

RECTIFIERS

by

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Mechanical Engineering Course

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TABLE OF CONTENTS

	Page
Introduction	4
Chapter I, General Survey of the Field	5
Chapter II, Kuprox Rectifier	10
Chapter III, Tungar Rectifier.	14
Chapter IV, Neon Tube.	17
Chapter V, Raytheon "B" Battery Eliminator	21
Chapter VI, Mercury Arc Rectifier.	25
Chapter VII, Calculations and Curves	27
Bibliography.	41
Approval.	42

INTRODUCTION

This thesis is a report of the limited study of alternating current rectifiers. It is written with the hope that some other student will realize the importance of alternating current rectifiers and make a thorough study of them.

This thesis was originally intended to include the comparison of rectifiers as to theory, efficiency, wave forms and general characteristics, but lack of time, information and the "Tungar" and "Mercury Arc" rectifiers made it impossible to determine the efficiencies and the wave forms of the "Tungar" and "Mercury Arc" rectifiers. This thesis, therefore, is a report of the study of the theory and general characteristics of the "Tungar" and "Mercury Arc" rectifiers and also the theory wave forms, and the general characteristics of the Raytheon "B" Battery eliminator, "Kuprox" rectifier, and the "Neon Tube."

The Author wishes here to express his indebtedness to Dr. C. A. Perkins for valuable suggestions offered in connection with this thesis.

May 15, 1929.

C. E. S.

CHAPTER I

GENERAL SURVEY OF THE FIELD

The Kuprox Rectifier

Although it has been known for many years that copper with its oxide has very peculiar properties and has been used extensively in lightning arresters and other similar apparatus, it was not until three years ago that a copper plate covered with copper oxide were found to be valuable in the rectification of alternating currents.

Investigations made by Mr. L. O. Grondahl showed that if a current was passed through a copper plate coated with copper oxide, at right angles to the surface of the plate, the resistances to the flow of the current were very different in the two directions. These investigations showed that the resistance when the current passed from the copper to the oxide was about three times that when passed in the reverse direction, but later developments prove that a much greater ratio of resistance may be obtained by improving the plates. It has been used very successfully for rectifying current for battery charging, and it is believed that it can be used for large currents in the near future, as the area of the plates can be varied so as to be suitable for the current and the elements connected in series for obtaining the desired voltage. Since this is a rather new phenomenon and indications point toward very valuable uses of it, it should be given much study and experimental investigation.

Tungar Rectifiers

The Tungar Rectifier is well adapted for rectifying low voltage currents as the voltage drop of the rectifier is small. The arc-drop of this

rectifier is only about ten volts and the voltage drop of the hot filament is about one and a half times the current flowing. The efficiency of this rectifier is about 25% when charging a six-volt battery with five amperes flowing. This compares rather favorably with other means of obtaining a direct current for charging storage batteries singly or in groups. However, an efficiency of about 50% or more can be obtained at higher voltages. The voltage drop of this rectifier may be greatly reduced by adding Argon gas to the tube, but this causes its ability to hold back high voltages in the reverse direction to be diminished.

A diagram of the Tungar rectifier is shown in Figure No. 1. It consists of a filament which is easily heated and an anode made of graphite. The filament is made of tungsten.

Neon Tube

The neon tube is of recent development. It requires high voltage for operation. It will allow current to flow in but one direction and can be made into a full wave rectifier by using two such tubes as shown in the diagram No. 2. This tube also makes a brilliant light.

Raytheon "B" Battery Eliminator

The Raytheon "B" battery eliminator is of recent development. It was developed for special work in connection with the radio. This eliminator takes the 110 volt lighting alternating current and changes it into 180 volts direct current for a substitute of the radio "B" battery, and also into 40 volts for "C" battery purposes. It is a very convenient source of power as it is small, compact, and requires no charging as do batteries for this purpose.

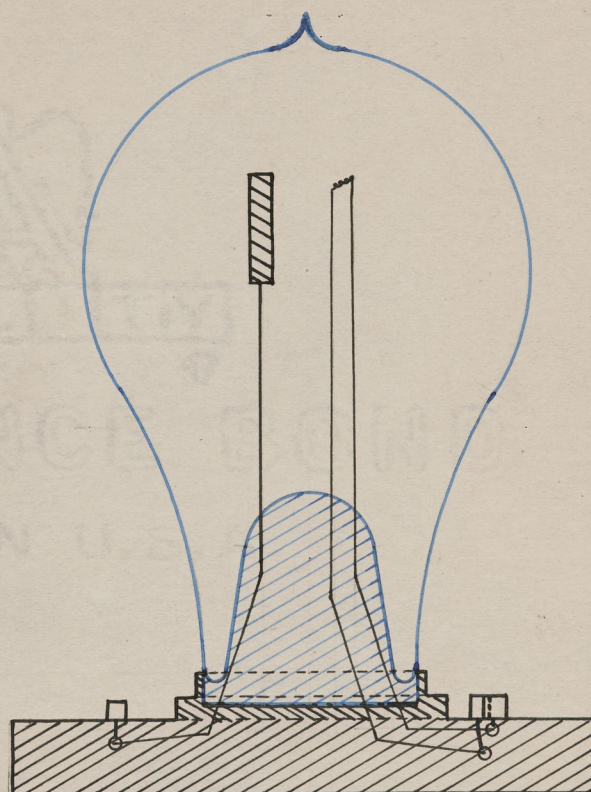
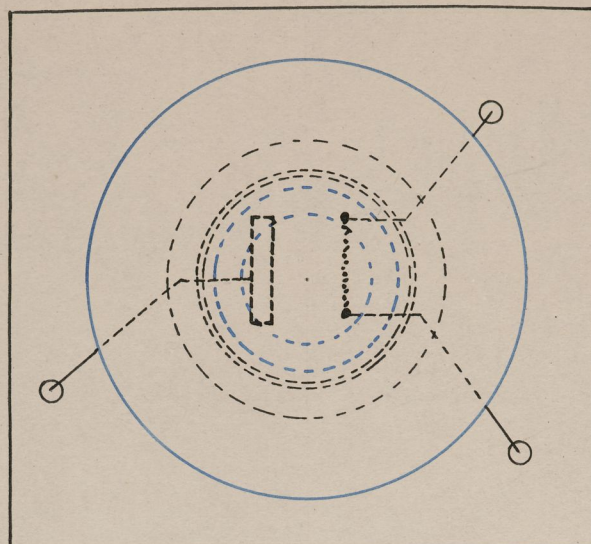


