COPPER OXIDE RECTIFIERS

by

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ELECTRICAL ENGINEERING COURSE.

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TABLE OF CONTENTS.

INTRODUCTION.

This thesis is a report of a small study of copper oxide rectification of alternating current. It is written with the hope that some other student will realize the vast possibilities of this type of rectifier and will make a much more extended study of it.

The thesis was originally intended to include the construction as well as the testing of a rectifier of this type,but lack of time and information available has made it impossible to carry out the construction. This thesis,therefore, is a report of the study of the action of a copper oxide rectifier known commercially as "Kuprox Rectifier".

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

R.L.H.

May 15,1928.

CHAPTER I.--GENERAL SURVEY OF THE FIELD.

It has been known for many years that copper with its oxide has very peculiar and interesting properties. Oxides have been used extensively in lightning arresters and other similar apparatus, but it was not until two years ago that the real possibilities of a copper plate covered with copper oxide were realized as being valuable in the rectification of alternating currents.

At a meeting of the American Physical Society held in Washington on April 23-24, 1926, a report was read showing the investigation of copper oxide rectification of alternating currents that had been carried on by Mr.L.O.Grondahl. It was found during the investigation of copper oxide formed on a copper plate that if current was passed thru the oxide in a direction at right angles to the surface of the oxide, the resistance to the flow of current in the two directions was very different. It was found that the resistance of the combination was very much less when the current flowed from the oxide to the copper than it was when the current was passed from the copper to the oxide. The ratio of resistances was found to be about three to one, but larger ratios can now be obtained in the more perfectly made plates. This phenomenon seems very different from anything previously known in rectifiers, and should be given much study and experimental investigation. Every characteristic is favorable to its widespread use as a rectifier of large and small currents. It has been successfully used in the rectification of alternating current for battery charging,and it is believed that it could be used,if properly made,to supply direct current for elevators and locomotives. The elements may be connected in series for obtaining any desired volyage,and the area of the plates varied so as to be suitable for the current.

CHAPTER 2--DESIGN.

Each rectifier element consists of a copper plate upon which a coating of copper oxide has been formed. Another plate such as lead or aluminum is placed against the oxide,and by means of an insulated bolt thru the center of the discs,the two are drawn tightly together so as to make a good electrical contact with the oxide.

Fig.I shows a typical element for single wave rectification.

For full wave rectification a circuit shown in Fig.2 or Fig.3 must be used. A convenient circuit and arrangement is shown in Fig.3 & Fig.4. No transformer tap is necessary,but four elements must be used for full wave rectification. Such a unit will furnish a direct E.M.F. of about six volts,depending upon the temperature of the unit. The maximum allowable current depends upon the area of the plates.

Since the power lost in the rectifier is transformed into heat,some provision must be made to dispose of that heat. The Kuprox Rectifier uses only a small current density and provides fins for radiation. To carry greater current densities than I-I.5 amperes per sq.in.,it is necessary to use forced air with the fins,or submerge the unit in oil.

The rectifier used in testing for this thesis is "The Kuprox Dry Metallic Rectifier",type A-IO,amperes .8-I.0, manufactured byKodel Radio Corporation,Cincinnati,Ohio.

Data sheet No.I,Fig.5,& Fig.6 show the relative resistance of the rectifier unit at different applied voltages,positive

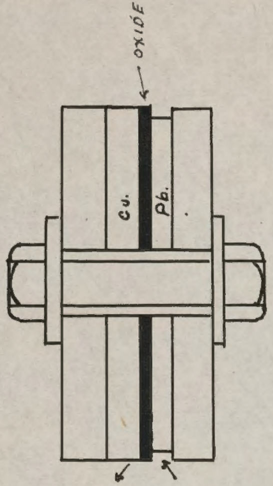

Fig.I.

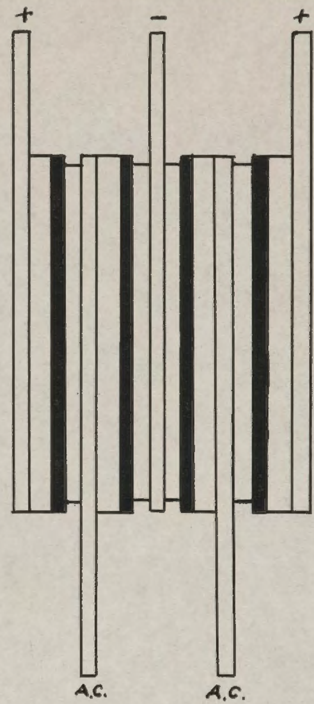

Fig.4.

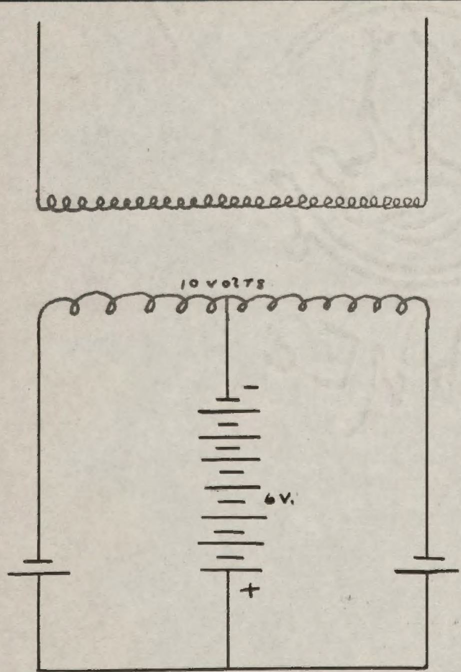

Fig.2.

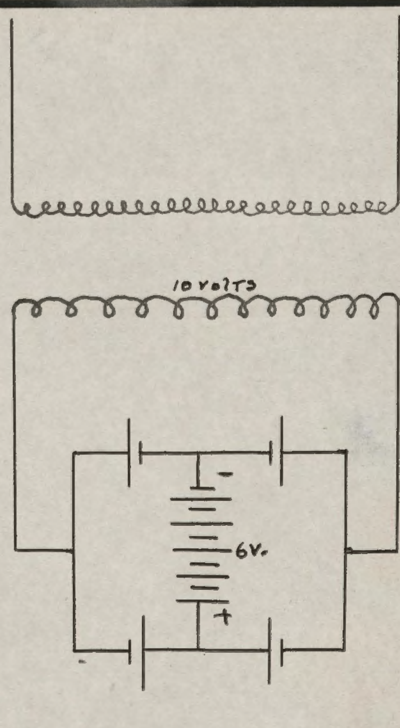

Fig.3.

R.L.H.

and negative. Six of the elements were used so as to give actual conditions that would exist while rectifying. Direct current was applied in the low and high resistance directions,the current and voltage measured,and the resistance calculated.

R--E/I

From the curves it will be seen that the reverse current must be very small. This is shown by Data sheet No.2 & Fig.7. In a full wave rectifier,as the one tested,the voltage across each element,during that part of the cycle when the voltage is applied in the high resistance direction,is much greater than it is when the voltage is applied in the low resistance direction. The voltage applied in the high resistance direction is large enough that,during this part of the cycle,the rectifier is working well beyond the maximum,but only for a very short time.

DATA No. I.

