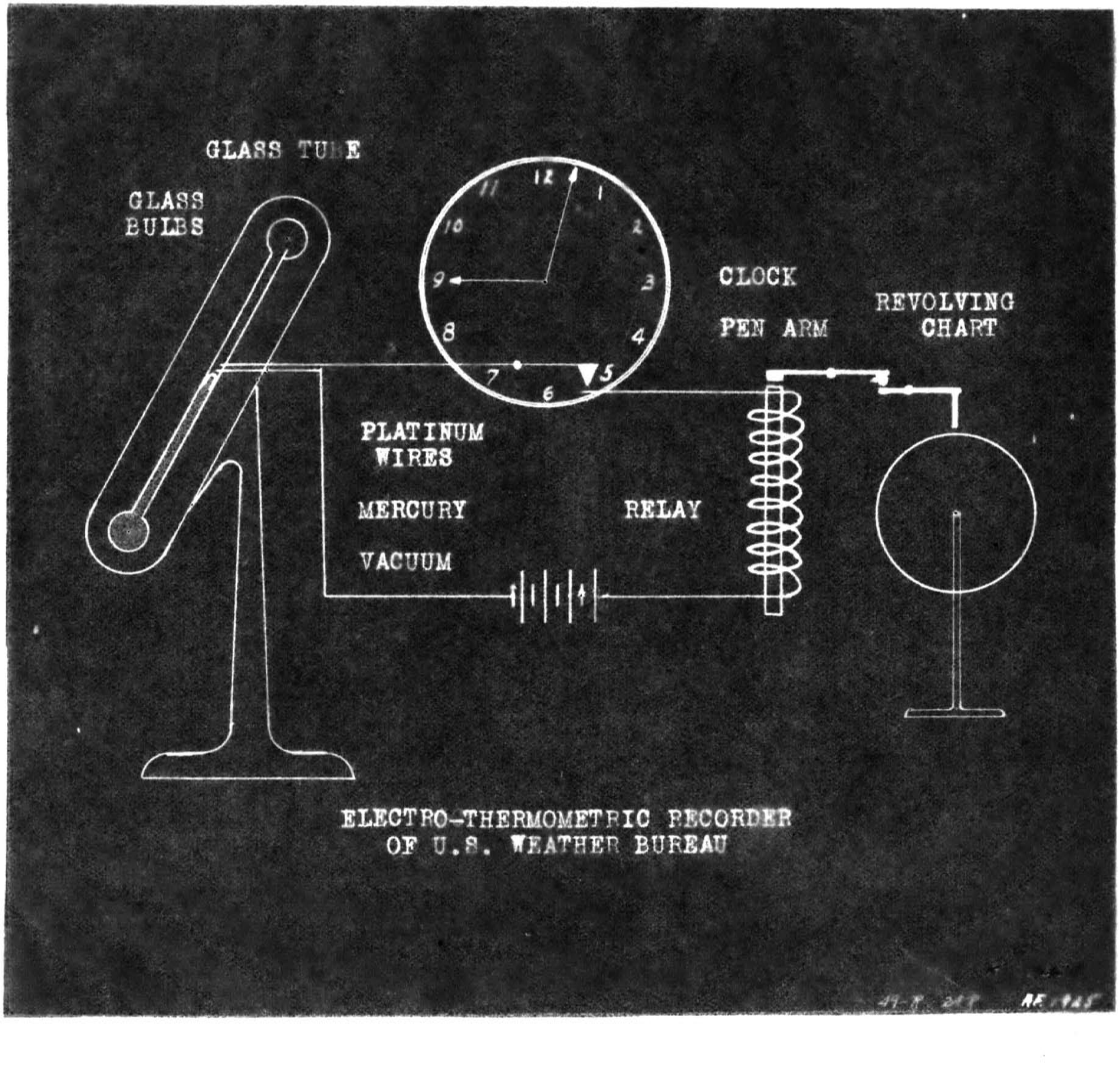

COMPENSATING COIL
RECEIVER
LAMP
BANK
VARIABLE
RESISTANCE
GALVANOMETER
BRIDGE ARMS
TIME CLOCK
VARIABLE RESISTANCE
DAYLIGHT RECORDER
NEW YORK EDISON COMPANY.

Fig. 2

roof. The recording device was worked out on the theory of a Wheatstone bridge- the lamp bank forming one arm while the other arm, known as the dark arm or balancing coil, consisted of approximately a 100 ohm resistance. The coil was completely shielded in order that it might not be affected by light in any way. The recording device was a Leeds & Northrup recorder with some modifications to meet the existing conditions.

An electric thermometric recorder is used by the Weather Bureau which, however, simply records by making contact on a revolving drum when the sun shines and does not give any direct or even relative readings of daylight intensity. It consists of a vacuum tube containing a special thermometer, a clock, an electric magnet, a revolving chart, and a battery, as shown in Fig.3. The thermometer is an air-filled, glass tube with a cylindrical bulb on each end, and is itself incased in a protective vacuum tube. The lower bulb, which contains a small quantity of mercury with a little alcohol, is smoothly coated with lamp black. The upper bulb is clear glass. When the sun shines, its rays are absorbed by the black bulb, whereupon the indicator rises in the glass stem toward the clear bulb.


GLASS TUBE
GLASS
BULBS
CLOCK
PEN ARM
REVOLVING
CHART
PLATINUM
WIRES
MERCURY
VACUUM
RELAY
ELECTRO-THERMOMETRIC RECORDER
OF U.S. WEATHER BUREAU

Fig, 3

Two platinum wires are set in the stem leading to the terminals through the vacuum tube. When the indicator rises high enough to touch these wires, the electric circuit is completed; the thermometer being so constructed that circuit is completed only when the sun is shining. The mechanism connected with the clock makes a connection automatically every minute regardless of weather conditions. If the sun is shining, this momentary connection completes the circuit and a mark, made by a pen arm drawn down by a magnet, appears on the paper of a slowly revolving carrier. If there is no sun, the chart remains blank-the circuit being incomplete.

The best daylight recorder as yet in operation is that developed by Dr.J.E.Ives of the United States Public Health Service. He has used a Case photo-electric cell with filter and shield in connection with a Leeds & Northrup recording potentiometer and has secured excellent results. The cell in use by the Office of Industrial Hygiene and Sanitation is mounted on a wooden platform, three feet above the surface of the roof. The cell is placed facing the zenith with the exhaust tip pointing south, and its axis has been carefully aligned so that it points directly north and south.

The electrical connections of the battery circuit are shown in Fig.4. For the battery, it is convenient to use five radio B batteries of 45 volts apiece in series giving a total of about 225 volts in all. The two sides of the resistance are connected to a Leeds & Northrup recording potentiometer. This recorder is merely a mechanism for making a chart record of a difference of potential between two points in any current circuit; in this device, the difference of potential is that across the resistance coil. In the operation of the recorder, the pen is moved by steps every two seconds. The extent of the motion of the pen is proportional to the deflection of the needle of a galvanometer incorporated in the construction of the recorder. The amount of the resistance used in the coil will determine the amplitude of the curve on the recorder paper; the larger resistance giving the greater motion. The recording potentiometer is operated on the 110 volt direct current lighting circuit while a Hartford time switch has been installed which opens the circuit shortly after sunset and closes it shortly before sunrise.

The only real device actuated by light intensity and really controlling an electric circuit

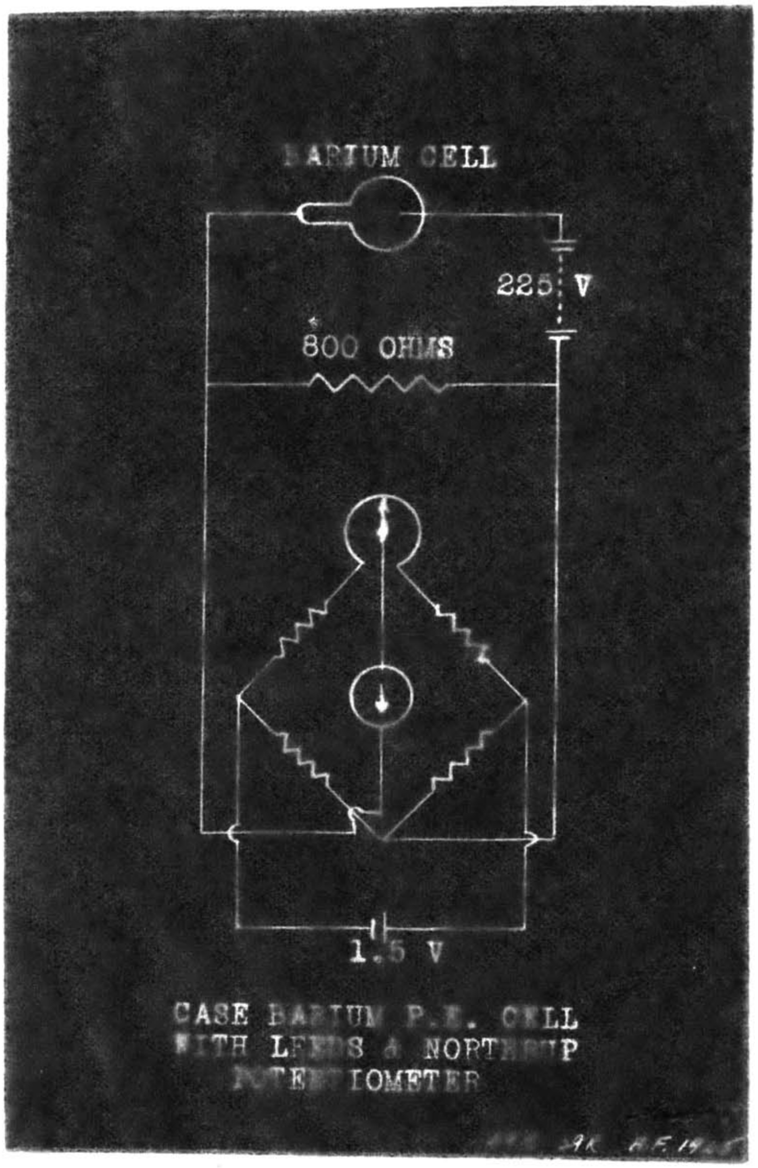

BARIUM CELL
225 V
800 OHMS
1.5 V
CASE BARIUM P.E. CELL
WITH LEEDS & NORTHRUP
POTENTIOMETER

Fig. 4

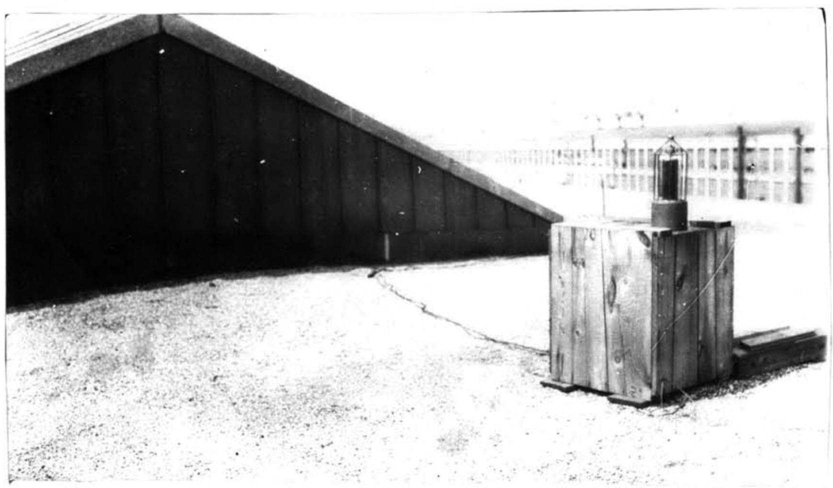
is one called a sun relay, This was developed by Mr.V.L.Oestnaes and is manufactured by the American Gas Accumulator Company of Elizabeth,New Jersey. This apparatus is a modification of a sun valve developed by the same company and used to function in the control of gas for illuminating lighthouses, channel lights, buoys, and other marine signals. These sun valves have been in use for several years and have proved to be very reliable and capable of performing their duties under all conditions of climate and weather.

The sun relay was primarily designed for use in railway signaling where it would control the lights in electrically lighted semaphor and switch signals, automatically lighting or extinguishing the light under the varying conditions of darkness or daylight. For this purpose it has been installed on various railroads, where it has given good service in controlling one or several lamps, with decided advantages over the old oil system or series electrical of signal-lamp lighting.

The sun relay utilizes the energy of light to open and close the contacts of an electrical circuit. Light, according to modern science, consists of electro-magnetic waves which are set up by some heated or light-producing body such, for instance, as the sun. These waves or radiations,if intercepted in their passage from the light-producing body, may be transformed into heat, the degree of transformation depending upon the nature of the intercepting body. Thus, light waves falling upon a body, the surface of which is dull and dark, are absorbed, and in the act of absorption are converted into heat, which, in its turn, is transformed into mechanical energy and manifests itself by the expansion of the body. It is well known that dark objects absorb more light and consequently more heat than lighter objects, and the sun valve is an application of this fact.

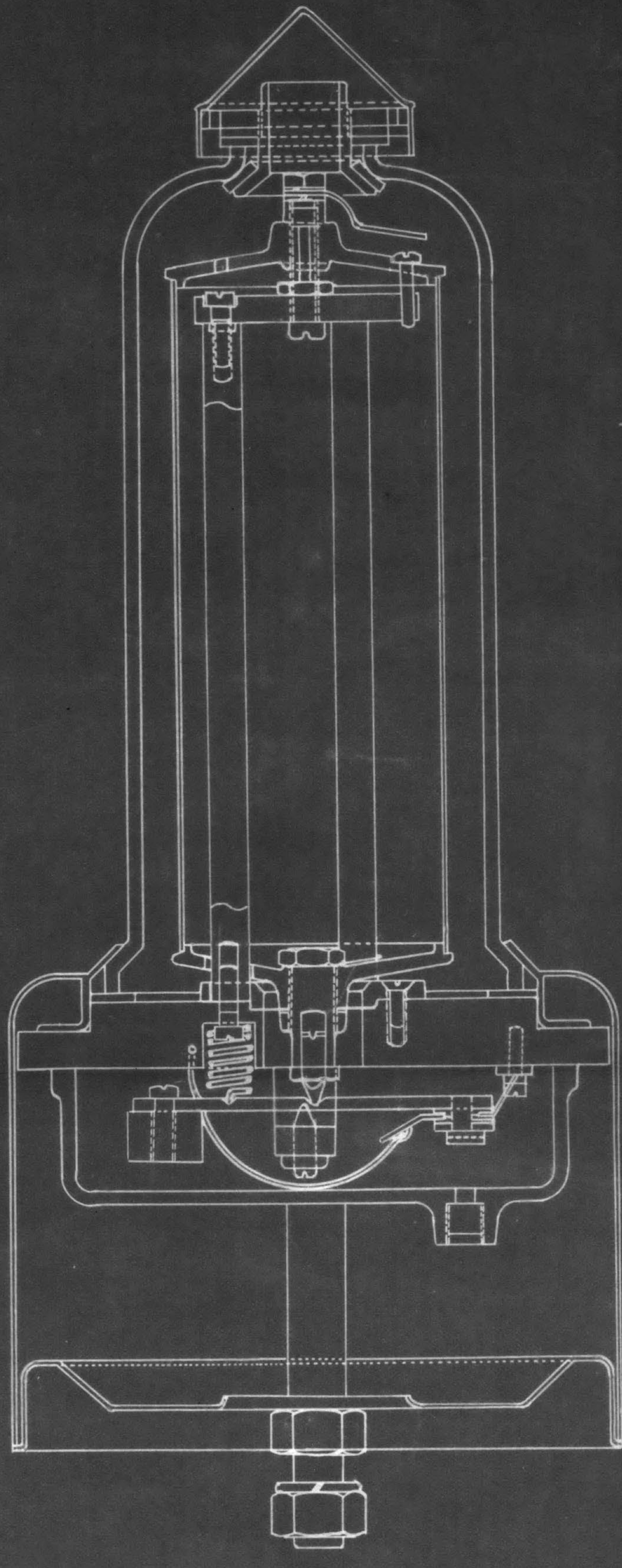
The active members comprise three round brass rods and a brass cylinder enclosed in a glass case which is covered by a removable metal case thus completely enclosing the bottom portion and providing a guard to prevent breakage of the glass case. See Figs. 5 to 9. The three rods are fastened rigidly to a metallic base plate in an upright position. The metal cylinder surrounds the rods and is rigidly attached to them at the top. This leaves the bottom of the cylinder free to move up and down as the cylinder expands or con-