Fig. No. 1

TUNGAR RECTIFIER

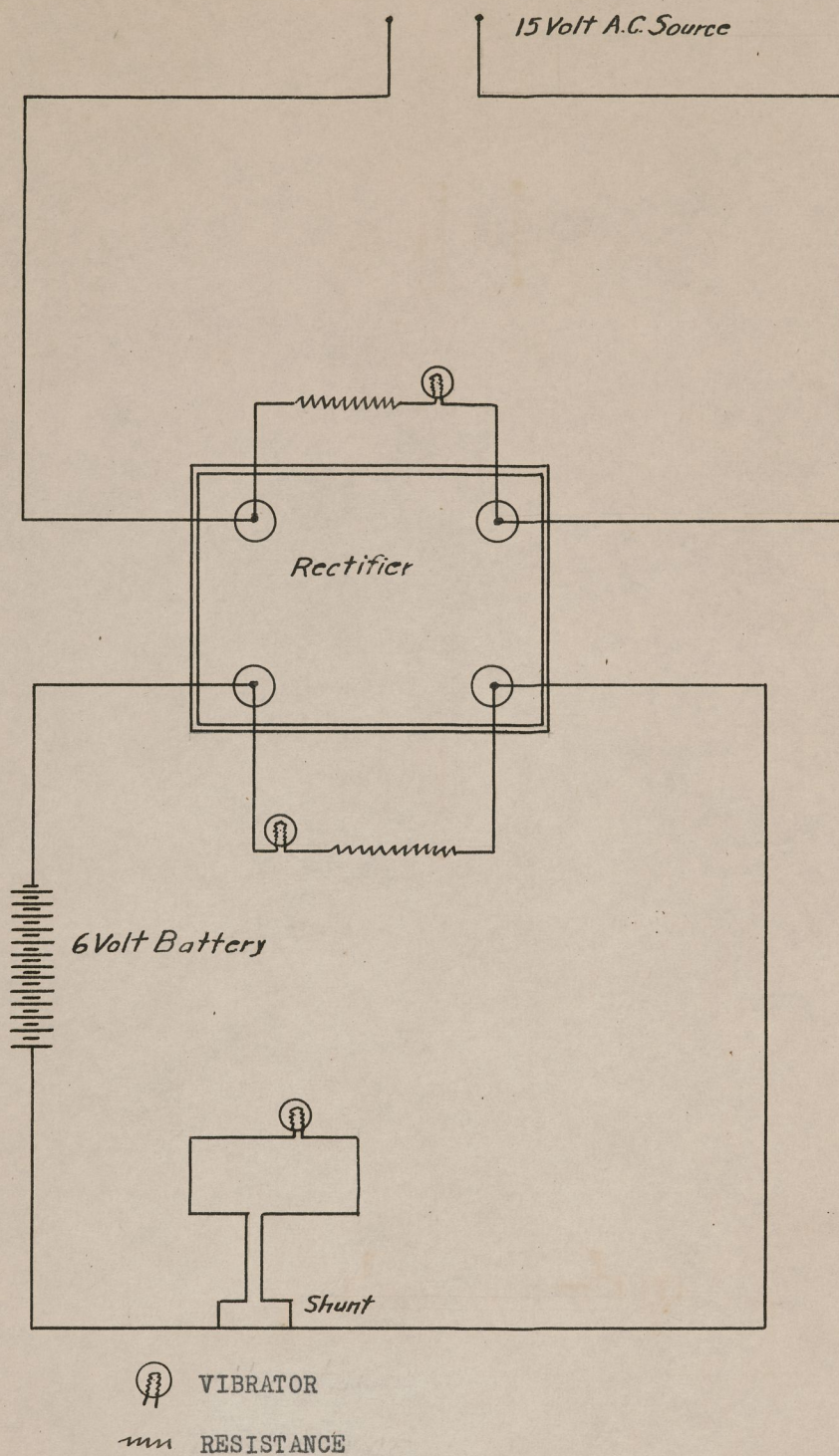


Fig. No. 2

Diagram of Connections for Determining Wave Forms
While Charging a 6-volt Battery with a Kuprox Rectifier

Mercury Arc Rectifiers

The field of the mercury arc rectifier lies between that of the tungar and Kenotron rectifiers. The cost of Automatic starting equipment causes the tungar rectifier to be used within its range instead of the mercury arc. However, the field of the mercury arc rectifier is very large, ranging from about 110 volts to 4000 or 5000 volts. It is by far the greatest commercially used rectifier. Although it has been used ever since 1900, it is still being experimented with and new improvements made each year.

CHAPTER II

Kuprox Rectifier--Design

This rectifier is made up of elements. An element consists of a copper plate coated with copper oxide and a lead or an aluminum plate placed against the oxide and drawn tightly together by means of an insulated bolt to make good connection. An element is shown in Figure No. 3.

Two such elements are required for full wave rectification. In this case one side of the direct current line is connected as a center tap of a transformer. This is shown in Figure No. 4. However, full wave rectification may be obtained, without the use of the center tap of the transformer, by using four elements as shown in Figure No. 5. The circuit diagram is shown in Figure No. 6. The amount of current flowing depends upon the area of the plates.

The rectifier is heated while in use as the power lost is transformed into heat. To dispose of this heat the rectifier is made with fins for radiation. However, if a current greater than 1.5 amperes per square inch is used, it is necessary to use forced air with the fins or submerge the rectifier in oil.

Theory of the Kuprox Rectifier

The action of this rectifier seems to take place at the junction of the copper and the oxide. Although several theories have been advanced to explain the action of this rectifier, only a few of them fulfill the experimental and physical conditions.

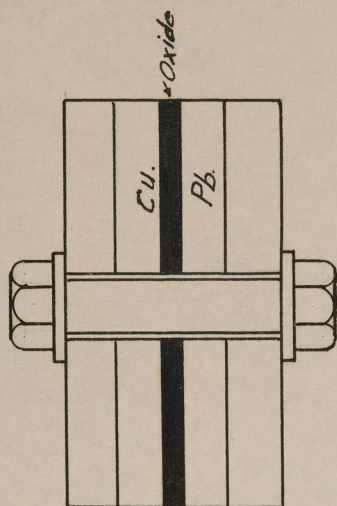


Fig. No. 3



Fig. No. 5

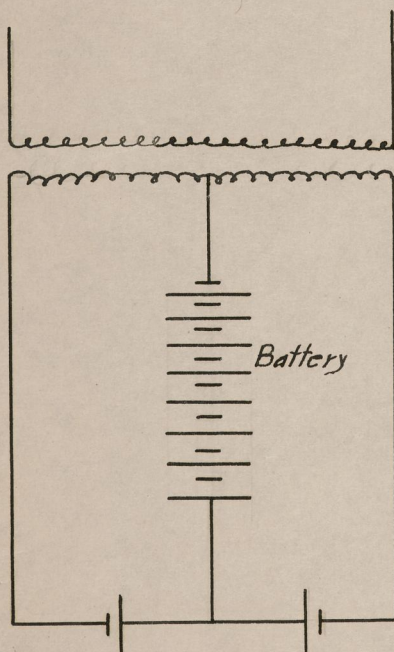


Fig. No. 4

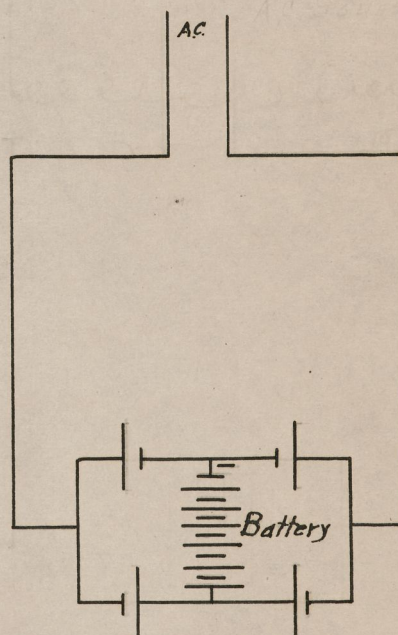


Fig. No. 6

One theory is that the junction of the copper and the oxide act in the same way as the "cat-whiskers" or crystal rectifier, but a study of this rectifier shows that the action takes place between the copper and the oxide rather than at the external surface. Another condition that this theory fails to satisfy is that it is sensitive over the entire surface which the crystal rectifier depends upon a sensitive spot which is small and unstable.

Another theory advanced as a solution is based on thermo-electricity. However, this does not seem to explain the phenomenon that takes place as the oxide in the rectifier is very thin, usually not over 0.001 of an inch thick, which would make it impossible to maintain a difference in temperature between the surfaces.

Some physicists offer electrolysis as a theory, but the characteristics of the rectifier show that it is not an electrolytic action. The current in the rectifier starts instantaneously, does not vary, and the plates show no signs of electrolysis, while the opposite is true of electrolysis.

Schottky's theory of involving the work necessary to carry an electron between the two plates, also seems to fail as a possible solution since the electron affinity of the copper is probably greater than that of copper oxide.

Mr. Jolley presents a theory which has not been proved incorrect. His theory is that the two layers are each made up of one constituent of the crystal. This may be true of the Kuprox rectifier and be the explanation of the rectification.

Another theory advanced by Mr. Grondahl seems to comply with the most of the experimental results. This theory is based on the fact that the copper and the oxide are in close relationship. It assumes that an electron

can pass from one substance to the other without going through the potential drop represented by the electron affinity of either substance, but merely through the drop represented by their difference. The resistance to the flow of electrons from the copper to the oxide is low, while it is high in the reverse direction. This is probably due to the small distance and comparatively large areas of the surface. Although this theory seems to explain the action of the rectifier, much more research should be done before saying definitely that the theory is correct.

Conclusions

The Kuprox rectifier is very different from any other type of rectifier known, but it has proved to be very useful. It can be successfully used with wavemeters, control apparatus telegraphy, detectors, "B" battery substitutes and in places where rectified current is desired.

This rectifier has no physical or chemical changes within the rectifier, is noiseless, is consistent in its behavior, its low resistance allows much current to flow, gives a smooth rectified current, has no electrolyte or moving parts to be replaced, requires no attention while in operation, is simple in construction, the voltage and current are limited only by the area and number of elements which can be varied to suit the specific use of the rectifier, and its life seems to be unlimited.