Low resistance direction.

volts	amps.	ohms
I.0	.006	I66
I.2	.0I4	86
I.4	.029	36
I.6	.048	33
I.8	.068	27
2.0	.090	22
2.2	.II8	I9
2.4	.I43	I7
3.0	.24	I3
4.0	.46	8.7
5.0	.62	8.I
6.0	.83	7.2
7.0	I.8	3.9
8.0	3.7	2.2
9.8	4.5	2.I6
I0.0	6.4	I.56
II.5	7.5	I.53
I2.0	8.5	I.4I
I4.0	I7.0	.825
I5.0	23.0	.650

High resistance direction.

volts	milliamps	ohms
2.62	3.I	845
3.0	3.6	834
4.0	5.0	806
5.0	6.2	800
6.0	8.0	750
7.0	9.5	738
8.0	II.5	695
9.0	I4.0	642
I0.0	I5.8	630
II.0	I7.7	6I9
I2.0	20.0	598
I3.0	22.0	590
I5.3	26.2	584
I6.6	28.8	577
I9.3	33.I	566
20.6	36.9	559
22.0	40.0	550
24.6	47.5	5I8
26.4	53.7	492
32.0	70.0	457

LABORATORY

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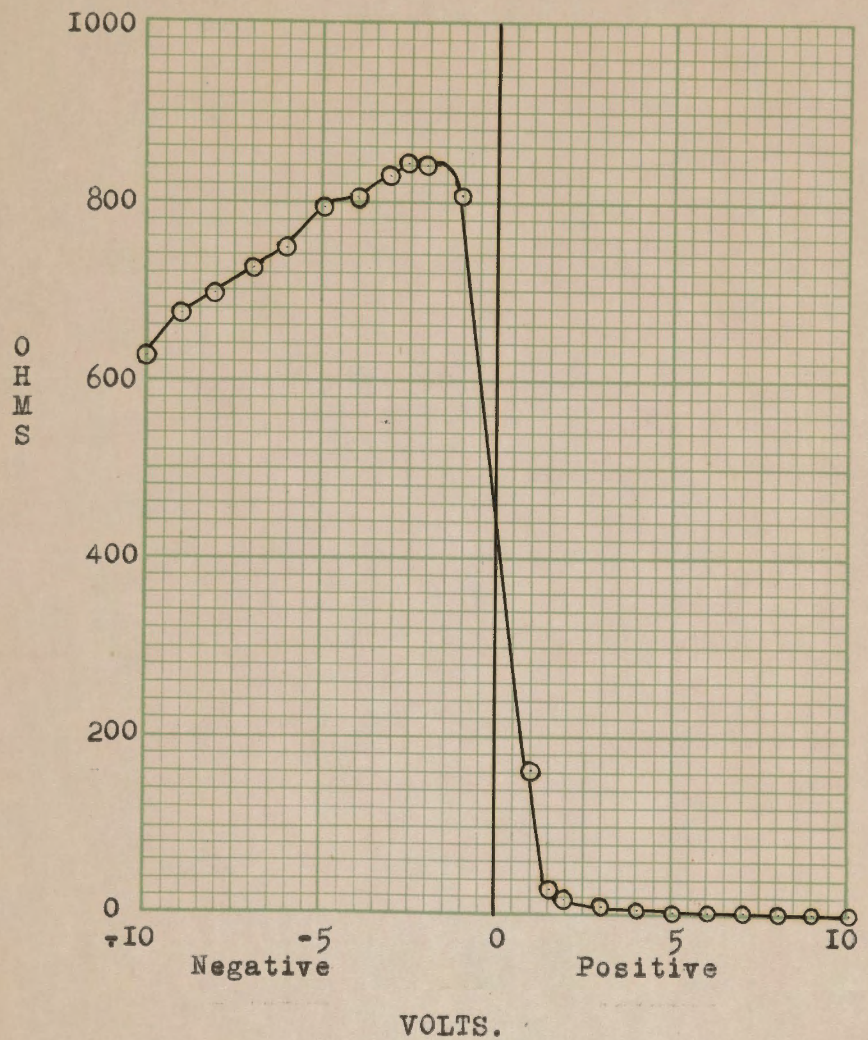

FIG. NO. 5.

TITLE:-

Resistance of rectifier.

INTERPRETATION OF CURVES

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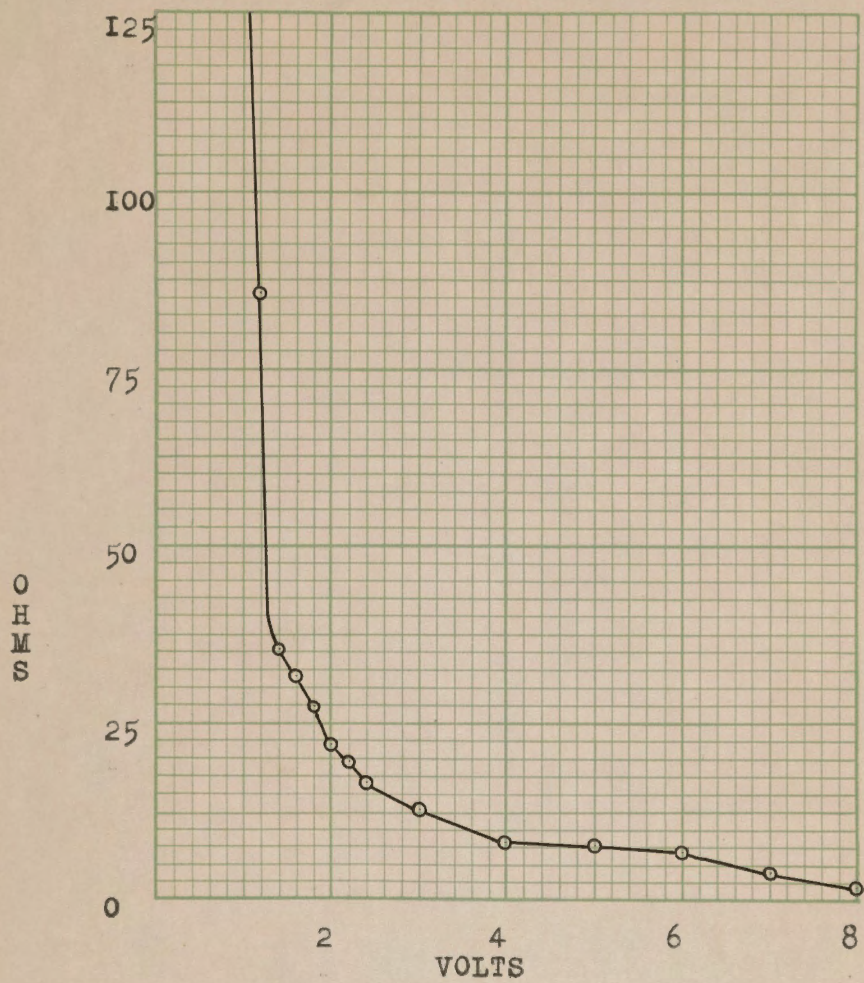

FIG. NO. 6.

TITLE:-

Enlargement of positive portion of Fig. 5.

INTERPRETATION OF CURVES

DATA No.2.