Sun Relay #2



Sun Relay #3

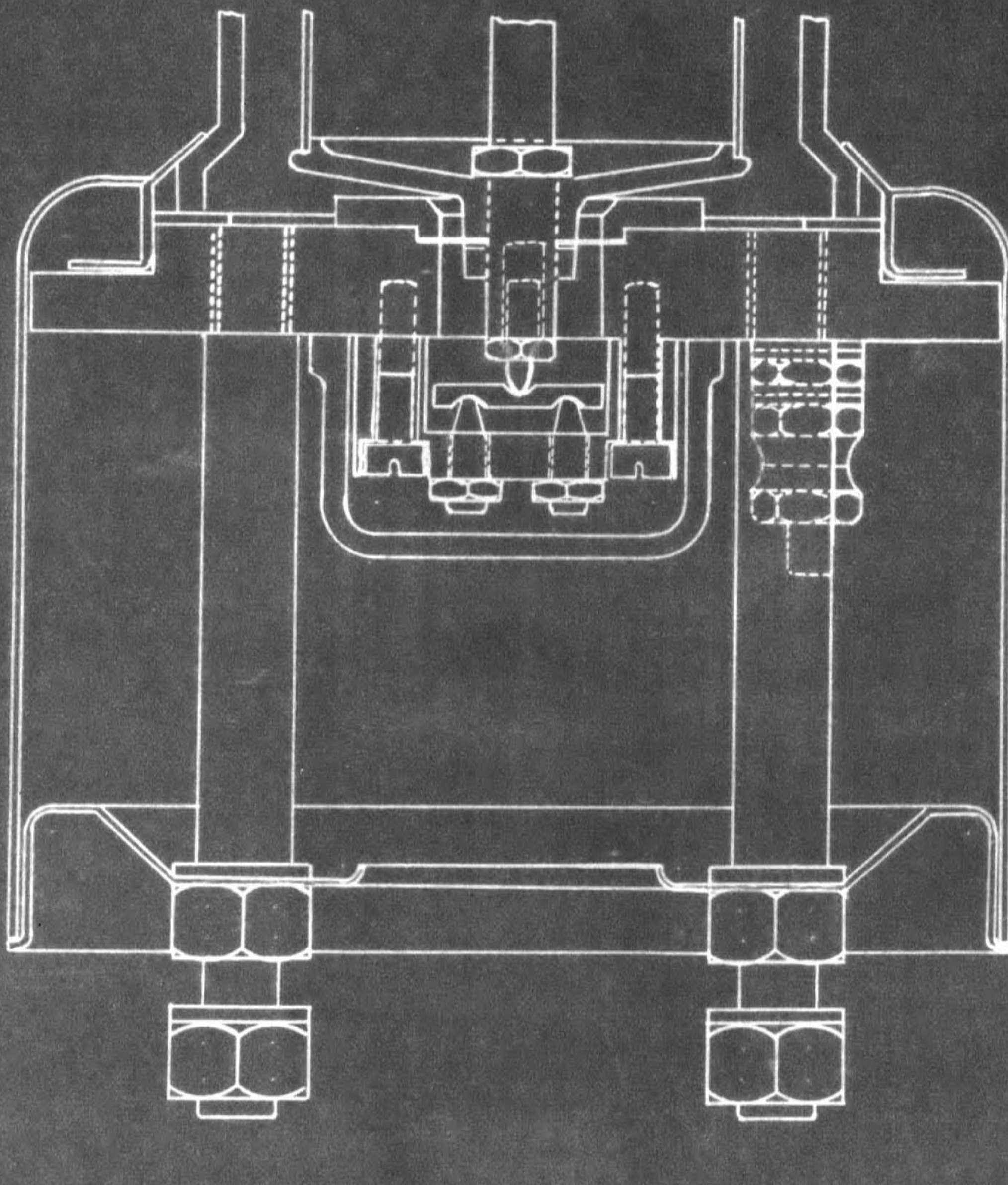
Fig. 5



A. G. A. Sun Valve

Fig. #6

Alvan Fisher 1925



A.G.A. Sun Valve

Fig. #6a

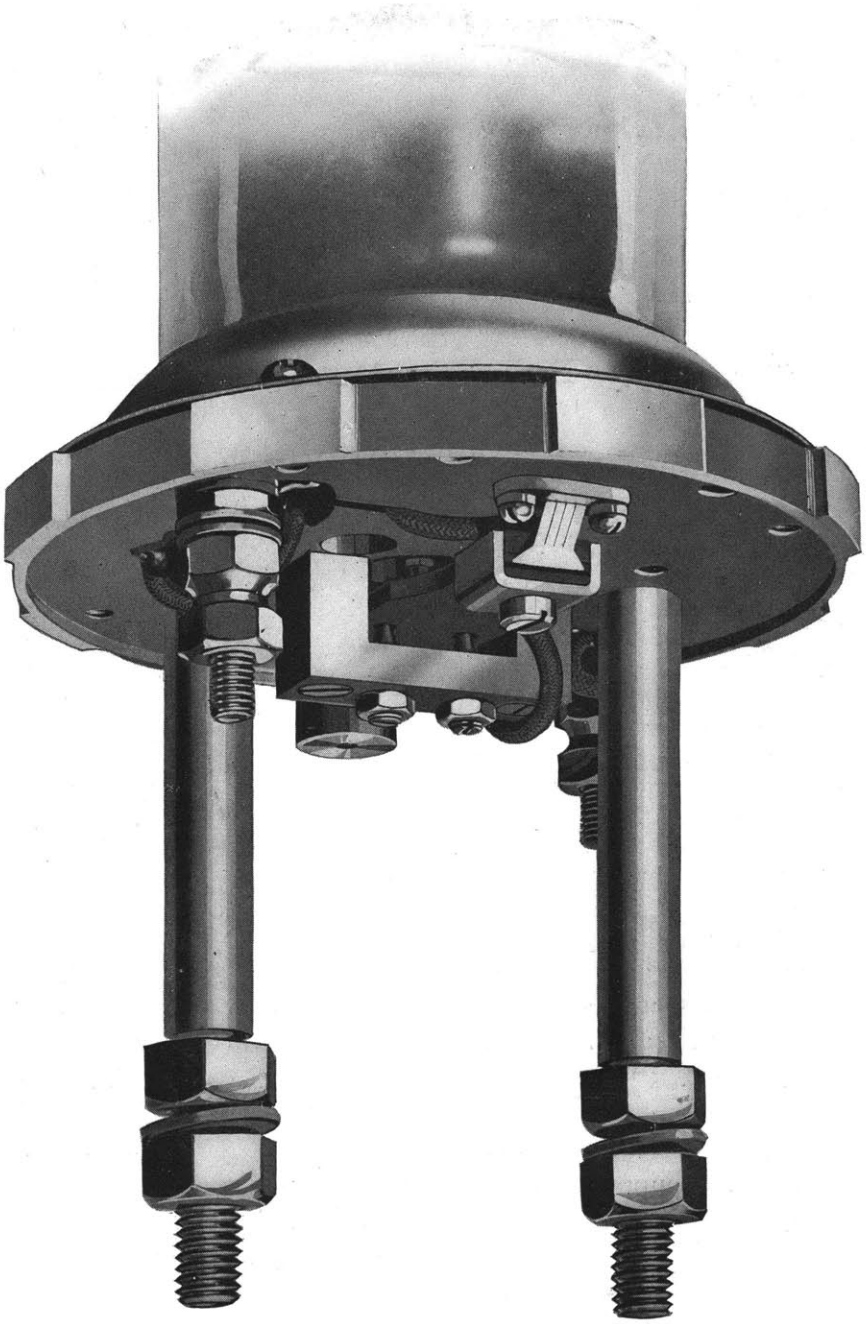
Alvan Fisher 1925

Sun Relay, Complete

Fig. 7

Sun Relay, Unhooded

Fig. 8



Enlarged View of Underside

of Sun Relay

Fig. 9

tracts. Expansion and contraction of this cylinder is effected by coating the outside surface with lamp black so that, under the influence of light, heat is produced to cause an expansion of the cylinder. Contraction of the cylinder occurs whenever the light is removed so that there is no longer production of heat. The first of these conditions occurs during day light hours and the second during hours of darkness. Having the bottom of the cylinder thus moved up and down, the lower end bears upon the top of a lever through a hardened steel pivot bearing. The lever is supported by two similar pivots on its under side. The length of the lever and the location of these bearing points are such that a lever ratio of one to twenty is secured. One side of the contact is therefore mounted on the end of the lever, the other side being fixed just above it so that the movement of the lever opens and closes the gap. The contacts are of coin silver and so constructed that dust cannot settle upon them. In addition, the points are enclosed in a dust and moisture-tight metal housing. The pressure on the contacts is nine pounds.

The relay is not supposed to be influenced by changes in atmospheric temperature because such changes not only re-act upon the cylinder but also upon the central rods. The temperature change is equal upon both so that the relative position of the bottom of the cylinder and, therefore, of the contact is supposedly not altered. It is only the differential action of light which strikes only the outside cylinder which results in a movement of the contact causing the opening and controlling. However, there is some doubt as to the automatic compensation for changes in atmospheric temperature and this will be considered later on in the paper.

In installing the relay, it is essential that it be located in a place where it is fully exposed to the sun during the entire day. It should be installed in a vertical position and no higher current than one and one-half amperes or higher voltage than six volts should be used.

The relay can be adjusted by unscrewing the metal cap on the glass protector and turning the adjusting nut within by means of a socket wrench. However, it is first necessary to have the set covered with a hood for at least two hours. Then, the critical point can be found and noted from the graduated scale on top of the cylinder. This is the point of adjustment at which the contact just makes or breaks the current,when turning the index hand back and forth. This point is determined by applying a voltmeter across the terminals, the reading of which will change instantaneously from zero to full voltage or the reverse. After approximately locating this point, the wrench should be slowly turned in a counter-clockwise direction until the exact point at which the relay closes is obtained. Having obtained the scale reading for this point, the wrench should be moved clockwise for forty-five degrees and then back to a position fifteen degrees beyond the critical point. The relay, when secured, is then ready for service.

Because of the success which this type of radiant energy control has achieved in railroad and marine work, two relays were secured for the purpose of testing their application to the control of street lights connected to the multiple house circuits. These sets were installed and tests made over a period of six months. The results and conclusions drawn from these tests will be considered further along in this paper.

METHODS OF ATTACK.

The solution of this problem seemed to divide itself into three methods of attack, namely through the selenium cell, the photo-electric cell, and some thermostatic arrangement. These will now be taken in their order and reasons given why or why not each method could be used.

THE SELENIUM CELL

The selenium cell is extra-ordinarily sensitive to light and because of this, it was seriously considered as an acceptable method of solving the problem at hand. Unfortunately, it has several objectionable characteristics which, it was found, rendered it entirely unsuitable for any purpose such as that desired.

The advantages of a selenium cell are that it is more compact, convenient to handle, and that its current is quite large requiring less delicate apparatus. The disadvantages of a selenium cell are that it is erratic in its behavior, shows a variation in its dark resistance, has a great dependence upon previous treatment, and has considerable inertia with marked fatigue. The cell is also affected by variation in temperature and by the presence of a film of moisture upon it.

Its greatest drawback is its great inertia or slowness to recover its normal "dark" resistance after exposure to light. In some tests made by Dr. W.W.Coblentz of the Bureau of Standards on various selenium cells obtained in the market(imported and domestic) and also on cells of his own construction, the cell under test was exposed for five seconds. After exposure to low intensities, it required thirty seconds for a certain cell to recover its normal resistance. Increasing the intensity twenty times, as measured with a thermopile, the response (galvanometer deflection),as indicated by the selenium cell was only eight times that of the low intensity,while the delay (two minutes) in recovery to normal resistance was increased four times. Exposure to daylight required more than ten minutes for recovery.

Ruhmer studied the excitation and recovery of five cells which he divided into two kinds, "hard" and "soft". Soft cells were those annealed at a temperature of 200^{o}, hard cells those annealed at a lower temperature and cooled more quickly. The soft cells, he found to be relatively more sensitive to weak excitations while the hard cells showed a more rapid recovery than the soft. The sensitivity of the selenium cell therefore depends upon the heat treatment and varies not only with the wave length but also with the intensity of the light stimulus.

The single crystals of selenium grown by Brown have an extraordinarily high sensitivity as compared with a selenium cell but they also have the characteristic slow recovery after exposure to light. From published data, it appears that a single crystal of selenium, 1 mm^2 in area is one hundred times as sensitive as the best selenium cell.

The wave-length sensitivity curve of a selenium crystal depends upon the temperature at which the crystal was formed. A crystal which was formed in the cooler part of the furnace has its maximum sensitivity in the violet. A crystal formed in the hottest part of the furnace had its maximum sensitivity in the extreme red, just as is true of an ordinary selenium cell which is, no doubt, composed of mixed crystals.

As a result of the investigation as to the reasonableness of the use of selenium cells for the method of control, it seemed as though their inherent characteristics made this type of control entirely unsuitable. But even in view of the adverse facts just reported, it is but fair to add that selenium is very sensitive and that a great deal of important experimental work has been accomplished through its use. However, a potassium hydride photo-electric cell has been found to be twenty-five to thirty times more sensitive.

A new selenium cell was suddenly placed on the market by the Electric Bean Grader Products Company of Ithaca, Michigan, and called the McWilliams cell. It consists of transparent selenium spread on pure gold wire which is in the shape of a very fine mesh. The manufacturers claim that this cell has no lag, will stand the strongest light, is very sensitive, quick acting, and reliable in action. However, after several ineffectual attempts to obtain more specific data as to their sensitivity, action, life, etc. the matter was dropped as it seemed evident that the company did not have any accurate data on these questions and it was, therefore, not worth the expense of investing in a doubtful cell that had not been fully tested and tried.

PHOTO-ELECTRIC CELLS.

The term, photo-electric cell, has been used in a general sense to designate a large variety of apparatus in which an electrical change may be caused by the influence of light. Since the first observation made by Hertz in 1887 on the effect of the ultra-violet light on a spark-gap, many photo-electric devices have been described and a very large number of substances have been found to be photo-active.

A photo-electric cell usually consists of a glass or quartz bulb containing two electrodes. One electrode-the cathode-is the photo-active material and is the surface to be illuminated. The anode usually consists of a loop or fine mesh of wire and serves as a collector of photo-electrons emitted by the photo-active material.

The photo-electrons are driven across the cell from cathode to anode as the result of an applied potential and the amount of current carried by them can be determined by any sensitive method of measuring current. In a cell having a very high vacuum,the entire current is carried across the cell by the photo-electrons. Providing the cell is properly designed, the number of these photo-electrons, and hence the photo-electric current, is directly proportional to the light intensity falling upon the cell. However,practically all of the photo-electric cells have not functioned as the human eye reacts but rather to the shorter lightwaves of the violet and ultra-violet. On the other hand, the distinguishing characteristics of the photo-electric cell is its selective sensitivity to various wave lengths,being most sensitive to the ultra-violet. Thus far it has not been possible to modify appreciably this inequality of sensitivity for different parts of the spectrum.

There are a good many photo-electric cells on the market at present, among which are strontium, barium, potassium, thallofide, calcium,rubidium,and sodium. Of these, the barium, potassium, and thallofide only were considered as they contained either the good or bad characteristics of each of the other cells.

The thallofide cell made by the Case Research Laboratory, is the most sensitive cell developed,as far as can be learned. It is extremely sensitive but has the serious drawback that it can not stand a high intensity of light and should not be exposed to any light for a period of more than five seconds. It was therefore, impossible to use this type of cell for this problem.

A potassium hydride cell, manufactured by the General Electric Company, was next considered. The sensitivity of potassium is increased one hundred times by changing the material into a hydride. The potassium cell would, it was found, stand up under constant exposure to daylight. However, it was also found that it had two grave faults. The first was that it was not sensitive enough to act at low light intensities unless the current was relatively high and this increase in current was found to greatly shorten the life of a cell. The gravest fault however, was that, because of the high intensity of illumination at mid-day,excessive electronic emission was caused to such an extent that the cell would burn up. These faults had been observed in some previous tests of the potassium cells by the laboratory of the General Electric Company. A wiring diagram for applying a potassium tube to such a use will be found in Fig.10. Thus, it was necessary to eliminate the potassium cell from the consideration of the problem.

The last photo-electric cell considered was the barium cell-also manufactured by the Case Research Laboratory. This cell is less sensitive than either the thallofide or potassium cells, but will stand up under continuous daylight and will not burn up under the high intensity of illumination at mid-day. Because this cell is the most applicable to the problem, a description of its construction and operation will be given.

The cell is made of hard glass in the form of a tubular bulb, about two inches in diameter and five

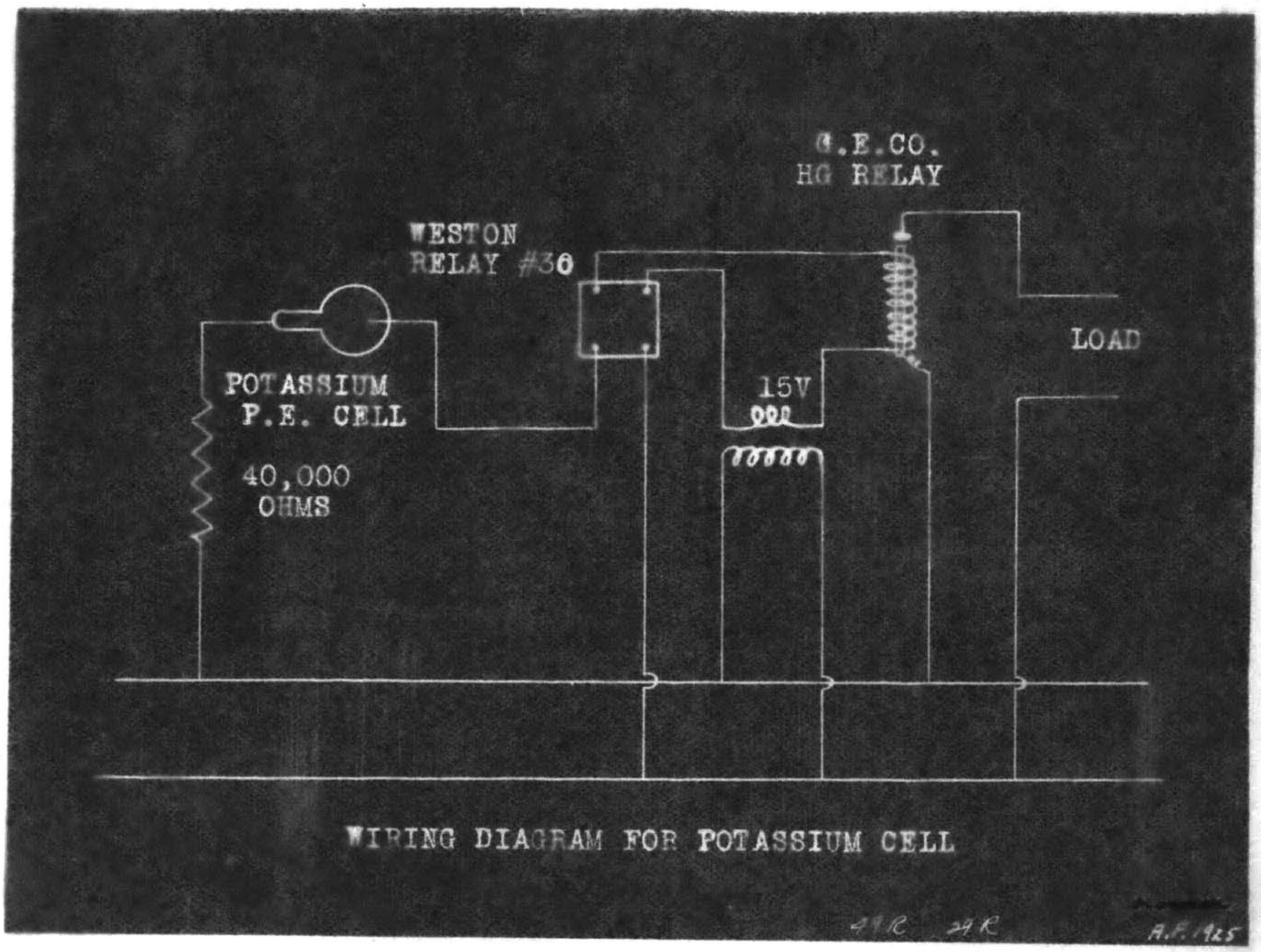

G.E.CO.
HG RELAY
WESTON
RELAY #36
POTASSIUM
P.E. CELL
40,000
OHMS
15V
LOAD
WIRING DIAGRAM FOR POTASSIUM CELL

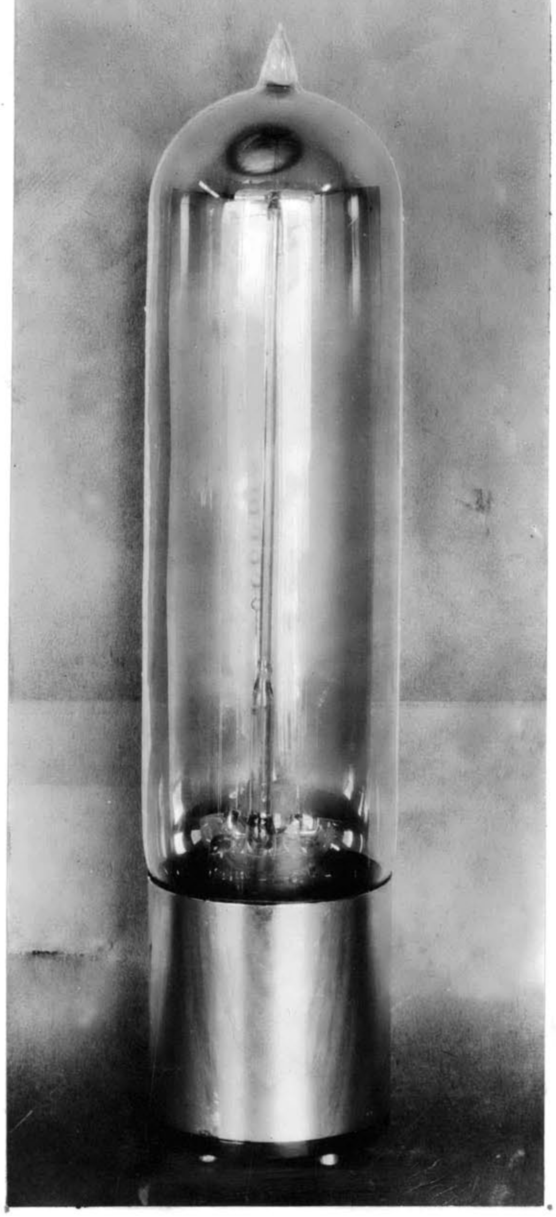
Fig. 10

and one-half inches long as shown in Fig.11. The negative electrode consists of a film of aluminum deposited by evaporation on about a third of the inner surface of the glass bulb. The positive electrode consists of a loop of twisted platinum ribbon, coated with an oxide of barium,in the axis of the tube. During the process of manufacture, the oxide of barium is reduced and a very thin layer of photo-active material is deposited upon the negative electrode, and also to a lesser degree upon the inner surface of the glass bulb. The cell has a very high vacuum and will retain its sensitivity for years.

