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AN INVESTIGATION OF
CONTACTS AND CONTACT
ENDURANCE
PAUL G. ANDRES
1924

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AN INVESTIGATION OF
CONTACTS AND CONTACT ENDURANCE

A Thesis Submitted to
The Faculty of
MICHIGAN AGRICULTURAL COLLEGE

BY

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JUNE 1924.

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CONTACTS AND CONTACT ENDURANCE

Connections are established in automatic telephony by means of the contacts on springs actuated by the armatures of relays and magnets. The contacts are either riveted or welded to springs of various materials and gauges and are then aligned in proper position on the spring assembly. Their position depends on the circuit duty, causing certain springs with their associated contacts to make or break when the relay is energized.

The duty to which any contact is subjected depends on its position in the circuit, that is, the operation of opening or closing the circuit may occur once in the establishment of a through connection as in the case of the ring cut off relay, or a number of times as in the case of the pulsing relay which responds to the impulses sent by the calling device at the subscriber's station. Again, the number of operations may be indefinite as given in the case of the rotary line switch which operates until it finds an idle trunk.

In order to insure definite electrical connection with the back or break contact, the armature springs are given a certain tension when in the normal or non-operate position of the relay. In every case the power of the relay when energized is more than sufficient to cause proper electrical contact of the armature spring contact with the front or make spring contact. These tensions are determined by the operating conditions together with the design and winding characteristics of the relay.

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[The remainder of the text is extremely faint and largely illegible due to the quality of the scan. It appears to be a multi-paragraph report or memorandum.]

Contact Materials:

Experiments over a large number of years have gradually reduced the kinds of material suitable for contacts in automatic telephony to three alloys of approximately the following compositions:

- Metal A Platinum with less than 2% Iridium
- Metal B Silver 90%, Gold 10%
- Metal C Gold 70%, Silver 25%, Platinum 5%

These metals will be referred to later as platinum, silver and gold, respectively.

The physical and chemical characteristics such as density, melting point, heat conductivity, hardness, mechanical wear, chemical corrosion and resistance to spark erosion largely determine the durability of a contact. Some of these characteristics in the case of the pure metals entering into contact materials are given below in Table 1.

Table 1.

<u>Material</u>	<u>Density</u>	<u>Melting Point</u>	<u>Resistance</u>	<u>Heat Con- ductivity.</u>
Platinum	21.37	1755	10.96 Microhms per cm ²	0.173
Gold	19.1	1063	2.22	0.705
Silver	10.6	961	1.47	1.006
Tungsten	19.3	3200	6.2	0.476
Nickel	6.9	1452	6.93	0.142
Copper	8.89	1083	1.77	0.91

It may be noted that platinum has the highest melting point, the greatest specific resistance and a relatively low heat conductivity. Silver on the other hand has a low melting

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3. The third part of the document describes the process of interpreting the data and drawing conclusions from it. It stresses the need for a clear understanding of the data and the ability to identify patterns and trends that are significant to the organization's goals.

4. The fourth part of the document discusses the importance of communicating the results of the analysis to the relevant stakeholders. It emphasizes that clear and concise communication is essential for ensuring that the information is understood and acted upon.

5. The fifth part of the document provides a summary of the key findings and conclusions of the study. It highlights the main points of the analysis and the implications of the results for the organization's future operations.

6. The sixth part of the document discusses the limitations of the study and the need for further research. It acknowledges that there are certain constraints on the data and the methods used, and that further investigation is needed to address these limitations.

7. The seventh part of the document provides a list of references and sources used in the study. It includes a variety of academic journals, books, and other sources of information that have been consulted during the research process.

8. The eighth part of the document is a conclusion that summarizes the overall findings of the study and provides a final statement on the importance of the research. It emphasizes that the information presented in the document is intended to provide a comprehensive overview of the current state of the field and to guide future research and practice.

point, a low specific resistance and a very high heat conductivity. Gold has characteristics between those of platinum and silver.

Mechanical Construction of Contacts:

Contact material is usually obtained in the form of wire of #14 and #18 3 & S gauge. Figs. 1 and 2 illustrate the size of this material formed into rivets and the corresponding welded contacts. Riveted contacts are placed in a perforation of the contact spring and consequently insure a rigid mechanical structure. Contacts welded by automatic machines insure an equally good mechanical structure, but because of the reduced area of contact surface between the contact and the spring it would appear that the electrical and heat conductivity of the contact might be reduced from that obtained with riveted contacts.

Generally, large or #14 gauge contacts are attached to springs of heavy gauge and consequently are more readily riveted than welded. Fig. 2 shows such a large contact riveted in a heavy gauge spring.

Electrical Resistance of Junction between Contact and Spring:

Measurements made by the drop of potential method give resistances on the order of 45 to 150 microhms for the junction resistance between 18 gauge silver welded contacts and standard pulsing relay armature springs. These measurements were made according to the outline given in Fig. 3. The resistance of the standard pulsing relay armature spring from terminal to contact is on the order of 5000 microhms.

Because the resistance between the contact and its

How do we know that the world is not a simulation? We know because we can see the code.

There are many ways to tell if you are in a simulation. For example, you can look at the physics of the world. In a simulation, the physics would be programmed to behave in a certain way. If you notice any anomalies, that could be a sign that you are in a simulation. Another way to tell is by looking at the behavior of other people. In a simulation, people would be programmed to behave in a certain way. If you notice any anomalies, that could be a sign that you are in a simulation.

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spring is so extremely small, in fact approximately on the same order as the spring material, this is not a point of increased resistance in the circuit; however, there may be a gain in thermal and electrical conductivity by riveting compared to welding, but this is difficult to determine.

Electrical Resistance between Contacts:

The electrical resistance between the point of contact where two different contact metals were used was measured by an accurate Wheatstone Bridge. The contacts were assembled with their springs in the relay structure and the pressure was gradually increased and readings taken at various pressures. The results are shown graphically in Fig. 4. After arcing had occurred at the contacts by operation in the standard circuit the resistance was again determined in the case of the #14 gauge platinum contact and was found to be slightly lower for the greater pressures than when the contacts were new, although the difference is not very great. After these contacts were cleaned with a sand blasted steel contact file the resistances as shown in Fig. 5 increased materially and the results were somewhat erratic, caused probably by the irregular surfaces in contact.

The Problem Stated:

A number of years ago it was noted that certain relay contacts, particularly those of the pulsing or line relay showed signs of forming a crater on the negative or back contact with a corresponding building up on the positive or armature contact, resulting in sticking contacts as well as decreased life of operation (Fig. 6). An investigation was started to determine the nature of this phenomenon and the results obtained to date are given below.

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Possibility of Reverse Current:

Since in a carbon arc a crater forms on the positive electrode, and a corresponding point on the negative, it was supposed that a reversal of current, as a condenser discharge, might be responsible for this action. To test this theory an oscillogram was made of the current flow through the contacts, and through the condenser circuit of a standard connector as shown in Fig. 7. The oscillogram O-51 shows that the condenser charges and discharges a number of times at the beginning of the pulse, and once at the end, but in no case is the current reversed through the contacts. From study of the circuit, as will be shown later, it is apparent that the condenser can charge only through the relay and can discharge only through the back and armature contacts in a direction the same as the relay supply current. At no time does a tendency exist for any current to flow contrary to the direction of the relay supply current.

Metal Arc different from Carbon Arc:

To determine the formation of the crater in a metallic arc instead of carbon, two copper electrodes 1/4" diam. were used. With a current of 2 amperes the crater formed on the negative. The positive electrode operated at a higher temperature than the negative, resulting in a small globule of molten copper and copper oxide being formed. Because of surface tension, the globule assumed a spherical form causing the negative electrode to assume a crater since the arc always played between this spherical globule and the shortest point to the negative electrode.

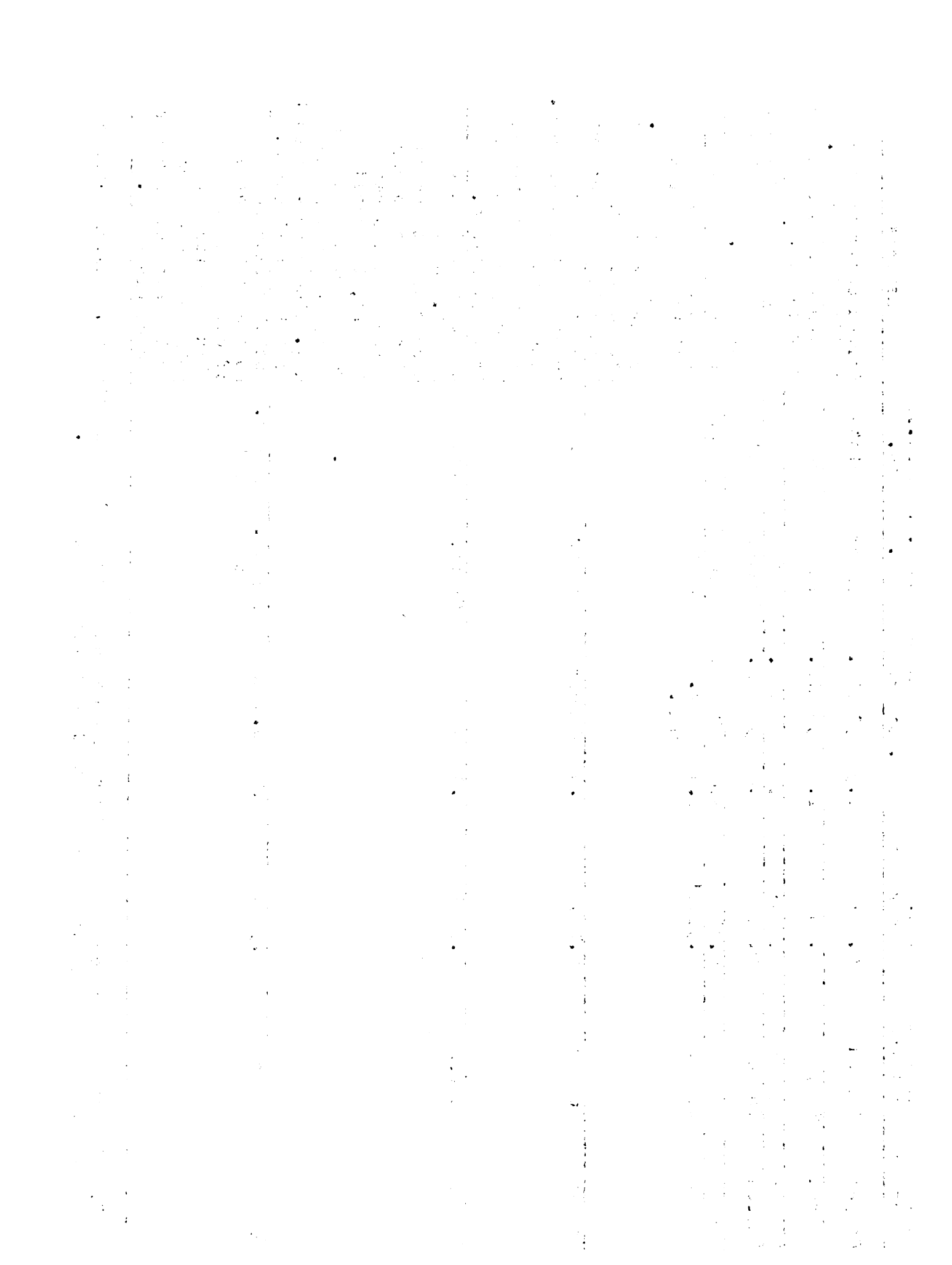
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TABLE 2.

Electrode Negative	Combination Positive	Diam. of Electrodes	I Amps. of Arc	Duration of Arc	Cond. of		Remarks
					Neg.	Pos.	
Copper	Carbon	0.25"	1.5	30 min.	Crater	Pointed	Carbon consumed more rapidly than copper.
Carbon	Copper	0.25"	1.5	30 min.	Crater	Bead	Carbon electrode hotter than copper.
Copper	Copper	0.125"	2.0	50 min.	Crater	Bead	Negative consumed faster
Carbon	Copper	0.25"	3.0	30 min.	Crater	Bead	Carbon consumed faster than copper.
Carbon	Carbon	0.25"	3.0	30 min.	Pointed	Crater	Positive is hotter
Copper	Copper	0.3125"	2.0	2 Hr. 35 min.	Crater	Bead	Molten copper of positive formed into beads and dropped off. Crater formed by short arc deeper than that formed by a longer arc.
Copper	Copper	0.125"	2.0	4 hours	Crater	Bead	Electrodes graduated in centimeter divisions. After test noted that negative was shortened by 50% more than positive electrode.
Copper	Copper	0.125"	2.0	4 hours	Crater	Bead	Negative lost 8% in weight. Positive electrode with beads of copper and copper oxide that dropped from it, increased weight 3%. This leaves 5% of weight lost on neg. electrode as amount lost in vaporization.
Copper	Copper	0.3125"	2.5	6.5 hours	Approx. flat	Approx. flat	Positive electrode kept cool by a stream of cold water flowing thru electrode from point 5 mm away from arcing surface to other end of electrode.

NOTE: All arcs took place in open air at a room temperature of 25° centigrade. Voltage across arc varied from 28 to 50 volts with line voltage of 110 volts.



When the electrodes were kept at room temperature except for the actual point of the arc, by running cold water in at one end of the electrode and out near the point of arc, the two electrode surfaces remained parallel except for slight irregularities.

This indicated that the electrodes could burn without forming a noticeable crater when the electrodes were kept cool or if the thermal conductivity was relatively large. Tests made on smaller electrodes showed that the formation of the negative crater increased rapidly as the diameter of the electrodes was decreased. The significance of these tests and their verification with contacts are again referred to later.

In every case metal was transferred from the negative to the positive electrode. Beads of copper and copper oxide formed and dropped from the positive electrode from time to time during operation. Table 2 gives the results of material transference when metallic electrodes are used, together with the physical forms of the electrodes after an arc has been maintained.

These tests on metallic arcs gave indication that thermal conductivity and size of the electrodes may affect the formation of the crater.

Pulsing through Resistances as Load:

From the tests on metallic arcs it was but a step to equip a number of pulsing relays with #18 gauge platinum contacts and then let these contacts intermittently pass a current through a non-inductive resistance of low value to hasten the contact deterioration. After impulsing through 2.75Ω for 15000 times the positive contacts developed a long point and the negative con-

1. The first part of the document discusses the importance of maintaining accurate records of all transactions. This is essential for ensuring the integrity of the financial statements and for providing a clear audit trail. The records should be kept up-to-date and should be easily accessible to all relevant parties.

2. The second part of the document outlines the various methods used to collect and analyze data. These methods include interviews, surveys, and focus groups. Each method has its own strengths and weaknesses, and it is important to choose the most appropriate method for the specific research objectives.

3. The third part of the document describes the process of data analysis. This involves identifying patterns and trends in the data, and then interpreting these findings in the context of the research objectives. It is important to be objective and unbiased in the analysis, and to avoid drawing conclusions based on anecdotal evidence.

4. The fourth part of the document discusses the importance of communication in the research process. This involves sharing the findings of the research with the relevant stakeholders, and ensuring that they understand the implications of the findings. It is important to use clear and concise language, and to provide supporting evidence for all claims.

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tacts a very deep crater (Springs 15,16,18,19). These contacts are almost identical with those obtained in practice which show a negative crater (Springs 25,26,34,35). The substitution of larger back contacts, that is #14 gauge platinum yielded a much less pronounced crater on the negative and a complete absence of black deposit around both contacts.

Spark Quenching:

The usual form of spark quencher consists of a condenser in series with a non-inductive resistance. This combination may be connected either across the contacts as shown in Fig. 8, or across the coil as shown in Fig. 9. On opening the circuit, the condenser absorbs the energy of the magnetic field about the coil which would manifest itself as a spark at the contacts without a condenser. The resistance in series with the condenser limits the momentary rush of discharge current of the condenser at the moment of make.

In either case the condenser charges in such a direction that the discharge across the contacts, if these be opened and closed with but a small intervening time interval, is in the same direction as the battery current. From Fig. 10, which gives the theoretical solution of the discharge of a condenser, it is seen that the current at the moment of make may be varied over a considerable range. The ideal case would be the one where the resistance in series with the condenser is very large at the moment of make, in order to let it discharge very slowly and at a low current value so as to prevent arcing and possibly welding at the contacts. On the other hand the same condenser should have no resistance in series at the moment of break in order that the condenser may act as an energy absorber as efficiently as possible.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business or organization. The text outlines various methods for collecting and organizing data, such as using spreadsheets and databases. It also highlights the need for regular audits to ensure the accuracy and integrity of the information.

The second part of the document focuses on the analysis and interpretation of the collected data. It describes different statistical techniques and models that can be used to identify trends and patterns in the data. The author provides examples of how these techniques can be applied in various contexts, such as marketing research and financial analysis. It also discusses the importance of visualizing the data to make it easier to understand and communicate.

The third part of the document discusses the challenges and limitations of data analysis. It acknowledges that there are many factors that can affect the accuracy and reliability of the results, such as data quality and sampling bias. The author offers practical advice on how to overcome these challenges and ensure that the analysis is as accurate as possible. It also discusses the ethical considerations surrounding data analysis and the importance of protecting the privacy of the individuals whose data is being used.

The final part of the document provides a conclusion and a summary of the key points discussed throughout the document. It reiterates the importance of data analysis in decision-making and the need for a systematic and rigorous approach to the process. The author encourages readers to apply the principles and techniques discussed in the document to their own work and to continue to explore the field of data analysis.

In practice, a resistance is usually chosen so as to offer a satisfactory mean between these two extremes. From the curve, Fig. 10, it will be noted that a ten ohm resistance will allow the discharge current to reach a maximum value of 5 amperes, but this current persists for only an infinitesimally small time; in fact after less than $4/10000$ of a second this current has been reduced practically to zero. In the case of a 100 ohm resistance with a 0.5 mfd. condenser the discharge current reaches a maximum value of 0.5 amperes and then reduces gradually to zero after $2/1000$ of a second. When a 250 ohm resistance is used with a 2.0 mfd. condenser the discharge current reaches a value of 0.2 amperes which reduces to zero very slowly in comparison to the previous cases as may be seen by reference to the figure. A ten ohm resistance, therefore, because of the short duration of the discharge current ought not to cause undue erosion of the contacts. This point will be mentioned again later where it will be shown that the contact trouble previously referred to may be eliminated without changing the value of resistance which unless noted otherwise remained at ten ohms during all succeeding tests.