Voltage	Ratio resistances
I.0	4.75
2.0	38.5
3.0	66.6
4.0	92
5.0	I00
6.0	I04
7.0	I89
8.0	322
9.0	396
I0.0	404
II.0	402
I2.0	424
I3.0	526
I4.0	834
I5.0	900

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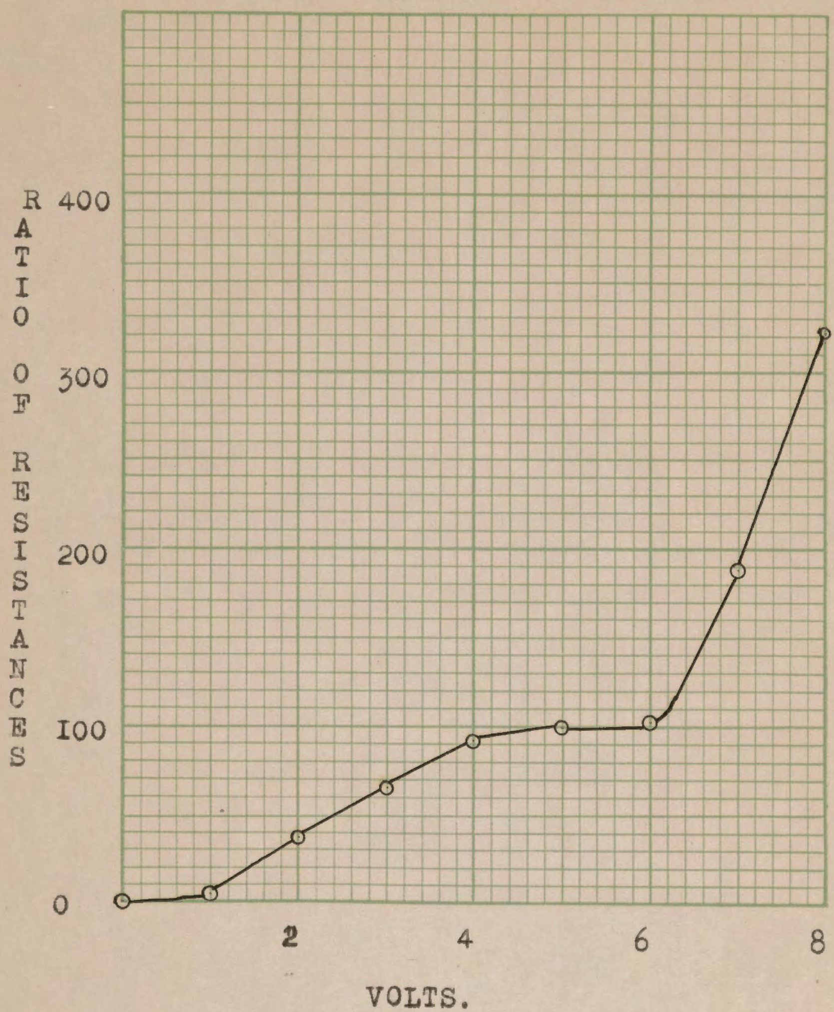

FIG. NO. 7.

TITLE:- Rectification ratio

INTERPRETATION OF CURVES

CHAPTER 3--THEORY.

In this new type of rectifier the rectification seems to take place within a microscopically thin layer at the junction of the copper and the oxide.

There have been numerous theories advanced to explain this new rectifier,but few of them fulfill the experimental and physical conditions.

It might be thought,because contact is made with the layer of oxide,that the rectifier might be placed in the same class with the "cat-whisker",or crystal,as used in radio work,but it must be remembered that the crystal has a very high resistance and is absolutely unsuitable for the rectification of any amount of power. A careful study of the copper oxide rectifier seems to show definately that it is not at the external surface of the oxide that the rectification takes place,but rather at the junction of the copper and the oxide. Also it is easily shown that this new rectifier is theoretically different from the "cat-whisker" type in that it is sensative all over its entire surface,while the crystal depends upon a sensative spot for its rectification,and is very unsatisfactory because of its instability. This new rectifier has a low resistance,therefore,allowing large amounts of power to pass. It is noiseless and is very consistant in its behavior. There is no chemical or physical change within the rectifier. Its life seems to be unlimited.

Data sheet No.I & Fig.8 also show the characteristics of the rectifier as to voltage and current in the two directions.

LABORATORY

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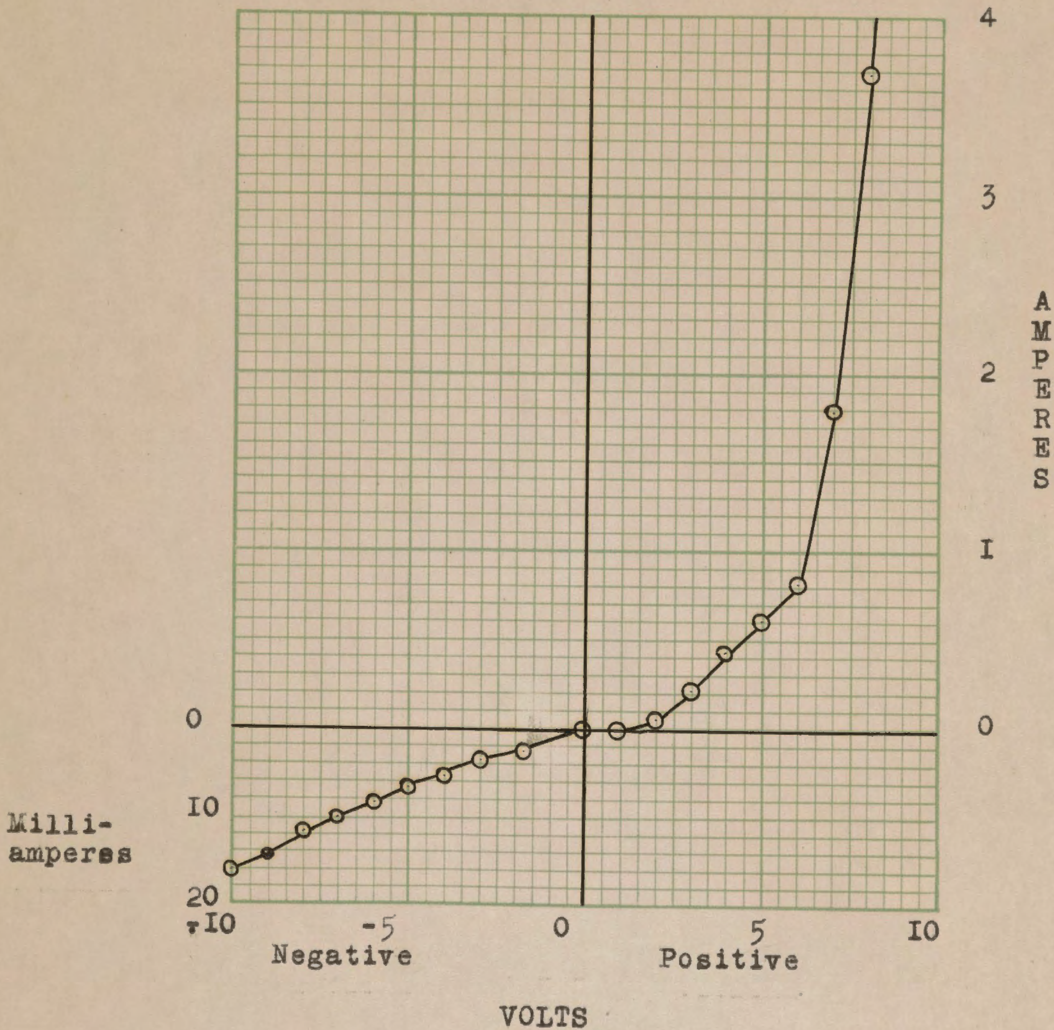

FIG. NO. 8.

TITLE:-

Positive and negative current that will flow thru the rectifier.

INTERPRETATION OF CURVES

Although the investigation of this new rectifier has not yet been carried on far enough to thoroughly understand its theory, it seems that it cannot be explained by the theories that are advanced for contact rectifiers.

Another theory advanced as a possible solution for this rectifier is based on thermoelectricity. Since the rectifying oxide in this rectifier is very thin, often not over .001 inch in thickness, it would be impossible to maintain any difference of temperature between the two surfaces. Experiments also show that the resistance is concentrated at, or near, this thin area at the junction of the copper and the oxide, and that the heating produced sets up an E.M.F. which is in the wrong direction for the rectification that actually takes place. This theory does not seem to hold in the case of the copper oxide rectifier.