Mr.Case claims that the photo-electric action of the cell is due to pure electron emission and is consequently practically instantaneous in response to the light stimulus. The photo-electric current increases with the applied voltage up to about 200 volt at which point saturation is reached. Above this voltage, the photo-electric current is independent of the voltage and is directly proportional to the intensity of the light incident upon it, In average sunlight, the photo-electric current is about 300 microamperes. The temperature effect is small at ordinary temperatures, being less than 2 % for a temperature range from 0° to 100° F.

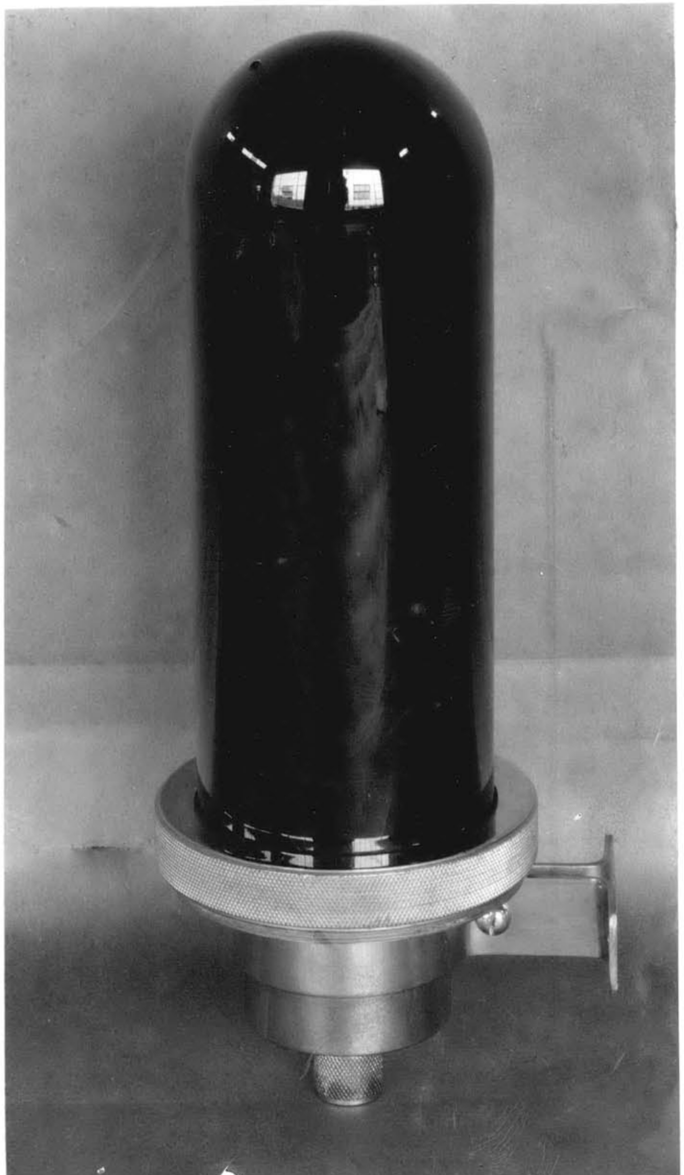
The photo-electric properties of the barium cell have been investigated by Coblentz and the results of his study are shown in the curves of Fig. 12. The response of the cell to light of different wave lengths is seen in curve B. It will be noted that the cell is active throughout the visible spectrum with a maximum in the blue violet. In order to use this cell for the purpose of recording visible illumination, it is necessary that it should respond to light of different wave lengths in approximately the same manner as does the human eye; in other words, that its response should follow the visibility curve. In Fig. 12, the curve D is the visibility curve of the average eye. To cut out some of the action in the blue violet region, making the curve of response of the cell correspond to the visibility curve, a light filter made of brownish yellow glass is placed over the cell. The spectro photo-electrical reaction of the cell, when covered by such a filter, shown by the dotted curve in Fig.12 indicates that its response to light of different wave lengths agrees very closely with the visibility curve.

Since this cell is to be operated by the horizontal component of the illumination, it is necess-



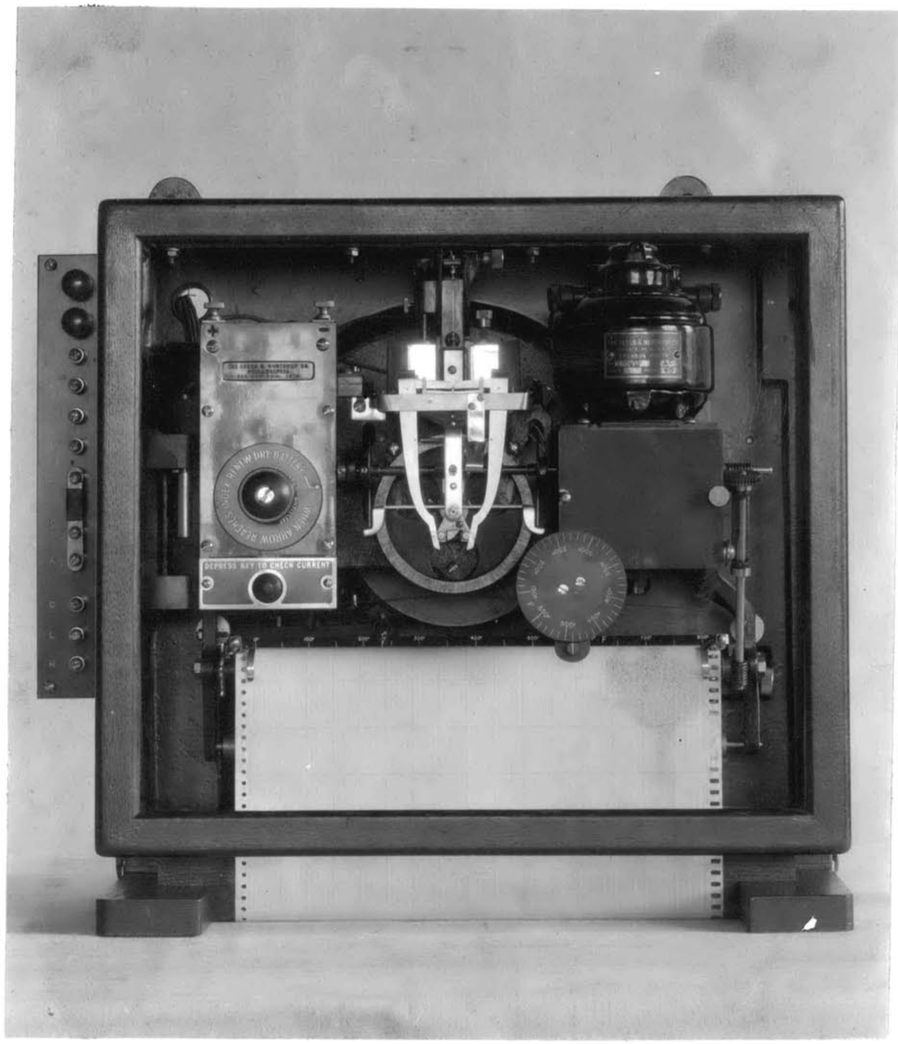
Case Barium Cell

Fig. 11



Case Barium Cell with Filter

Fig. 11b



Potentiometer Used with Case Barium Cell

Fig. 11c

ary,according to Case, to use in connection with the cell a further device so that the cell will obey the cosine law of reflection. This is necessitated by the fact that some of the photo-active material is deposited not only on the aluminum plate within the tube, but also upon the inner surface of the glass itself. In order to correct for this error, a boat-shaped metal shield, shown surrounding the tube in Fig.13, has been designed. In Fig.14, taken from Bulletin #6 of the Case Research Laboratory, is shown the response of the cell, with and without the shield to a moving source of light. The cosine curve has been plotted in this figure and it will be seen that, when the shield is used, the curve of response agrees more or less closely with the cosine curve.

This type of cell appeared to have exactly the qualities desired except that of sensitivity. Unfortunately, the light intensity, at the time when the cell should operate, was not sufficient to cause enough electrons to be emitted to allow sufficient current to flow to even operate a sensitive relay. There was but one solution to this-it was necessary to step up the photo-electric current.

After corresponding with the Case Laboratory, it was learned that such a circuit as shown in Fig.15

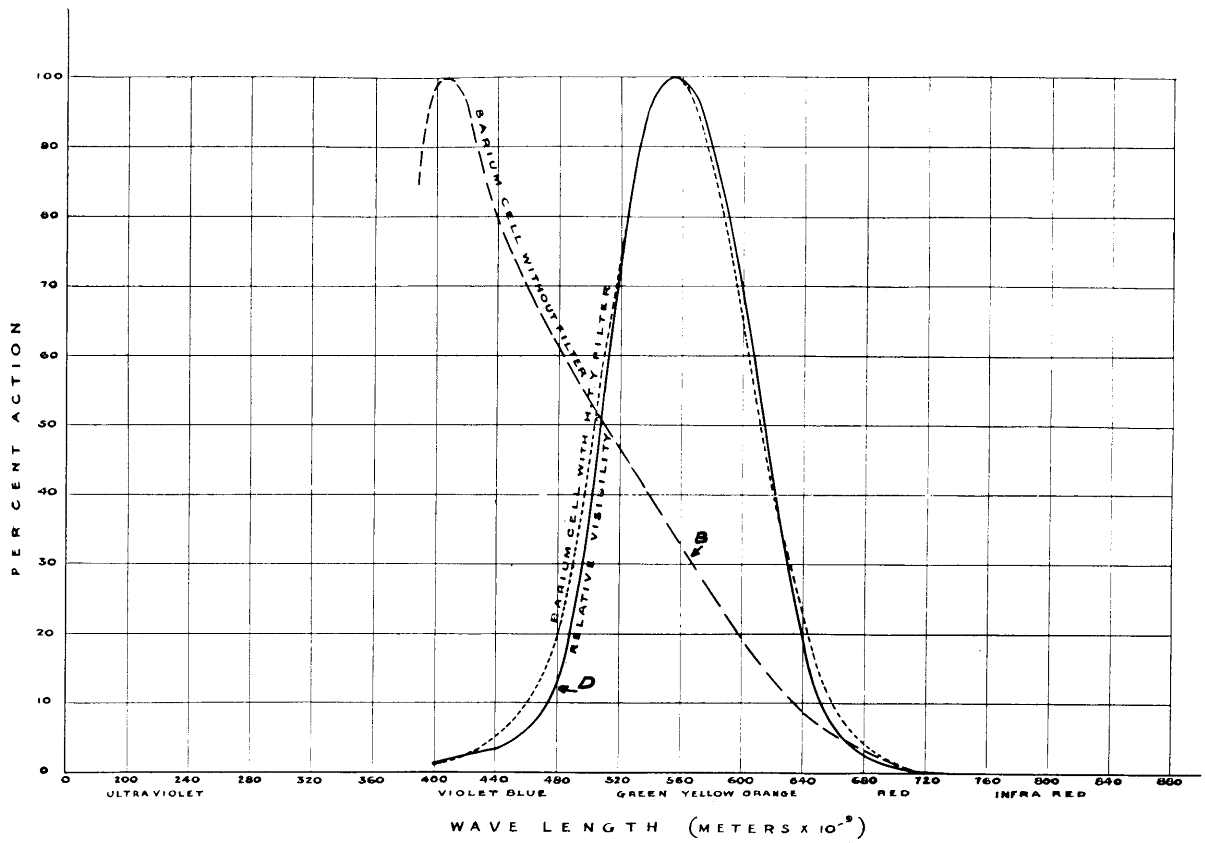

PER CENT ACTION
100
90
80
70
60
50
40
30
20
10
0
BARIUM CELL WITHOUT FILTER
BARIUM CELL WITH H.Y. FILTER
RELATIVE VISIBILITY
B
D
0
200
240
280
320
360
400
440
480
520
560
600
640
680
720
760
800
840
880
ULTRA VIOLET
VIOLET BLUE
GREEN YELLOW ORANGE
RED
INFRA RED
WAVE LENGTH (METERS x 10⁻⁹)

FIG. 12

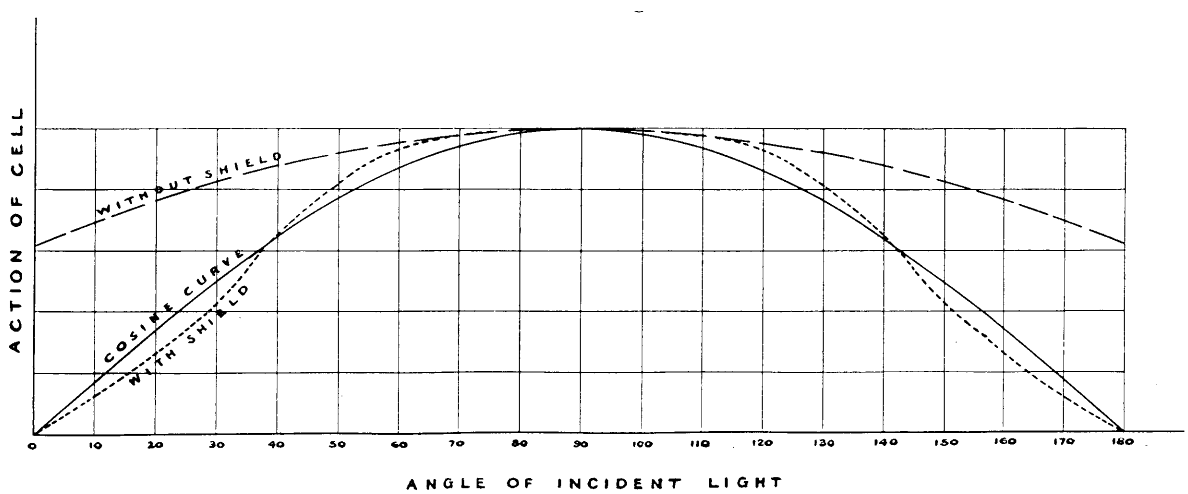
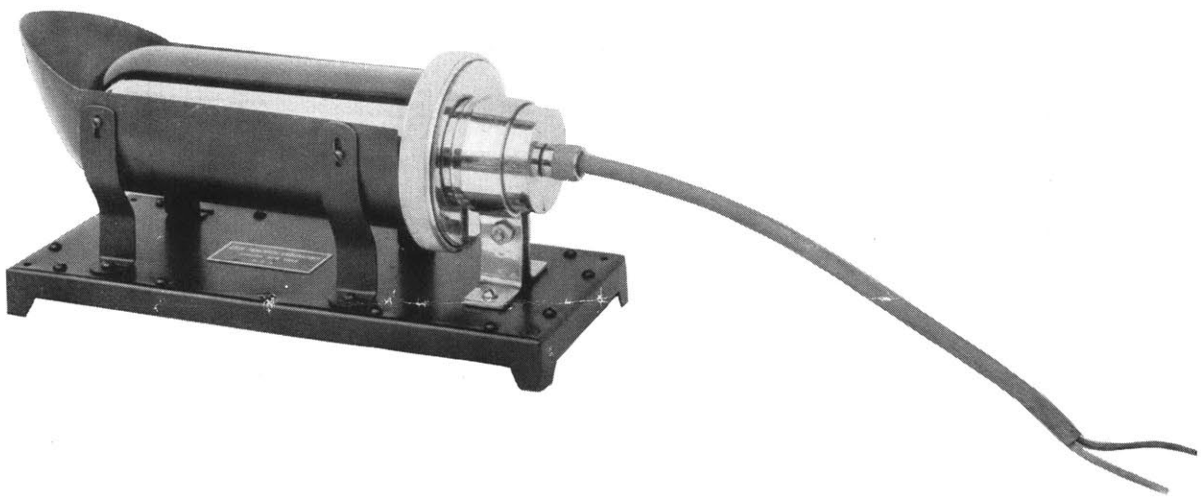

ACTION OF CELL
WITHOUT SHIELD
COSINE CURVE
WITH SHIELD
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
ANGLE OF INCIDENT LIGHT

FIG. 14



Case Barium Cell with Shield
and Filter.

Fig. 13

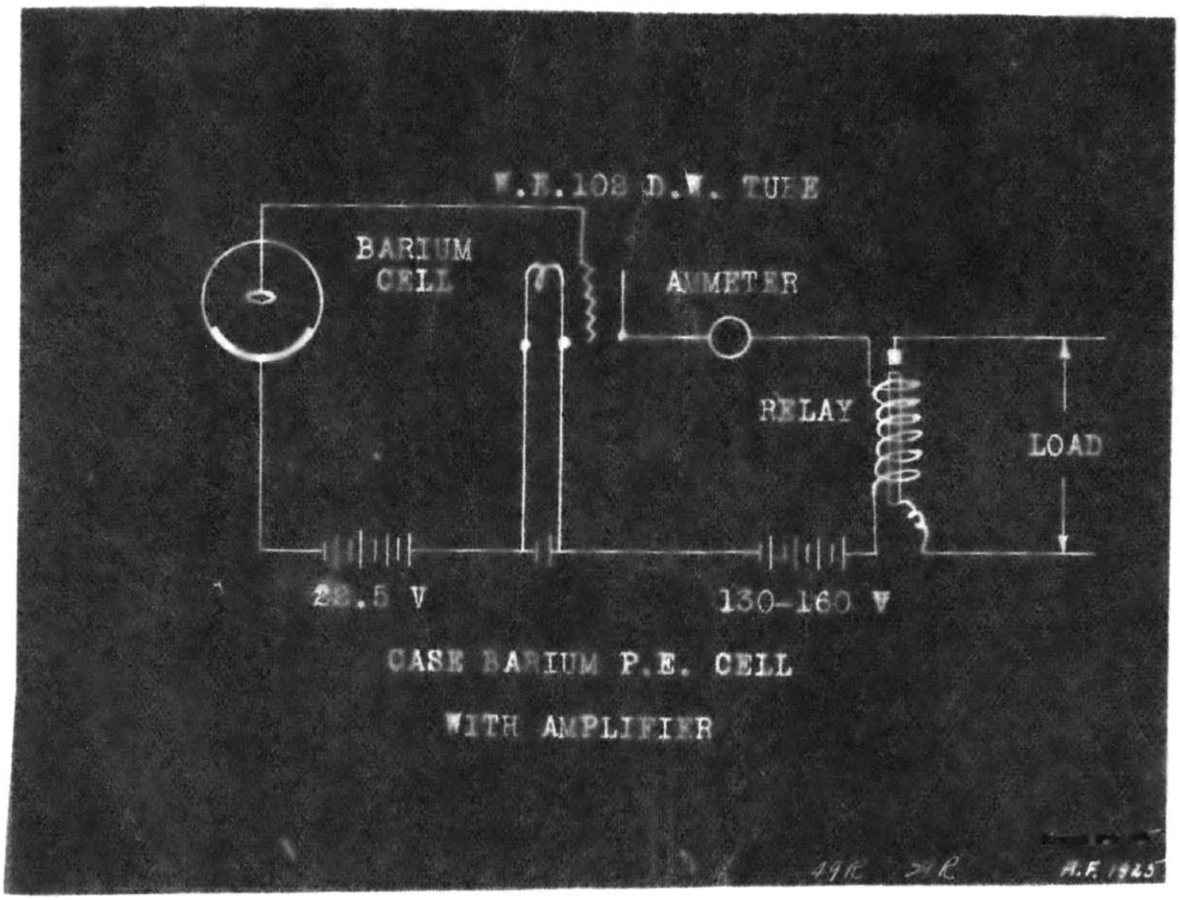

W.E.102 D.W. TUBE
BARIUM CELL
AMMETER
RELAY
LOAD
22.5 V
130-160 V
CASE BARIUM P.E. CELL
WITH AMPLIFIER
A.F. 1925

Fig. 15

would give a working current of three milli-amperes for a light intensity of five foot candles, when the barium cell had no filter. Naturally, another stage of amplification would make the entire arrangement even more sensitive while using the filter would cut down the sensitivity, somewhat.