Although the theory of this rectifier is still somewhat of a mystery, the above characteristics are causing it to attract the attention of many technical men. No doubt some of these men will emerge with a satisfactory theory or great improvements in the near future that will cause the entire field of rectification to change.

CHAPTER III

TUNGAR RECTIFIER

Design

This rectifier is usually filled with argon gas to a pressure of about five centimeters of mercury when the bulb is cold.

In construction the parts are assembled in the bulb, and a ring of magnesium wire placed around the anode. After the air is pumped out and the argon admitted, the tube is sealed off from the pumping system, and the anode heated. This vaporizes the magnesium, and it combines with any traces of air or water vapor which may have been left in the bulb. The resulting compounds and all excess magnesium are condensed on the surface of the bulb where they are no longer able to affect the electrical behavior of the rectifier, but the magnesium continues to absorb gases and other impurities throughout the life of the tube. The magnesium gives the glass a dark mirror-like appearance which is so characteristic of the tungar bulbs.

Theory

The theory of the Tungar rectifier seems well agreed upon by authorities.

At the filament surface, the current consists of positive ions entering and the electrons leaving it. As the electrons represent by far the greater portion of the current, it is apparent that the filament emission is of considerable importance. This emission of the electrons vary as the temperature of the cathode. The cathode is heated by an alternating current and and current to be rectified connected to one terminal of the cathode and

to the anode. Since the electrons leaving the cathode represent the greater portion of the current, the current will only flow from the cathode to the anode. This rectifier if the set-up used is the same as that shown in the diagram of connections, Figure No. 7.

Conclusions

This rectifier is well fitted for low voltage current rectification. Its cost is low which is an essential characteristic for low voltage rectifiers. It is very simple, is noiseless, requires no attention during operation, has no moving parts, starts quickly, and has a long life, being limited only by the positive ions corroding the tungsten filament. However, it is only adapted to low voltages as high voltages cause an objectional current to flow in the reverse direction. It is used very extensively in battery charging.

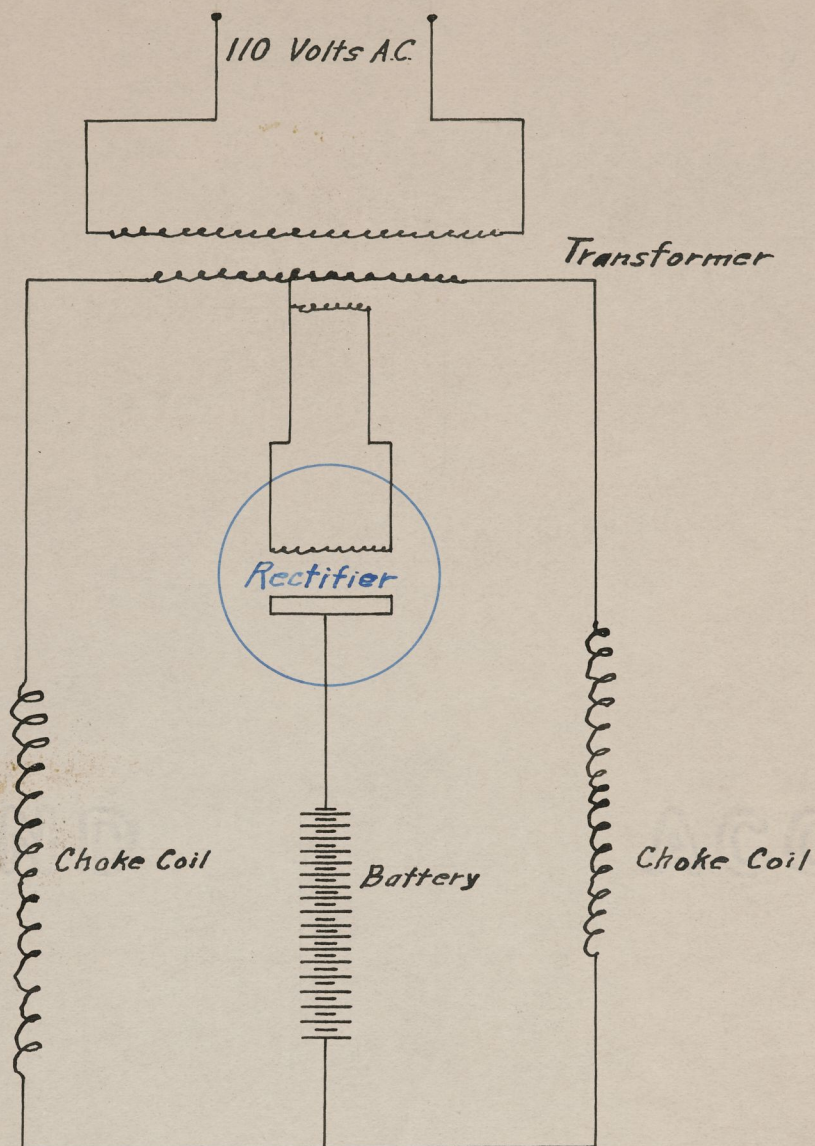


Fig. No. 7

Diagram of Connections for Tungar Rectifier

CHAPTER IV

Neon Tube

Design

The neon tube has the general shape of an electric lamp bulb as shown in Figure No. 8. It is filled with neon gas which aids the flow of electricity from the cathode to the anode. The electrodes are of metal. One is a cylinder about $\frac{1}{2}$ inch in diameter and 2 inches high. The other is a small square plate placed directly over the cylinder about $\frac{1}{4}$ inch above it. This tube is usually made with a screw socket bottom which will fit in a common light socket.

Theory

The electrodes are connected to the alternating current source. This causes first one and then the other of the electrodes to be the cathode. The neon gas carries the charge from one to the other. During one half of the cycle the current is flowing in one direction and in the opposite direction the other half of the cycle. This is really an alternating current, but due to the great differences in the areas of the electrodes, the current flowing in one direction is several times that in the other. The ratio of the amount of current flowing in the two directions is approximately proportional to the ratio of the areas of the electrodes. The tube then acts much like an electric check valve or a rectifier, due to the small amount of current flowing in one direction as compared to that flowing in the other direction.

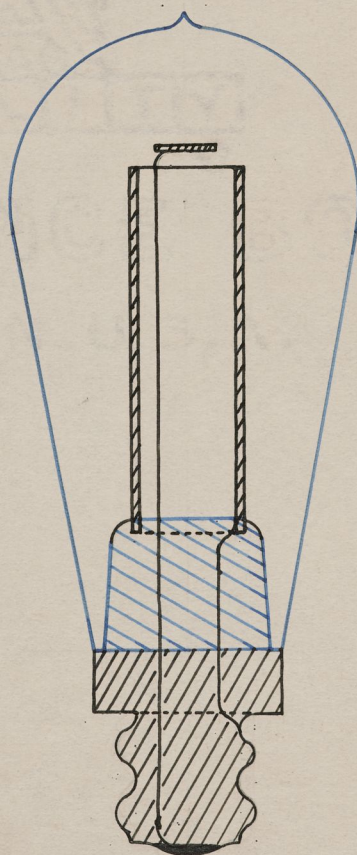
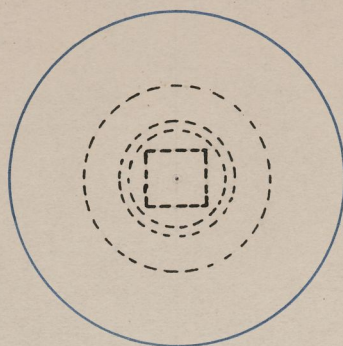


Fig. No. 8

NEON TUBE

Conclusions

The neon tube is very simple, quiet in operation, and its cost is rather low. It may be used either for a light, an electric check value, or as a full wave rectifier when two are used as shown in Figure No. 9.