The action of the condenser in series with the resistance (Fig. 6) when placed across the contacts is somewhat different than when the combination is connected across the coil. In the first case the condenser, while in a discharged condition, acts as a shunt circuit to the contacts at the moment of break. At that instant the resistance of the circuit is only that offered by the series resistance. As the condenser charges the counter electromotive force increases, and that to all intents and purposes is the same as adding resistance. If the contacts are completely

separated before this apparent resistance of the condenser reaches an appreciable value, the condenser prevents arcing at the contacts. For a definite rate of break such as that of a relay, a minimum value of capacitance exists which will offer such a low apparent resistance during the separation of the contacts. A larger condenser may be used, but in that case the series resistance must be increased in order that the discharge current on make will be held within reasonable bounds. A 0.5 mfd. condenser was used as a spark quencher in all subsequent tests, since this value of condenser has apparently enough capacity to act as a sufficiently low resistance shunt across the contacts until these are completely separated to prevent arcing.

The action of the condenser across the coil, Fig. 9, may be analyzed in a different manner since in this case the capacitive reactance should be equal and opposite to the inductive reactance of the coil at that particular speed of current interruption. If the condenser breaks down, the battery is short circuited during operation and therefore this adaptation of the condenser and series resistance has not found application and will not be further considered.

Relay Chattering:

From the oscillogram 0-51 and similar ones 0-52 and 0-53, it was noted that the relay armature chattered when de-energized, that is, the armature did not come to rest gradually on return, but caused the relay contacts to open and close several times. An oscillogram was made of the currents as in the previous 0-51, but in addition a mirror was mounted on the residual screw of the armature of the relay. The results obtained as shown on 0-53 indicate that the armature rebounds at least two times

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that proper record-keeping is essential for transparency and accountability, particularly in the context of public administration and government operations. The text highlights how detailed records can help identify inefficiencies, prevent fraud, and ensure that resources are used effectively.

2. The second part of the document focuses on the role of technology in modern record-keeping. It explores how digital systems and software solutions can streamline the process of data collection, storage, and retrieval. The author notes that while technology offers significant advantages, it also presents challenges such as data security, system integration, and the need for staff training. The text suggests that a balanced approach, combining traditional methods with modern technology, is often the most effective solution.

3. The third part of the document addresses the legal and ethical considerations surrounding record-keeping. It discusses the importance of ensuring that records are maintained in accordance with applicable laws and regulations. The text also touches on the ethical implications of data privacy and the potential for misuse of information. The author argues that organizations must have robust policies in place to protect sensitive data and ensure that records are used only for their intended purposes.

4. The fourth part of the document provides practical advice for implementing a successful record-keeping system. It suggests that organizations should start by conducting a thorough audit of their current records to identify gaps and areas for improvement. The text also recommends establishing clear roles and responsibilities for record-keeping and ensuring that all staff are trained and aware of the importance of their work. Finally, the author emphasizes the need for regular reviews and updates to the record-keeping system to keep it relevant and effective.

5. The fifth and final part of the document concludes by summarizing the key points discussed throughout the text. It reiterates that accurate and secure record-keeping is a fundamental requirement for any organization, particularly in the public sector. The author encourages readers to take the time to evaluate their current practices and implement the necessary changes to ensure long-term success and compliance.

between the armature stop and the armature spring, causing the current to be interrupted and resulting in sparking at the contacts.

The movement of the relay armature may also be checked visually by the aid of successive sparks from an induction coil. When the sparks occur separated by a time interval of slightly more than the interval of a cycle of operation of the relay, the operation of the relay appears to pass through its cycle of operation at a greatly reduced speed.

Since the rebound of the armature occurs between the armature stop and the armature spring oscillograms were made to determine the effect of increasing or diminishing this gap. In O-80 comparison is made between armature chattering with the armature stop in the normal position, and when entirely removed. There is no doubt that the armature stop is not the only contributing cause to the rebound. Subsequent investigations led to the belief that the residual magnetism of the relay core acted as a restraining force and rebound is established by means of this and the periodicity of the spring. Apparently the clearance of the armature stop does not affect the rebound. A check test shown in O-81 where the clearances on the same relay were 0.003" 0.010" and entirely removed verifies these conclusions.

Elimination of Relay Chattering:

From the above tests it became apparent that some means for holding the armature against the armature stop on release would eliminate the chattering and the resulting sparking at the contacts. Accordingly, tests were made with a "C" type spring acting from a point under the residual screw and terminating under a screw on the heel piece. With the proper adjustment of the

The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that proper record-keeping is essential for transparency and accountability. The document also highlights the need for regular audits and reviews to ensure that all information is up-to-date and correct.

In addition, the document outlines the various methods and tools used for data collection and analysis. It mentions the use of spreadsheets, databases, and specialized software to manage large amounts of information. The document also discusses the importance of data security and privacy, particularly in the context of handling sensitive information.

The second part of the document focuses on the implementation of these practices. It provides detailed instructions on how to set up a record-keeping system, including the selection of appropriate software and the establishment of clear protocols. It also discusses the role of training and education in ensuring that all staff members are familiar with the procedures and understand the importance of compliance.

Finally, the document concludes by summarizing the key points and providing a checklist of actions to be taken. It emphasizes that the goal is to create a robust and reliable system that can support the organization's operations and provide the necessary data for decision-making.

armature spring which now was influenced by the tension in the "C" spring, the arcing was materially reduced at the contacts. An oscillogram 0-12 shows the effect in the vertical magnet circuit with and without the "C" or damper spring.

Numerous damper springs were made as for example one which lies against the armature spring as shown in Fig. 11, and others where the force is applied to the armature arm as shown in Figs. 12 and 13. One of the latter where the spring acts against the arm near the bushing has been found to be very satisfactory with regard to spark elimination. The adjustment for any such damper spring in order to be effective may vary between 10 and 20 grams back pressure, measured on the armature just back of the armature stop and just as the armature leaves the stop.

When two 18 gauge welded platinum contacts are operated on the armature and back springs of the pulsing relay of a standard connector the result as mentioned above consists of a deep crater on the negative or back spring and a corresponding building up of material on the positive or armature spring. A check test made at this point on a standard connector resulted in the verification of the above and is shown by the spring contacts 31 and 32. These contacts operated for 1,515,140 impulses after which time the switch became inoperative due to the contacts sticking.

The same connector on the identical impulsing circuit was then equipped with a similar pair of contacts, but the damper spring last mentioned was added to prevent chattering of the relay. Sparking at the contacts was practically eliminated and the switch operated 765,520 impulses with the contacts bright and clean with a slight indication of a crater in the positive. The wear on the contacts was insignificant (Springs 27 and 28; see also Fig.

signature spring which now was influenced by the tension in the "Q" spring, the spring was materially reduced at the contacts. An oscillogram Q-22 shows the effect in the vertical magnet circuit with and without the "C" or damper spring.

Numerous damper springs were made as for example one which lies against the armature spring as shown in Fig. 11, and others where the force is applied to the armature arm as shown in Figs. 12 and 13. One of the latter where the spring acts against the arm near the pushing has been found to be very satisfactory with regard to spark elimination. The adjustment for any such damper spring in order to be effective may vary between 10 and 20 grams back pressure, measured on the armature just back of the armature stop and just as the armature leaves the stop.

When two 18 gauge welded platinum contacts are operated on the armature and back springs of the pulling relay of a standard connector the result as mentioned above consists of a deep crater on the negative or back spring and a corresponding pitting up of material on the positive or armature spring. A check test made at this point on a standard connector resulted in the verification of the above and is shown by the spring contacts 31 and 32. These contacts operated for 1,515,140 impulses after which time the switch became inoperative due to the contacts sticking.

The same connector on the identical impaling circuit was then equipped with a similar pair of contacts, but the damper spring last mentioned was added to prevent spattering of the relay. Operating at the contacts was practically eliminated and the switch operated 767,280 impulses with the contacts bright and clean with a slight indication of a crater in the positive. The wear on the contacts was insignificant (Springs 27 and 28; see also Fig.

14). Because of the appearance of the indication of a slight positive crater a check test was made on the same connector, the contacts of which after 788,960 impulses yielded similar results (Springs 29 and 30).

These tests together with similar ones prove conclusively that the pitting of the negative platinum welded contact and the building up on the corresponding positive contact can be eliminated by the use of this damper spring resulting in a longer life for the contacts and freedom from contact troubles.

Effect of Larger Contacts - Thermal Conductivity:

From the experiments on the thermal conductivity of the metal arcs mentioned above and the fact that reduced sparking resulted from a non-chattering relay, it appeared that the 18 gauge platinum contacts were perhaps too small to carry the heat away quickly between impulses or groups of impulses.

Springs were made with large contacts of platinum, gold and silver and assembled in the standard connector. The results of these tests are given in Table 3. Of the various combinations tried, #18 gauge welded platinum as a positive on the armature spring when mated with #14 gauge riveted silver contact as a negative on the back spring formed a combination which after impulsing over three million times showed a pair of contacts perfectly flat with but little wear; bright and entirely free from any black deposit around the contacts (Springs 43 and 44).

These tests which were made without damper springs indicate that even though a relay chatters and causes additional arcs, this arcing does not cause the contacts to wear away, nor the pitting action to occur provided the negative contact be made sufficiently large. These results have been borne out in

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Effect of Larger Contacts - Thermal Conductivity:

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practice over a number of years.

Tests were made with a relay equipped with such contacts and a damper spring in addition, and after operation for several days with no noticeable sparking, the contacts were examined and they showed absolutely no deterioration nor burning at the points. All the above tests were made on the circuit as given in Fig. 7, and with a spark quencher consisting of a 0.5 mfd. condenser with 100 Ω non-inductive resistance in series. It, therefore, appears that a pulsing relay when equipped with a #18 gauge platinum contact on the armature spring and a #14 gauge silver contact on the back spring and having in addition a properly tensioned damper spring will perform with only occasional sparking and with a resulting long life.

Check Tests. Results with various Contact Metals:

Using the impulsing device Fig. 15 and various contact metals and combinations on a standard connector Fig. 7 results were obtained which agree with the previous results obtained in the general way of contact performance. The back contact was large and riveted in every case while the armature contact was a #18 gauge platinum welded contact. No damper spring was used. The contacts were pulsed between two and a half and three and a half million times in each case. Tabulated data is given in Table 3.

TABLE 3.

<u>Spring No.</u>	<u>Contact</u>	<u>Pulses</u>	<u>Condition of Contact</u>
{ 39 +	Pt. 18 ga. W	2582500	Very slightly pitted
{ 40 -	Ag. 14 ga. R	2582500	Flat, Edges rise slightly
{ 41 +	Pt. 18 ga. W	2636600	Flat
{ 42 -	Ag. 14 ga. R	2636600	Flat

The first part of the document discusses the general principles of the system, which are based on the concept of the "unitary" system. This system is designed to be flexible and adaptable to various circumstances. The second part of the document describes the specific details of the system, including the structure of the units and the way they are organized. The third part of the document discusses the implementation of the system, including the role of the central authority and the way the units are coordinated.

The fourth part of the document discusses the results of the system, including the way the units have performed and the way they have adapted to various circumstances. The fifth part of the document discusses the future of the system, including the way it can be improved and the way it can be expanded to include more units.

Unit Name	Location	Capacity	Status
Unit A	Location 1	100	+ (A)
Unit B	Location 2	150	- (B)
Unit C	Location 3	200	+ (C)
Unit D	Location 4	250	- (D)

{43+	Pt. 18 ga. W.	3028540	Flat, Slightly irregular
{44 -	Ag. 14 ga. R	3028540	Flat, Slightly irregular
{45+	Pt. 18 ga. W.	3000060	Flat
{46 -	Ag. 14 ga. R	3000060	Flat
{47+	Pt. 18 ga. W	2896960	Flat, Black deposit
{48 -	Au. 14 ga. R	2896960	Flat, Black deposit
{49 +	Pt. 18 ga. W	2887800	Flat, Black deposit
{50 -	Au. 14 ga. R	2887800	Flat, Black deposit

The material lost on the positive springs 39 to 45 was slightly less than the amount lost with springs 47 and 49.

Test on Self-Interrupting Rotary Lineswitches:

Metal arcs at contacts and the resulting formation of negative craters, particularly those as shown in the previous Fig. 6, may depend on still other contributing causes than those outlined above. Concurrent with the above tests data was obtained on the performance of various combinations of the three contact metals, both riveted and welded, when operated in the lineswitch circuit Fig. 16.

Condenser charge and discharge oscillograms for one switch are given in the oscillogram O-174 to O-177 for one, one and two, one to four and one to six switches operating simultaneously off the same current supply. An interaction is indicated. Just as a number of these switches may operate simultaneously in practice so were a number of switches never less than six operated in obtaining the data listed in Table 4. It is very difficult to describe the condition of the contacts, and conclusion and comparisons can only be made by reference to the original samples.

(1) $\log_2 2 = 1$
 (2) $\log_2 4 = 2$
 (3) $\log_2 8 = 3$
 (4) $\log_2 16 = 4$
 (5) $\log_2 32 = 5$
 (6) $\log_2 64 = 6$
 (7) $\log_2 128 = 7$
 (8) $\log_2 256 = 8$
 (9) $\log_2 512 = 9$
 (10) $\log_2 1024 = 10$
 (11) $\log_2 2048 = 11$
 (12) $\log_2 4096 = 12$
 (13) $\log_2 8192 = 13$
 (14) $\log_2 16384 = 14$
 (15) $\log_2 32768 = 15$
 (16) $\log_2 65536 = 16$
 (17) $\log_2 131072 = 17$
 (18) $\log_2 262144 = 18$
 (19) $\log_2 524288 = 19$
 (20) $\log_2 1048576 = 20$

• The above sequence is a geometric progression with a common ratio of 2. The first term is 1 and the 20th term is 1048576. The sum of the first 20 terms of this sequence is $2^{20} - 1 = 1048575$. The product of the first 20 terms is $2^{20 \times 20} = 2^{400}$.

• The above sequence is also a harmonic progression with a constant difference of 1 in the denominator. The first term is 1 and the 20th term is 1/1048576. The sum of the first 20 terms of this sequence is $\sum_{k=1}^{20} \frac{1}{2^k} = 2 - \frac{1}{2^{19}}$. The product of the first 20 terms of this sequence is $\frac{1}{2^{20 \times 20}} = \frac{1}{2^{400}}$.

Micro-photographs of some of these test specimens are attached. The relation of electrolytic action, thermal conductivity, etc. between the various contact metals on each other when operated in such a circuit can perhaps be better correlated after further tests which are now in progress are completed.

In a general way the results obtained in this self-interrupting circuit are similar to those obtained with the pulsing type relay. That is, a large contact on the negative and a smaller platinum contact on the positive spring result in a combination yielding long life, freedom from excessive sparking and very small wear.

It is to be noted, however, that such tests as the above because of the greater current, increased rapidity of operation and heavier duty cause the deterioration to proceed at a greater rate than in the pulsing relay where the operation through several million pulses requires from three to four weeks continuous operation.

Conclusions:

Metal arcs may produce a crater in either positive or negative electrodes or contacts. The intensity of the spark and the ensuing rise of temperature at the positive contact form a small bead of molten metal which gradually is enlarged into a long point causing a corresponding depression in the negative contact. Such a combination of contacts causes irregular action due to sticking of the contacts and a deviation from the normal adjustment of the springs and air gap.

By the elimination of relay chattering, the sparking is materially reduced, and in particular its effect since during

The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes the need for transparency and accountability in financial reporting. The second part outlines the various methods used to collect and analyze data, including surveys, interviews, and focus groups. The third part presents the findings of the study, highlighting key trends and insights. The final part concludes with recommendations for future research and practical applications of the findings.

chattering the current is interrupted at a high rate which does not allow the contacts to cool between interruptions. Chattering in a relay may be prevented by the adaptation of a suitable damper spring. The use of a large negative contact further increases the life of the contact combination.

The best combination on the pulsing relay within the scope of contact metals tested consists of a 318 ga. platinum positive contact, either riveted or welded on the armature spring, operating with a 314 ga. silver negative contact riveted on the back spring. In addition the relay is equipped with a suitably tensioned damper spring.

P. G. ANDRIS
Research Engineer

April 5, 1924.

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T A B L E 4

Sheet 1.

PERMIAN #18 G.L. WILSON

POSITIVE

+	-	-	#Imp-	+ Contact	- Contact Con-
No.	No.		ulses	Condition	dition
52	51	#14 A.L.	4027500	Irregular Cone	Lost
75	76	#18 A.L.	3166200	+ Came off	Test being repeated
54	53	#14 A.L.	5296275	Smooth Convex	Smooth Shallow Crater
73	74	#18 A.L.	3582950	Small Even Cone	Small Even Crater
60	59	#18 ft.	2616125	Smooth Convex	Smooth Shallow Crater
62	61	#18 ft.	2444525	Smooth Small Cone	Shallow Irregular Crater
71	72	#18 ft.	3304825	Smooth Small Cone	Small Even Crater

PERMIAN #18 G.L. WILSON

NEGATIVE

-	+	+	#Imp-	- Contact	+ Contact Con-
No.	No.		ulse	Condition	dition
59	60	#18 ft.	2616125	Smooth Shallow Crater	Smooth Convex
61	62	#18 ft.	2444525	Shallow Irregular Crater	Smooth Small Cone
72	71	#18 ft.	3304825	Small Even Crater	Smooth Small Cone
84	83	#18 W.E.	3605175	Smooth Crater	Smooth Even Small Cone
66	65	#14 A.E.	3508175	Long Smooth Frong	Very Deep Crater
78	77	#18 A.E.	3861000	Deep Smooth Crater	Long Pointed Cone

CONTENTS

Introduction	1
Chapter I. The History of the English Language	1
Chapter II. The English Language in the Middle Ages	1
Chapter III. The English Language in the Sixteenth Century	1
Chapter IV. The English Language in the Seventeenth Century	1
Chapter V. The English Language in the Eighteenth Century	1
Chapter VI. The English Language in the Nineteenth Century	1
Chapter VII. The English Language in the Twentieth Century	1
Appendix A. The English Language in the Middle Ages	1
Appendix B. The English Language in the Sixteenth Century	1
Appendix C. The English Language in the Seventeenth Century	1
Appendix D. The English Language in the Eighteenth Century	1
Appendix E. The English Language in the Nineteenth Century	1
Appendix F. The English Language in the Twentieth Century	1
Index	1

T A B L E 4

Sheet 2

SILVER CONTACT METAL #18 WELDED

POSITIVE

+ No.	- No.	-	#Imp- ulses	+ Contact Condition	- Contact Condition
77	78	#18 Pt.	3861000	Long Pointed Cone	Deep, Smooth Crater
79	80	#18 A.E.	3667250	Deep Crater "V" Shaped	Wedge Shaped Point
81	82	#18 W.E.	3757225	Deep Round Crater	Large Round Cone
*56	55	#14 A.E.	2362125	Rough Shallow Crater	Small Irregular Cone
*64	63	#14 A.E.	669900	Small Rough Crater	Small Irregular Cone
*65	66	#18 Pt.	3508175	Very Deep Crater	Long, Smooth Prong
*69	70	#14 W.E.	3362525	Very Deep Crater	Lost

SILVER CONTACT METAL WELDED #18 GA.