This arrangement would undoubtedly give good results and come very close to the ends sought. However, it has the one big disadvantage of not being capable of being set on top of a light pole and left for some time without need of repair or adjustment. Such an arrangement is more suitable for the Laboratory than for the field because of its numerous connections and batteries and because it would need constant attention to see that the batteries and amplifying tubes were in good condition. The cost of one cell, alone, is prohibitive though it is understood, on good authority, that this cost could be brought down to a very reasonable amount if cells were to be manufactured on a production basis.

Some consideration was given to using a barium cell in conjunction with a Leeds & Northrup potentiometer as in Dr.Ive's set-up. Then, instead of operating a pen, some type of a contact arrangement could be rigged up. This,however, was given up because of the high cost attached, complicated apparatus, and frequent settings necessary.

It was decided, therefore, that the barium cell and, for that matter no known type of photo-electric cell was capable of being used to solve the problem.

There was one more opportunity given along this line from the announcement that Dr.Zworykin of the research department of the Westinghouse Electric and Manufacturing Company had developed a new type of ph oto-electric cell. From the meager description obtained, it had four electrodes, two of which were assumed to be for amplification purposes . Information was requested concerning the characteristics of the tube but none was obtainable at this date.

THERMOSTATIC METHOD

Two sun relays were secured from the American Gas Accumulator Company and installed. One was placed in an excellent position on the top of building #40 at the plant of the General Electric Company at West Lynn,Massachusetts. This relay was placed in the most optomistic position possible on the top of a building about sixty feet high where no shadows could fall on it and where it could absorb the earliest light rays in the morning and the last beams of light in the evening. The other relay was placed in a decidedly pessimistic position on top of 40-G- a one story building adjoining #40. Here it received direct sunlight for less than half the day as it was set four feet notheast of building #40 which shadowed it for the second half of each day. Both relays were set upon and secured to boxes at a distance of two feet from the roof. The pessimistically located relay will be considered as valve #2 while the optimistically placed relay will be considered as valve #3.

Valve #2 had a very simple set of connections (Fig.16-a) and its readings were secured by watching the small tell-tale lamp. This could be done to a fair degree of accuracy as there was always some one working in the small room where the light was

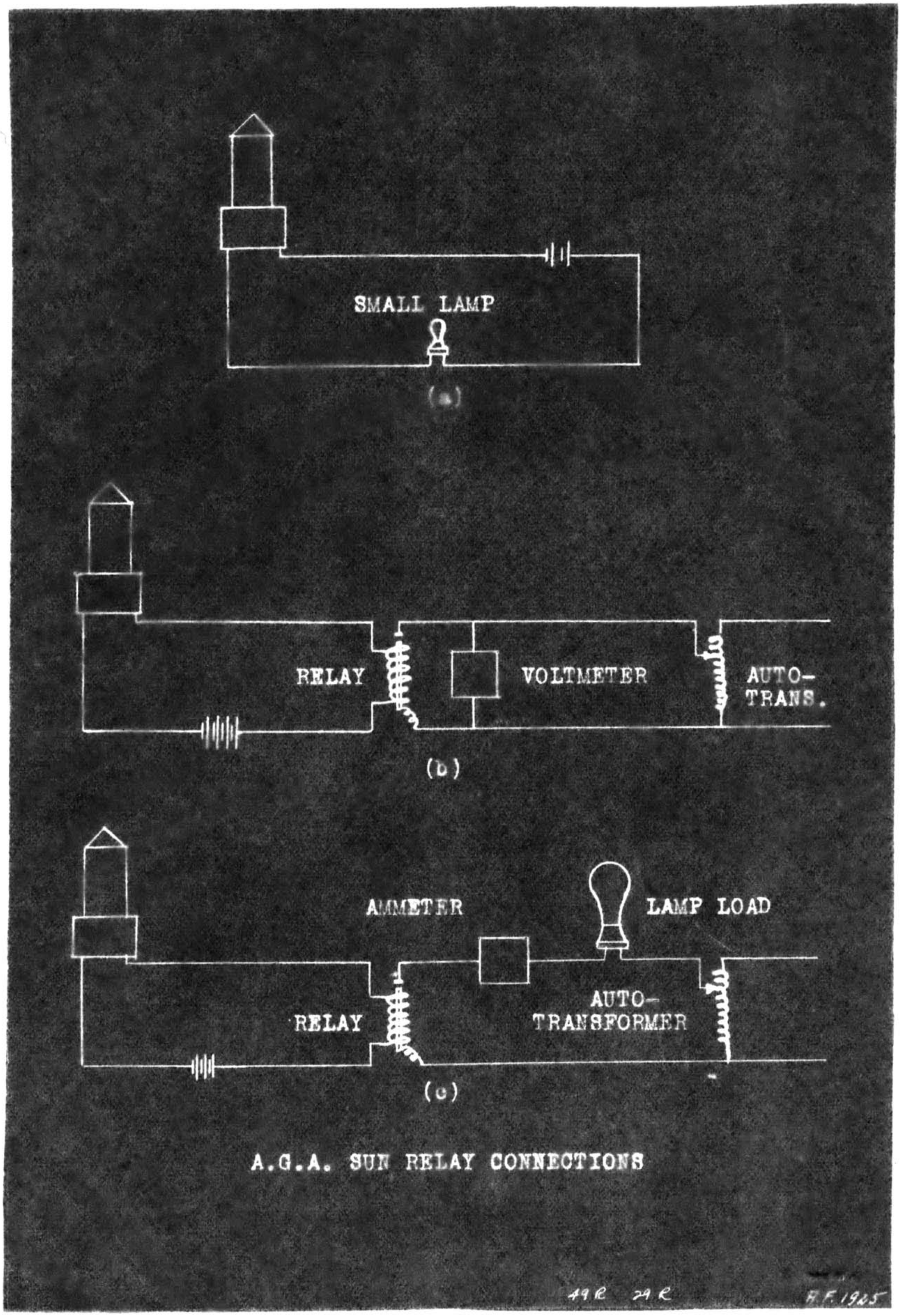

SMALL LAMP
(a)
RELAY
VOLTMETER
AUTO-
TRANS.
(b)
AMMETER
LAMP LOAD
AUTO-
TRANSFORMER
RELAY
(c)
A.G.A. SUN RELAY CONNECTIONS
49 R 29 R
R.F. 1925

Fig. 16

located. The connections for valve #3 were slightly more complicated (see Fig.16-b and c) as a recording voltmeter, and later a recording ammeter, was used to record the time of making and breaking the circuit. It was deemed that valve #3 was located in a position more similar to that of actual conditions than was valve #2 and so more care was taken with its readings.

The energy for the primary side of each circuit was furnished by dry cells-varying from two to four in number and never giving a voltage of more than four and a half volts. Any change in the amount of primary energy caused no appreciable difference in the operation of the sun relay. Valve #3 was first connected with a recording voltmeter in the circuit to accurately record the times of operation but, after several weeks of operation, it was found necessary to have this instrument thoroughly overhauled. As there was no other recording voltmeter available, it was necessary to use a ten ampere recording ammeter in series with a 500 watt lamp in the circuit The light was for the purpose of causing sufficient load to give enough current to allow a good reading to be made by the recording instrument. The secondary energy was obtained from the 220 volt shop line and was stepped down by an auto-transformer.

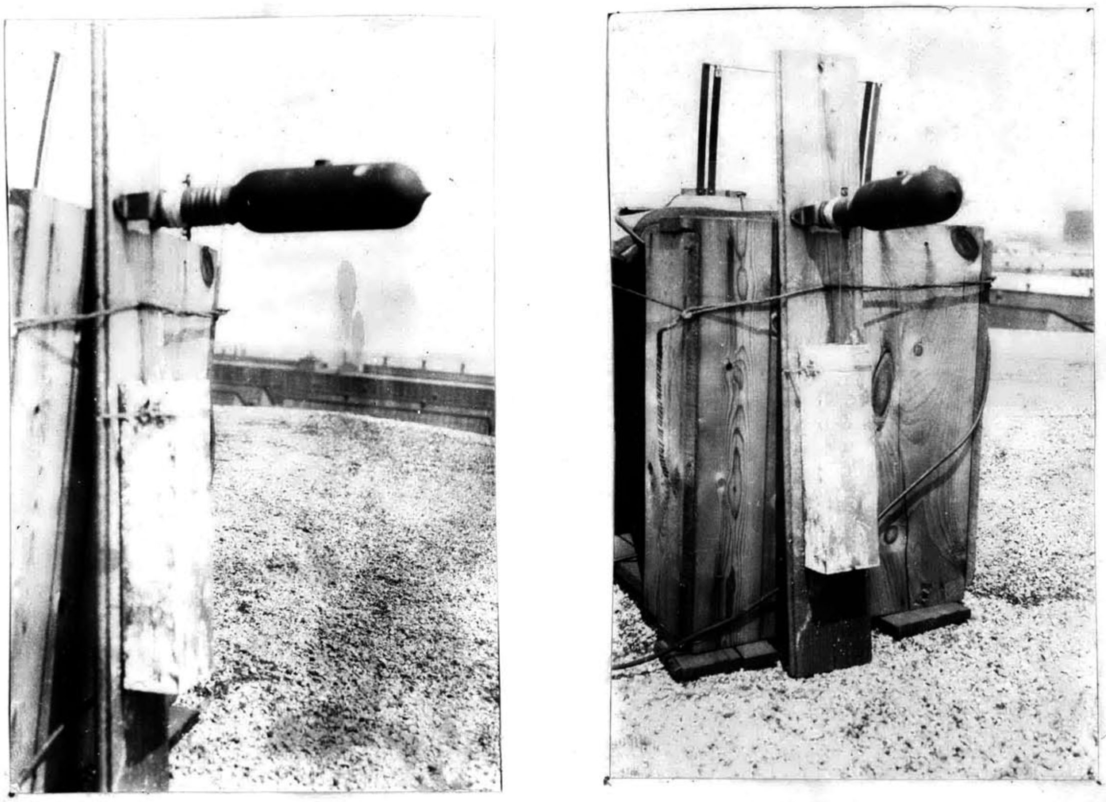
The voltage used varied from 85 to 115 volts at different times but as nothing depends upon the voltage the definite values at any one time will not be given. However, it was found that the current drawn by the 500 watt lamp was excessive as it caused a great deal of trouble in the telegraphic relay-once burning up the contacts completely. This was caused by the contacts opening and causing an arc which would form a rough spot. Then, when the contacts closed again, they would not fit snugly to each other and another arc would be formed roughening the contact surface still more. This effect was cumulative and it was finally necessary to rebuild the telegraphic relay and put in tungsten contacts which have given good service. To partially eliminate this, the 500 watt lamp was replaced by a 300 watt lamp. The relay used was an ordinary telegraphic relay having a resistance of 175 ohms. It was operated by having two like coils energized when the primary circuit was closed, which attracted an armature, operating a lever arm which closed the secondary circuit. The first telegraphic relay was thought to have a weak adjustment spring so another relay of the same type having a resistance of 20 ohms was obtained.

This outfit was tested in all conditions of weather except that of the hot summer months but there is no doubt but what readings over such a period would average up to the same result as those obtained. It can not be said, however, that the readings obtained were entirely consecutive as this was not exactly the case. There were several kinds of delays caused which prevented readings from being recorded. Among these delays was that of the relay burning up, the paper jamming in the recording voltmeter, the telegraph relay sticking, various waits for new apparatus, etc.-all of which at various times caused a great deal of trouble.

The results obtained and a discussion of them will be given in a later part of the paper.

In trying to develop some thermostatic method of controlling a circuit by means of light intensity, it was self evident that some sort of a radiometer would be necessary. It was realized, of course, that radiometers, as a whole, are much less sensitive to light than a photo-electric or selenium cell but, due to the drawbacks and limitations of these two types, it was hoped that some suitable means of control could be evolved. If a radiometer type of control was to be developed, there were three methods of attack; namely by the expansion and contraction of gases, liquids, or solids.

Before anything definite was done along these lines, however, it was decided that a little knowledge about the radiant energy during either the early or later part of the day should be known. To this end, after a study of the various methods, used by the United States Weather Bureau to measure temperatures, was made, an apparatus was made up and located on the top of building #40. This apparatus (see Fig 17) consisted of a moving picture bulb with a hole blown in the center and which was painted a dull lusterless black with a thin coating of lacquer. A rubber cork was inserted in the hole while a 100° Centigrade thermometer was inserted into the bulb through a hole in the cork. This was all air tight so that there could be no leakage of air in or out of the bulb. A square tin tube, twelve inches long, was placed as shown and painted on the outside with a light aluminum paint. The inside of the tube was left with its original dull finish. Another 100° Centigrade thermometer was suspended in this tube so that no direct sunlight could reach it. The blackened bulb would pick up radiant energy and transmit it into heat, causing the temperature of the air in the bulb to give a reading higher than the true temperature. The tube with its light



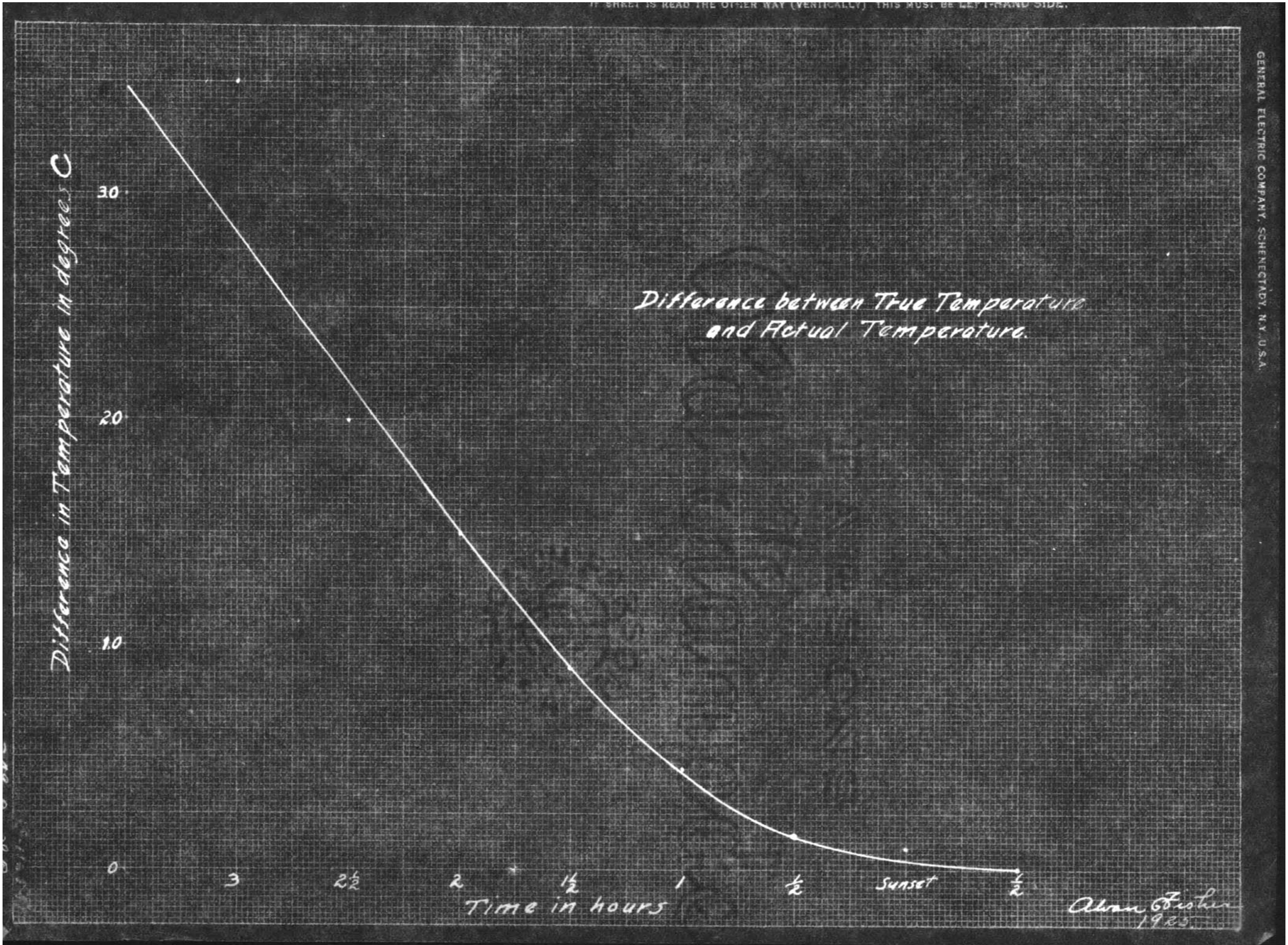
Radient Temperature Outfit

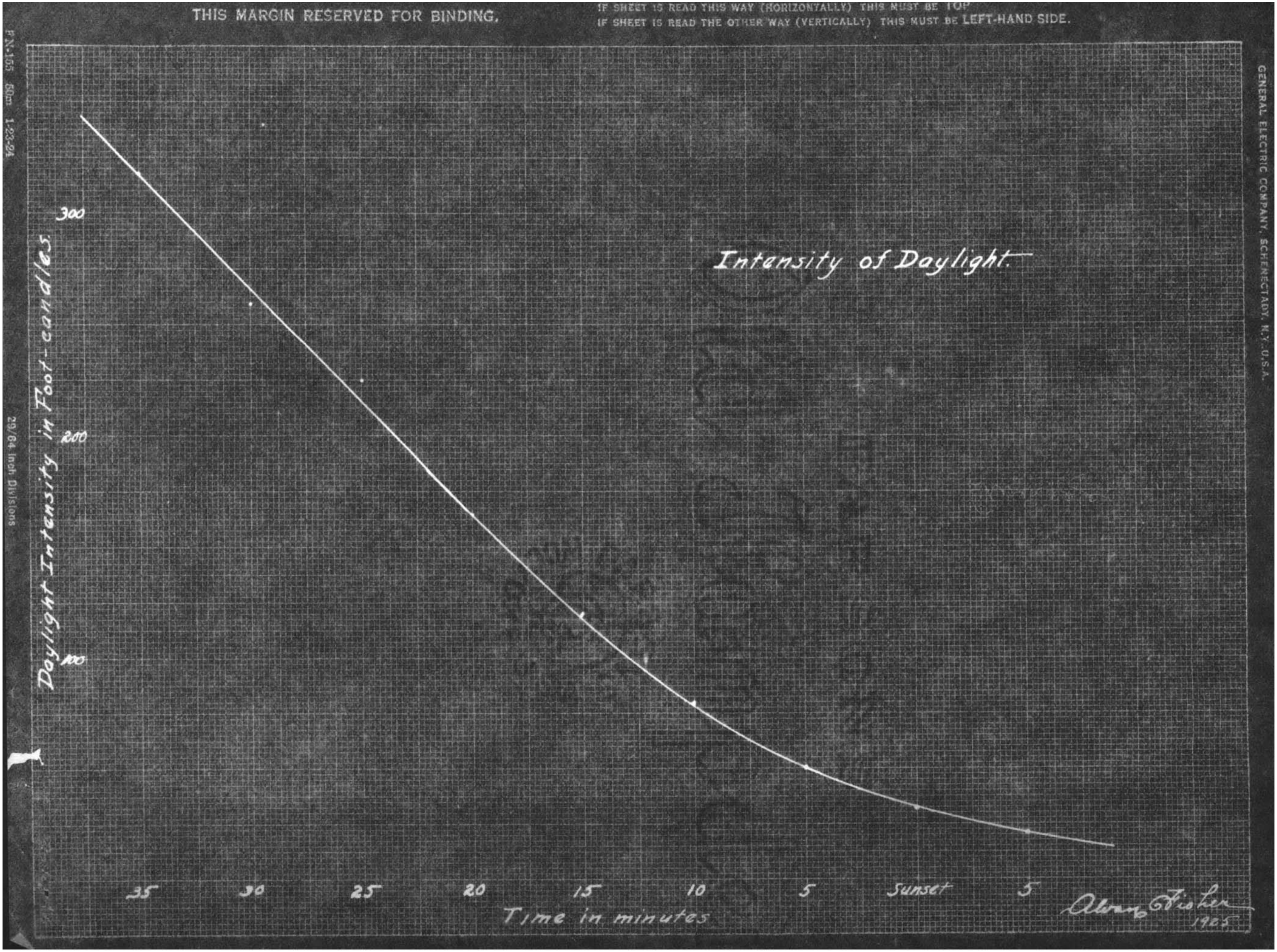
Fig. 17

paint would reflect the radiant energy and in turn cause a current of air to pass upwards through the tube, thus causing the thermometer therein to record the true temperature of the air. The difference between the two temperature readings- the thermometers being calibrated-would then give the radiant heat that could be expected at that time. A curve showing the results of this test is shown in Fig.18 and is made up of the average readings of ten different days during the last part of October and the first part of November. From this curve, it is seen that about one tenth of a degree Centigrade of radiant heat is available at sunset ant that very little radiant energy is present after sunset.