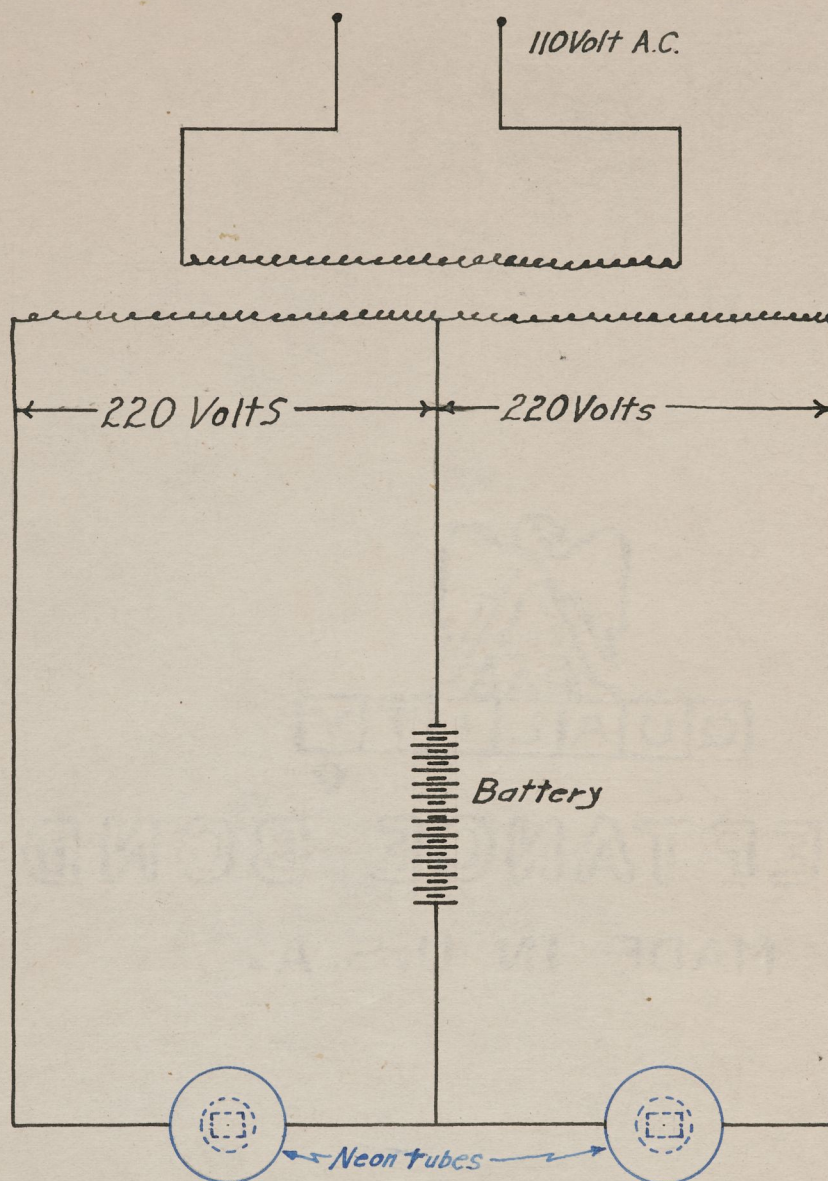


Fig. No. 9

Connections for Neon Tube Rectification

CHAPTER V

Raytheon "B" Battery Eliminator

Design

The eliminator studied has a transformer which steps the 110 voltage lighting voltage up to 600 volts alternating current. This is impressed on a Raytheon tube, 300 volts to each terminal. The tube rectifies this current and the current passes through a filter to make it a steady current. The tube is full wave rectifying as shown in the diagram, Figure No. 10. The filter consists of two choke coils of 50 henries inductance each, and nine condensers distributed along the circuit as shown in the diagram, Figure No. 11. A large resistance is placed across the direct current terminals behind the filter, and tapped at various places as shown in Figure No. 11, in order to obtain either 90 or 180 volts for the "B" battery service and either 4 or 40 volts for "C" battery use. This eliminator has a maximum current capacity of 125 milliamperes which is sufficient for radio receiving sets. The Raytheon tube has a metal enclosure mounted on a glass foundation inside the tube. This enclosure is filled with helium gas and contains a rectangular graphite plate and two metal points, one on either side of the plate, for the electrodes. These electrodes are connected by five wires to separate plugs at the bottom of the tube. This tube has four such plugs much like those of the common radio tube, but one of them is dead. A diagram of the tube is shown in Figure No. 10.

Theory

The Raytheon tube is much like the neon tube in that it depends on the gas in it to allow the current to flow and the relative sizes of the electrodes to keep back reverse currents. The rectangular plate is alter-

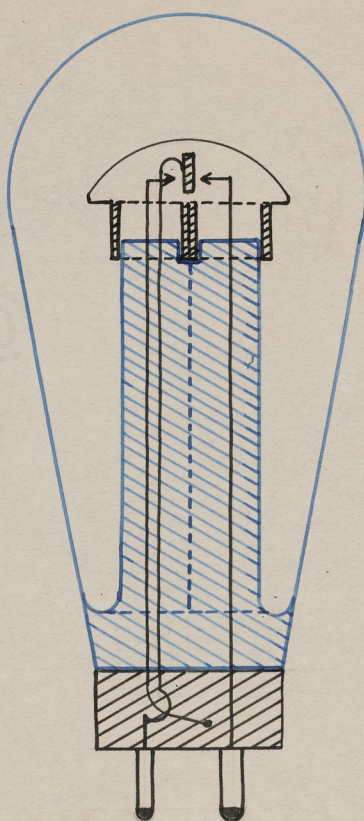
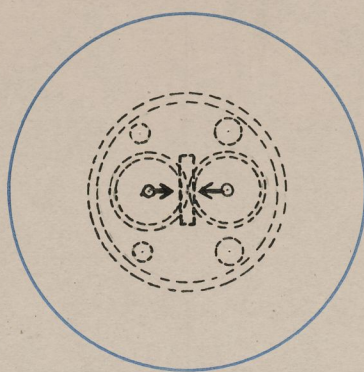
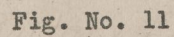


Fig. No. 10

RAYTHEON TUBE



23.

nately the anode for one of the points connected to one side and then the anode for the other. Since the area of the points is small as compared to the plate, the points will discharge to the plate, but the plate will not discharge to the points.

Conclusions

This eliminator is gaining much favor in that it is small, compact, and easily operated. It also gives a steady current, and has a variation of voltage. It has a long life. It will probably be the most used source of power for "B" and "C" battery purposes in radio receiving sets in the next few years.

CHAPTER VI

Mercury Arc Rectifiers

Design

This rectifier is built of either glass or metal case. It has a mercury pocket which has a bright spot that forms the cathode. This spot is maintained by the passing of the current. For high currents several spots may carry the current. This spot requires something to start it so a starting anode is placed near the pool of mercury until the arc starts. The starting anode is then removed and the arc goes from the mercury to the anode. This rectifier may have several cathode spots as the arcs do not interfere with each other. This type of rectifier has two or more anodes if a large current is to be carried. The larger types have to be cooled to condense the mercury vapor. They are usually water-cooled, although some are cooled by the use of fins either in still or forced air.

Theory

This rectifier allows the current to flow from the cathode to the anode by means of the ionized mercury vapor. The mercury is vaporized by the heat at the cathode spot, and the vapor carries the current to the anode. The voltage drop is slightly higher than that of the tungar rectifier, but does not require an extra current to keep the cathode hot after it is once started. This rectifier is very efficient.

Gunther-Schulze¹ offered a theory that part of the current was caused by electrons leaving the mercury and part by the positive ions entering it.

¹ Engineering Progress, August, 1925, pp. 251-256

He believed that the former represented 56 per cent. of the current and the latter 44 per cent. of it. However, his theory is not generally accepted.

Conclusions

This rectifier plays the larger part in commercial rectification. This is because it can be made to deliver much power at high voltages and can be made to rectify any number of phases. Several large companies are developing this rectifier. One of the largest of these companies is the General Electric company at Schenectady, New York. This company has a large laboratory for testing these rectifiers and a large research laboratory which spends much time and money on the mercury arc rectifier. No doubt this rectifier will become one of the greatest and most important electrical apparatuses within the next few years.

CHAPTER VII

Calculations and Curves

Kuprox Rectifier

The rectifier used in testing for this thesis is the "Kuprox Dry Metallic Rectifier," type A-10, 0.8 to 1.0 amperes, manufactured by the Kodel Radio Corporation, Cincinnati, Ohio.