NEGATIVE

- No.	+ No.	+	#Imp- ulses	- Contact Condition	+ Contact Condition
74	73	#18 Pt.	3582950	Small Even Crater	Small Even Cone
86	85	#18 W.E.	3725475	Smooth-Flat, Edges Black	Smooth Flat Edges Blackened
80	79	#18 A.E.	3667250	Wedge Shaped Point	Deep V Shaped Crater
*53	54	#18 Pt.	5296275	Smooth Shallow Crater	Smooth Convex
*68	67	#14 W.E.	3414375	Flat Rough, Edges Black	Flat Rough Granular
*55	56	#14 A.E.	2362125	Small Irreg- ular Cone	Rough Shallow Crater
*63	64	#14 A.E.	669900	Small Irreg- ular Cone	Small Rough Crater

*Indicates #14 Gauge Silver Contact Riveted

Table 1 (continued)

Table 1 (continued)

Table 1 (continued) *Estimated regression coefficients*

Dependent variable	Control variables	Control variables	Control variables	Control variables
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000

• *Standard errors are in parentheses below the coefficients*

Table 2

Dependent variable	Control variables	Control variables	Control variables	Control variables
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000
Number of children	0.000	0.000	0.000	0.000

T A B L E #4

Sheet 3

GOLD CONTACT METAL #18 WELDED

POSITIVE

+ No.	- No.	-	#Imp-ulses	+ Contact Condition	- Contact Con- dition
83	84	#18 Pt.	3605175	Smooth Even Small Cone	Smooth Crater
85	86	#18 A.E.	3725475	Smooth - Flat Edge Blackened	Smooth - Flat Edge Blackened
87	88	#14 W.E.	3757225	Rough-Wedged Shaped Edges Blackened	Rough V shaped Crater. Edges Blackened
*58	57	#14 W.E.	4466850	Nearly Flat Slightly Con- vex	Very Shallow Crater, Nearly Flat
*67	68	#14 A.E.	3414375	Flat-Rough- Granular	Flat-Rough Edges blackened

GOLD CONTACT METAL #18 GA. WELDED

NEGATIVE

- No.	+ No.	+	#Imp-ulses	- Contact Condition	+ Contact Condition
76	75	#18 Pt.	3166200	+ Came off.	Now trying again
82	81	#18 A.E.	3757225	Large Round Cone	Deep Round Crater
*51	52	#18 Pt.	4087500	Lost	Irregular Cone
*57	58	#14 W.E.	4466850	Shallow Crater Nearly Flat	Slightly Con- vex, Nearly Flat
*88	87	#18 W.E.	3757225	Rough "V" shaped Crater Black edges	Rough Wedge shaped, Edge Blackened
*70	69	#14 A.E.	3362525	Lost	Very deep crater

*Indicates #14 Gauge Gold Contact Riveted

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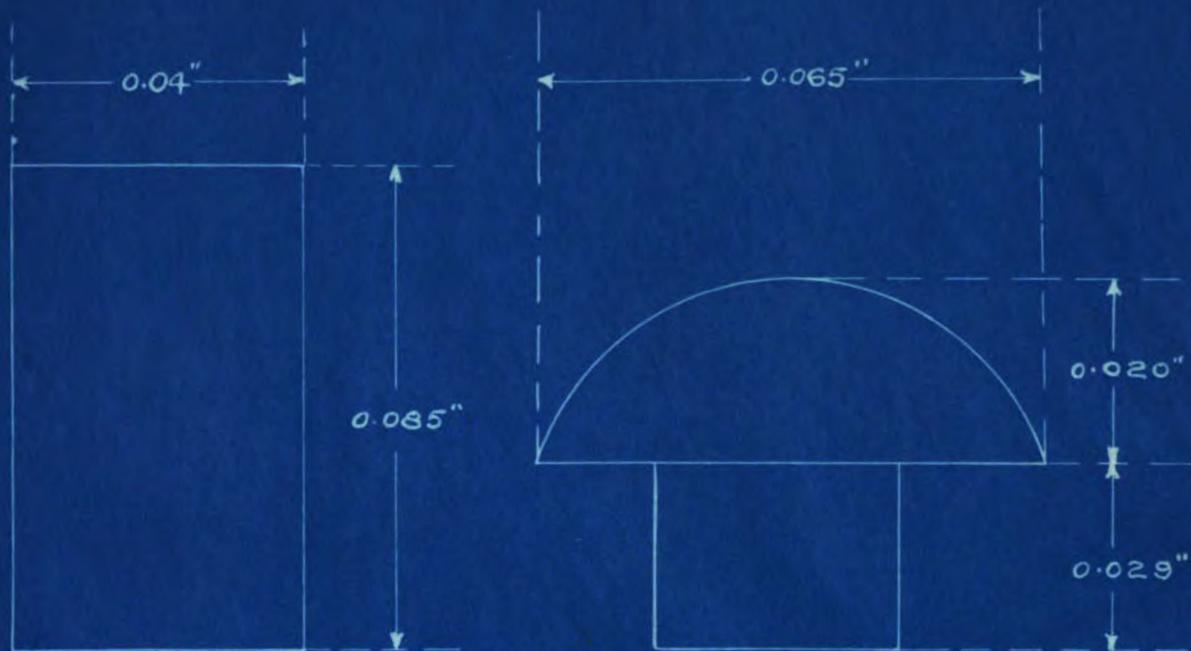
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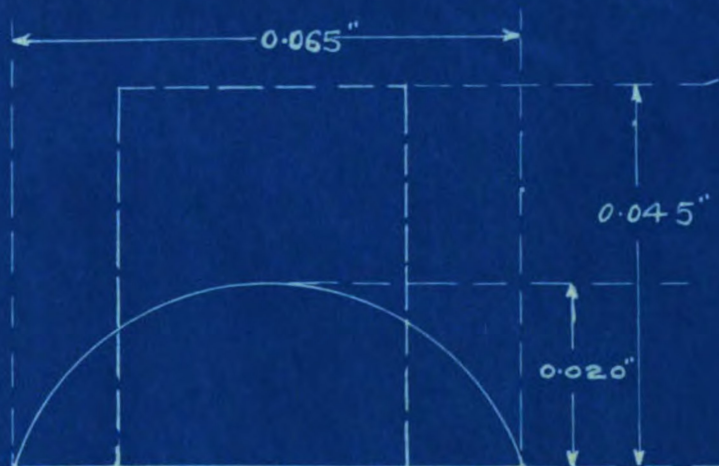
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BLANK FOR RIVETED CONTACTS.

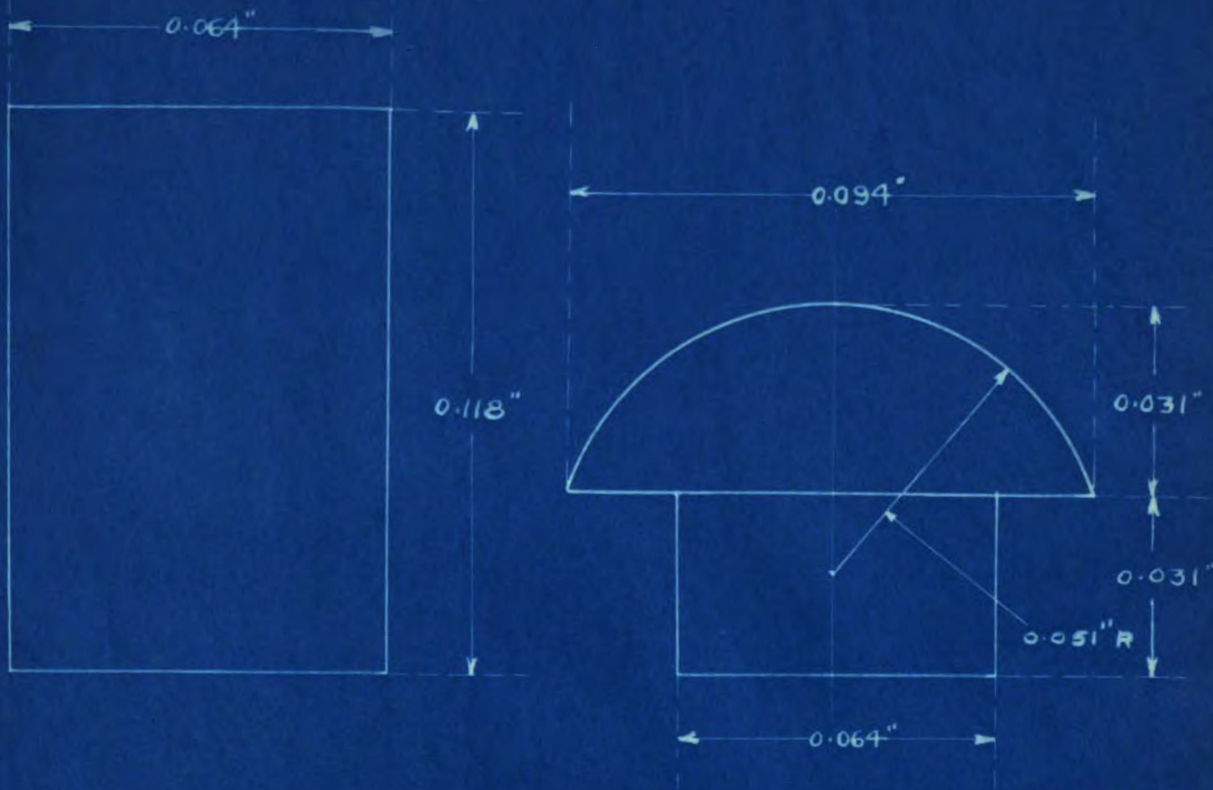


BLANK FOR WELDED CONTACTS.

FIG. 1

NO. 18 B+S GAUGE CONTACTS.

APPROVED *Alfred*



BLANK FOR RIVETED CONTACTS.

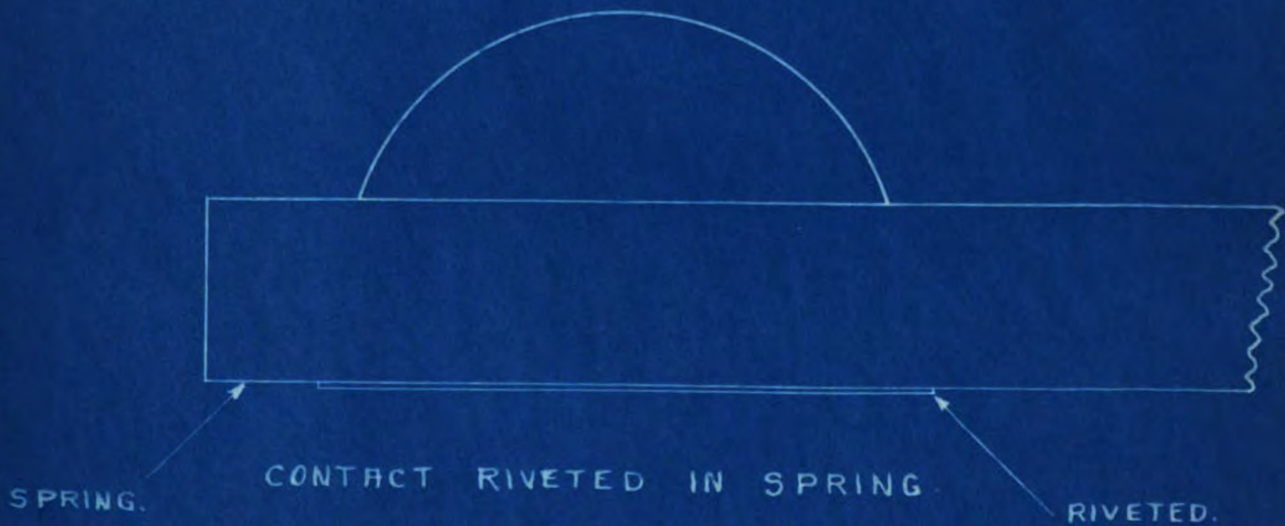
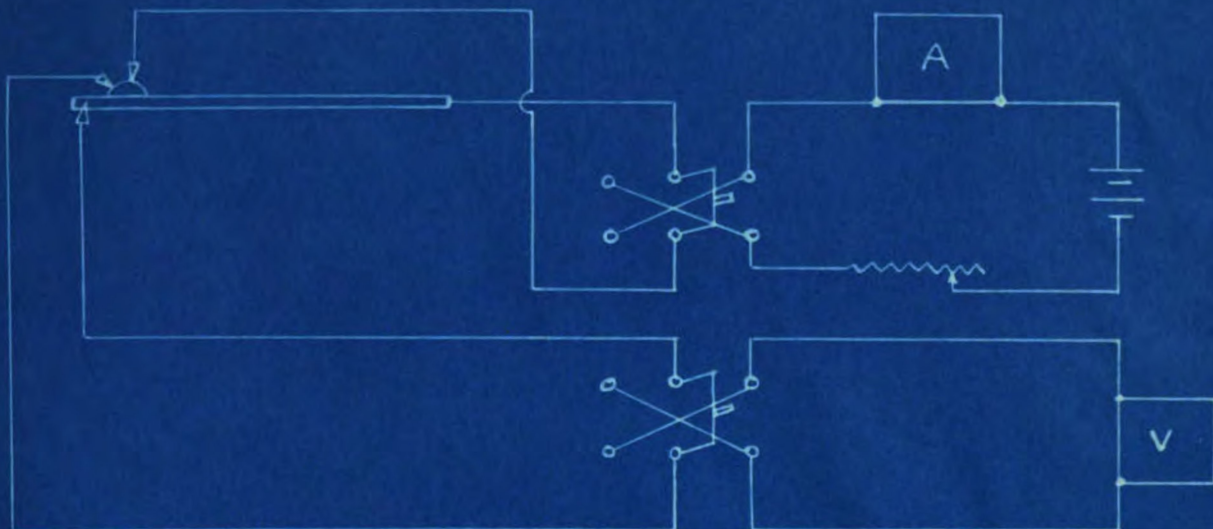


FIG. 2

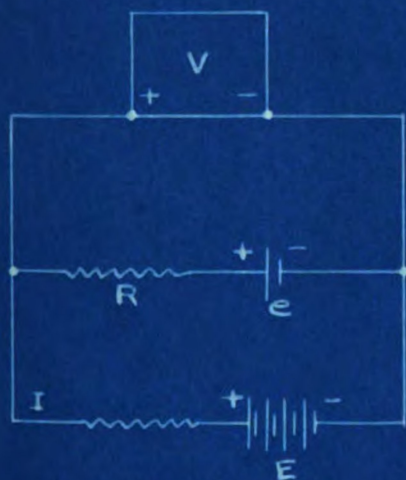
NO. 14 B+S GAUGE CONTACTS.

JUNCTION RES. BETWEEN CONTACT + SPRING.



A = 0-6 AMPS.

V = 0 TO 0.0025 VOLTS RES. = 100 ω

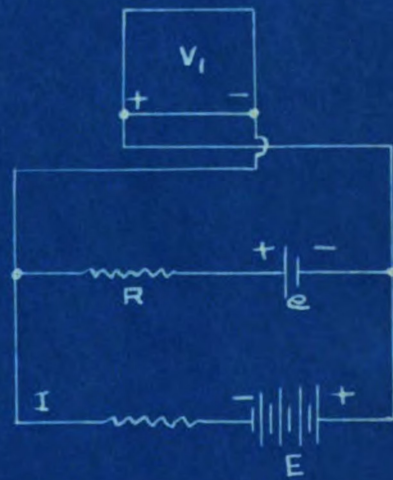


$$V = IR + e$$

$$V_1 = IR - e$$

$$V + V_1 = 2(IR)$$

$$\frac{V + V_1}{2} = IR$$

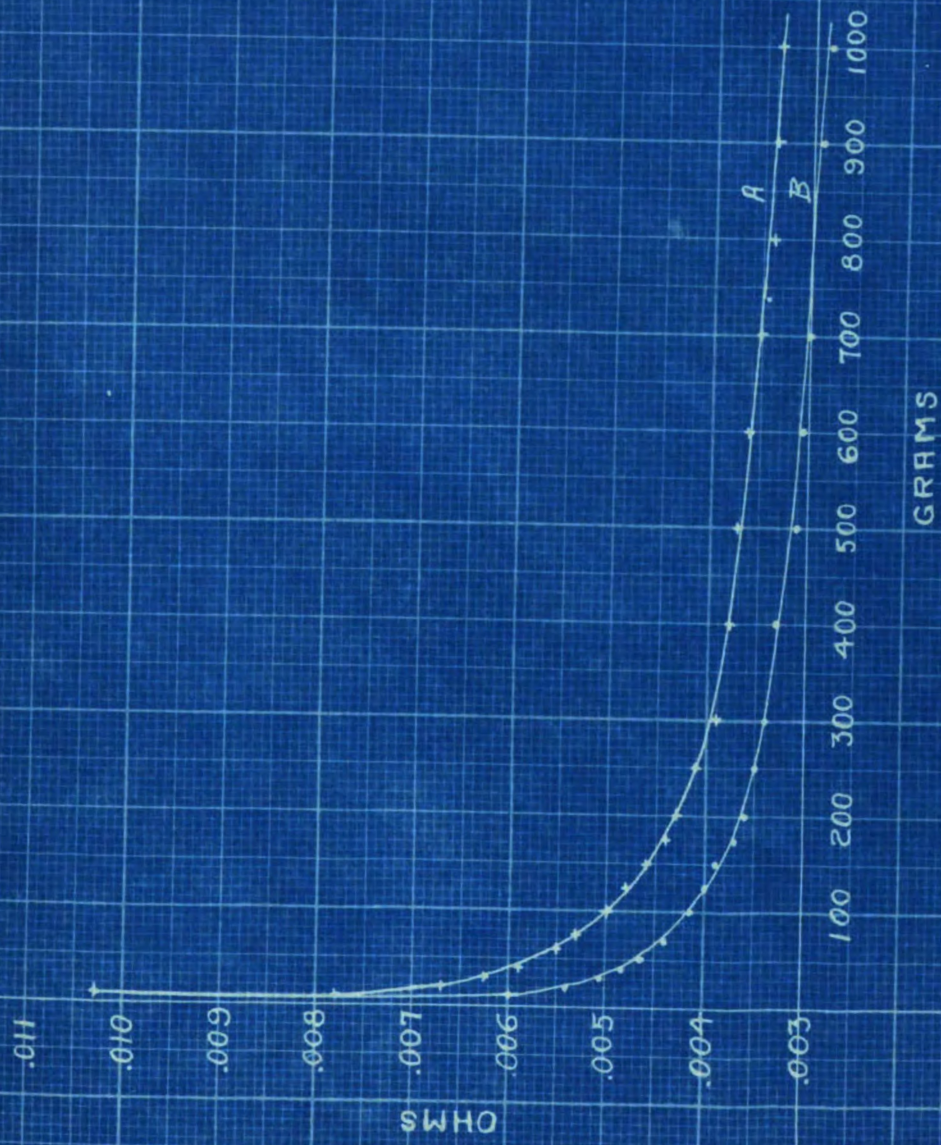


$$V_1 = IR - e$$

FIG. 3

e = THERMAL E.M.F.