Simultaneously with these readings, a test was made of the foot candle intensity of the day light for a period of at least half an hour before sunset until after sunset. A curve showing the average for ten different days is shown in Fig.19, which gives the light intensity at sunset as thirty-two foot candles.

Knowing then that the amount of radiant energy at sunset or thereafter is very low, it became necessary, in devising any radiometer, to work it out theoretically so that no unnecessary time would be


IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.
GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y. U.S.A.
Differance between True Temperature and Actual Temperature.
Difference in Temperature in degrees C
3.0
2.0
1.0
0
3
2½
2
1½
1
½
Sunset
½
Time in hours
Alvan G. Fisher
1923


THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.
GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y. U.S.A.
Intensity of Daylight.
Daylight Intensity in Foot-candles
300
200
100
35
30
25
20
15
10
5
Sunset
5
Time in minutes
Alvan Fisher
1925

lost in experimenting with dimensions that would not give action.

GAS RADIOMETER.

Working along this line, a radiometer, operaing on the principle of expansion of gases, was devised. It consists of two moving picture bulbs connected by a small glass tube as shown in Fig.20. One bulb is shaded with a cardboard box so that no light can fall upon it. The box is carefully vented so that air may circulate freely and therefore the temperature, and the pressure resulting therefrom, will be the true temperature and pressure of the air. The other bulb, being completely coated with a thin layer of dull black lacquer, will pick up radiant energy from the light and, in addition to the true air temperature, will have an increase in temperature proportional to the amount of radiant energy absorbed. This extra heating, then, will cause an inequality of pressures in the two bulbs and if a slug of mercury were in the connecting tube, sealing each bulb from the other, it would be moved until the inequality of the pressures would be overcome. This then, is the principle upon which experimentation was based with the hope of devising an effective sun valve.

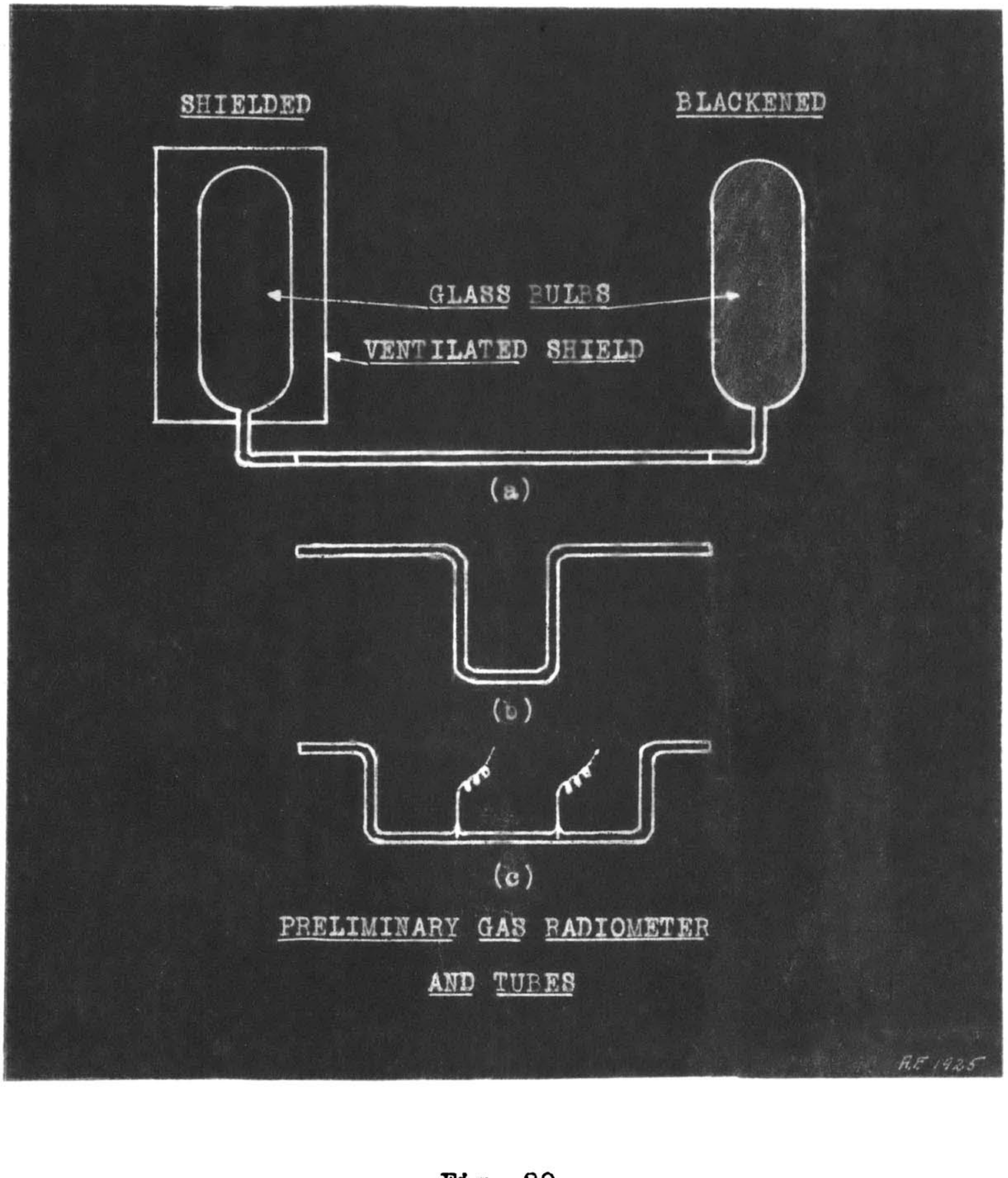

SHIELDED
BLACKENED
GLASS BULBS
VENTILATED SHIELD
(a)
(b)
(c)
PRELIMINARY GAS RADIOMETER
AND TUBES
R.F. 1925

Fig. 20

When figured out theoretically, so that limits could be decided upon, the following was the result. The volume of each bulb was approximately equal to 34 cubic inches; it was slightly more than this but the error is small and will give only a pessimistic answer. Then, a change of $.1^{\circ}$ C at a temperature of 15° C will be used as a basis on which to work. It is assumed that a movement of one half an inch of the mercury will be sufficient to allow for any variation due to a rise in the external temperature.

Absolute temperature $= 273 + 15 = 288$

$$\frac{34}{V_1} = \frac{288}{288.1}$$

$$V_1 = \frac{19795.4}{288} = 34.012$$

or the volume in the blackened tube is increased by .012 cubic inches.

The largest working diameter of the connecting tube will be found as follows:

$$\frac{.012}{A_t} = 1.00 \qquad A_t = .012 = \text{area of tube}$$

$$R_t^2 = \frac{.012}{3.1416} = .0038$$

$$R_t = .0616''$$

Thus the maximum inside diameter of the tube $= .1232''$

or approximately $\frac{1}{8}$".

This shows that, theoretically, any tube less than an eighth of an inch inside diameter should give good results.

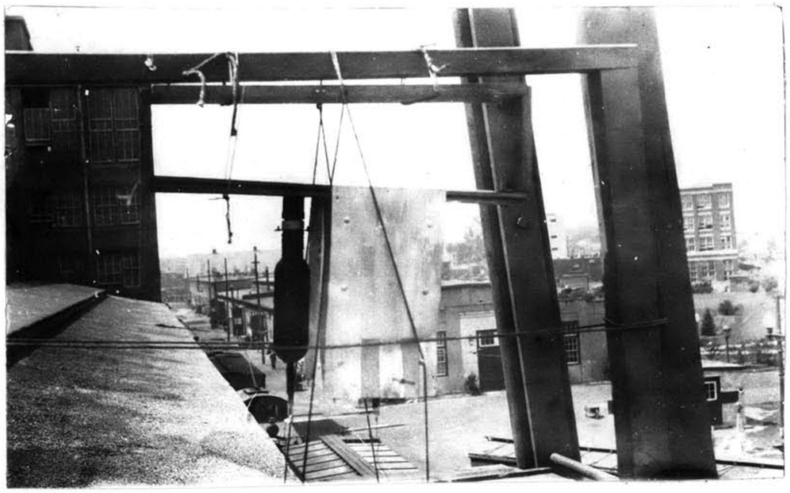
Knowing these limitations, a set was made up as shown in Fig. 20 a. This proved that the device was capable of giving motion to a slug of mercury. In order to determine what shape would be best for the glass connection tube, shapes as shown in Fig.20 b and 20 c were also made up. It was decided that the shape in Fig. 20 c was the best and so another was prepared having two tungsten contact points sealed into the glass as shown.

The idea of this was that, if a slug of mercury was located so that it would just touch each tip of the tungsten point, a complete electrical circuit would be available. Then, when an inequality of pressure existed, the mercury would be driven away from one of the contact points and the circuit would be broken.

This was tried out for some time but it gave very eccentric readings. The greatest drawback was the extremely hard proposition of getting the slug of mercury accurately located so that it would just touch each contact point. Because of this inherent difficulty, this form was given up and another type devised which worked on the same general principles.

The form of the new device is shown in Figs. 21 and 22. It again consisted of two bulbs of the same size as before, with one shaded and one blackened. However, the connecting tube was quite different in shape. The principle of expansion is still used but this time, instead of moving a slug of mercury from a contact, the pressure forces the mercury down until it breaks over the sharp point, thus breaking the electrical circuit. The end of the tube connected to the shaded bulb was much larger in diameter than the rest of the tube in order to gain a slight mechanical advantage when the mercury was forced up into it. The whole outfit was mounted on a hinged board, as shown, so that it could be pivoted and thus regulate the heighth of mercury over the point. Doing this also allows one to adjust the sensitivity of the outfit, for naturally a high column of mercury in the tube will require more pressure, and therefore a higher differential temperature than a short column of mercury to force it down enough to break the circuit.

A great deal of difficulty was encountered



Final Gas Radiometer

Fig. 21

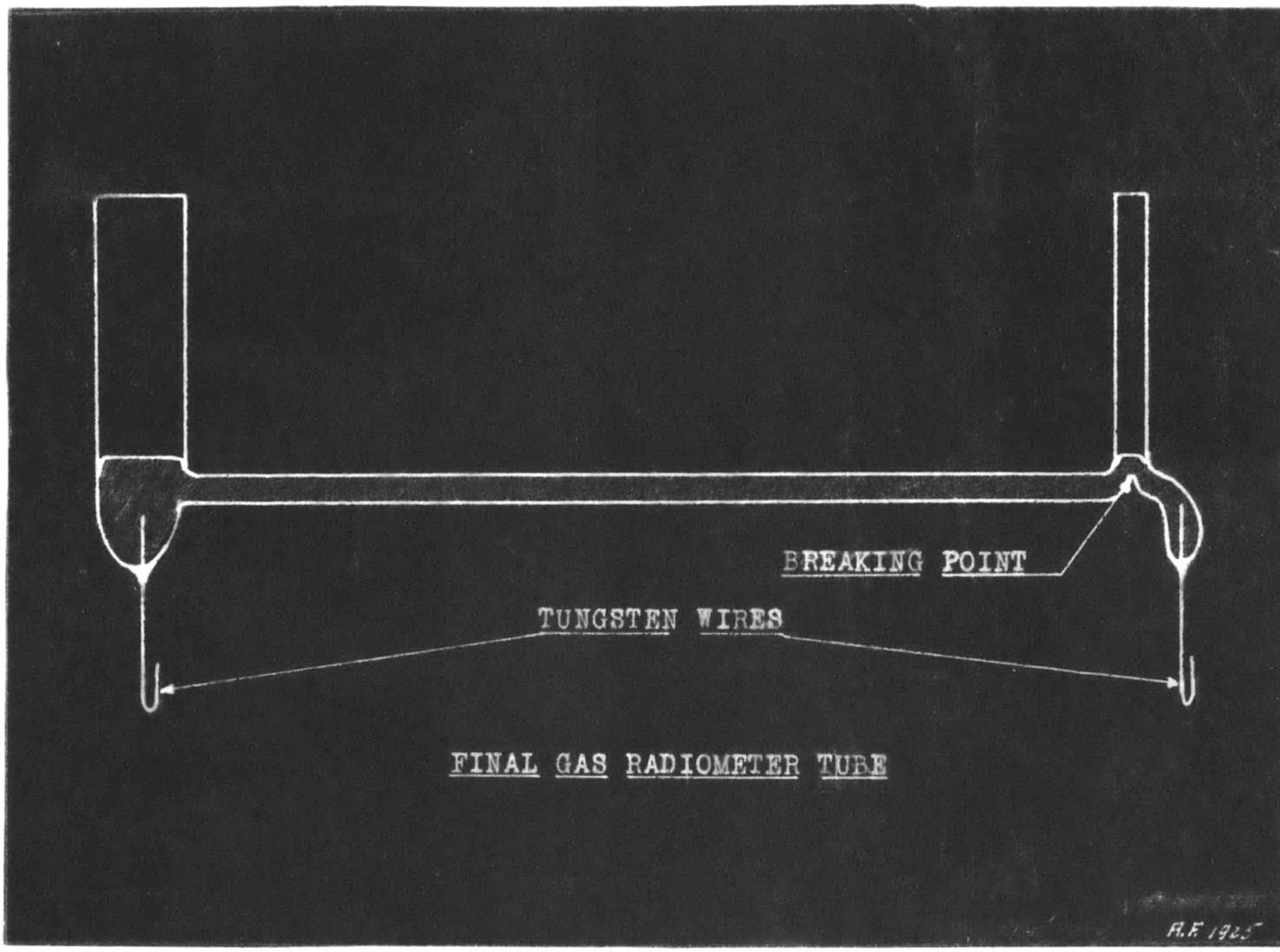

BREAKING POINT
TUNGSTEN WIRES
FINAL GAS RADIOMETER TUBE
A.F. 1925

Fig. 22

with this outfit. The biggest problem was that of overcoming air leaks. While this could be done satisfactorily for a permanent set-up, it was rather difficult to get any flexible arrangement that could be easily changed and still make a good seal. The method used, which gave varying results dependent upon the care taken in making the seals, consisted of rubber tubing with an inside diameter slightly smaller than the outside diameter of the glass tubing. This gave a good close fit which was increased by several tight turns of wire near each end of the rubber tubing. A thick heavy grease was applied over the rubber tubing and around the ends which helped greatly in lessening any leakage. This seal gave good results when properly applied.

The entire outfit was necessarily a temporary one as changes were constantly being made in it. The box covering the tube was made of heavy cardboard and could not, of course, withstand a heavy rain. As it was, several new boxes had to be made. The glass tubes being of a small diameter, were very brittle and a strong wind could break them; this occurred several times. In fact, the outfit that has been working most satisfactorily was destroyed by one heavy storm- only a few small pieces of glass remaining.

Because of this frailty, and the fact that the weather was so continuously bad during the past few months, no consecutive readings of any value have been secured. Readings have been secured, it is true, but they have been only valuable as a means of setting the apparatus for its most sensitive point. However, the outfit does work and is quite sensitive. At midday, on a bright clear day, a blanket was held between the black bulb and the sun, causing the mercury to immediately move three quarters of an inch. This proves that its action is positive and immediate. The results obtained from this type of radiometer will be discussed later in the paper.

LIQUID RADIOMETER.

An outfit using the expansion of a liquid as the prime mover in the action to control a circuit was also tried. This arrangement was given up, however, because of the difficulties met with in setting and controlling a liquid.

The outfit, as shown in Fig.23, consisted of two bulbs filled with mercury and connected to each other by a glass tube containing a slug of mercury. One bulb is black and the other covered as before. The expansion of mercury in the blackened bulb will

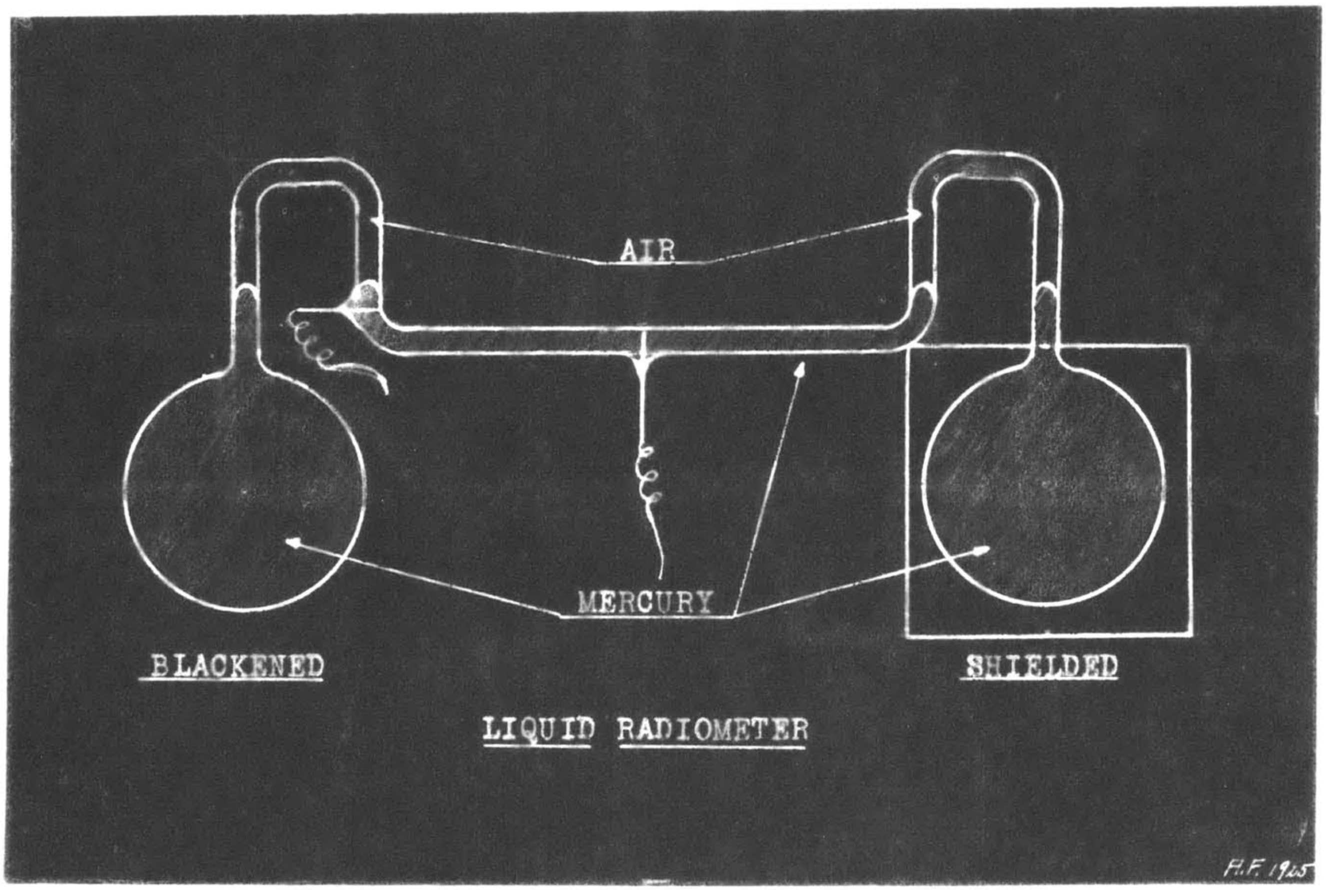


Fig. 23

cause an inequality of pressure on the mercury slug and move it away from the tungsten contact. The theoretical principle is the same as in the gas expansion arrangement.