Data sheet No. 1 and Figure No. 12 show the resistance of the rectifier. A diagram for the set-up is shown in Figure No. 13. A direct current was passed through the rectifier in both the high and low resistance directions. The voltage and the amperes were measured and the resistance calculated from $R = \frac{E}{I}$. The wave forms were taken for the rectifier by the use of the oscillograph for both resistance load and for charging a battery. These wave forms are shown in Figures No. 14 and 15, respectively. The diagrams for the set-up are shown in Figures No. 16 and 17, respectively.

Tungar Rectifier

No laboratory tests were made on this rectifier as the rectifier was not available.

Neon Tube

The wave forms of the rectified current and the impressed voltage were taken for the neon tube by the use of the oscillograph. These forms are shown in Figure No. 18. The diagram for the connections for this test is shown in Figure No. 19.

Raytheon "B" Battery Eliminator

The eliminator used for testing this thesis was the "Grehe Socket Power," type 671-B, 110 volts and 60 cycles A. C. The eliminator was taken

apart and the construction examined. The diagram of the connections is shown in Figure No. 11. The wave form was found by the oscillograph as shown in Figure No. 20. The set-up was as shown in Figure No. 21.

Mercury Arc Rectifier

No laboratory work was performed on this rectifier as such a rectifier was not available.

A diagram of a small glass tube mercury arc rectifier is shown in Figure No. 22.

DATA NO. 1

High Resistance Direction				Low Resistance Direction			
Milliamperes:	D. C. Volts:	Ohms Res.:		Milliamperes:	D. C. Volts:	Ohms Res.	
1.8	0.36	199.0		21.0	0.74	35.2	
5.5	1.10	199.0		49.0	1.10	22.4	
8.2	1.57	190.5		86.0	1.40	16.3	
11.5	2.15	186.0		170.0	1.86	10.9	
16.0	2.90	180.2		240.0	2.20	9.2	
19.5	3.40	173.2		360.0	2.68	7.5	
24.0	4.20	174.0		440.0	3.00	6.8	
41.0	6.80	164.8		520.0	3.20	6.2	
50.0	8.00	159.2		600.0	3.50	5.8	
60.0	9.20	152.3		640.0	3.60	5.6	
108.0	10.40	95.4		720.0	3.80	5.3	
150.0	12.50	82.4		820.0	4.20	5.1	
260.0	15.10	57.1		900.0	4.30	4.8	
320.0	17.60	54.0		1000.0	4.70	4.7	
460.0	18.30	38.8					

LABORATORY

DATE

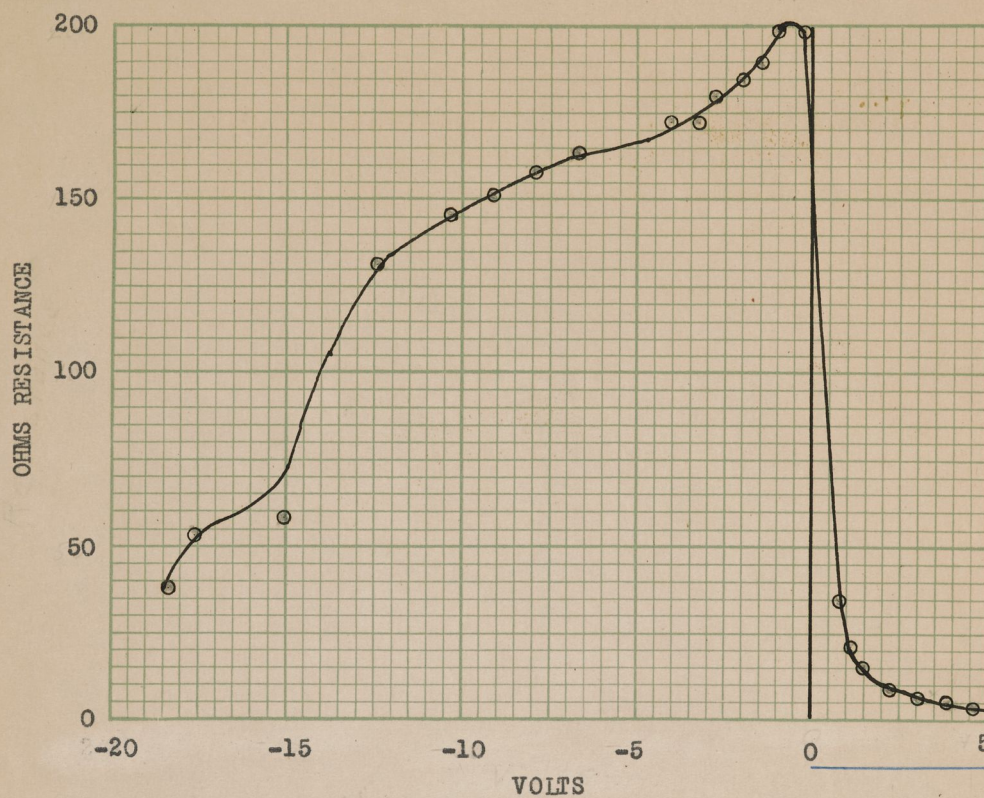
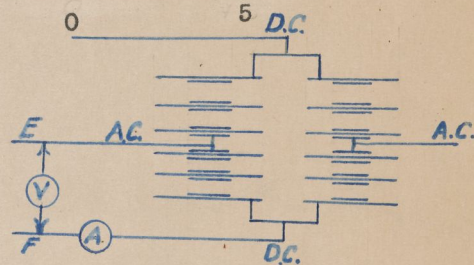