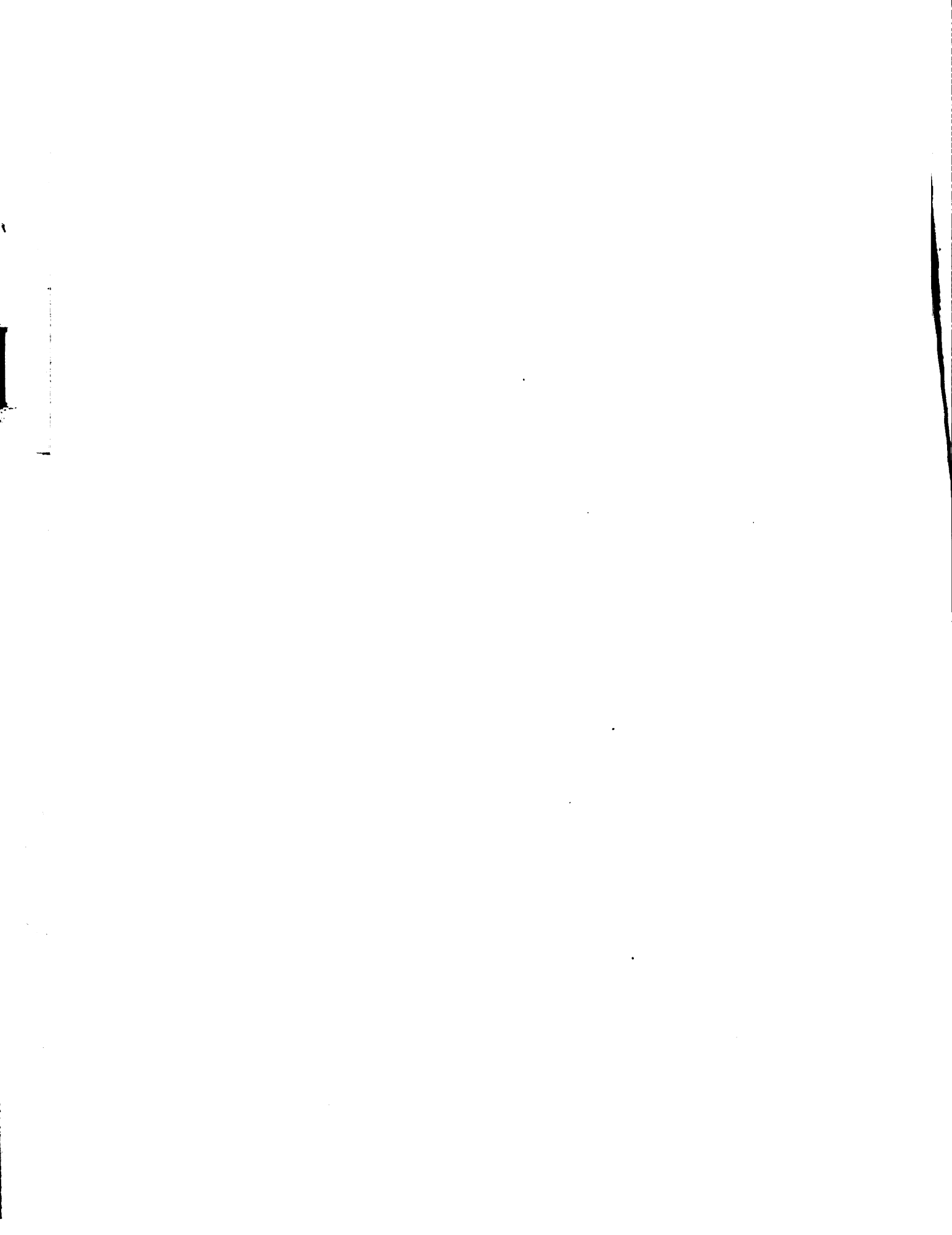
APPROVED *Mudra*

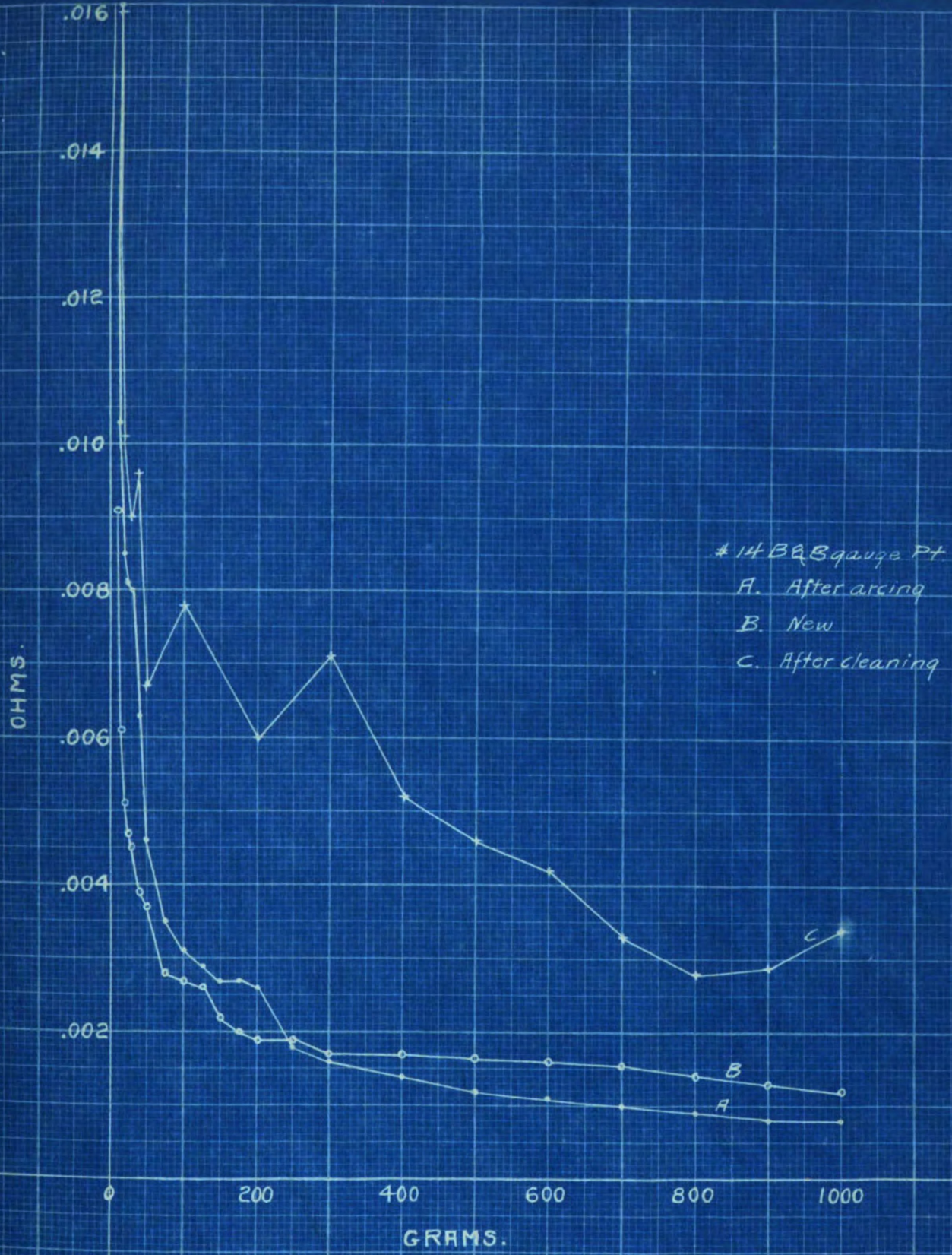


A #18 B&S Ga. Gold.
 B #18 B&S Ga. Platinum.

Variation of Resistance with
 Pressure between Two Contacts.

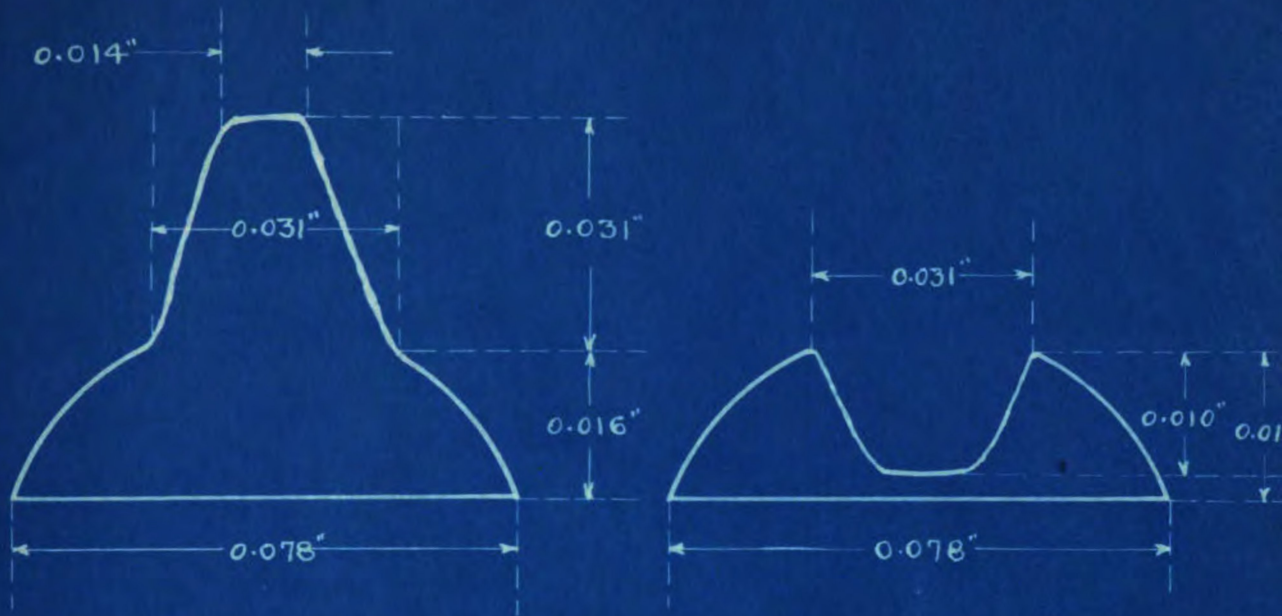
Contact and Contact Endurance.
 Fig. 4.





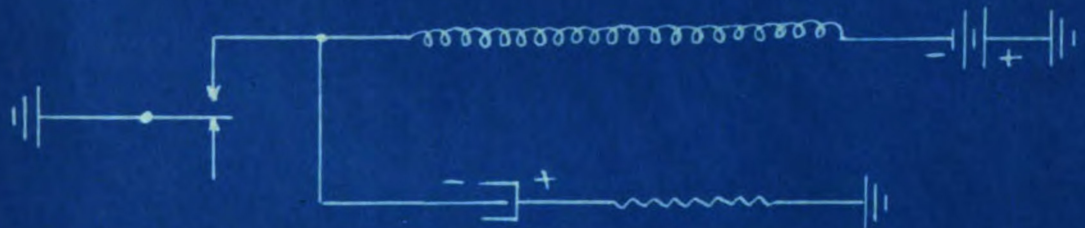
Contact Resistance vs Pressure

Contacts and Contact Endurance
Fig. 5.



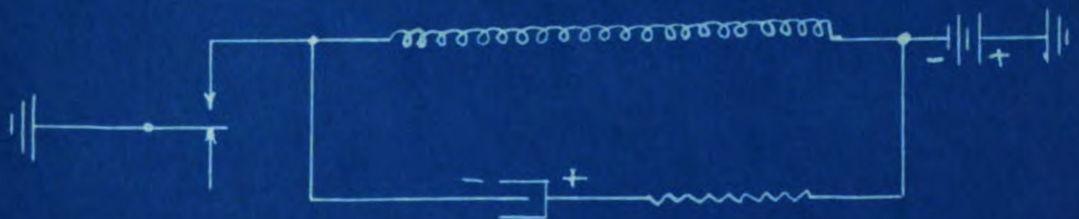
APPROX. SIZE OF NEGATIVE CRATER + POSITIVE POINT.

FIG. 6



SPARK QUENCHER ACROSS CONTACTS.

FIG. 8

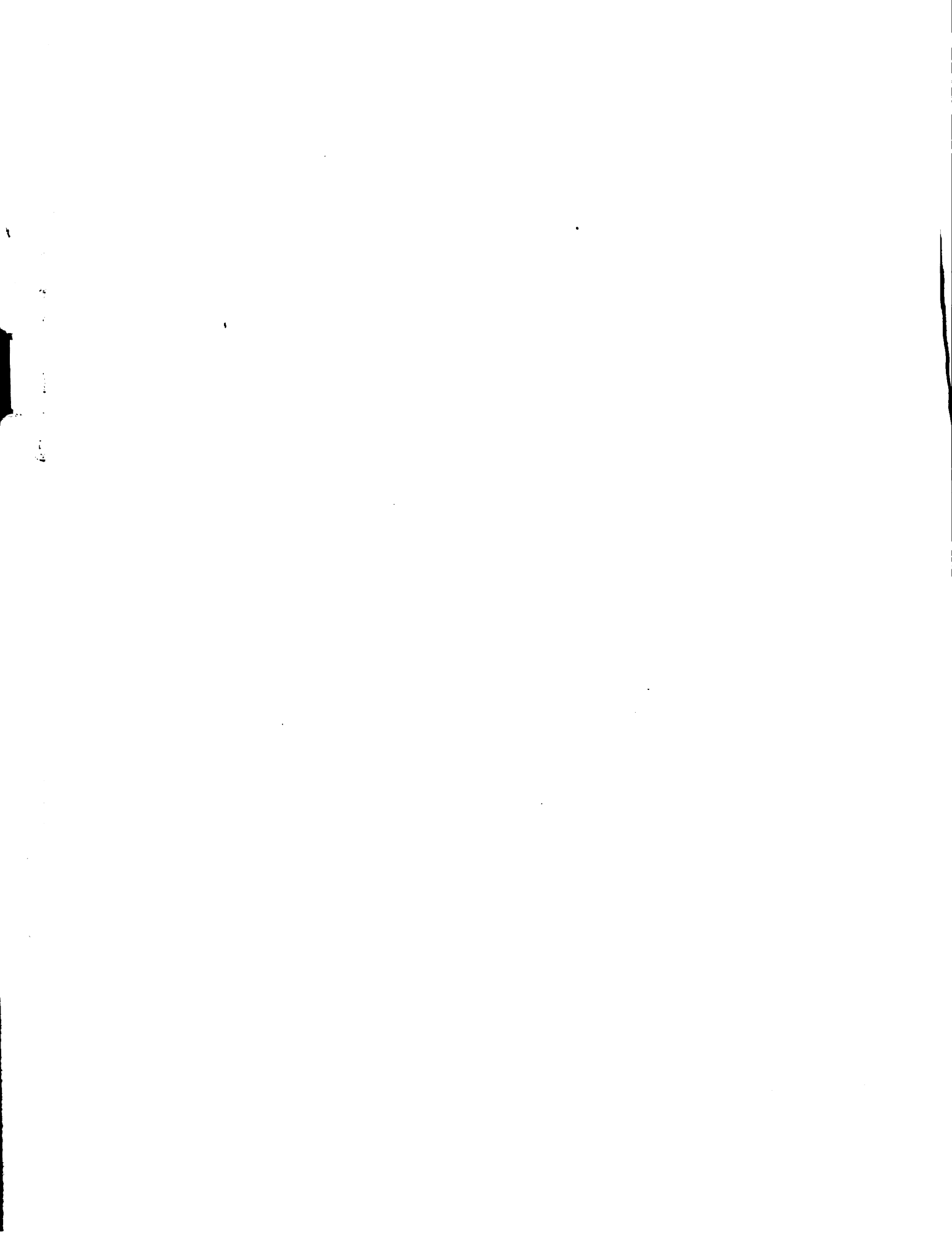


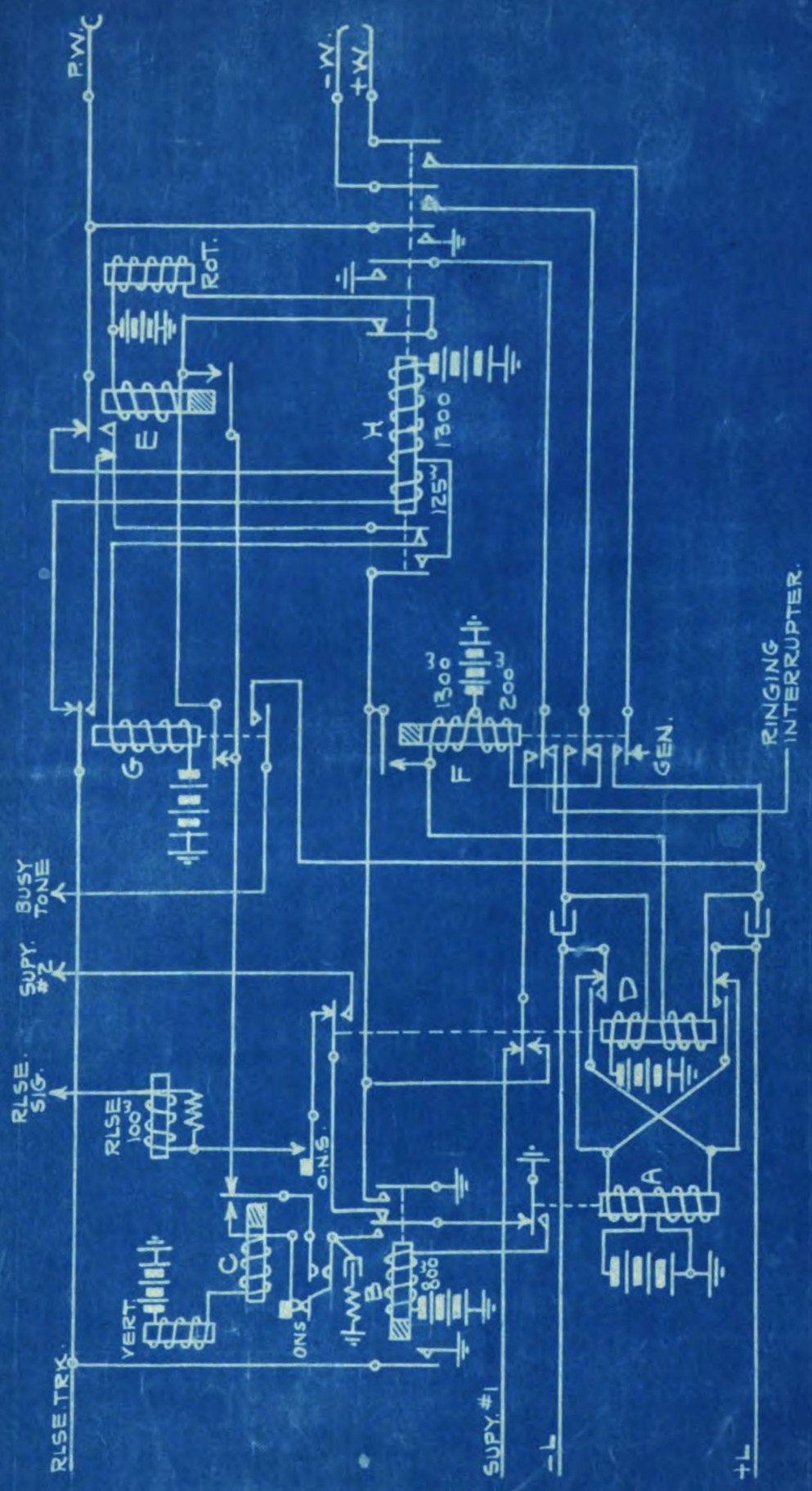
SPARK QUENCHER ACROSS COILS.