The daylight recorder used by the United States Weather Bureau operates on the same principle as has been worked out here except that it does not compensate for temperature changes. An arrangement using this principle could perhaps be arranged.but it seems as though it would be a very complicated set-up and so no further thought was given to it.

METAL THERMOSTATS

Knowing that some metals and substances have a high coefficient of expansion, it was thought that some arrangement could perhaps be developed so that this advantage could be utilized.

To this end, two aluminum rods-one half inch in diameter-were arranged as in Fig.24. One end of each rod was securely fastened to a base while the other ends were joined by a thin, stiff strip of copper-.016" thick-which also had a long copper pointer in the same piece of material. One rod was blackened with a thin coating of a dull black lacquer and the other was shaded by a hollow tube. The blackened

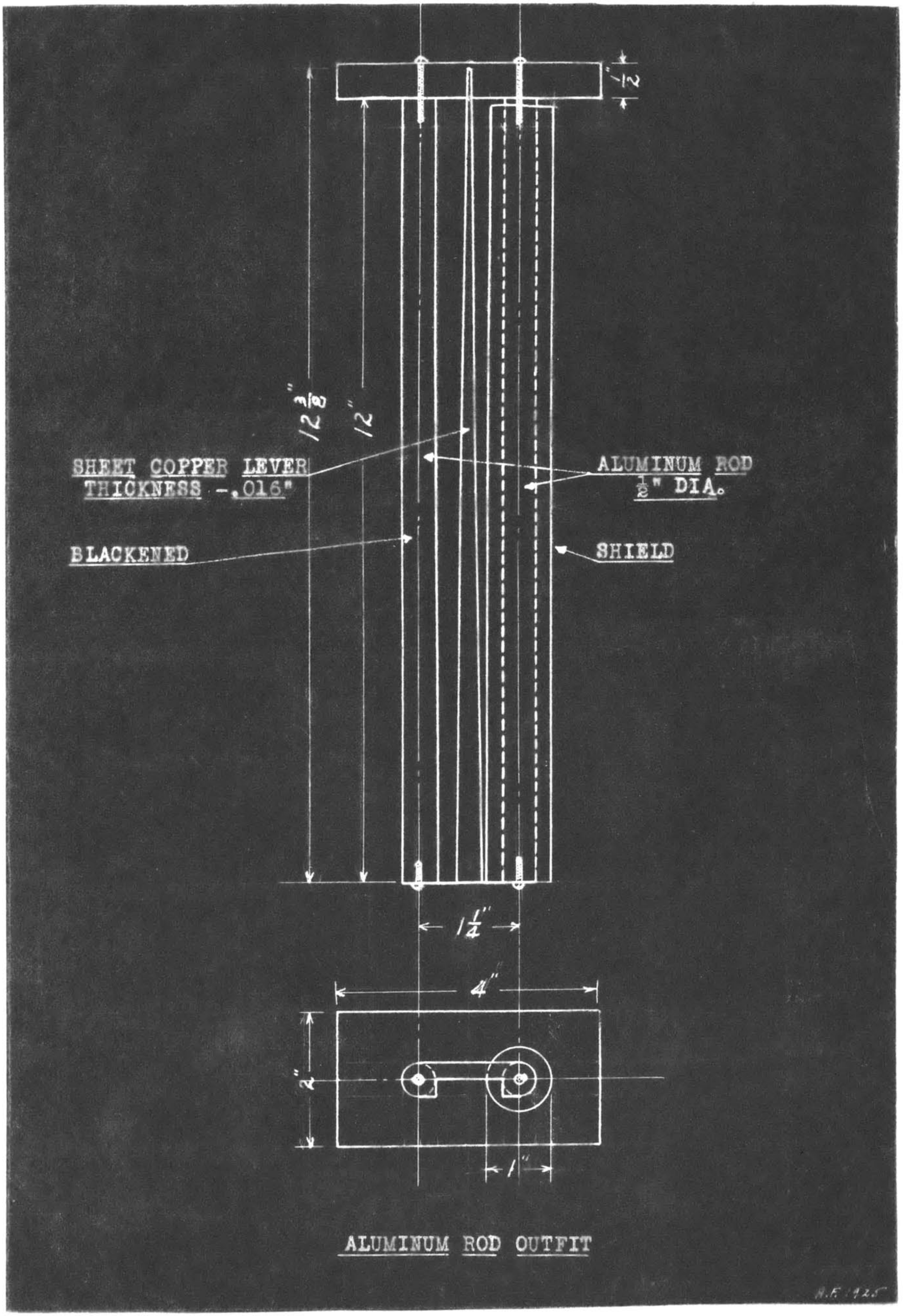

1/2"
12 3/8"
12"
SHEET COPPER LEVER
THICKNESS -.016"
ALUMINUM ROD
1/2" DIA.
BLACKENED
SHIELD
1 1/4"
4"
2"
1"
ALUMINUM ROD OUTFIT
H.F. 1925

Fig. 24

rod was supposed to expand to a greater length and impart a movement to the copper strip which in turn would give an increased movement at the end of the pointer where some sort of a spring contact could be arranged. This outfit, however, failed to give any appreciable motion.

Following this, an arrangement was thought of whereby two aluminum strips, riveted or soldered together, would form a helix about a light steel shaft as shown in Fig.25. One end of the combined strip was to be fastened securely to some rigid base and the other end secured to the rod, which was pointed and resting in pivot bearings. Then, if one strip of the combined strip was painted black and the other polished, the black one would tend to extend over a greater length and cause a twisting motion to the steel rod. This motion would be increased by a small arm extending out at right angles to the rod and having the contact point at its end.

However, before this idea was put into practice another scheme along the same line was worked out. It consisted of two helices, one inside of the other, and wound in opposite directions, of thin aluminum strips-.025" in thickness, .5" in width, and 24" in length. Each helix was to have one end fastened to

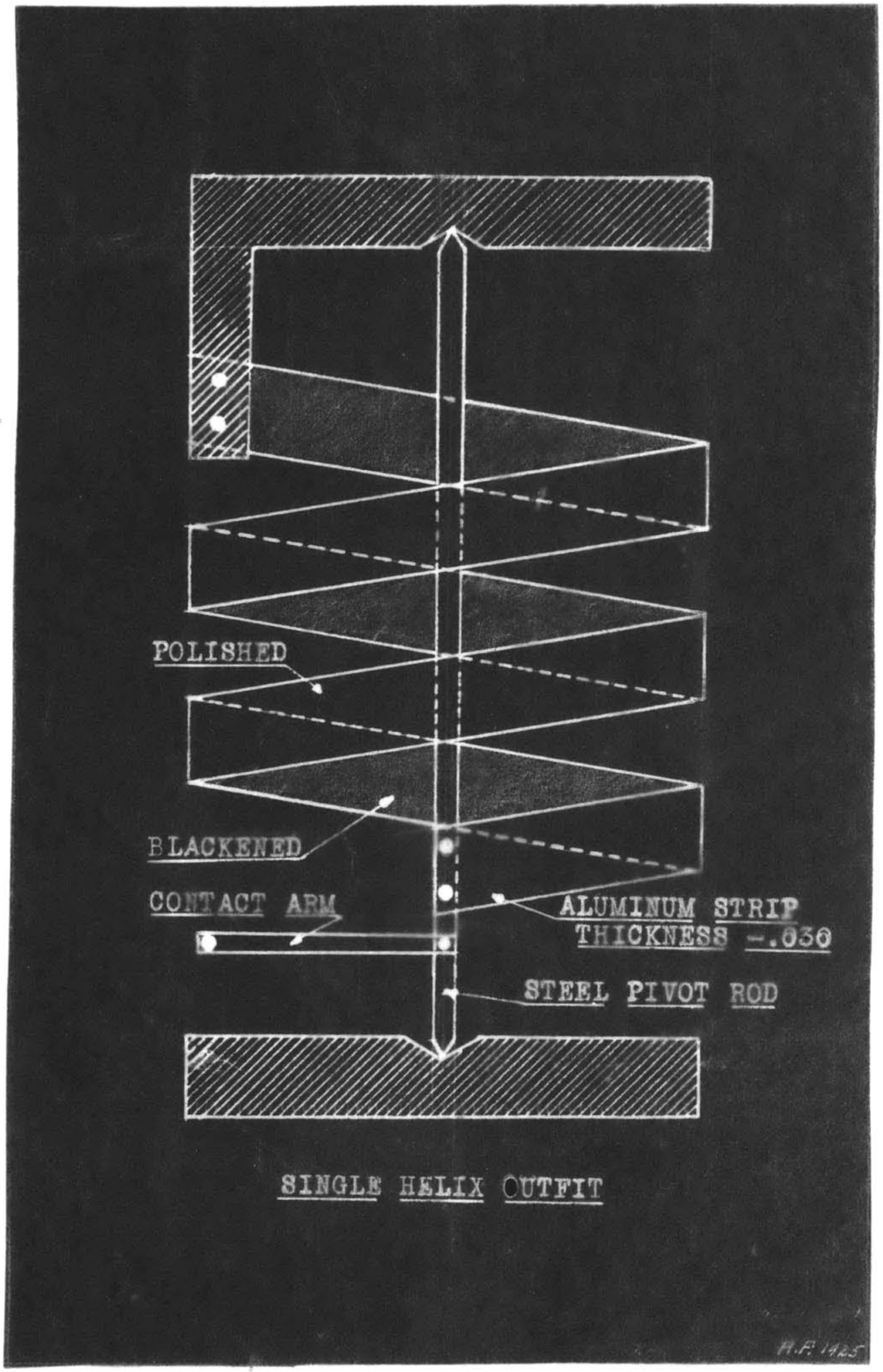

POLISHED
BLACKENED
CONTACT ARM
ALUMINUM STRIP
THICKNESS -.036
STEEL PIVOT ROD
SINGLE HELIX OUTFIT

Fig. 25

some immovable part while the other ends were connected to an arm coming out from a steel shaft similar to the one in Fig. 25. This arm was to be extended out to bear against a copper pointer. This pointer was six inches long and the lever ratio of the point of contact to the point of bearing was eight to one. One strip was to be polished and one blackened with the latter expanding to a greater length on picking up radiant energy. This would cause motion of the shaft arm, which, in turn, would impart motion to the pointer and the original motion magnified.

Such an arrangement was made up but failed to operate at all satisfactorily. The main trouble was probably due to the fact that instead of imparting its motion due to an increase of length to the shaft arm, it merely increased the radius of the helix. In other words, the motion was in a radial rather than an axial direction. There was some consideration of placing this in a large glass tube so that the outer helix would bear against the glass and thus prevent this axial motion. This idea, however, was discarded as it would still allow the inner helix to have a radial motion and the friction between the metal and the glass would probably be too great to allow any motion of the arm. The same disadvantage was inherent in both the spiral forms and so both were discarded.

The next attempt was in the use of a thermostatic bi-metal. A simple outfit was made up consisting of two bi-metal strips as shown in Fig. 26. These strips were home made out of steel and duralumin riveted together. One duralumin and one steel strip were blackened and the others polished and then assembled as shown. For temperature increases, both strips will bend to the right because of the duralumin. Duralumin, having a greater coefficient of expansion than steel, would tend to lenghten more than the steel and force the latter to bend. However, when the blackened sides pick up radiant energy, they will tend to increase more in length than that due to temperature. This, then, would cause the right hand strip to bend more to the right as the duralumin again increases its length. The left hand strip will have a motion to the left due to the steel increasing its length and overcoming some of the bend caused by the duralumin. These two motions, in opposite directions, would

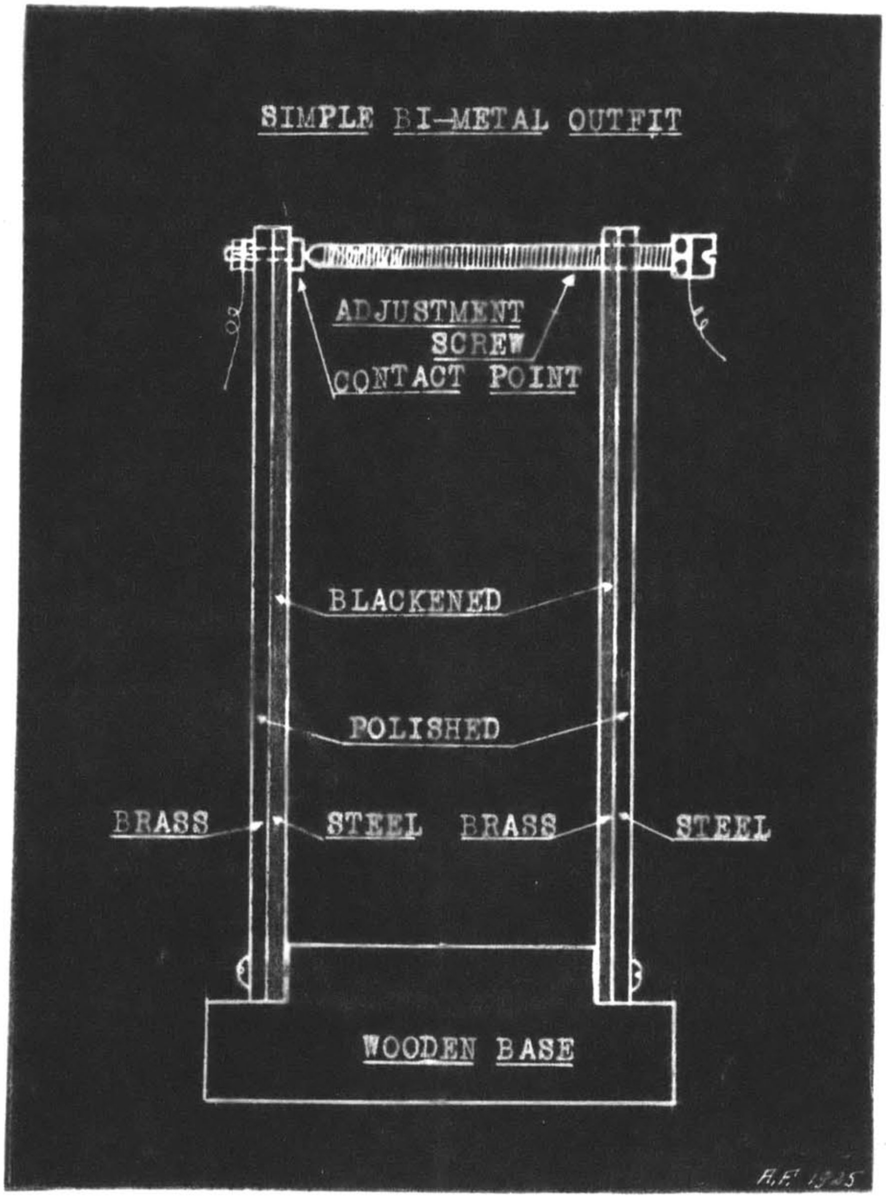
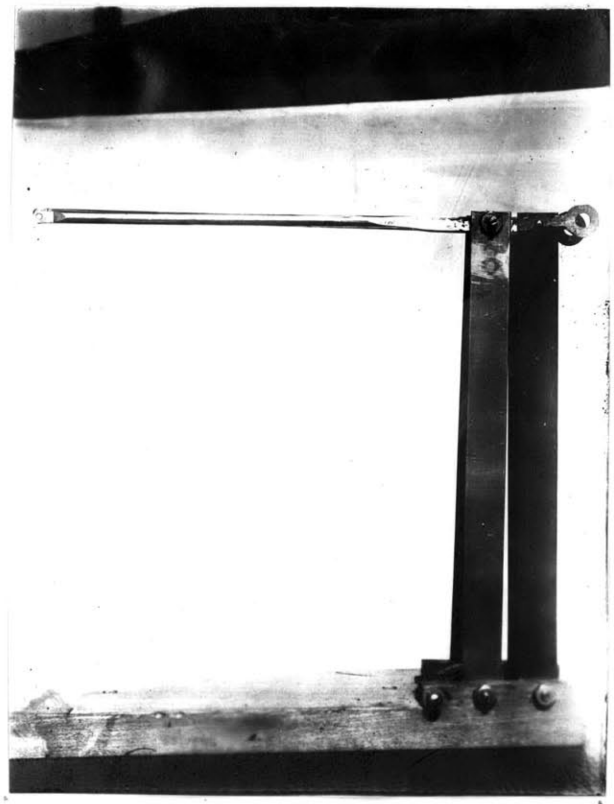

SIMPLE BI-METAL OUTFIT
ADJUSTMENT
SCREW
CONTACT POINT
BLACKENED
POLISHED
BRASS
STEEL
BRASS
STEEL
WOODEN BASE
R.F. 1925

Fig. 26

therefore tend to open up the circuit made by the contact screw on the contact disc. This arrangement worked after a fashion, with a small telltale lamp and dry cell in series with it to indicate its action. However, due to the crudeness of the bi-metal and the very little theoretical motion possible, it was given up. Later, another bi-metal relay was developed which seemed as though it had good possibilities. This is shown in Figs. 27, 28, and 29. The function of the relay is to operate when affected by radiant energy from any source, such as the sun, and at the same time compensate for temperature differences. The relay consists of four thermostatic bi-metal strips which are rigidly fastened to a base. At the top of these strips is fastened a lever arm which will be rigidly connected to bars 1 and 2 and have a sliding connection to bars 3 and 4. This latter connection should permit motion to the lever arm, as regards these strips, in a plane parallel to the face of strips 3 and 4 but not normal to them.