Electrolysis is another theory offered by some physicist. Very probably electrolysis is applicable to some types of contact rectifiers. In such rectifiers we have the following conditions: The E.M.F. being applied, some time is required for it to maintain a steady current. The current is very irregular and at times shows sudden variations. The plates show signs of electrolysis and must be replaced after a short time. In the present rectifier we have none of these conditions. The current starts instantaneously with the voltage applied and at once reaches and renains at a constant value. There are also no signs of electrolysis on the plates after being in survice for several months. The electrolysis theory does not satisfactorilly explain our new rectifier.

Since the electron affinity of copper is probably greater than that of copper oxide, it seems safe to say that Schottky's[1] theory involving the work necessary to carry an electron across the boundary between the two plates, also fails to solve the mystery of the copper oxide rectifier.

In "Alternating Current Rectification", Mr. Jolley speaks of a theory where two layers exist, each layer made up of one constituent of the crystal. In the present rectifier this condition may exist. It may be that beyond the last layer of oxygen atoms, there is a layer of copper atoms which are mixed chemically with the oxygen, and thus produce a combination that is instrumental in the rectification.

Mr. Grondahl[2] gives us a theory that seems to fit at least part of the experimental results. His theory is based on the fact that the copper and oxide are in very close relationship. The transfer of an electron from the copper to the oxide or from the oxide to the copper could take place without passing thru the whole potential drop represented by the electron affinity of either substance, but thru a drop represented by their difference. Assuming this condition, it would be possible that, even at ordinary temperatures and no E.M.F., electrons would leave the copper and go into the oxide. The purpose of the copper then is to keep an excess of electrons in the oxide. Due to the small distance of separation and the comparatively large area, the resistance to the flow of electrons from the

1- Schottky:- Zeits. fur Physik, I4, p63, March I923.

2- L.O. Grondahl:- Science, Sept. 24, I926, Vol. 64, No. I656, p306-308.

copper to the oxide is low,while the resistance to the flow of electrons from the oxide to the copper is high.

This theory serves very well to explain the action of this new electronic rectifier,but a great deal of research must be done to formulate a theory,and say definately that it explains correctly the action of the rectifier.

CHAPTER 4--CALCULATIONS AND CURVES.

The following data and curves as well as the preceeding ones were obtained by the author in the Electrical Laboratory of The University of Tennessee. The Kuprox Rectifier was used.

Data sheet No.3 & Fig.5 show the efficiency of the rectifier at different values of the output current. It will be noticed that the maximum efficiency is reached at an output current of .45 amperes.

Data sheet No.4 & Fig.IO shows the load test of the rectifier and the different efficiencies at that load. The load was a variable number of Edison cells as shown in the extreme right column. The current was held constant at .5 amperes.

Fig.II shows oscillograms of the current and voltage. These curves were plotted on the sheet from observing the oscillograph screen.

By using data from Data sheet No.I it was possible to show the relation of the voltage and current input to the rectifier at different instantaneous values of time during the cycle. This is shown in Fig.I2. The load on the rectifier was a six volt storage battery.

Data sheet No.5 & Fig.I3 show(I)the voltage,(2) theinput, and(3)the output of the rectifier at different values of time when loaded with a variable resistance and using D.C. input to the rectifier.

Data sheet No.6 & Fig.I4 show(I)the voltage,(2)theinput, and(3)the output of the rectifier at different values of time when loaded with a 7.2 volt Edison battery and using D.C. input to the rectifier.

Data sheet No.8 and Fig.I5 show(I)the voltage,(2)the input, and(3)the output of the rectifier at different values of time when loaded with a 6.7 volt Edison battery and using A.C. input to the rectifier.

Data sheet No.7 & Fig.I6 show(I)the voltage,(2) the input, and(3)the output of the rectifier at different values of time when loaded with a variable resistance and using A.C. input to the rectifier.

Data sheet No.9 & Fig.I7 show the D.C. voltage and resistance of six elements in series when the voltage is applied from IO volts to 85 volts. The voltage was applied in the reverse direction on the elements. It will be noticed that the voltage was steadily increased and the resistance remained high until 60 volts was reached. From 60 volts to 85 volts the current increases and the resistance decreases rapidly. Any voltage above 60 would have burned the unit,had it been allowed to remain for any length of time. At55 volts the resistance broke down and an excessive current was allowed to flow. Considerable heat was radiated from the plates.

DATA No.3.

A.C. INPUT.				D.C. OUTPUT.			
E	I	P	Cos θ	E	I	P	Eff.
10.4	1.25	13.0	1.000	6.6	.82	5.41	41.6
10.48	1.11	11.5	1.000	6.95	.70	4.85	42.3
10.59	.995	10.5	.992	7.15	.62	4.43	42.3
10.65	.89	9.3	.981	7.38	.55	4.02	43.2
10.77	.75	8.0	.990	7.42	.48	3.56	44.5
10.89	.70	7.3	.968	7.7	.41	3.16	43.4
10.92	.50	5.5	.992	8.1	.26	2.11	38.4
11.00	.40	4.4	1.000	8.4	.19	1.60	36.6

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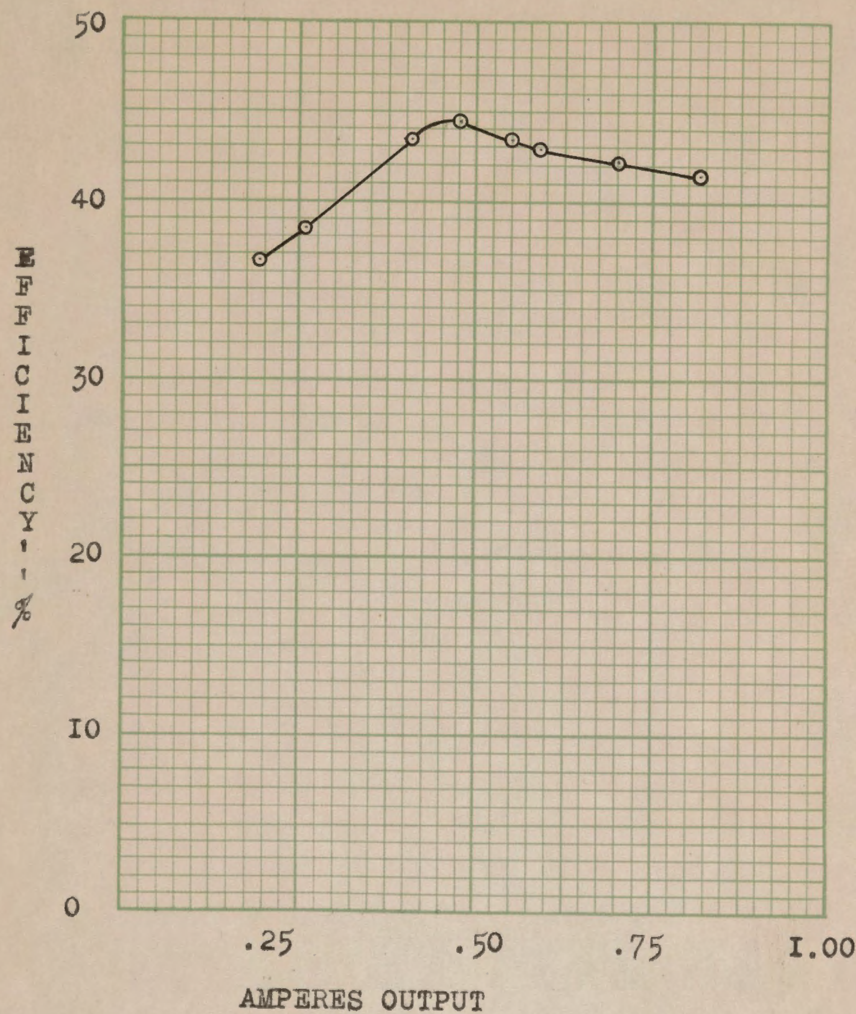

FIG. NO. 9.