FIG. 9

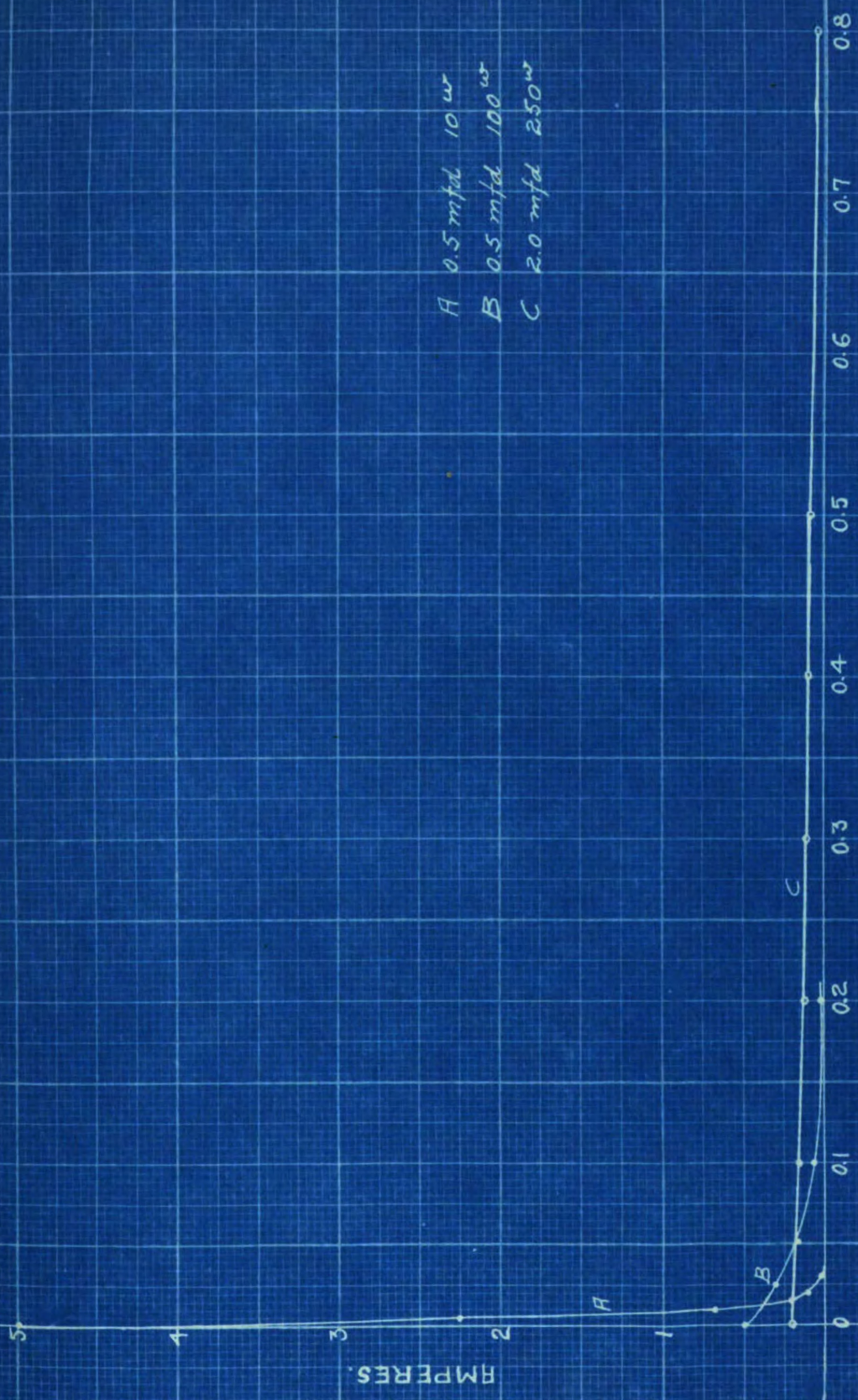
APPROVED

Dynamis



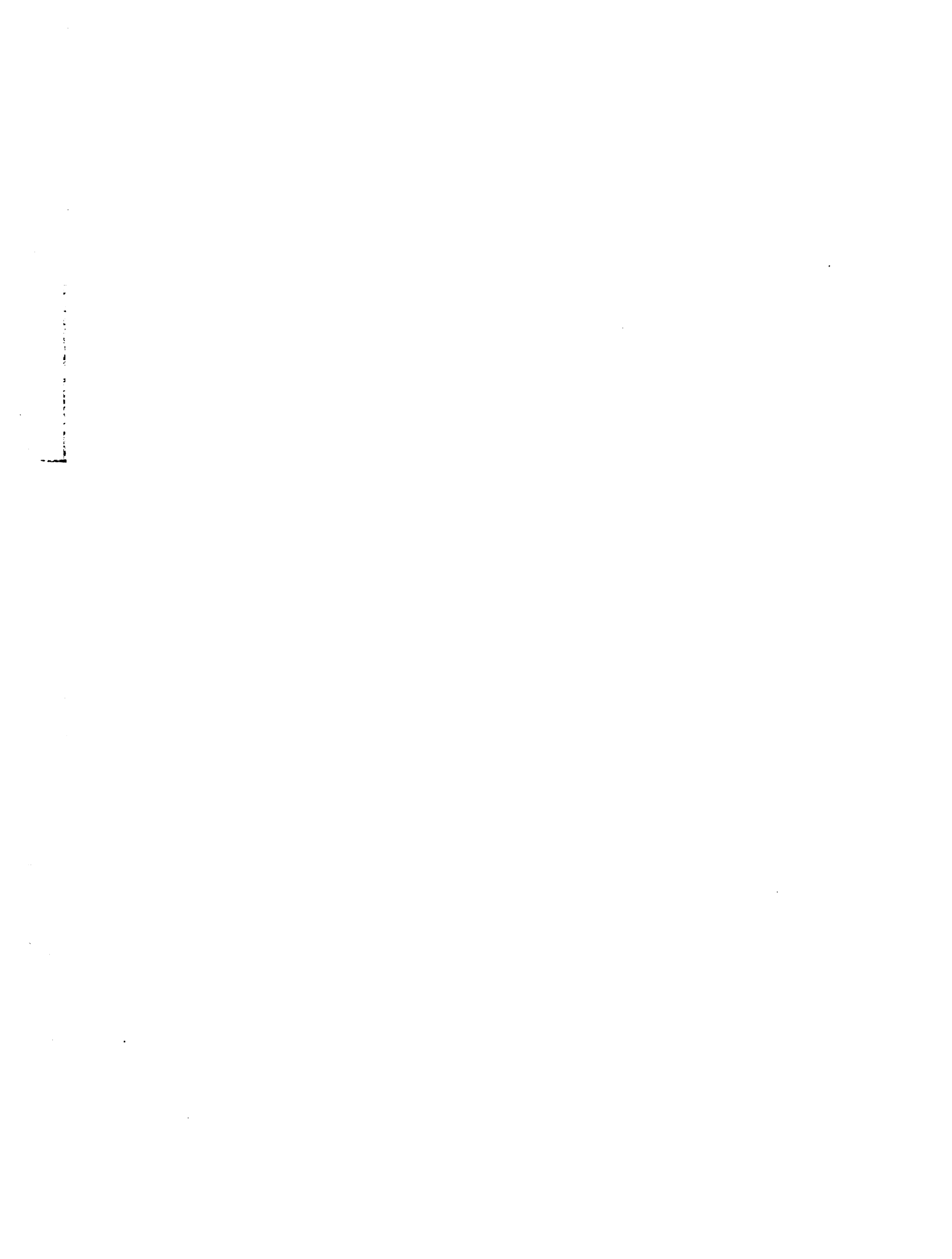


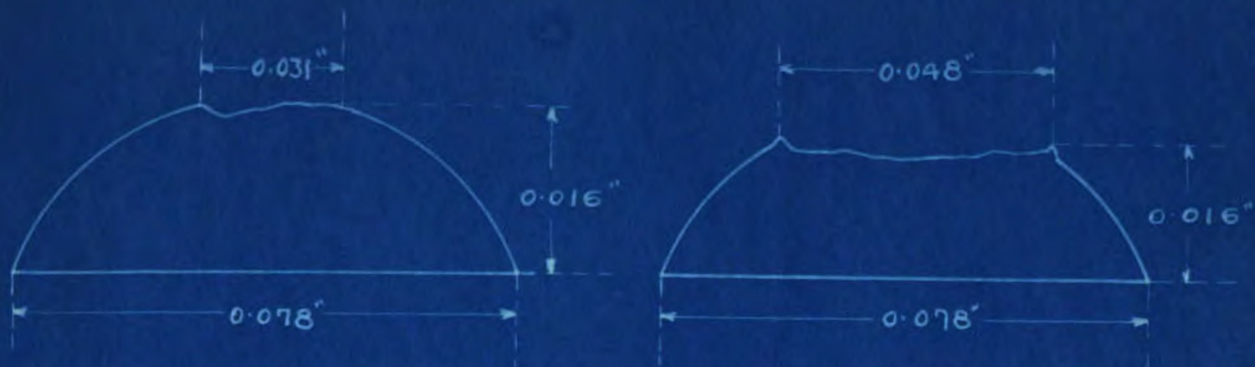
Contacts and Contact Endurance.
Fig 7.



Current Time Decay.
Spark Quencher.

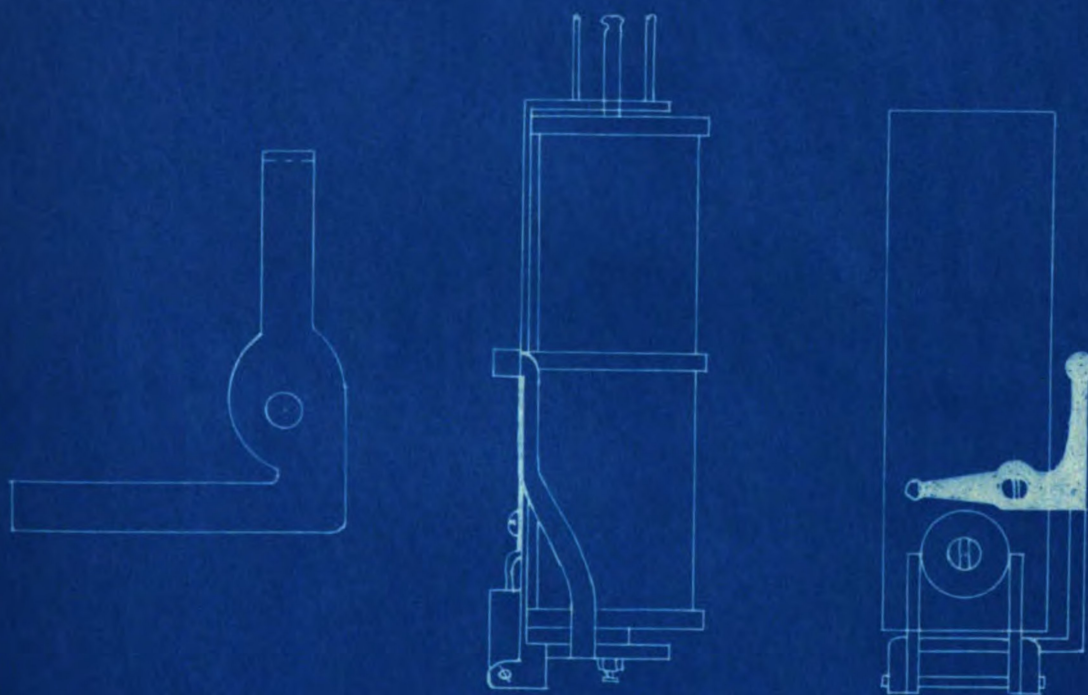
Contacts and Contact Endurance.
Fig. 10





APPROX. SIZE OF NEG. & POS. CONTACTS AFTER USE WITH DAMPER SPRING

FIG. 14.



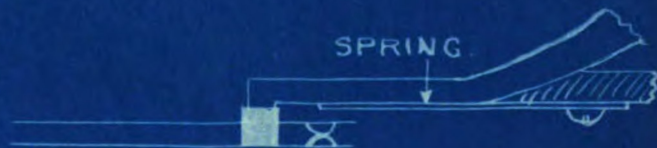
ADAPTATION OF DAMPER SPRING TO RELAY.

FIG. 13.



DAMPER SPRING AGAINST SPRING.

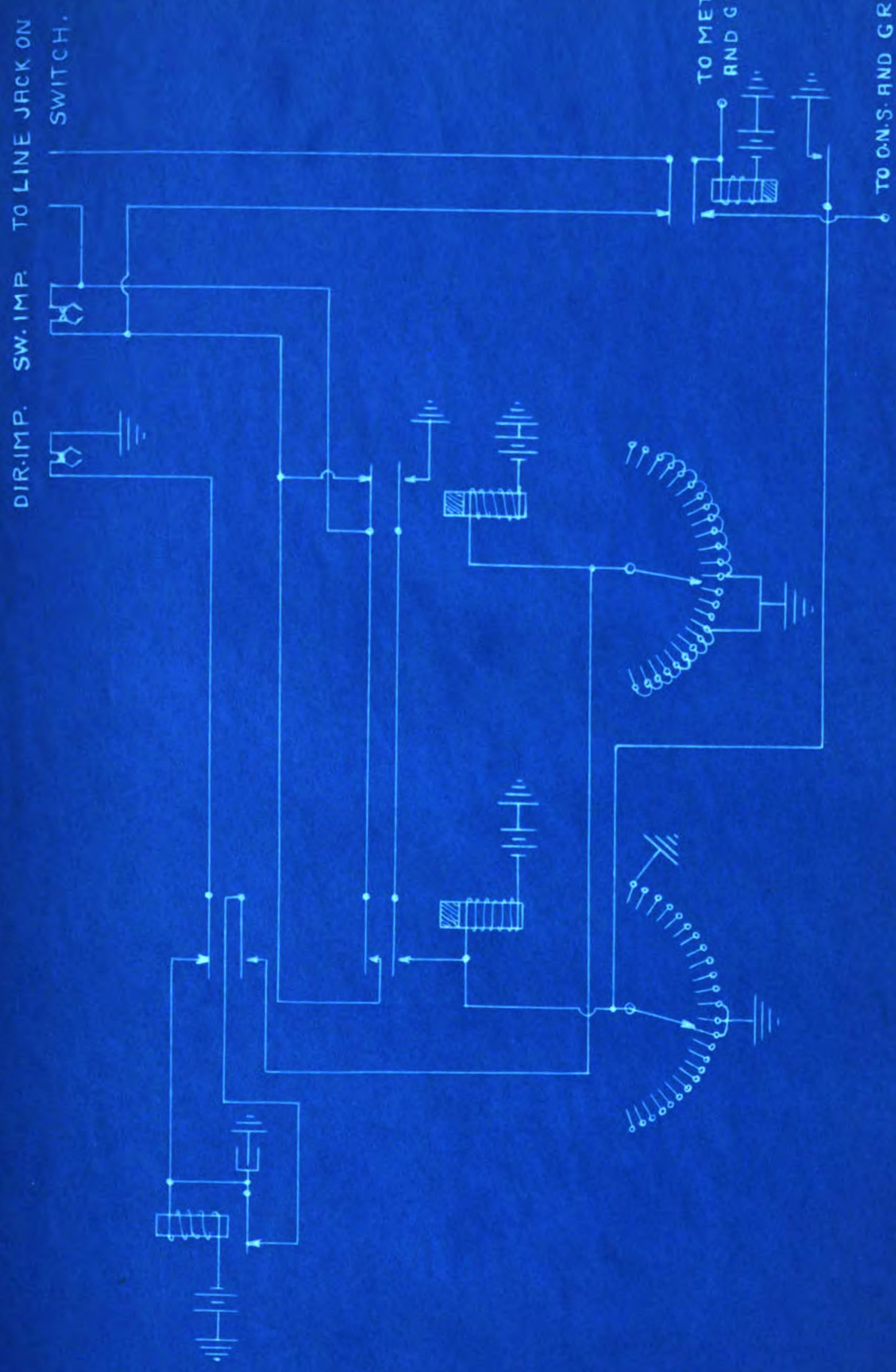
FIG. 11



DAMPER SPRING AGAINST ARMATURE ARM.

FIG. 12.