FIG. NO. 12

TITLE: Resistance of Kuprox Rectifier



INTERPRETATION OF CURVES

Set-up as Shown in Blue

Ⓥ Voltmeter

Ⓐ Ammeter

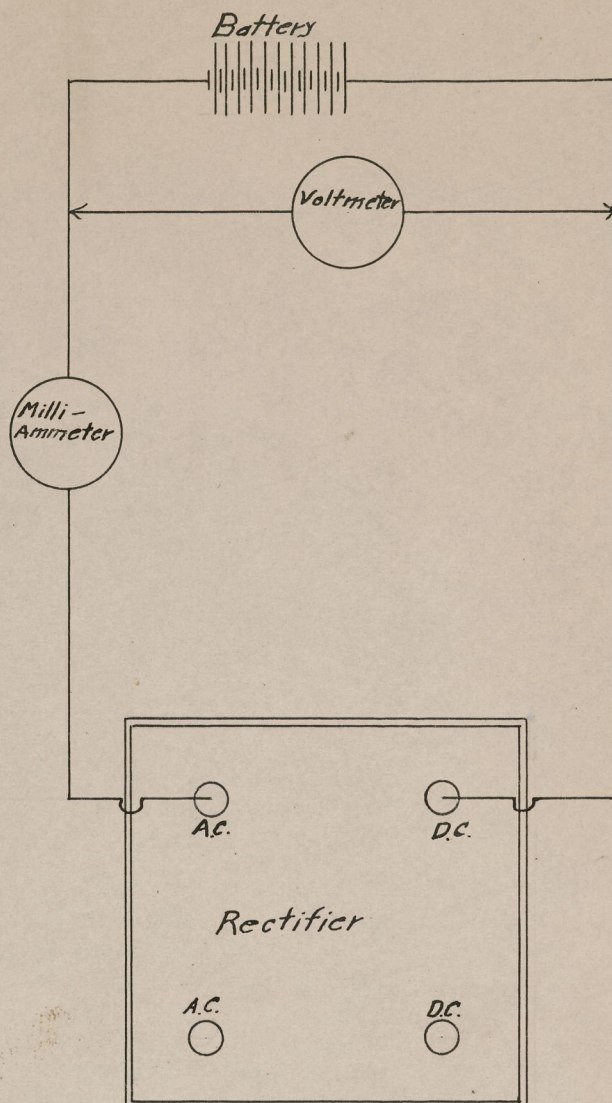


Fig. No. 13

LABORATORY

DATE

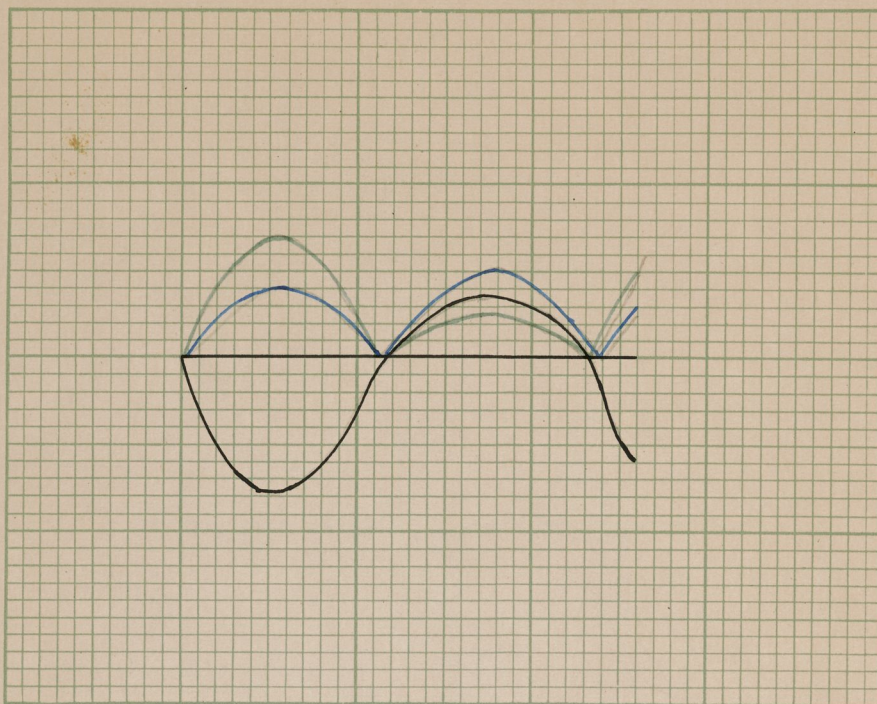


FIG. NO. 14

TITLE:- Curves for Kuprox Rectifier with Resistance Load

INTERPRETATION OF CURVES ——— Alternating Current Voltage
———— Rectified Current
———— Rectified Voltage

LABORATORY

DATE

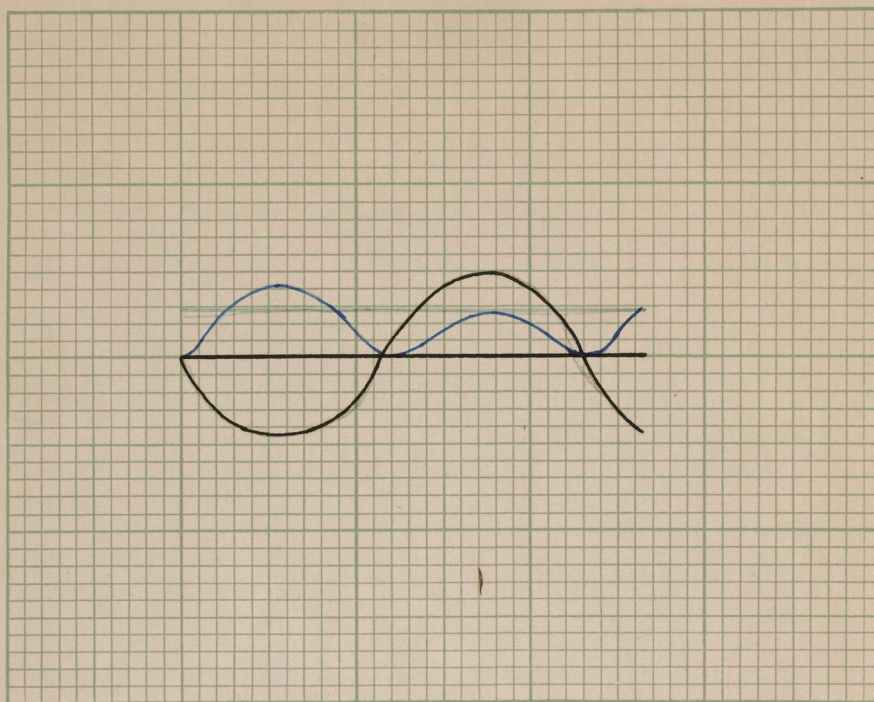


FIG. NO. 15

TITLE:- Curves for Kuprox Rectifier Charging a 6-volt Battery

INTERPRETATION OF CURVES

- Alternating Current Voltage
- Rectified Current
- Rectified Voltage

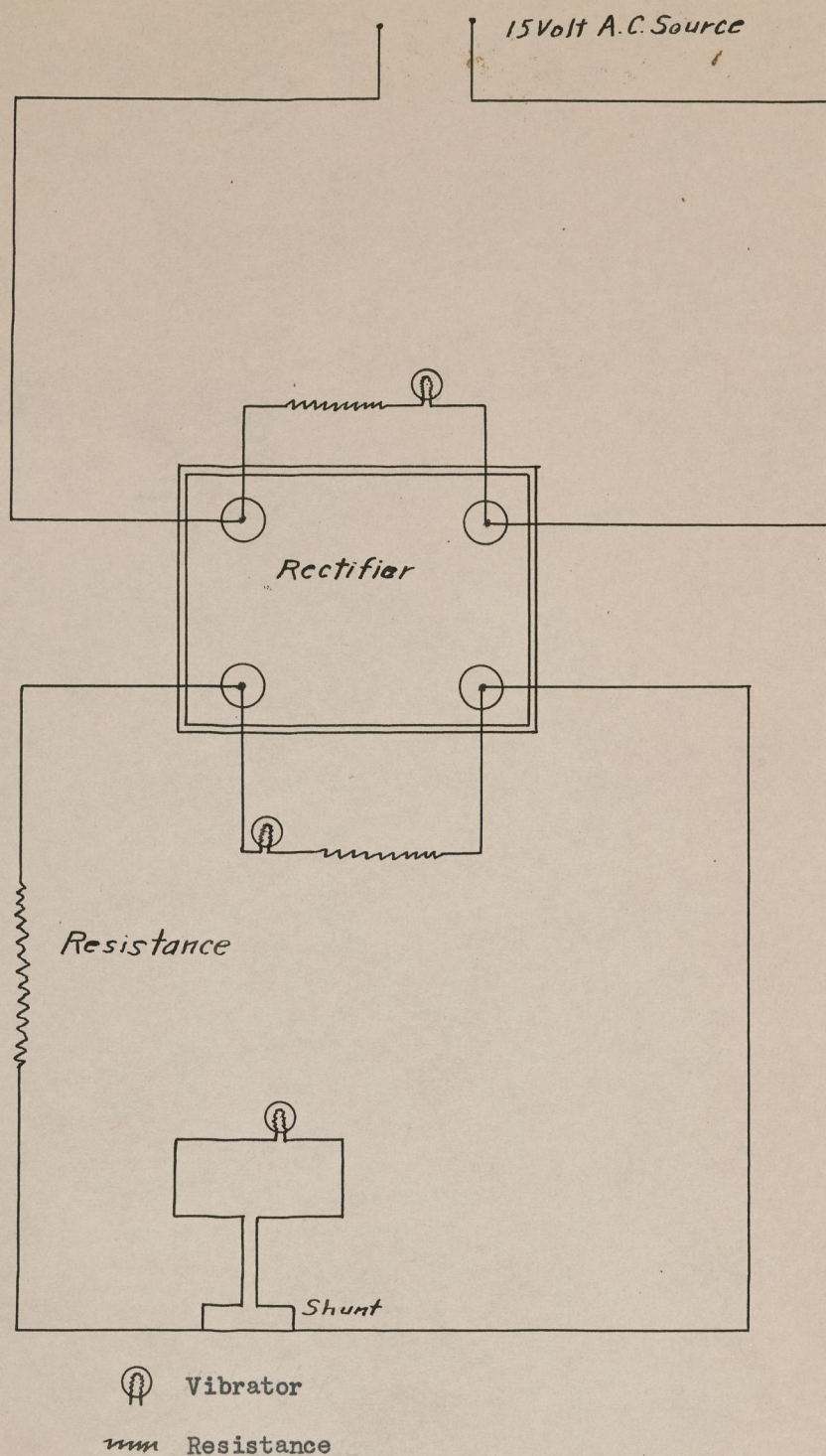


Fig. No. 16

Diagram of Connections for Determining Wave Forms of
a Kuprox Rectifier With Resistance Load