TITLE:- Efficiency of rectifier

INTERPRETATION OF CURVES

DATA No.4.

A.C.INPUT.						D.C.OUTPUT	
E	I	P	Cells	E	I	P	Eff.
5.0	.75	3.7	I	I.3	.5	.65	I7.5
6.8	.80	5.4	2	2.6	.5	I.3	24.2
7.8	.85	6.6	3	3.9	.5	I.95	29.6
8.6	.92	7.9	4	5.2	.5	2.6	33.0
I0.4	I.00	I0.2	5	6.6	.5	3.3	32.4
I2.0	I.18	I4.0	6	7.8	.5	3.9	27.8
I2.8	I.33	I7	7	9.I	.5	4.5	26.5
I4.4	I.64	23	8	I0.5	.5	5.3	22.6
I6.0	2.55	40	9	II.6	.5	5.8	I4.5
I9.5	6.I3	II8	I0	I2.4	.5	6.2	5.2

LABORATORY

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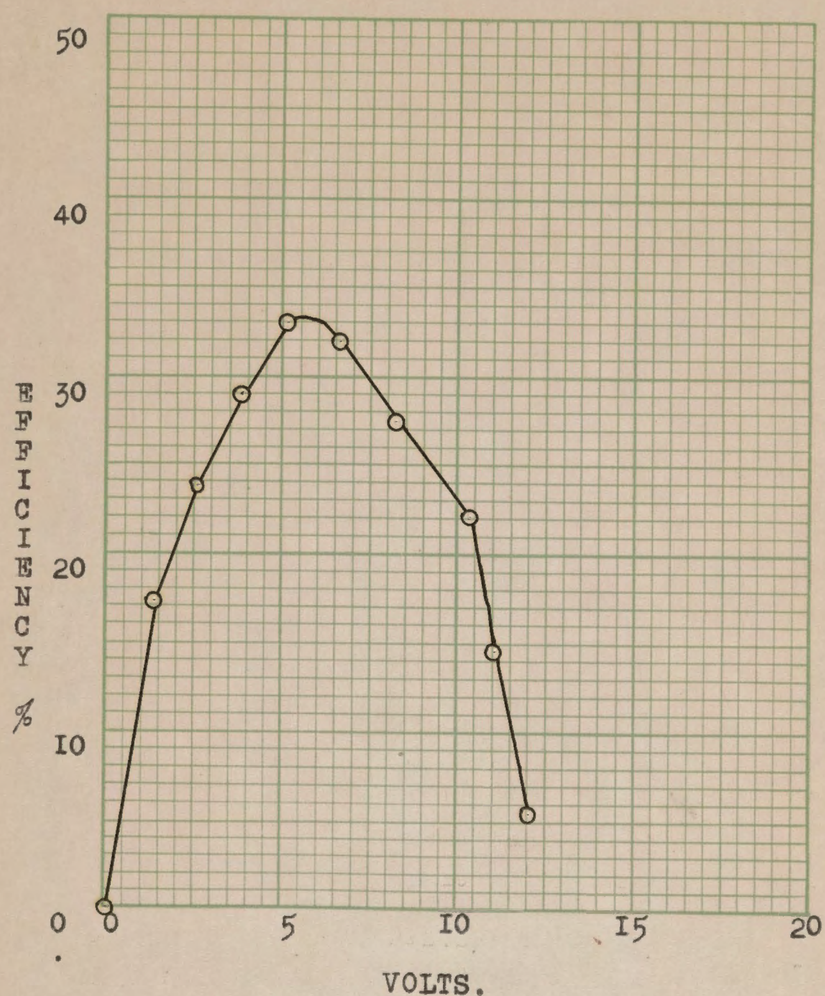

FIG. NO. 10

TITLE:-

Curve showing the efficiency of the rectifier at different output voltages. Constant current of 0.5 amperes.

INTERPRETATION OF CURVES

LABORATORY

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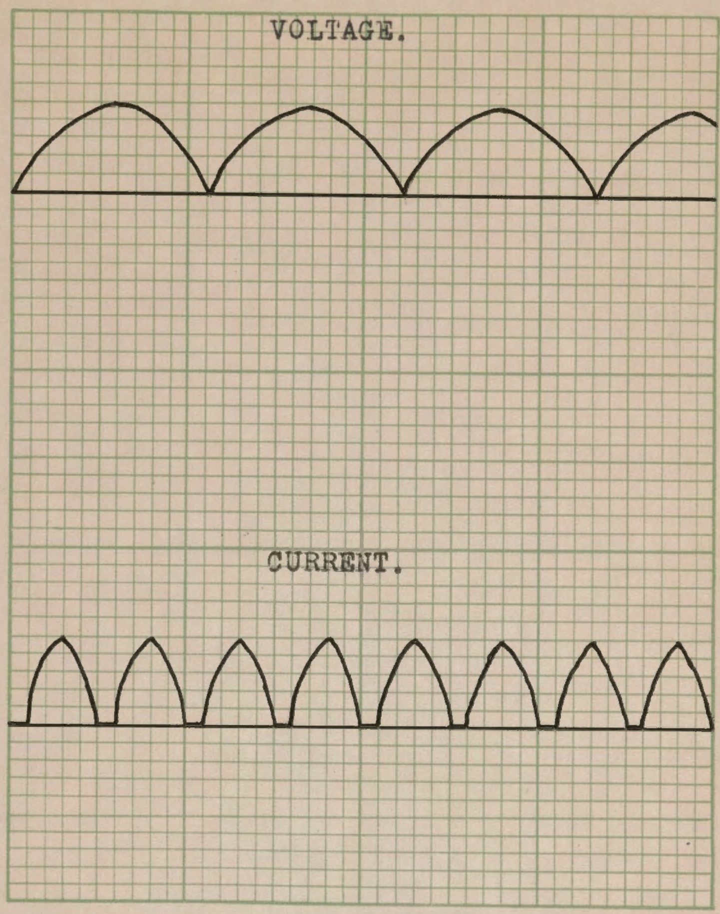

FIG. NO. II

TITLE:- Voltage & current oscillograms.