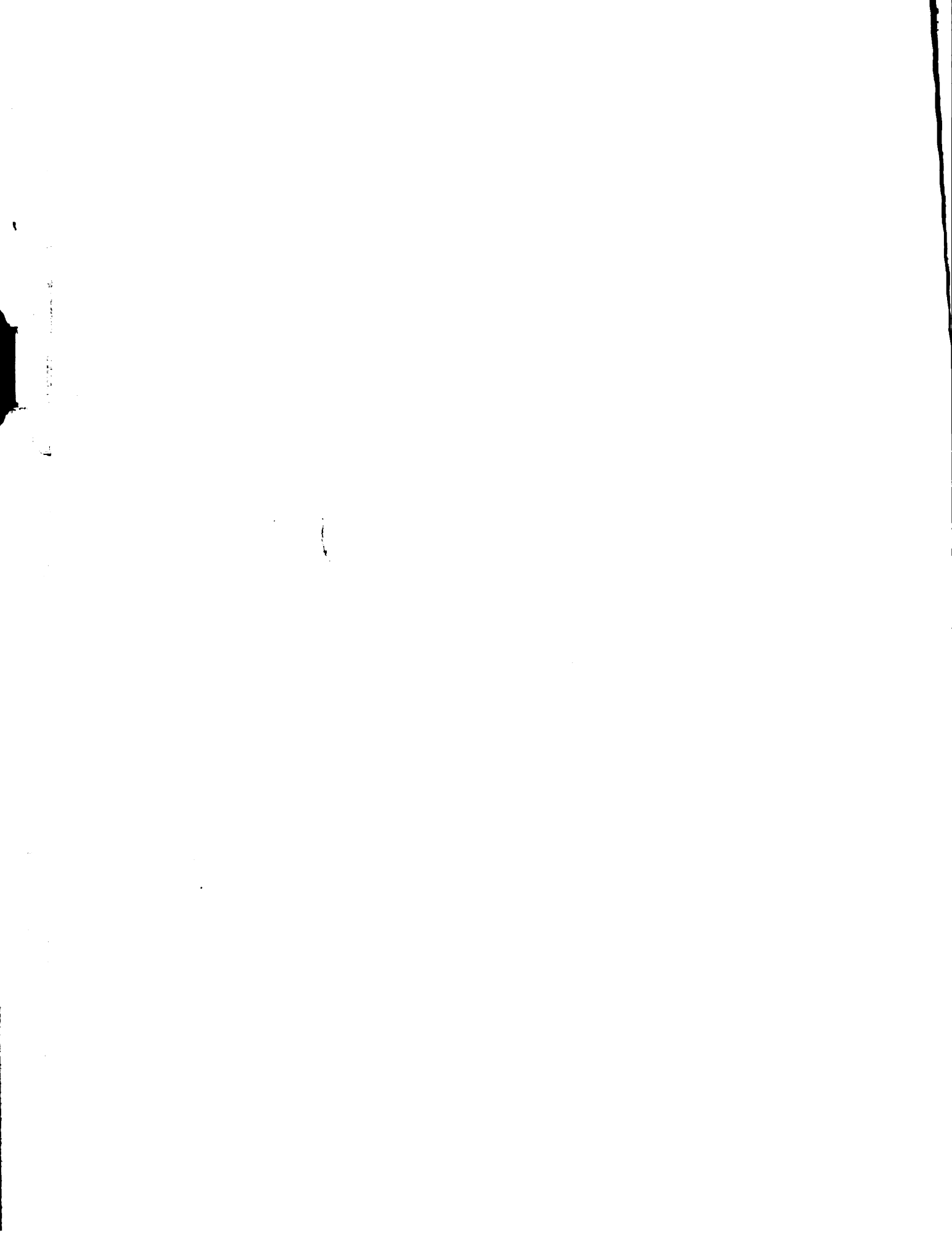
APPROVED *Spencer*



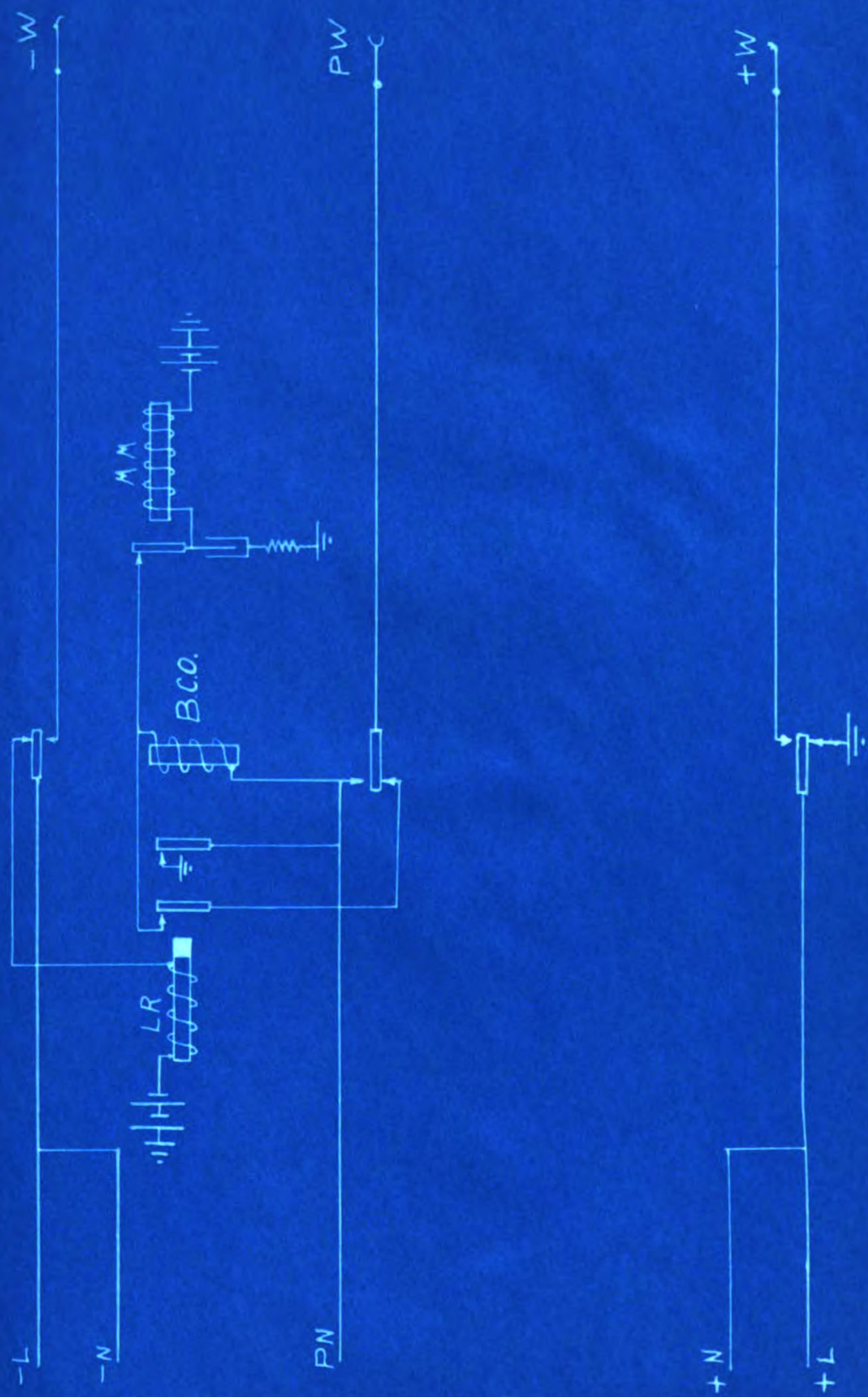
IMPULSE SENDER FOR CONTACT LIFE TEST.

Fig 15.

GH



APPROVED



SIMPLIFIED ROTARY LINESWITCH
CIRCUIT DIAGRAM.
Fig 16.

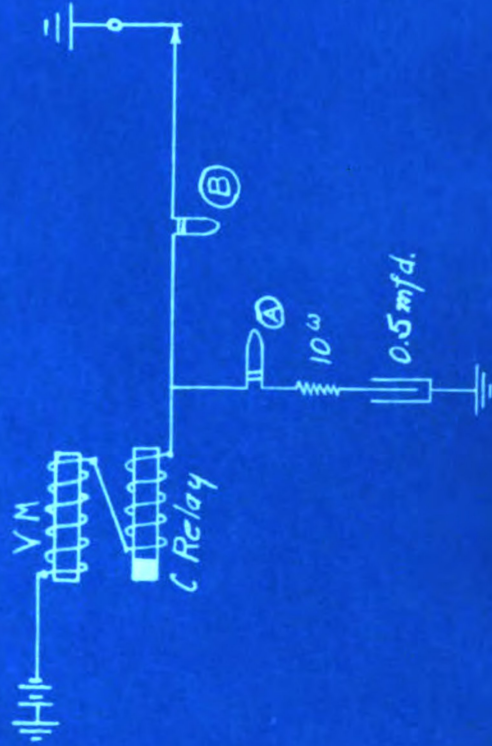
BPH

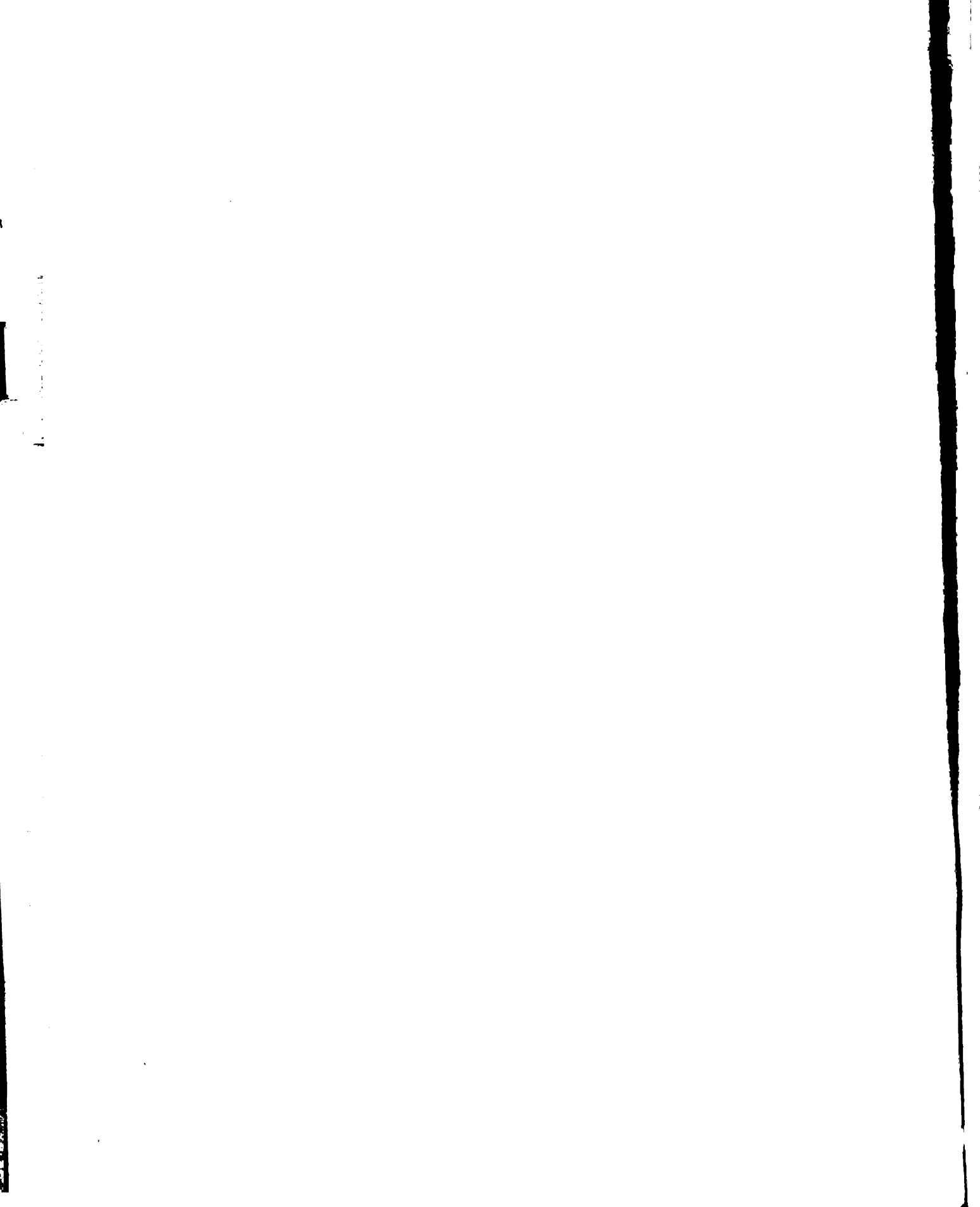
Current in Spark
Quencher Circuit.

Current in
C Relay and VM

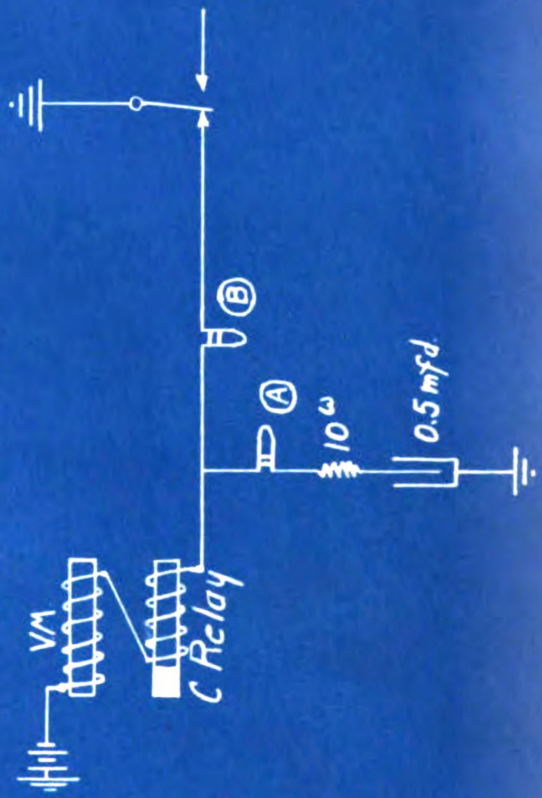
0-52

100 μ



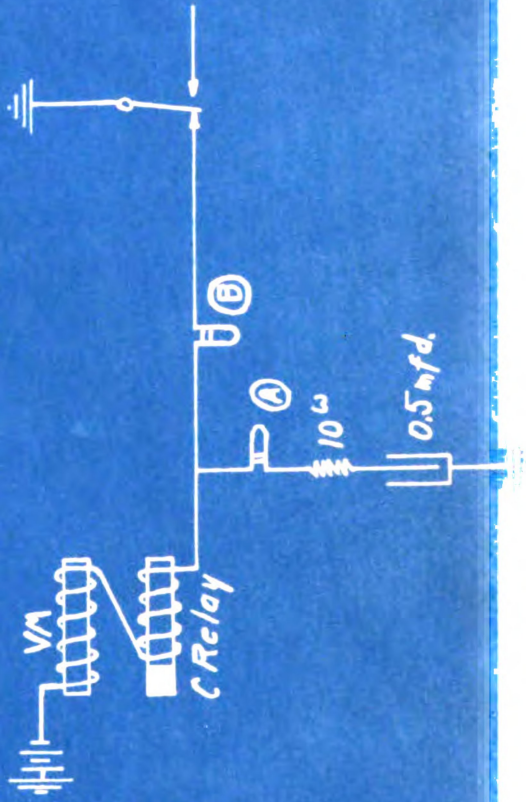


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Experiment 10 - Transient
Response of an RC Circuit

Objective:
To study the transient response of an RC circuit.

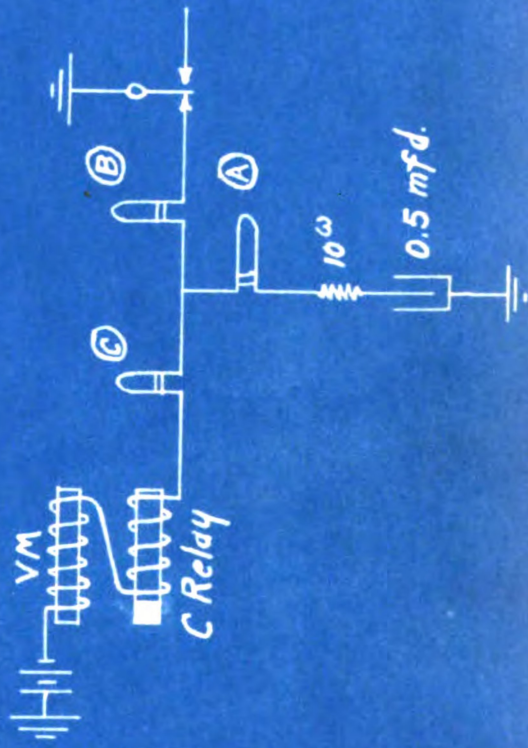


Problem 10.9

Example 10.10

Example 10.11

10.12



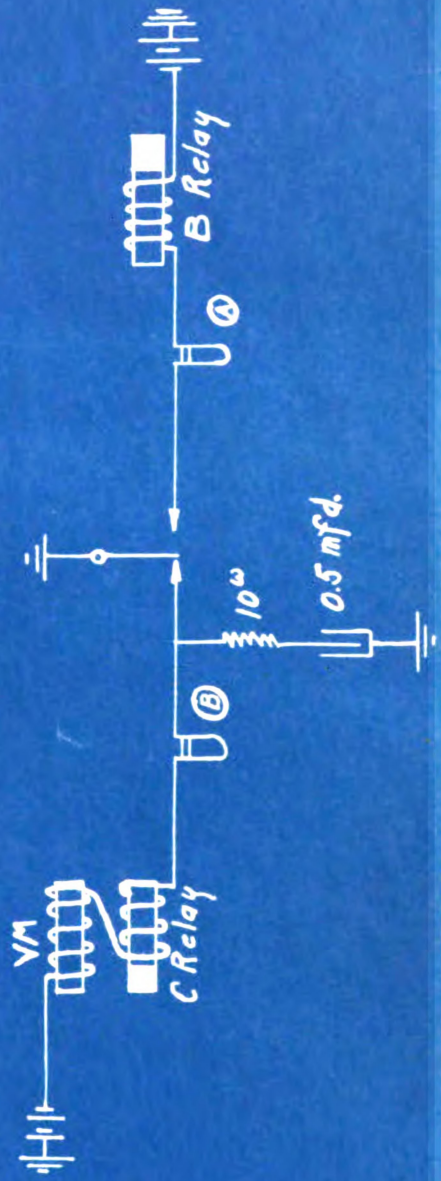
Q.10

Diagram

Diagram

Diagram

Diagram

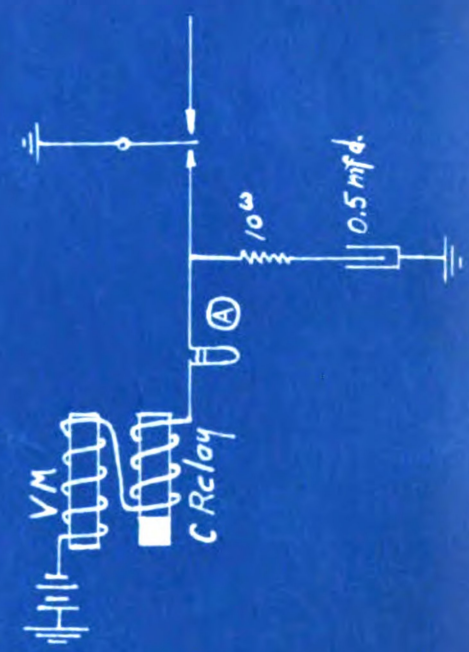


1000

(1000)

[Faint handwritten notes]

[Faint handwritten notes]



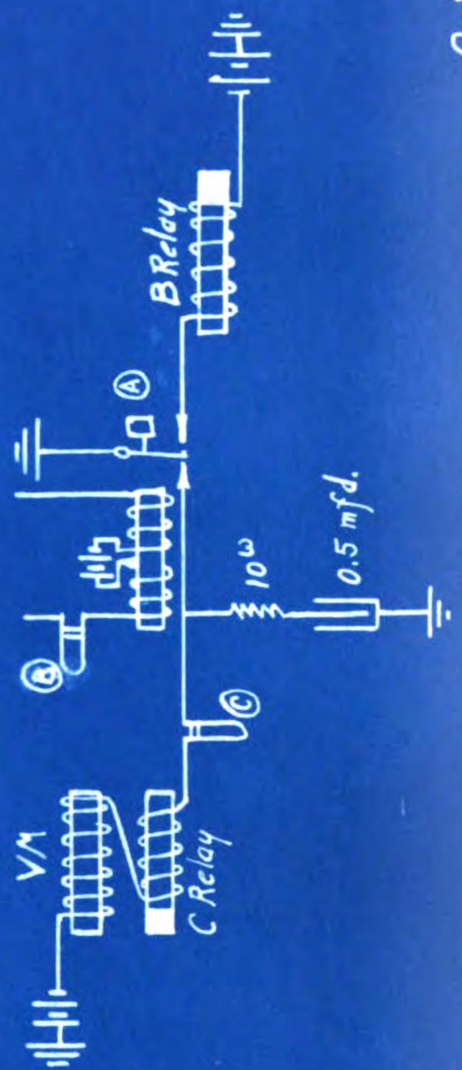
100

1. The relay is a device which is used to control a circuit by a low power signal.

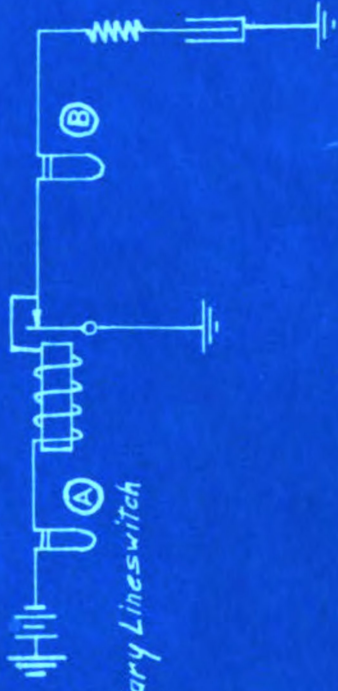
2. It is used to control a high power circuit by a low power signal.