Then, under any changes of temperatures, the bi-metal strips will all bend in the same direction, as shown by the full arrows, as a result of the bimetal action. Now, if the brass section of strips



Bi-metal Relay

Fig. 27

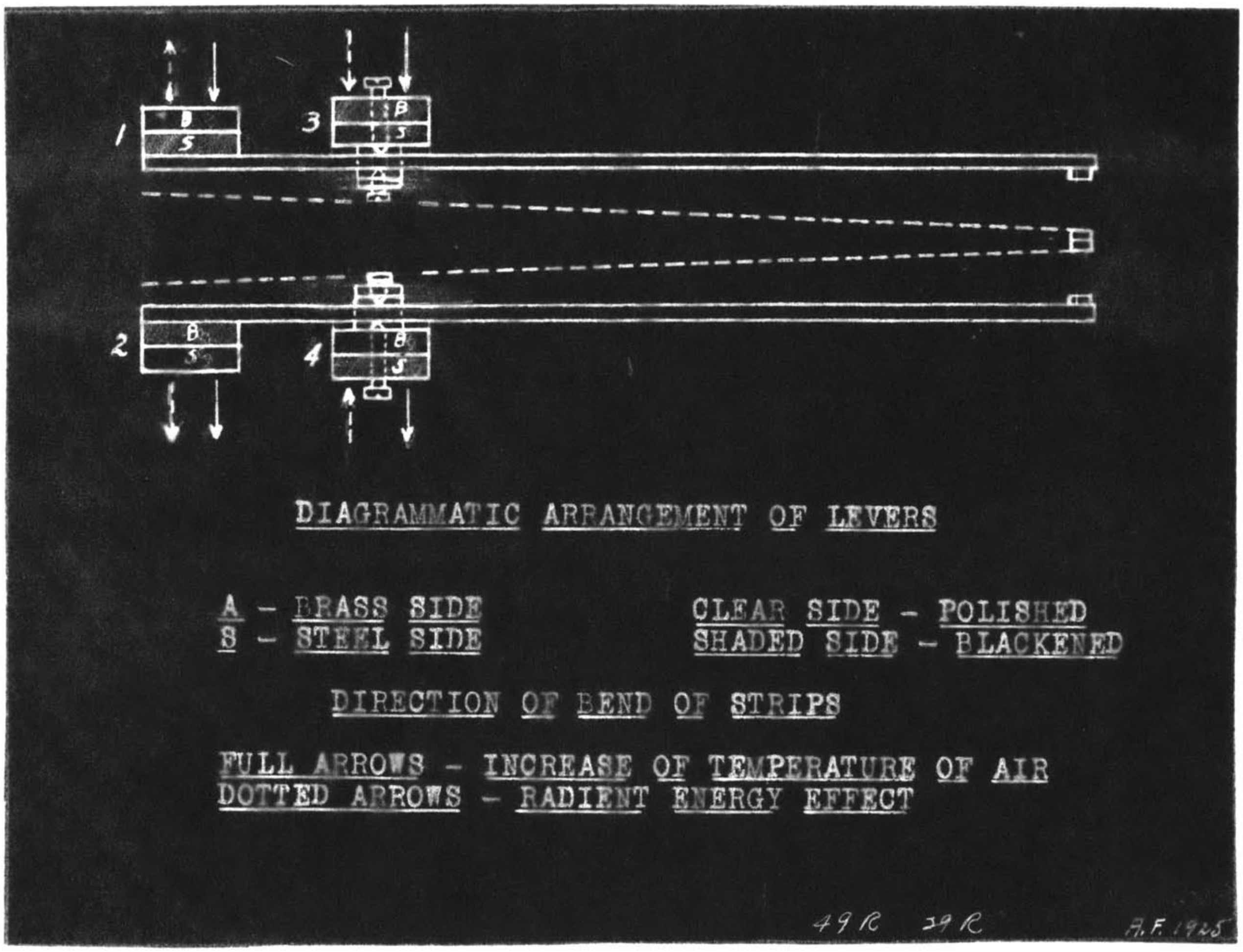

1
3
2
4
B
S
DIAGRAMMATIC ARRANGEMENT OF LEVERS
A - BRASS SIDE
S - STEEL SIDE
CLEAR SIDE - POLISHED
SHADED SIDE - BLACKENED
DIRECTION OF BEND OF STRIPS
FULL ARROWS - INCREASE OF TEMPERATURE OF AIR
DOTTED ARROWS - RADIENT ENERGY EFFECT
49 R 39 R
A.F. 1925

Fig. 29

2 and 3 and the steel section of strips 1 and 4 be blacked and the remaining sections be highly polished, the blackened sections will pick up more radiant energy from the energy source and cause a motion as shown by the dotted arrows. This means that, for an increase in temperature, strips 2 and 3 will have motion due to both temperature and radiant energy, while the other strips will have a smaller motion because of the bucking effect. Then, considering strips 1 and 4 as fulcrums, it will be seen that a lever action is the result, the ratio depending upon the distance between the centers of the strips to the distance between the fulcrum point and the contact point. Strips 2 and 4 are mounted upon a small base which can be moved about a pivot by means of a regulating screw. By this means, the distance between the contact points can be regulated.

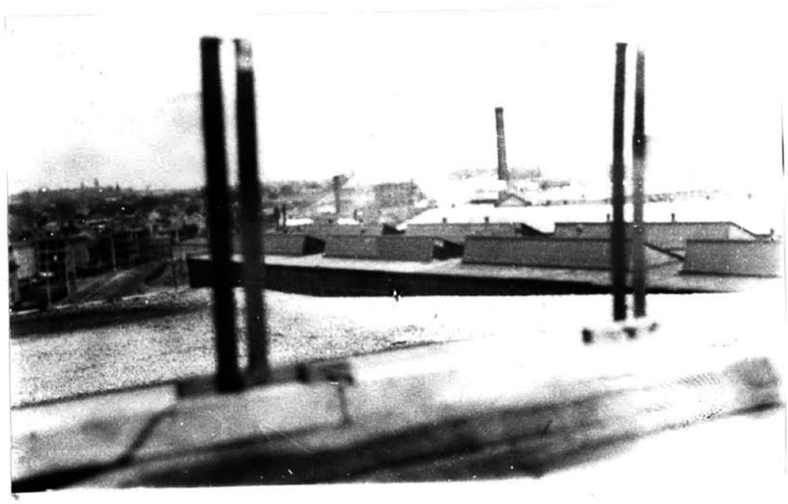
The sensitivity of the relay can be increased by either increasing the length or decreasing the thickness of the bi-metal strips, by increasing the lever ratio by lessening the distance between the centers of the strips or increasing the length of the lever arm, or by decreasing the distance between the contact points. If the length is tripled and everything else held the same for the kind of bi-metal used, the deflection will be increased to nine times its original value. If the length is held constant and the thickness tripled the deflection will be reduced to one third of its original value.

This device seemed to be very practicable and, meeting with the approval of Professor Elihu Thomson, a patent was applied for, subject to the patent agreement with the General Electric Company.

One set was made up using strips of Wilco Thermostatic metal- .040" in thickness, .5" in width, and 6" in length. This metal was secured from the H.A.Wilson Company of Newark, New Jersey, The lever arms were six inches long and the centers of the strips were three quarters of an inch apart, giving a lever ratio of eight to one. From curves obtained from the Wilson Company, a strip of their bi-metal, 6" x ½" x .040", would have a deflection of .0135" for a .2°F change in temperature. It was considered that .1°C was approximately equal to .2°F; the .1°C being previously found to be the radiant temperature at sunset. This deflection, when multiplied by the ratio of the lever arm and again multiplied by two for each set of levers, would give a motion at the contact points of .208 inches. To make this outfit more sensitive, it is only necessary to lessen the distance between the contact points to less than this amount by means of the adjustment screw. Though it is realized that the lever ratio for the lower strip, as shown in Fig.27, is not as high as that of the upper, it is considered to be the same since no attention was paid to the deflection due to the steel sides straightening out. The answer obtained is then a pessimistic one and slightly better results can be expected.

Before this outfit had been really tested, a change was decided upon; that the two strips of bimetal for each lever should not be close together but spread apart as shown in Fig.30. The reason for this change was due to the thought that one set of strips would shadow the other. This time the strips were .020" in thickness, .5" in width, and 7.5" in length- the idea being to make as sensitive a relay as possible with the material at hand. This outfit gave a deflection of .674" for a change in temperature of $.2^{\circ}F$. The paint for the blackened strips was the same dull black lacquer as used before,

Fig. 30



Modified Bi-metal Relay

Fig. 31

while the polishing was done on a buffing wheel. The polished sides were afterward coated with a thin white lacquer to preserve their polish.

The results obtained from this relay will be discussed among the final results.

GECO RESISTORS

Acting along the lines of the discovery of Mr. F.A.Swan, it was decided to try out some arrangement whereby the change in resistance of a substance due to the light falling upon it might be used to advantage. To this end, an outfit was assembled as shown in Fig. 32. To determine any change, if there were any, a DH-5 mid-scale differential voltmeter was used in a circuit with two Geco resistors. The voltmeter had been fixed so that a full scale deflection was given for .005 amperes, making it very sensitive. The resistors were made up of 66 inches of iron-wire-4.7 mils in diameter. Their form is similar to the moving picture lamps previously described except that the iron wire is run lengthwise through the bulb in place of the filament. The resistor was used for this experiment as it was available while such a tube with tungsten wire would have taken weeks to secure. It was also considered that

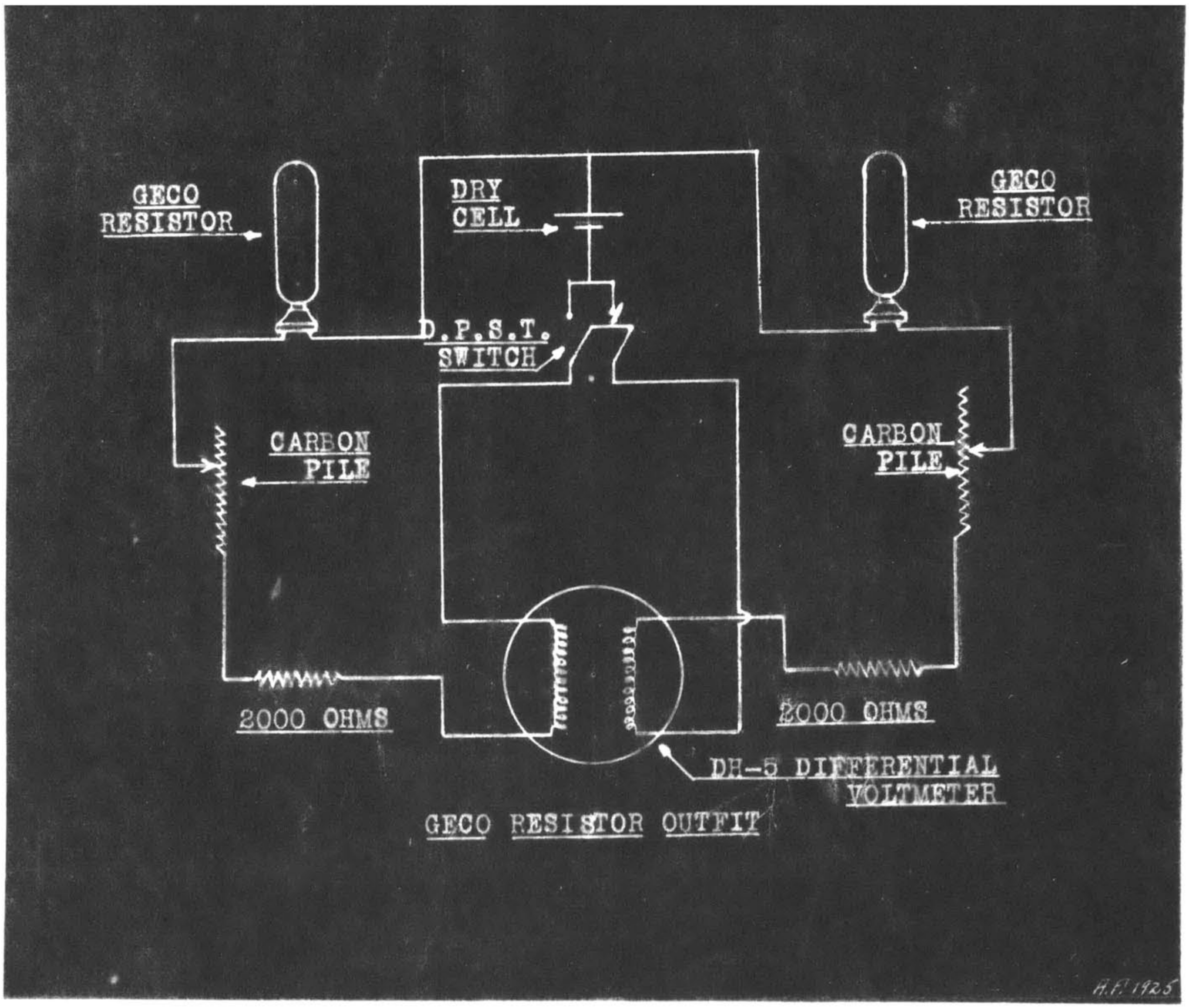

GECO RESISTOR
DRY CELL
GECO RESISTOR
D.P.S.T. SWITCH
CARBON PILE
CARBON PILE
2000 OHMS
2000 OHMS
DH-5 DIFFERENTIAL VOLTMETER
GECO RESISTOR OUTFIT
A.F. 1925

Fig. 32

with such a high degree of sensitivity an idea, at least, of how such an arrangement would act could be gained. Then, if it showed promise, a differentially wound relay could be substituted for the voltmeter. The fixed two thousand ohm resistances consisted of two wire resistance tubes.

After the arrangement had been accurately balanced so that the voltmeter read zero, both hands were clasped around one bulb and held there for ten minutes. There was no deflection of the voltmeter. The same thing was tried again. There was still no deflection. Such an arrangement was therefore considered to have no vlaue, as the heat from the hands was undoubtedly greater than that which would be received from radiant energy at sunrise and sunset and even that caused no deflection in an extremely sensitive instrument.

THERMOCOUPLES

On the advice of Dr.W.W.Coblentz of the United States Bureau of Standards, no effort was made to develop any scheme in which thermocouples were used.

RESULTS OF TESTS.

The results obtained from the tests on the American Gas Accumulator sun relays have been worked out and tabulated as follows;

SUN RELAY #3

Average time of lag after sunrise..........1 hr.4.5 min.
Based on 110 actual readings
Average time of lead before sunset.........50.4 min.
Based on 105 actual readings
Total waste time per day(sunrise to sunset)1 hr.50.9 min.
Total waste time per day on street lighting contract-
2 hr. 50.9 min.
Total waste time per year on street lighting contract..................................1062.85 hrs
= 26.57%

The best sunrise reading was 9 minutes before sunrise. A leading sunrise reading was obtained twice. The best sunset reading was 6 minutes after sunset. A lagging sunset reading was obtained twice with one reading exactly at the time of sunset. These readings all occurred under exceptionally bright clear conditions.

The worst sunrise reading was 3 hours 51 minutes late.

The worst sunset reading was 4 hours 5 minutes early.

The sun relay failed to operate at all on four stormy days.

SUN RELAY #2

Average time of lag after sunrise......1 hr.2.3 min.
Based on 77 actual readings
Average time of lead before sunset.....1 hr.26.7 min
Based on 57 actual readings

The results obtained from this test were somewhat as expected. The average time of lag after sunrise, for both the optomistically placed and the pessimistically placed sun relays, checked very closely-better in fact, than one might expect. The reason for this was that both were directly in the path of the morning light and therefore should be acted upon in the same manner. The evening readings, however, show that relay #2 operated on an average of thirty-six minutes before relay #3. This again was to be expected as relay #2 was in very poor position to receive the late afternoon light and, therefore, necessarily would close the circuit ahead of the better located relay. This proves then that a location with an unobstructed horizon is vitally necessary to the most efficient operation. Although there were several readings before sunrise and after sunset, it is seen that they are the exception rather than the rule and therefore should not be seriously considered. These results, when communicated to the chief engineer of the American Gas Accumulator Company checked very closely with their confidential test results so that an accurate and satisfactory test can be considered to have been made.

It is at once clearly evident that the American Gas Accumulator sun relay is entirely unsuitable for use in controlling street lights. While it is true that it functions in all sorts and conditions of temperature and weather, it does not give sensitive enough control and therefore is useless. Street lighting contracts, based on four thousand operating hours a year, have been in force for years and any operation of lights over this period is a direct and distinct loss to the lighting company unless the contract could be changed, which is practically impossible. No city or town will pay for light when it is not necessary. Besides all this, it would be a great economic waste which this generation is trying to eliminate as much as possible. Any advantages, then that might accrue from multiple wiring, elimination of power station equipment, etc. would soon be lost through the generation of unnecessary power due to the inexact control of the lighting circuits.

There is one statement made by the American Gas Accumulator Company which was not borne out by these tests, however. The company claims that the sun relay will accurately compensate for changes in temperature. This was not found to be true. The critical point is the position at which the two contacts just touch each other enough to make an electrical circuit. Therefore, if the relay accurately compensated for changes in temperature, the setting for the critical point would remain the same under all conditions. This was not found to be the case. On October 14, the critical point was found to be at 235° with a temperature of about 70°F. On December 23, when it was found that the sun relay was not working well, the critical point was relocated and found to be at 150° with a temperature of 20°F. On February 6, though the sun relay was still operating properly the critical point was again relocated and found to be at 220° with a temperature of 44°F. The relay, in each case, was hooded for at least twelve hours previous to the setting. The critical point was found by the voltmeter method and was the mean of at least ten readings taken in a slow, accurate manner according to instructions. The final setting, each time, was 15° from the critical point and better operation was at once noticeable.

This variation in the location of the critical point was without a doubt, due to the variation in the temperature during the different seasons of the year. Mr.Oestnaes, chief engineer of the American Gas Accumulator Company, was notified of the variation and it is understood that he is now working towards an elimination of this fault. The variation is undoubtedly due to the difference in cross-section area of the cylinder and a rod.

It was found that the average light intensity at sunset for ten different readings was thirty-two foot candles and that the average light intensity, for the times that the relay operated during the days that this record was kept, was two hundred and ten foot candles. The curve showing this is given in Fig.19.

No definite results, from which to draw accurate conclusions, have as yet been obtained from the gas radiometer. The device has been in operation and is giving readings each day. These readings have been, however, for the purpose of resetting the outfit so that it will give a more sensitive reading. It was not possible to give as careful attention to this or the bi-metal set as their supervision was, by necessity, more or less erratic. Also, because of the temporary frailty of the set, it was always securely covered and fastened down whenever there was a storm and, with the prevalent spring rains, this was quite a common occurrence. All this necessarily meant that the test progressed much slower than desired and, at the writing of this paper, it is still in the experimental stage. However, it has been giving good readings, especially in the evening when the readings well after sunset have not been at all uncommon. This, sorry to say, does not hold good for sunrise as there has been average lag of about an hour up to the present time . This lag has possibilities of being corrected, though. There is some doubt as to whether the device will operate the same in the winter as in the summer due to the contraction and expansion of the mercury. This will have to be worked out in case the test is carried any further.

The final bi-metal outfit was installed on the roof of building #40. It was found to be extremely sensitive to vibrations of any kind and so, to offset this, it was placed on top of a felt pad-1" in thickness- and covered over with a large glass globe. It functioned and gave fairly good results. As a proof of its sensitivity, a shadow was cast on it, one day at noon, causing it to move to close its circuit at once. However, its extreme sensitivity to vibrations made it necessary to disconnect it as its continual opening and closing the circuit, when the contacts were close together, was very hard on the relay, tending to burn it up. Time was not given to build an outfit which would not be so sensitive to external factors, and still would function well. The arrangement has good possibilities, though, and would undoubtedly give good results if a happy medium in its dimensions could be found.

Conclusion

For the reasons advanced within the report, it is evident that neither the selenium and photo-electric cells nor the sun relay are applicable to the solving of the problem. Nor can the other thermostatic methods developed, save perhaps the gas radiometer and bi-metal arrangements, be used as an accurate solution. These latter two methods have shown good possibilities and seem worthy of having a longer and more thorough test applied to them.

Considering automatic operation of street lights in its entirety, outside of just control by means of solar radiation, there are two other methods by which a remote control can be effected; namely, by clock mechanisms or by wired wireless operating a selective relay. Of these, it appears that the wired wireless control would be the superior. A resume of an actual wired wireless attempt at control will be found in the appendix.

It is therefore recommended that, in spite of the possibilities offered in the gas radiometer and bi-metal outfits, any further research into this problem should be conducted along the lines indicated by the wired wireless experiments. It appears that experimentation in that direction will be much more conducive to successful attainment than research along other lines.