INTERPRETATION OF CURVES

LABORATORY

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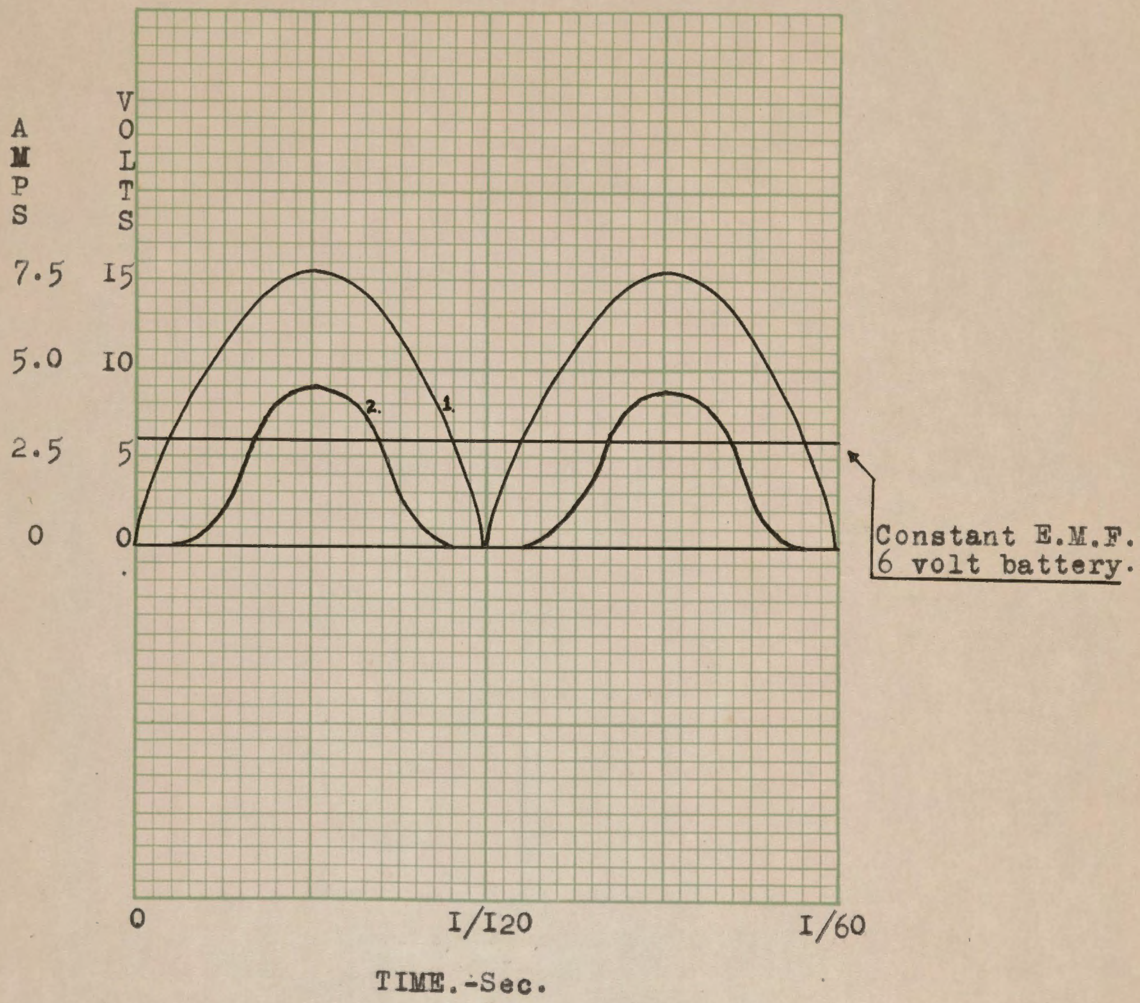

FIG. NO. I2.

TITLE:-

Curve showing instantaneous values of current and voltage when charging a six volt storage battery. The current values were found from resistance and voltage.

INTERPRETATION OF CURVES

Curve I--Voltage

Curve 2--Current

DATA No.5.

D.C.INPUT			D.C.OUTPUT.		
E	I	P	E	I	P
5	.18	.90	3.2	.15	.48
6	.21	1.26	4.0	.18	.72
7	.25	1.75	4.5	.22	.99
8	.30	2.40	5.1	.26	1.33
9	.34	3.06	6.0	.30	1.80
10	.40	4.00	6.9	.35	2.32
11	.45	4.95	7.5	.38	2.85
12	.51	6.12	8.3	.42	3.49
13	.56	7.28	9.0	.46	4.14
14	.60	8.40	10.0	.57	5.70
15	.64	9.60	11.0	.62	6.80

LABORATORY

DATE

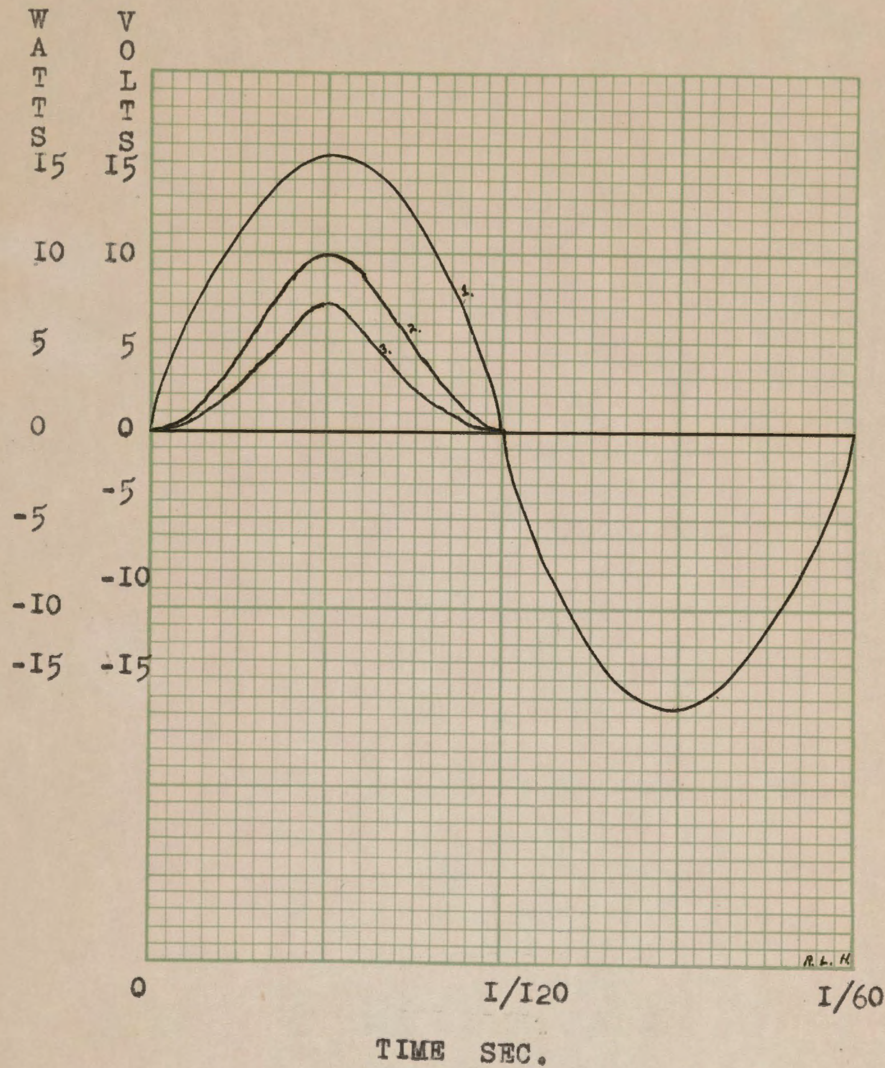

FIG. NO. I3.

TITLE:-

Curves showing the action of the rectifier with D.C. supply and resistance load.

INTERPRETATION OF CURVES

Curve I--Voltage

Curve 2--Watts input

Curve 3--Watts output.

DATA No.6.