3. It is used to control a high power circuit by a low power signal.

4. It is used to control a high power circuit by a low power signal.



A
B
C





SIMILAR TO NO. 174 EXCEPT 3 SWITCHES
IN PARALLEL

0-175

0-176

A

B

C

SIMILAR TO NO. 174 EXCEPT 4 SWITCHES
IN PARALLEL.

0-176

R

B

C

0-177

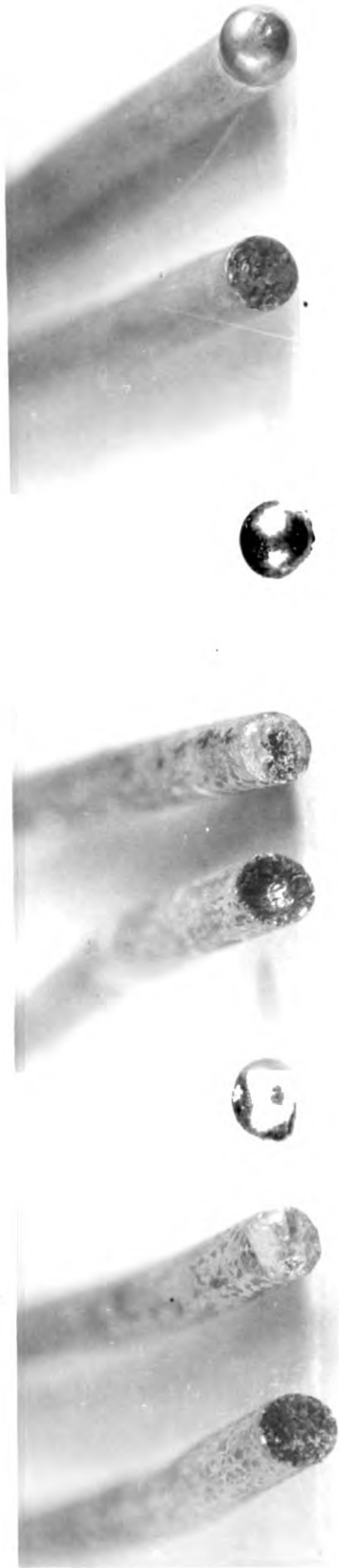


SIMILAR TO NO. 174 EXCEPT 6 SWITCHES
IN PARALLEL.

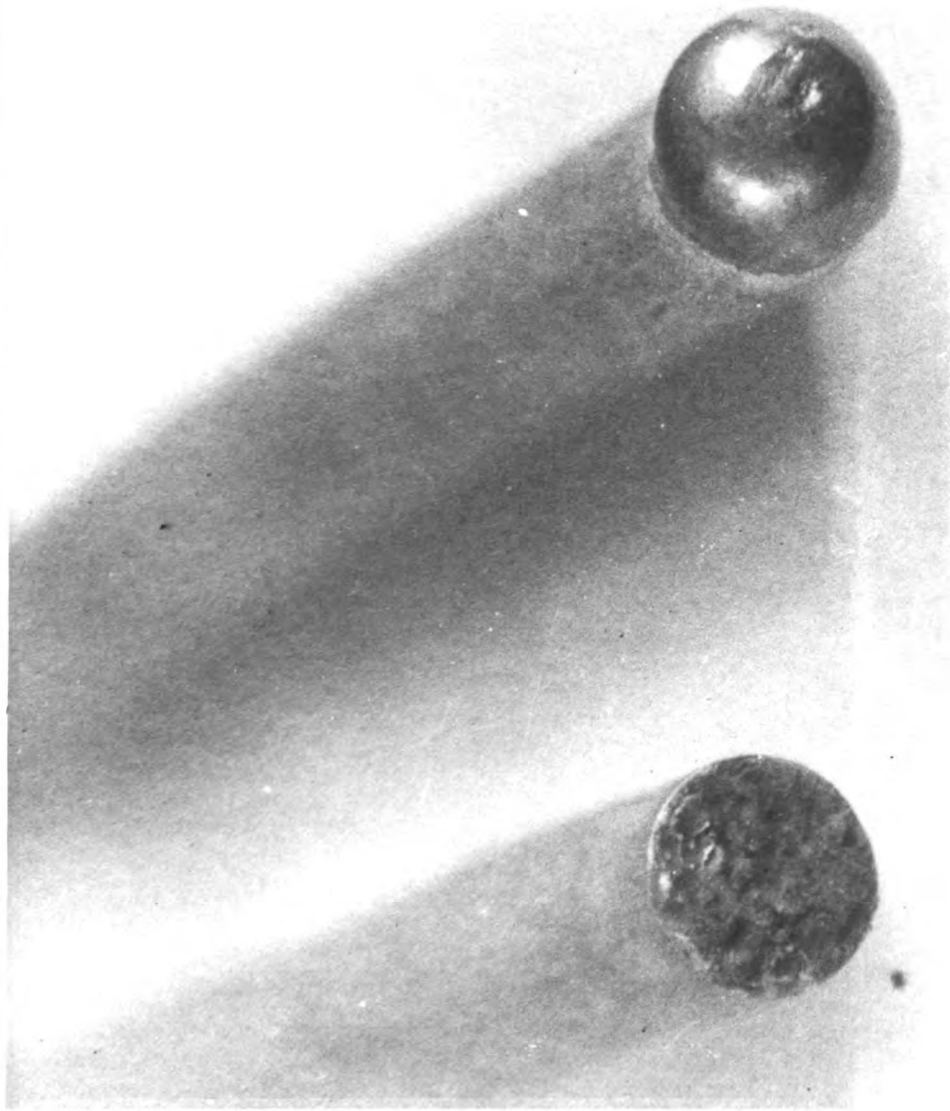
0-177



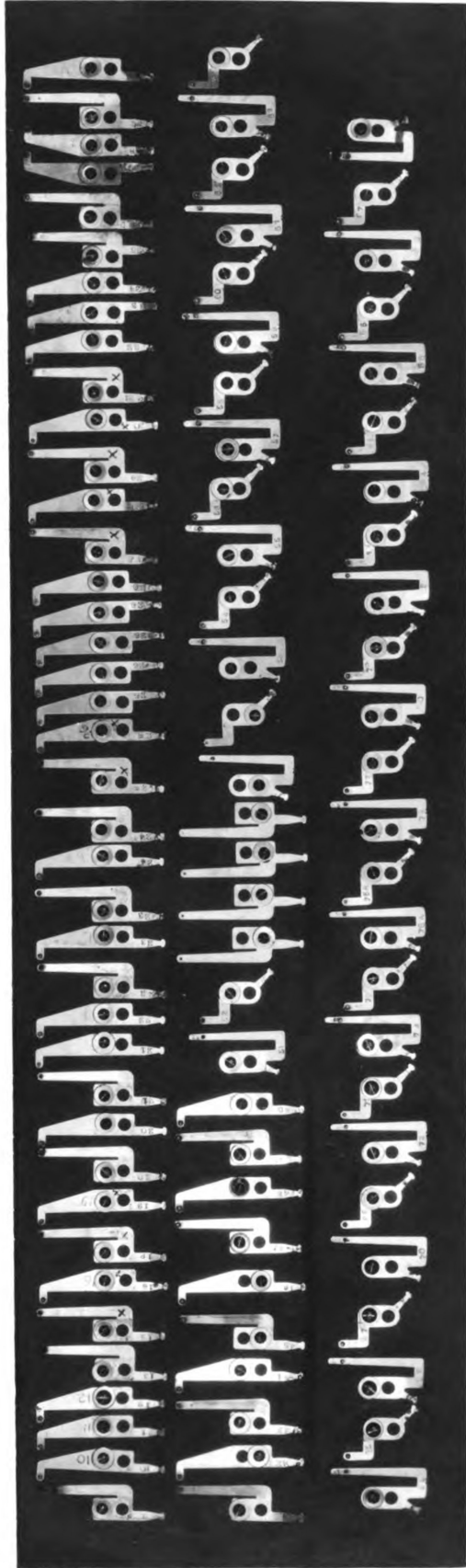
METALLIC AND CARBON ELECTRODES.



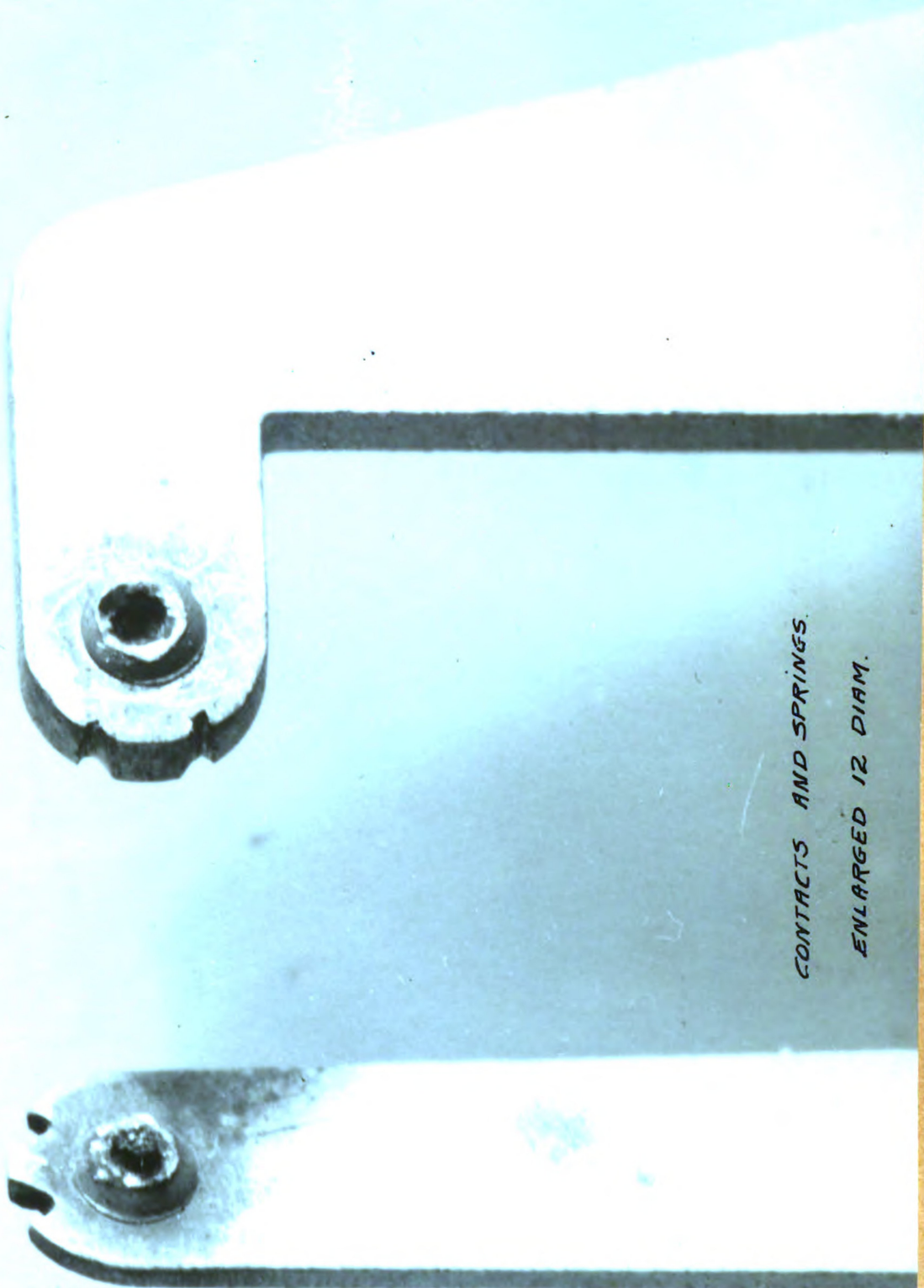
METAL ELECTRODES, - CRATER + BEADS.



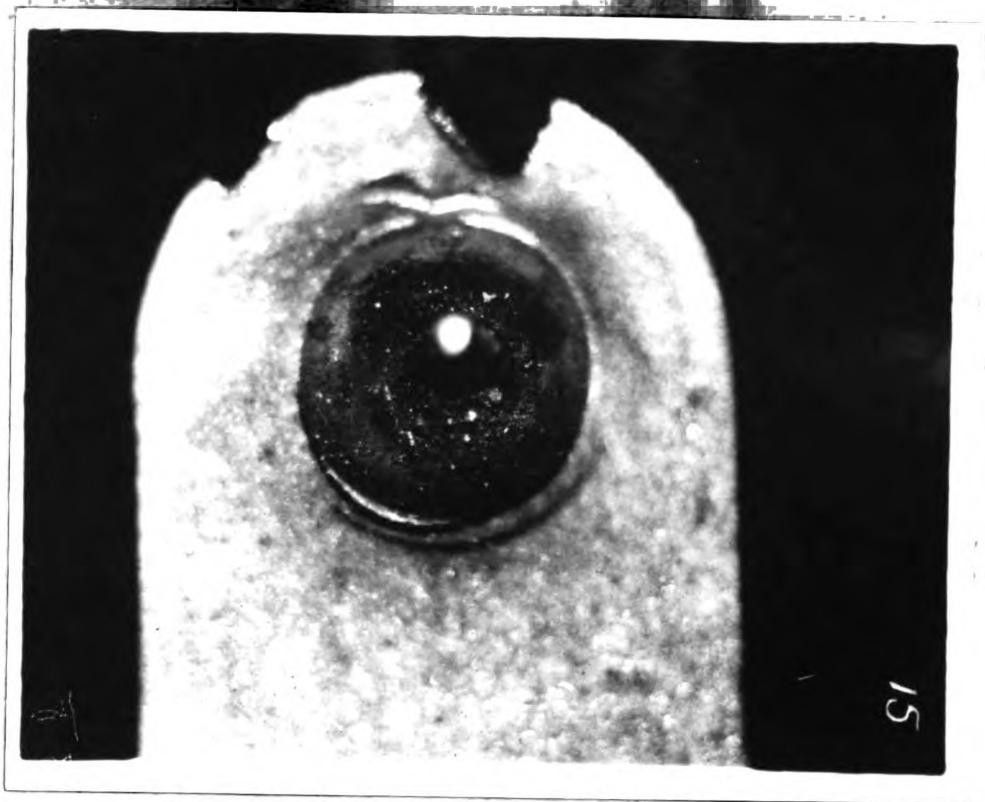
ENLARGED NEG. CRATER. POS. BEAD.



CONTACTS AND CONTACT SPRINGS.



CONTACTS AND SPRINGS.
ENLARGED 12 DIAM.



C15. Pt. #189a. 15000 impulses. Pos.