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APPENDIX

WIRED WIRELESS STREET LIGHTING INSTALLATION BETWEEN LYNN AND NAHANT

The remote control of distant lighting circuits or individual lamps by means of carrier current consists of superimposing on a line, alternating current of a predetermined frequency. This current is drained off at the desired point, by utilizing circuits, selective to the impressed carrier frequency. Obviously the power so taken can be employed in operating a device which is also responsive to the carrier frequency.

The decided advantage of this system lies in the fact that the existing power lines can be used as the conductor for the carrier current. In addition several relays widely located on the system can be operated at the will of the station attendant. It is also possible to provide for operating any one of a number of relays without actuating other relays on the same system.

An actual demonstration was provided by the General Electric Company using the system of the Lynn Gas & Electric Company.

In the generating station of the Lynn Gas & Electric Company at Lynn, a high frequency generator, consisting of a low power three-element vacuum tube and its associated circuits was used to convert power from the 110 volt 60 cycle lighting circuit into power at the carrier frequency.

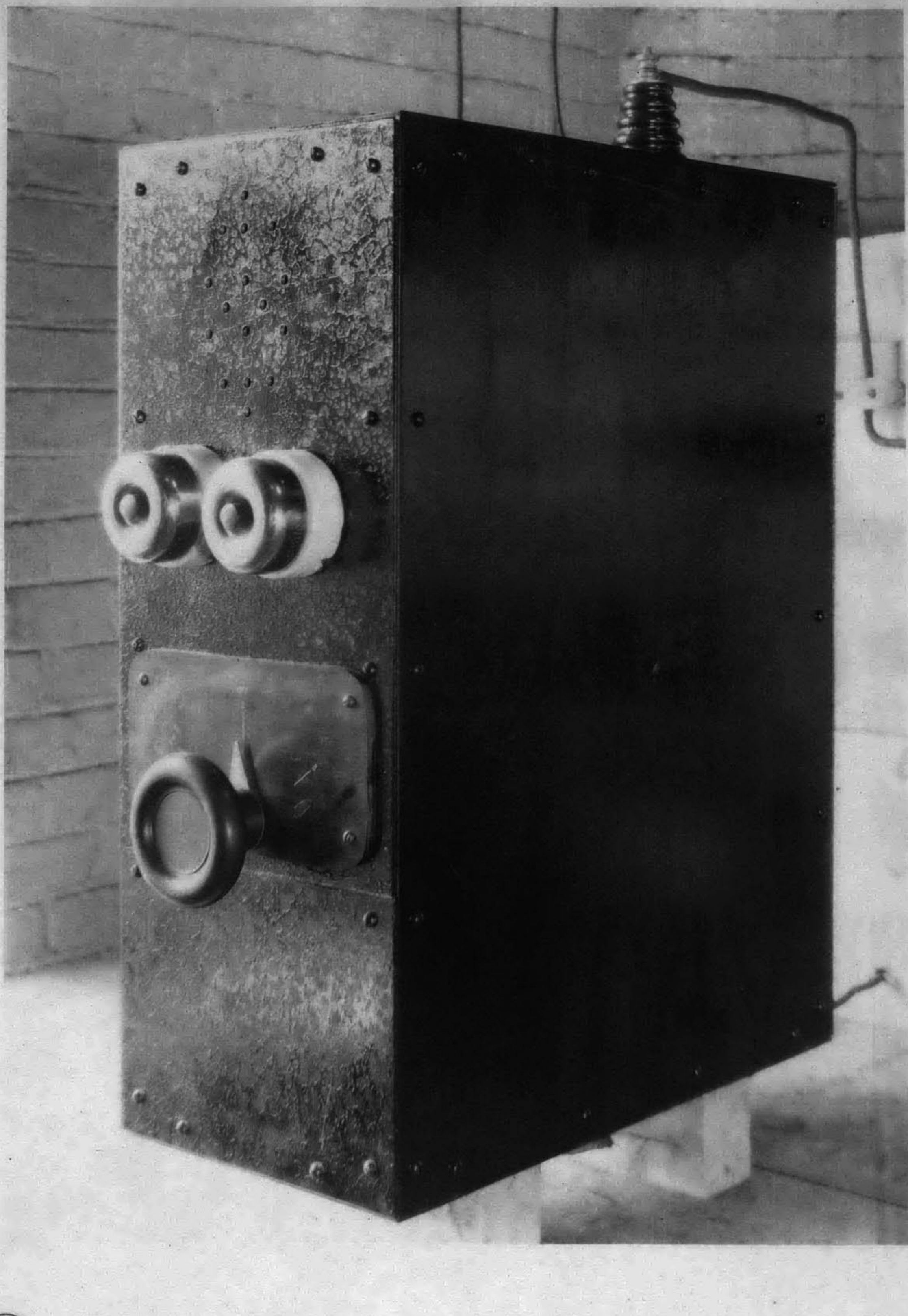
The output of this generator was then superimposed on the 4400 volt three phase grounded neutral, house-lighting feeder circuit. That section of the feeder circuit between the generating station and the remote point consists of three miles of aerial line and one mile of underground cable, making a total of four miles.

The demonstration was so arranged that either of two circuits could be controlled. One of these, the Little Nahant section of the D.C. street lighting loop, consists of 18 incandescent and two arc lamps. The other load comprised two 1000 watt searchlights, two 500 watt floodlights and one pendent lantern.

The control of these loads is accomplished at the Central Station as follows:-

A frequency selecting switch is moved to that position corresponding to the operation it is desired to perform. It is only necessary for the operator to push a button which causes the relay to function. It should be noted that the high frequency generator is in operation only when the button is depressed. This sequence of operation applies to either connecting or disconnecting the distant street lighting load.

6-13-22



157317 50 WATT DRIVER FOR CARRIER CURRENT CONTROL.

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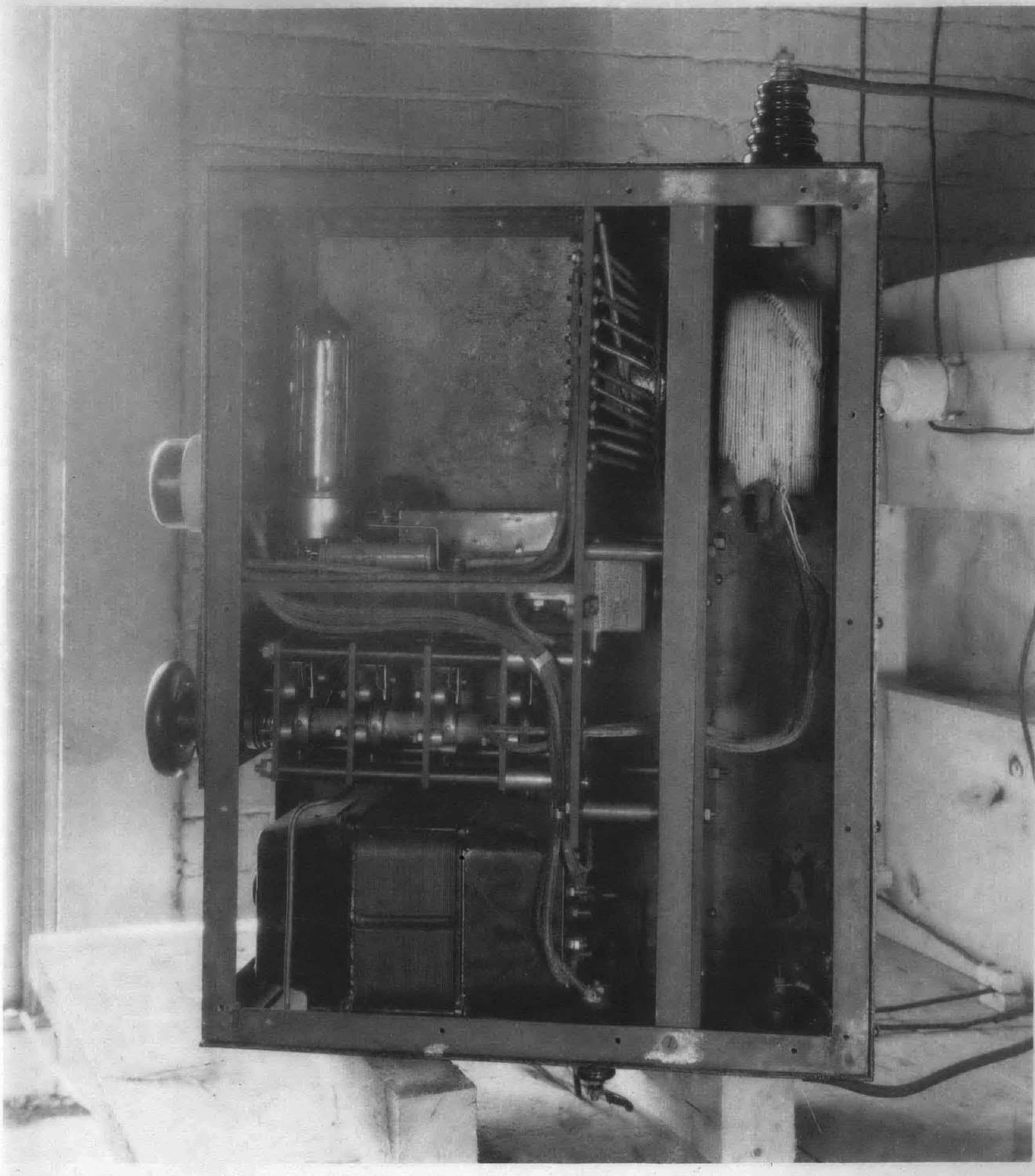

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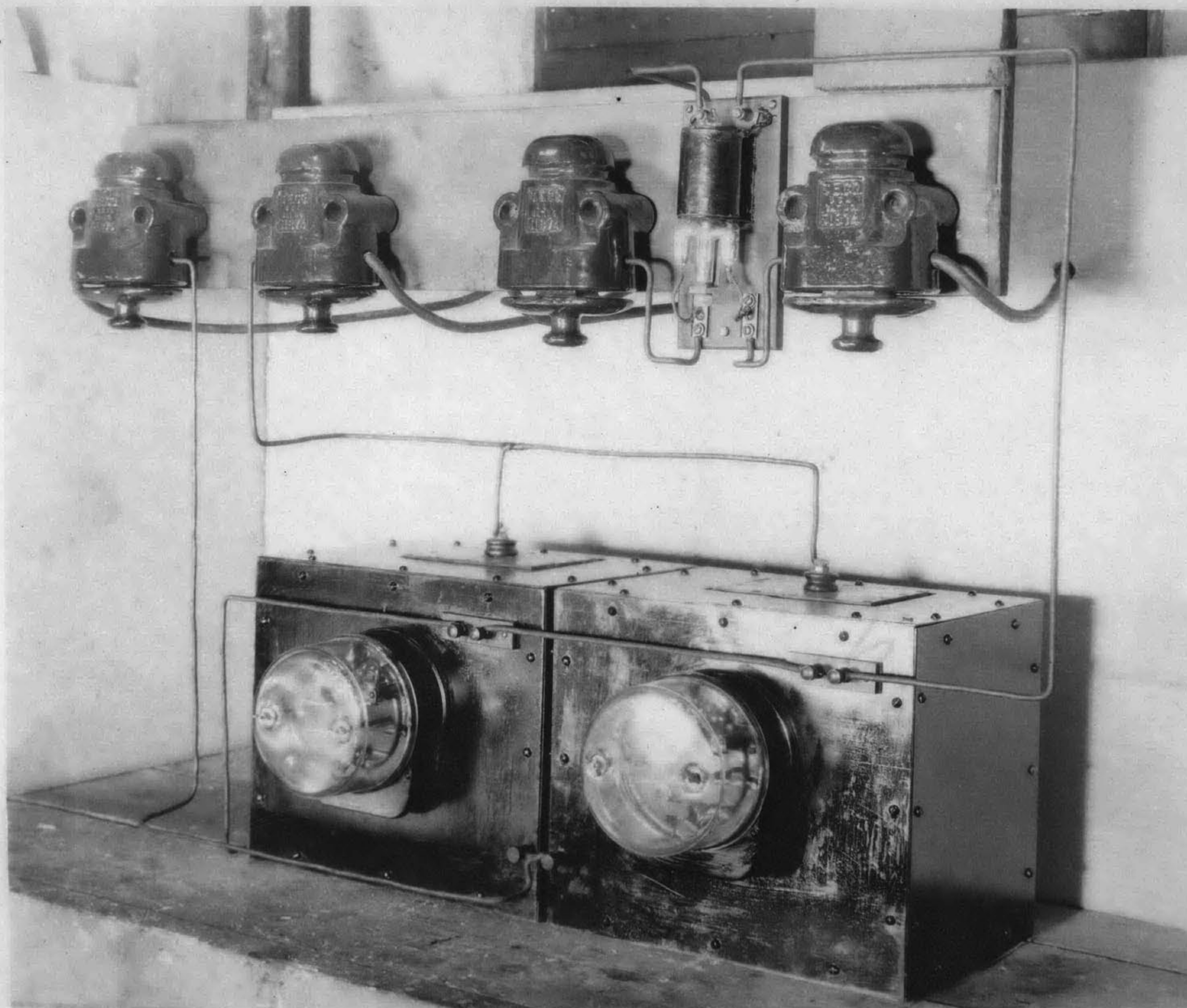

157320 COMPLETE RELAY ASSEMBLY CARRIER CURRENT CONTROL.

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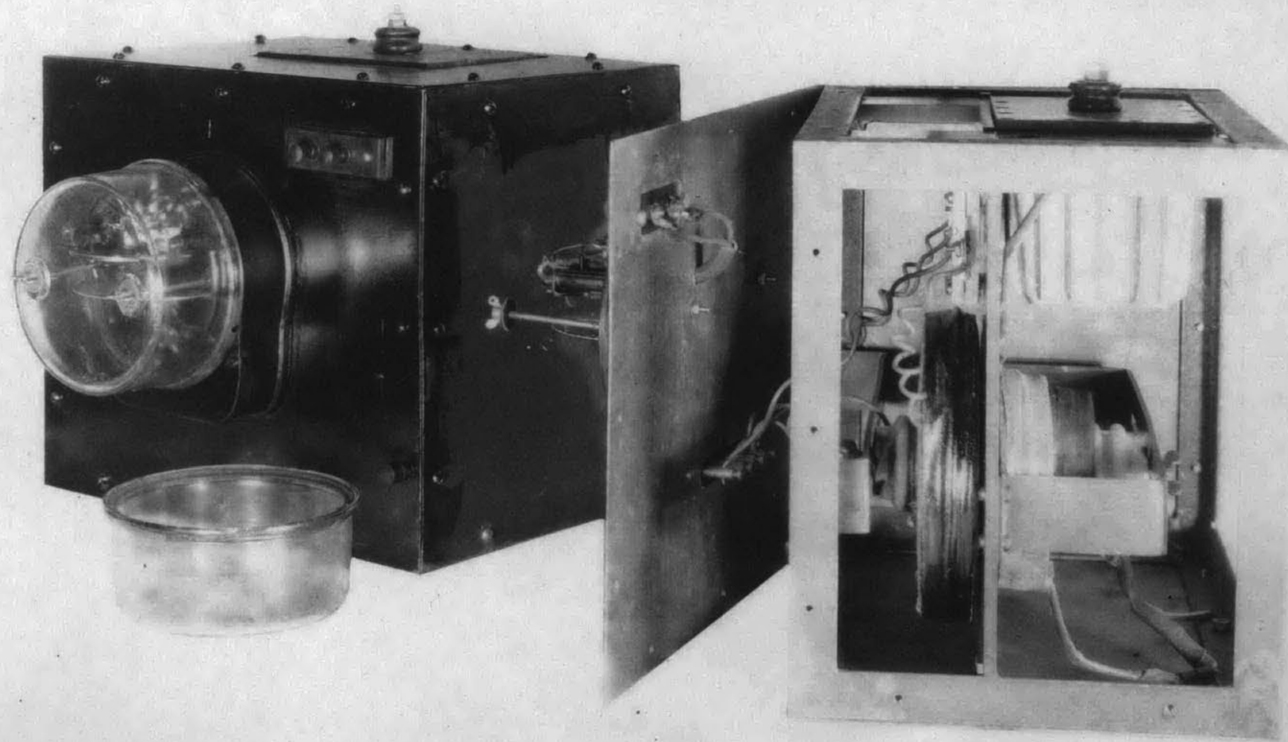

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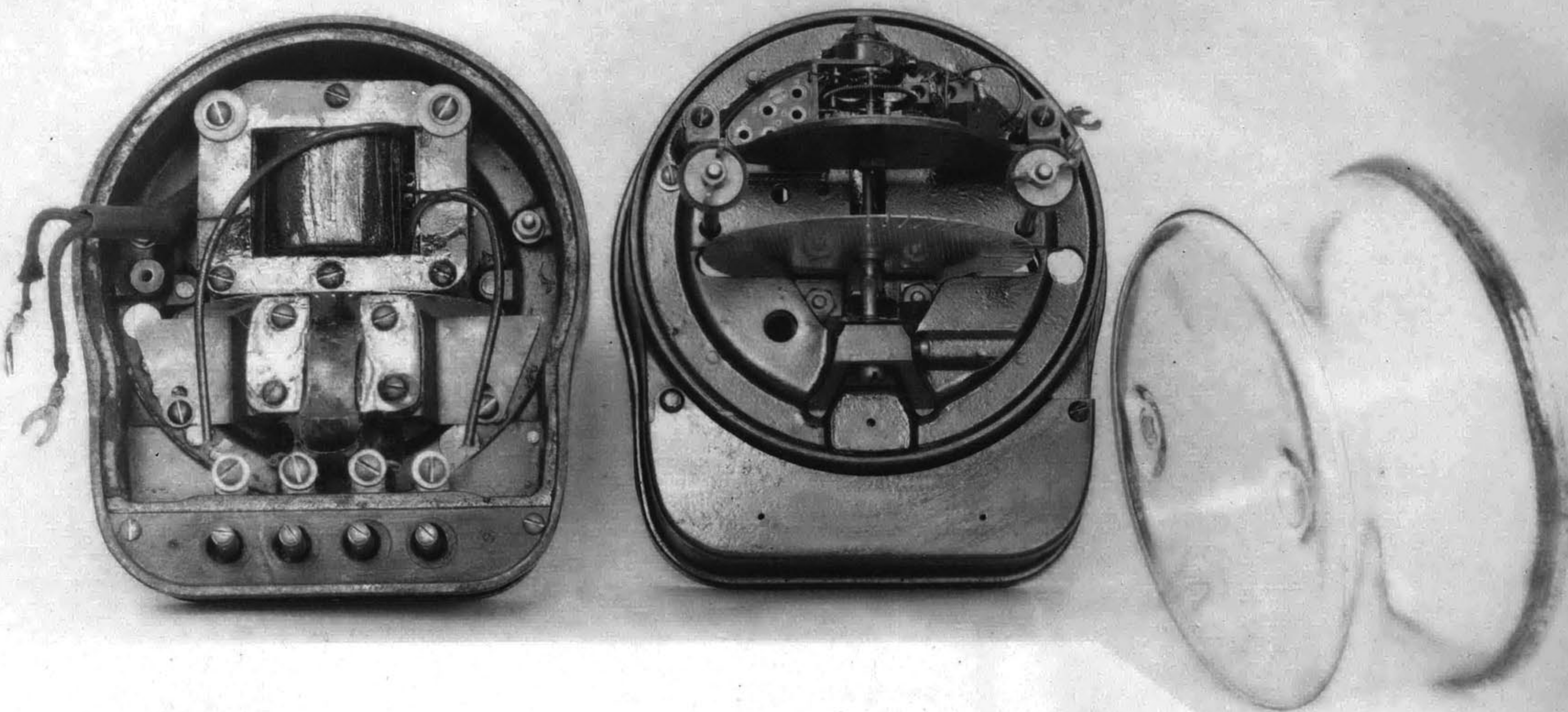

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