D.C.INPUT			D.C.OUTPUT.		
E	I	P	E	I	P
8	.02	.I6	7.2	0	0
9	.I0	.90	7.2	.06	.43
I0	.37	3.7	7.2	.25	2.8
II	.46	5.06	7.2	.43	3.I
I2	.66	7.92	7.2	.69	4.97
I3	.8I	I0.5	7.2	.84	6.05
I4	.90	I2.6	7.2	.96	6.9
I5	I.7	25.5	7.2	2.0	I4.4

LABORATORY

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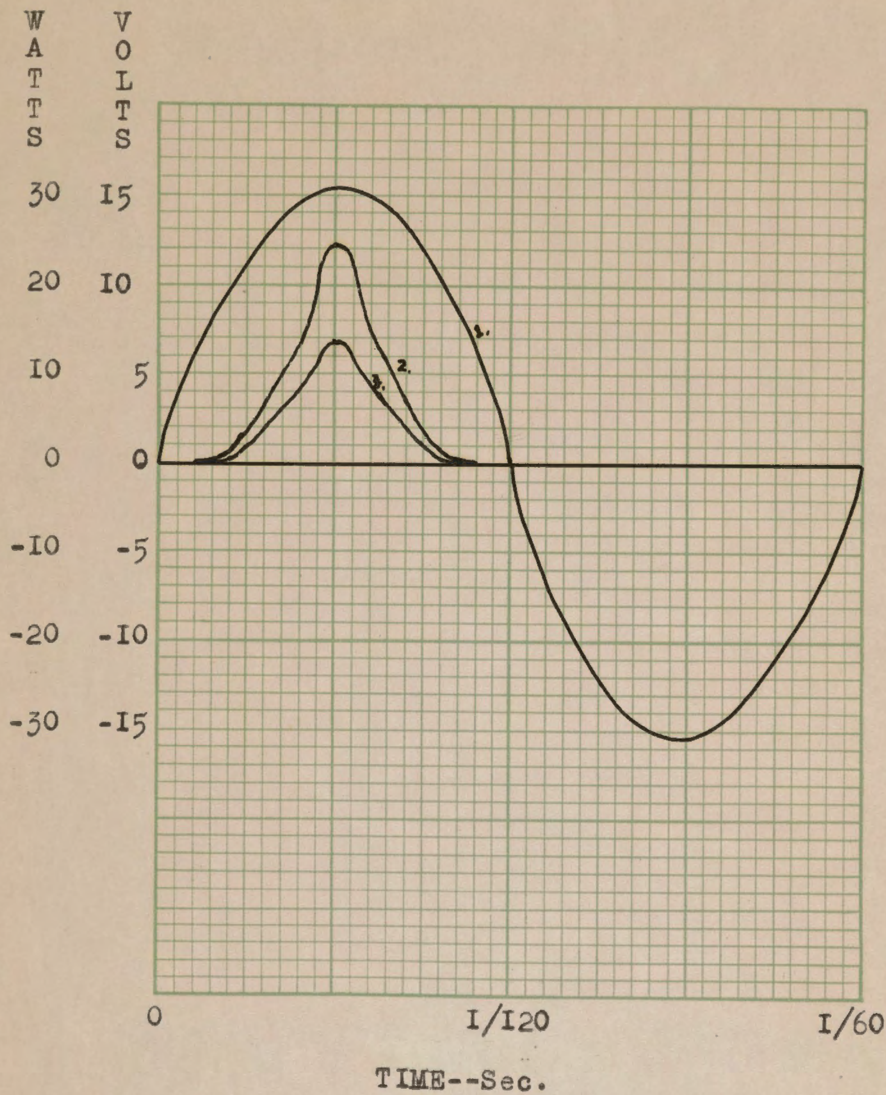

FIG. NO. 14.

TITLE:- Curve showing action of rectifier with D.C. input and Edison battery load--E.M.F.-7.2 volts.

INTERPRETATION OF CURVES

Curve 1--Voltage

Curve 2--Watts input

Curve 3--Watts output

DATA No.7.

A.C.INPUT.				D.C.OUTPUT.		
Ee	Em	I	P	E	I	P
3.3	4.6	.40	1.14	.18	.31	.056
4.0	6.6	.54	2.1	.20	.43	.086
5.0	7.0	.58	2.5	.80	.45	.36
6.0	8.4	.79	4.4	1.1	.62	.68
7.0	9.8	1.05	6.5	1.4	.79	1.11
8.0	11.2	1.46	12.0	2.0	1.17	2.34
9.0	12.6	1.81	16.0	2.5	1.46	3.65
10.2	14.3	2.20	23.0	3.1	1.78	5.5
11.0	15.4	2.40	26.0	3.6	2.20	7.9

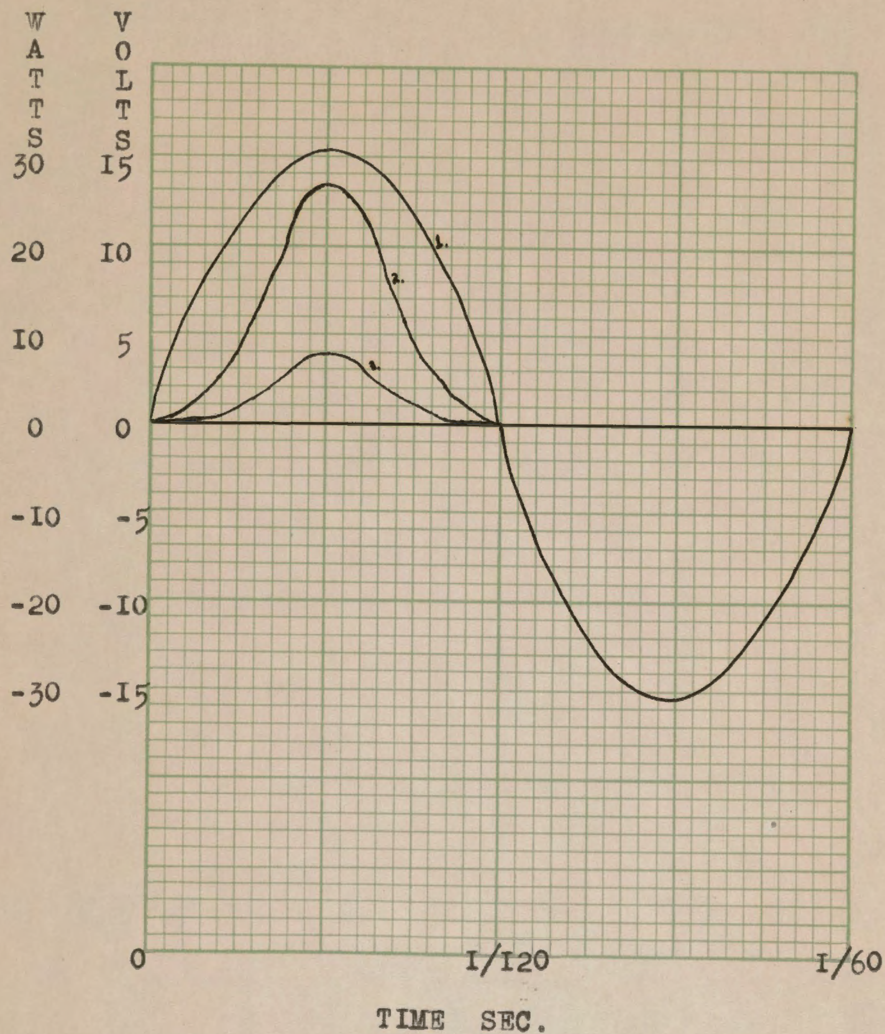

FIG. NO. 16.

TITLE:-

Curve showing action of rectifier with A.C. input and resistance load.

INTERPRETATION OF CURVES

Curve 1--Voltage

Curve 2--Watts input

Curve 3--Watts output

DATA No.8.