LABORATORY

DATE

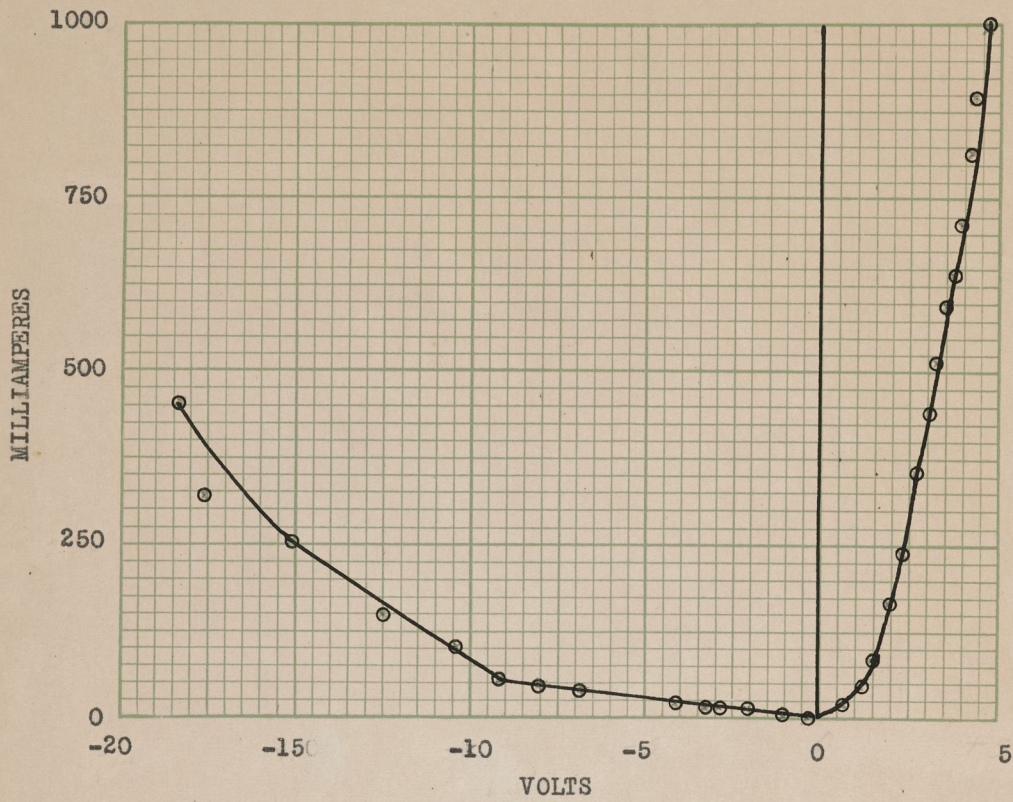


FIG. NO. 17

TITLE:-

INTERPRETATION OF CURVES

LABORATORY

DATE

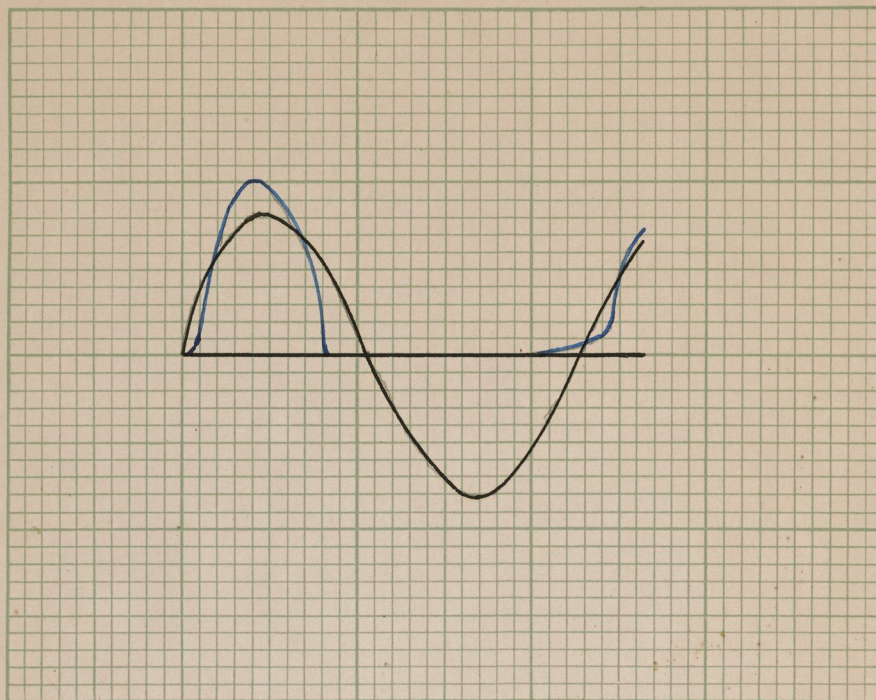


FIG. NO. 18

TITLE:- Wave Forms for a Neon Tube on a 220-volt Circuit

INTERPRETATION OF CURVES ——— Impressed Alternating Voltage
———— Rectified Current

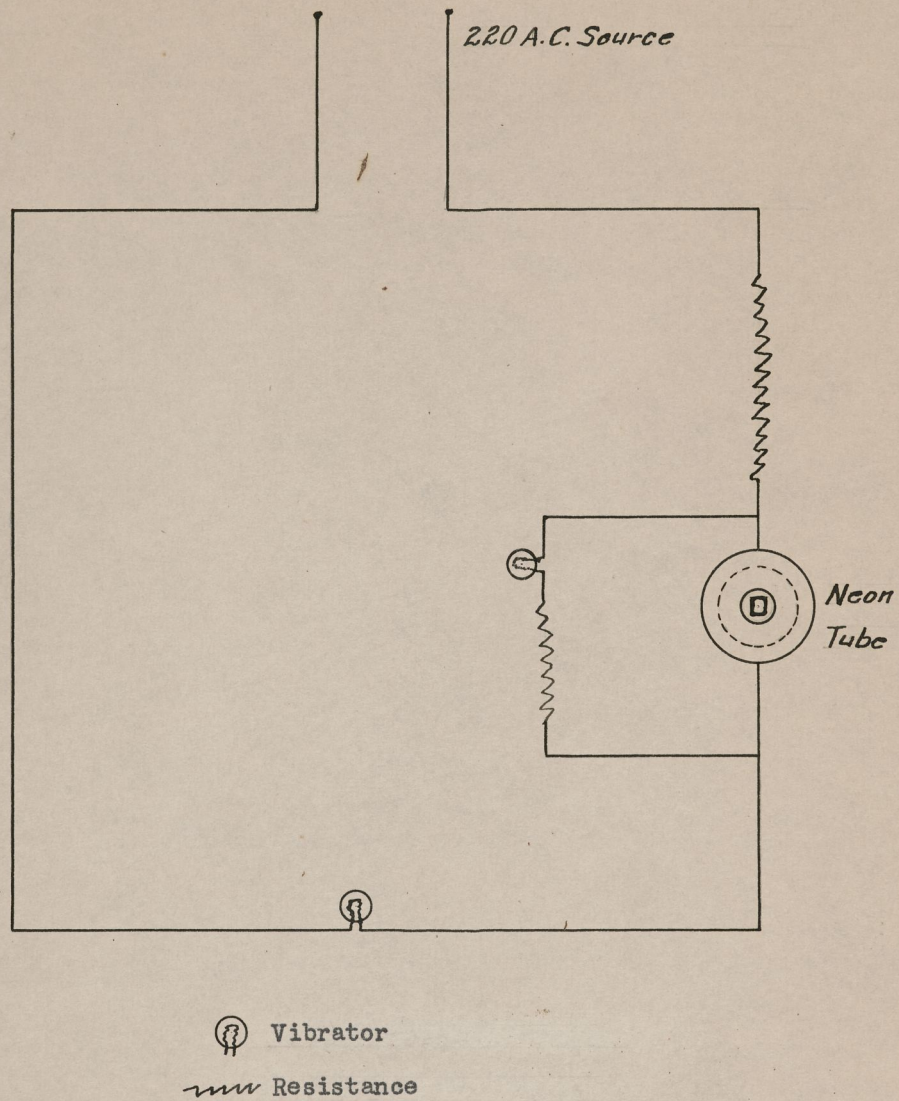


Fig. No. 19

Diagram of Connections for Determining the Wave Forms
of a Neon Tube on a 220-volt Circuit

LABORATORY

DATE

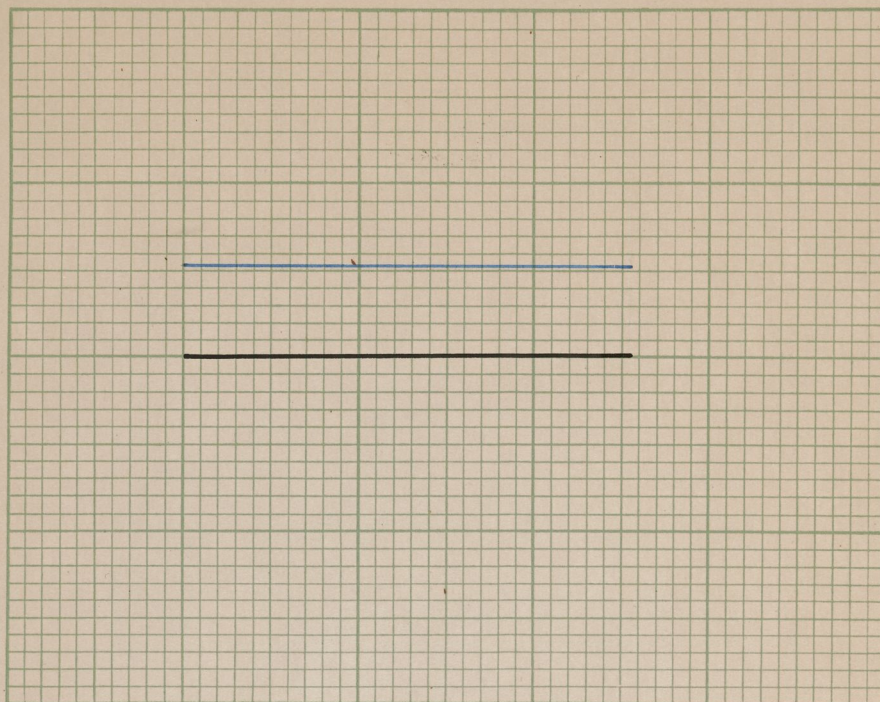


FIG. NO. 20

TITLE:- Wave Form of "B" Battery Eliminator on a 110-volt Circuit

INTERPRETATION OF CURVES ——— Rectified and Filtered Current

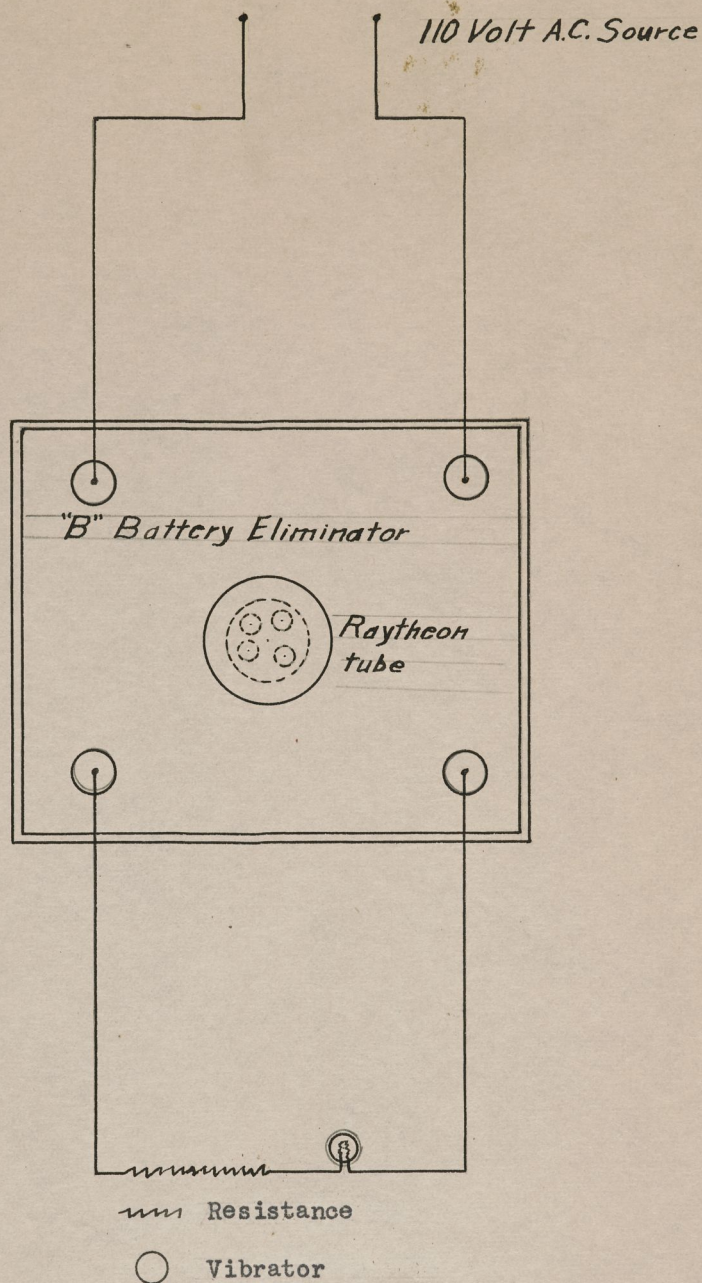


Fig. No. 21

Diagram of Connections for Determining the Wave Forms of
the "B" Battery Eliminator

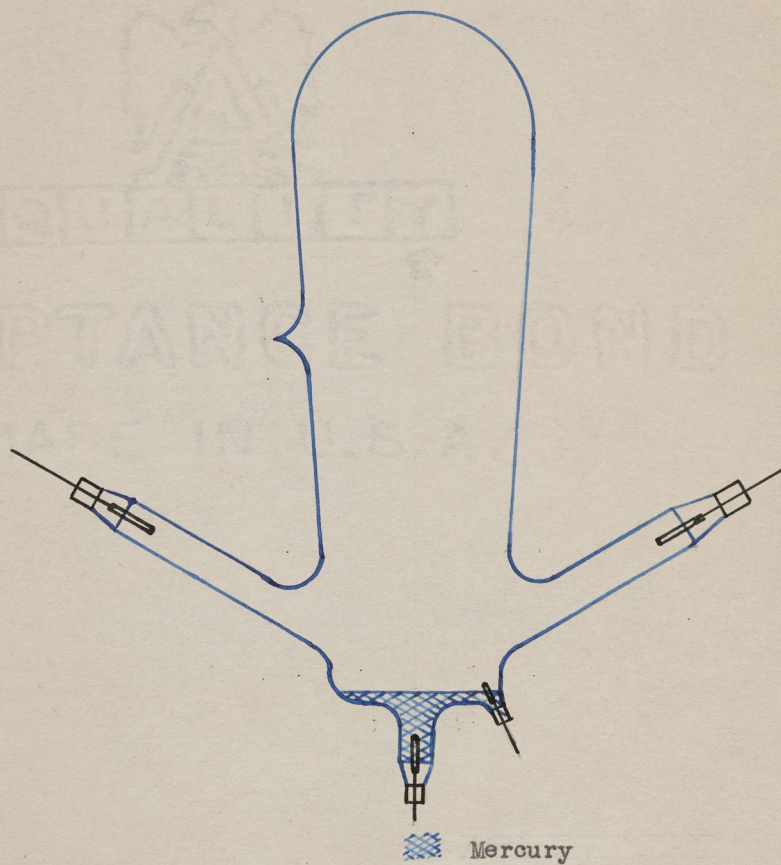
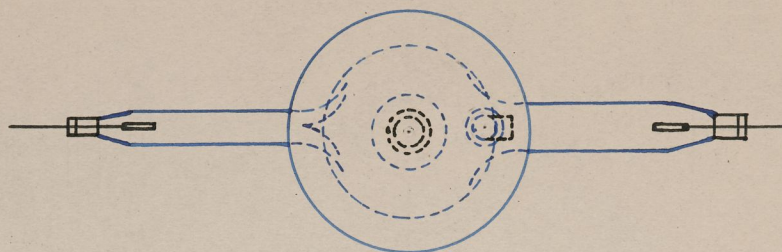


Fig. No. 22

Single-Phase, Glass Tube, Mercury Arc Rectifier

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5. Radio Engineer, 1928
6. Engineering Progress, August, 1925, p. 251-256
7. Science, September, 1926, Vol. 64, p. 306-308

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves this thesis only for the purpose for which it is submitted.

Name.....*Chas. A. Perkins*.....

Title.....*Professor Electrical Engineering*.....