Ee	Em	I	P	E	I	P
7	9.8	.10	.4	6.7	.01	.067
8	11.2	.25	1.4	6.7	.10	.67
9	12.6	.42	3.2	6.7	.22	1.47
10	14.0	.66	5.7	6.7	.48	3.2
10.7	15.0	.92	10.0	6.7	.56	3.8

LABORATORY

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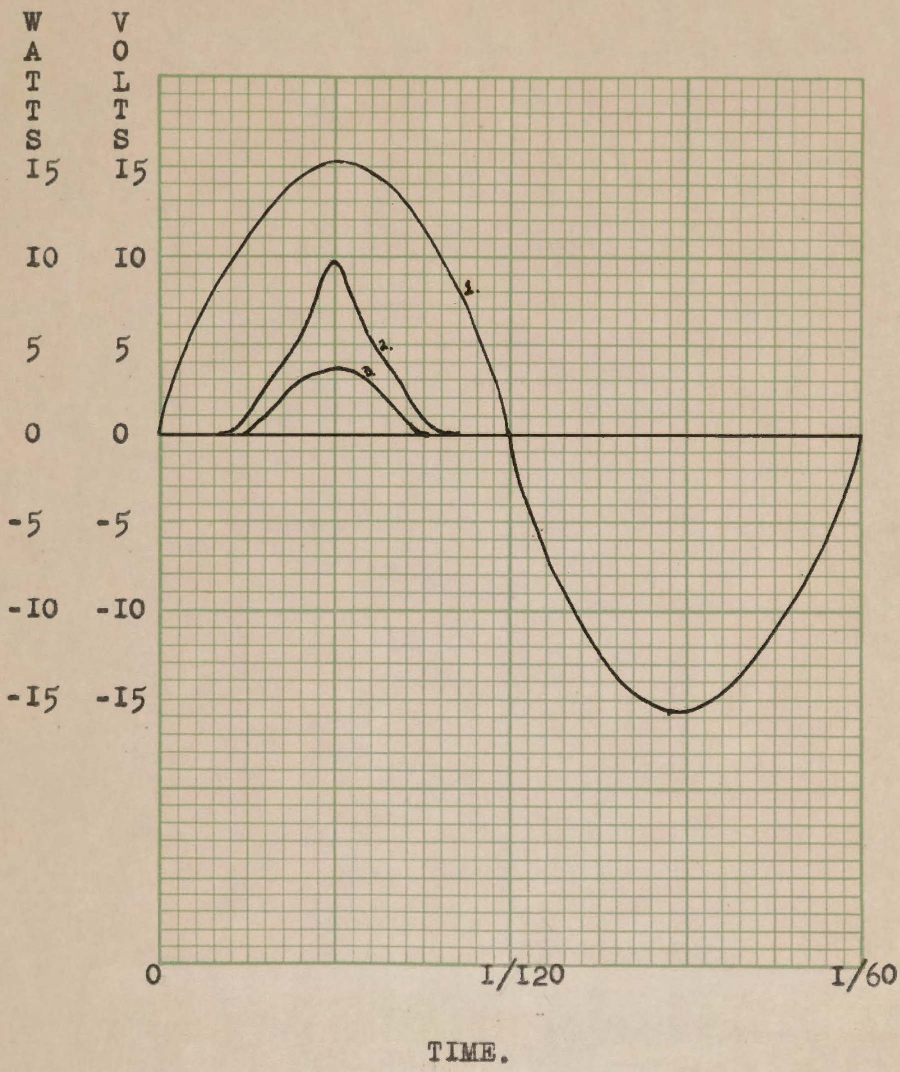

FIG. NO. 15.

TITLE:- Curve showing action of rectifier with A.C. input & Edison battery load--E.M.F.--6.7

INTERPRETATION OF CURVES

Curve I--Voltage

Curve 2--Input

Curve 3--Output

DATA No.9.

E	I	R
IO	.OI6	600
I5	.043	350
20	.08	250
25	.I2	208
30	.I7	I80
35	.2I	I66
40	.3I	I29
45	.35	I28
50	.44	II4
55	.53	I04
60	I.75	34.4
65	3.3	I9.7
70	5.0	I4.0
75	6.5	II.5
80	7.5	I0.6
85	I0.0	8.5

LABORATORY

DATE

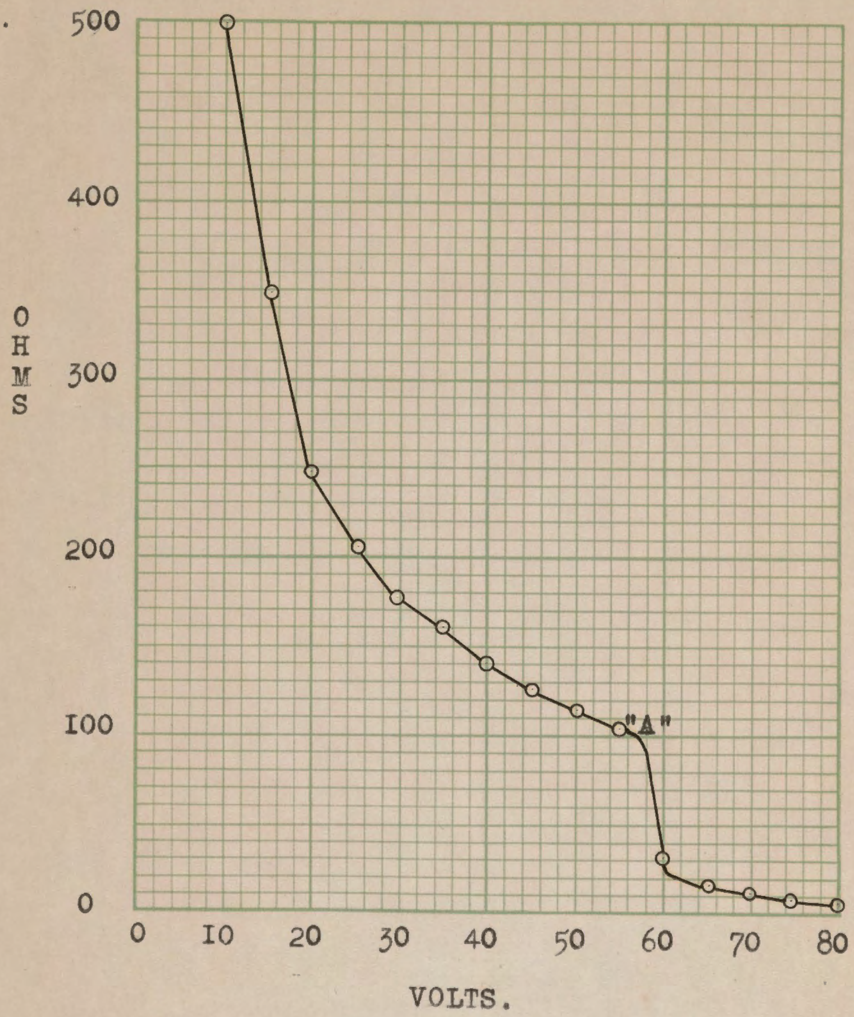

FIG. NO. 17.

TITLE:-
Variation of resistance when the voltage is applied in the reverse direction.

INTERPRETATION OF CURVES

"A"--Flash over or failing point of rectifier.

CHAPTER 5--CONCLUSIONS.

The new electronic rectifier of the copper oxide type is very different from any rectifier previously known. It may be successfully used as a battery charger,in connection with D.C. instruments on A.C. lines,with wavemeters,control apparatus, telegraphy,detectors,by-pass for field switches,Edison direct current systems,"B"battery substitutes in radio work,and in any place where it is desired to rectify alternating currents.

The theory of the rectifier,as yet,is not definately known, but no doubt the vast amount of experimental work that is now being done will disclose the cause of rectification.

The copper oxide rectifier gives a smooth rectified current which seems to have been commutated from a perfect commutator. It has characteristics that are constant. It requires no electrolyte or moving parts to be replaced. It requires no attention for operation. Each element of the rectifier represents a small increment of current and voltage,thus any amount of current or voltage may be obtained.

This little rectifier,though simple in construction and silent in operation,has bound up within its structure,possibilities that are capable of changing the entire field of rectification both in power and radio work.

Finis.

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2. Alternating Current Rectification, L.B.W.Jolley.

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 is submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statements made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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