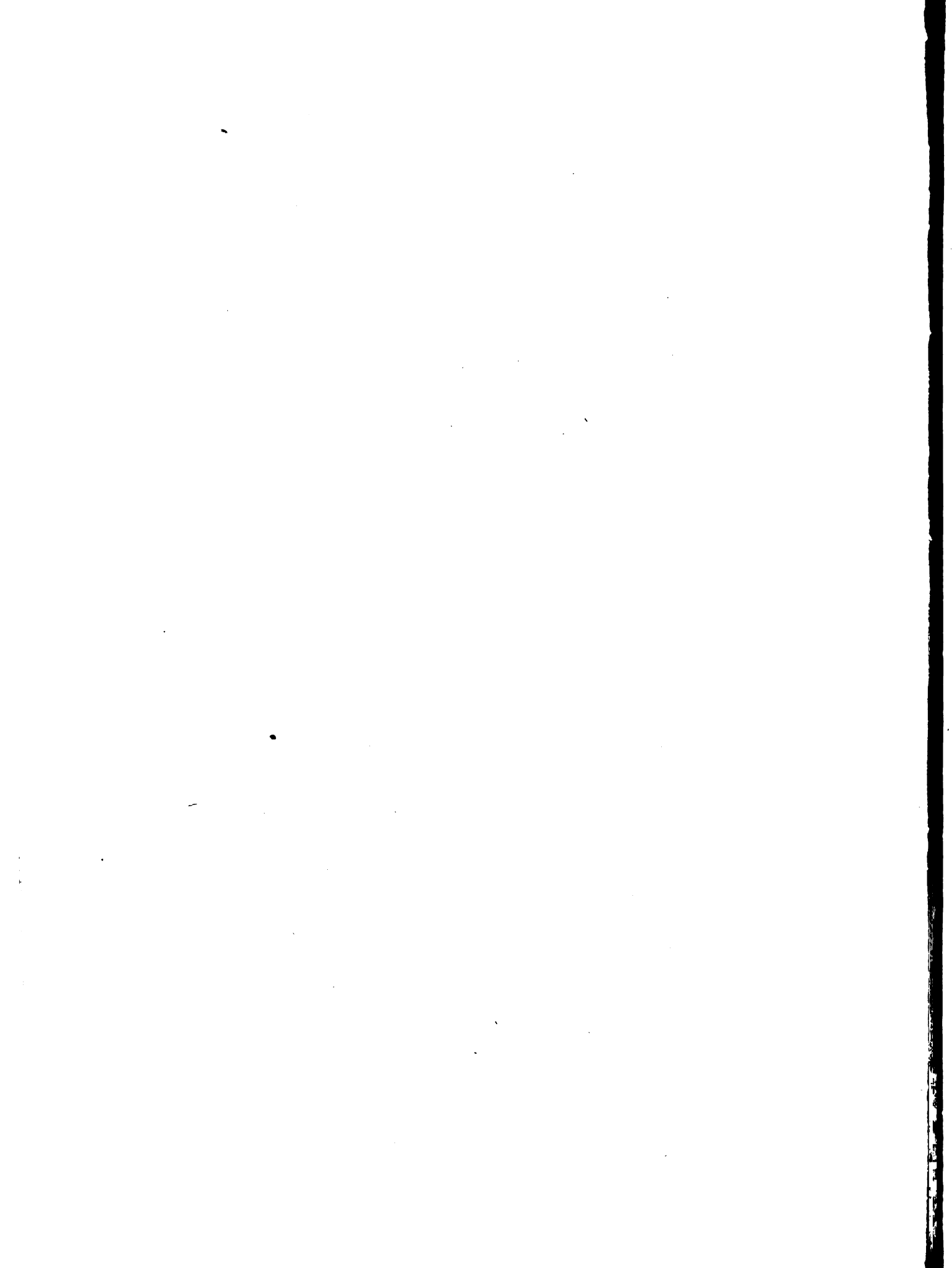


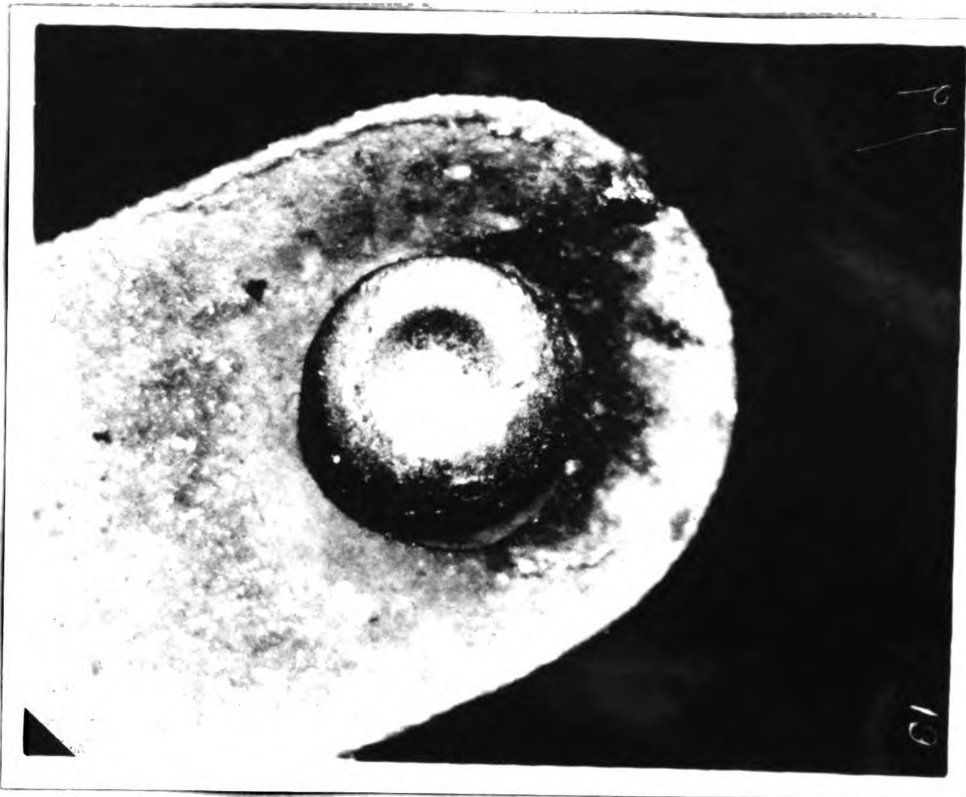
C16. Pt. #189a. 15000 impulses. Neg.



C18. Pt. #189a. 15000 impulses. Pos.

Side View.

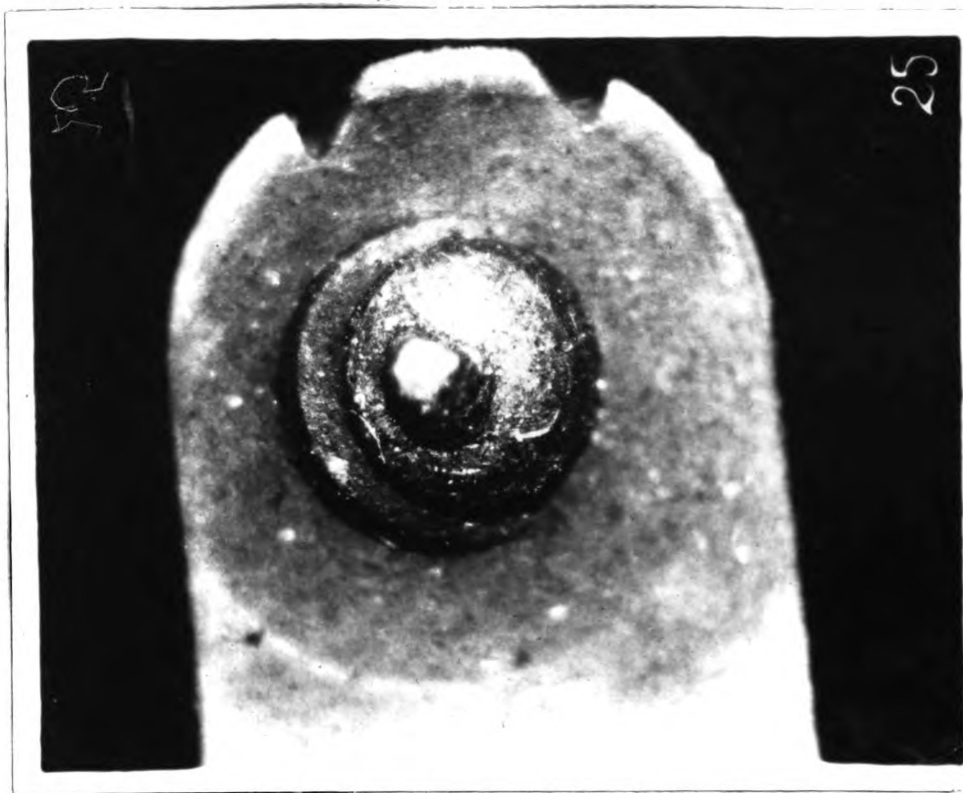




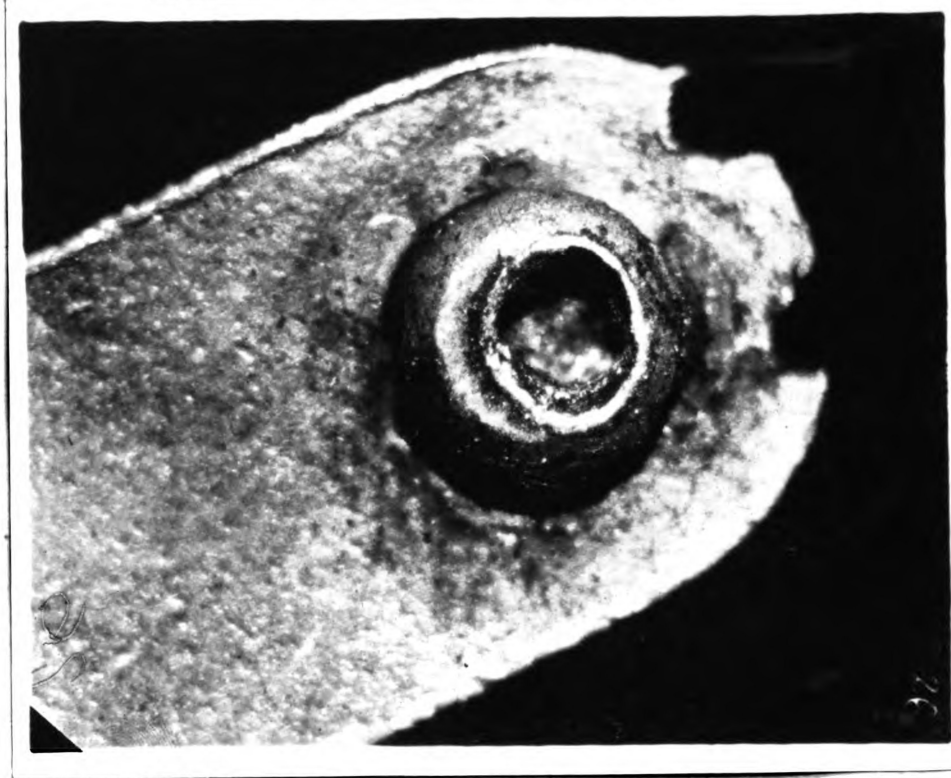
C19. Pt. #189a. 15000 impulses. Neg.



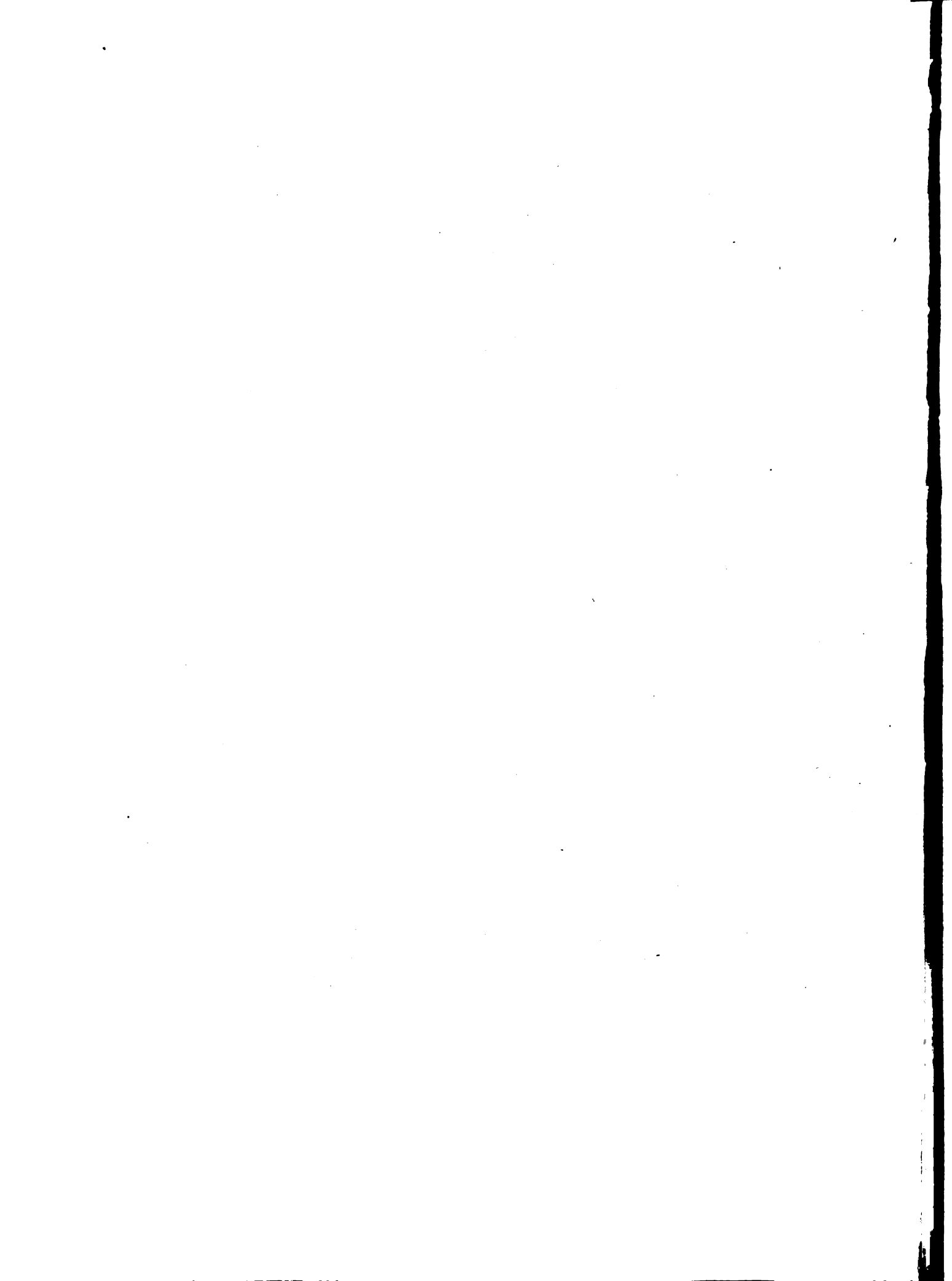
C18 Pt. #189a. 15000 impulses. Pos.

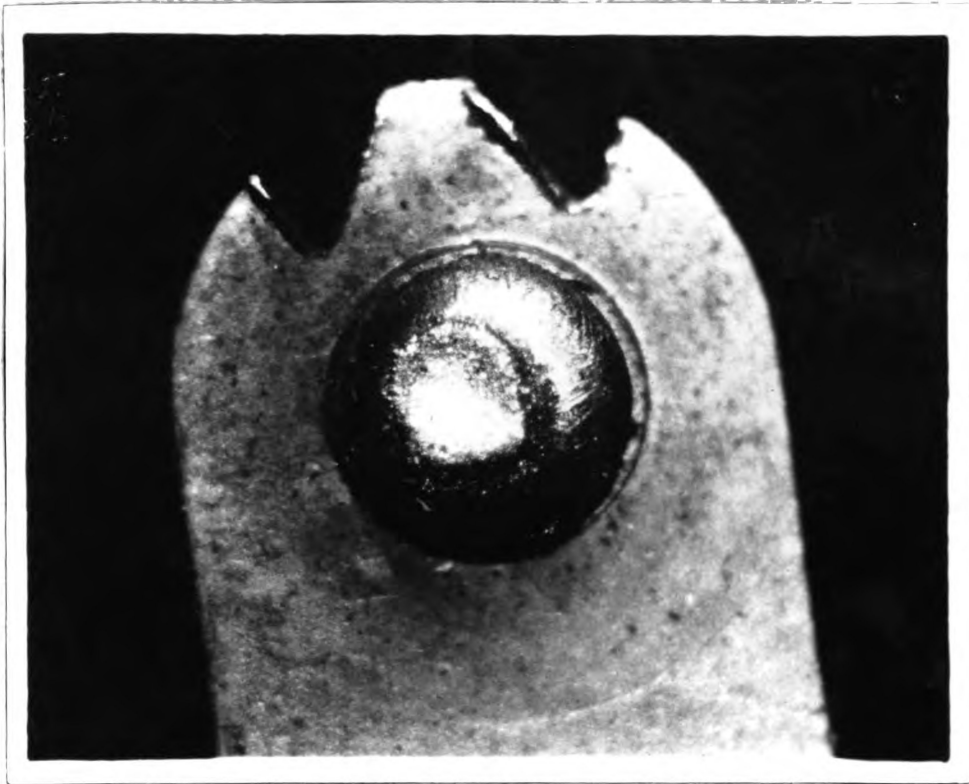


C25. Pt. #189a. 1yr. Service. Pos. Los Angeles, Cal.

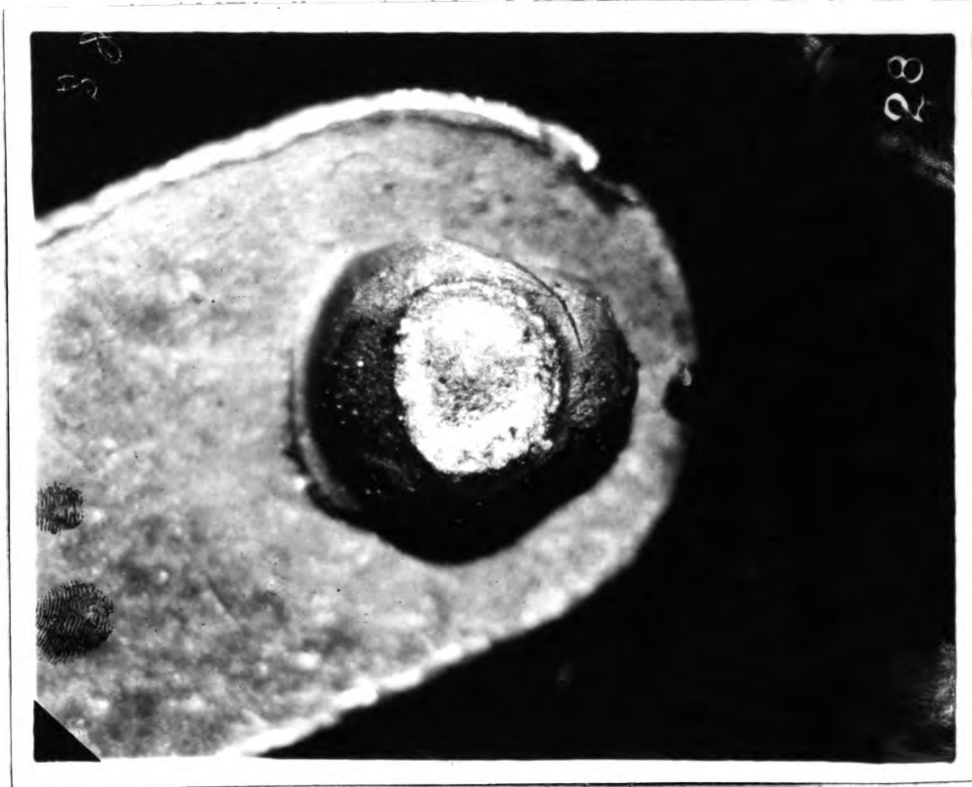


C26. Pt. #189a. Neg. Honolulu, Hawaii, H.T.

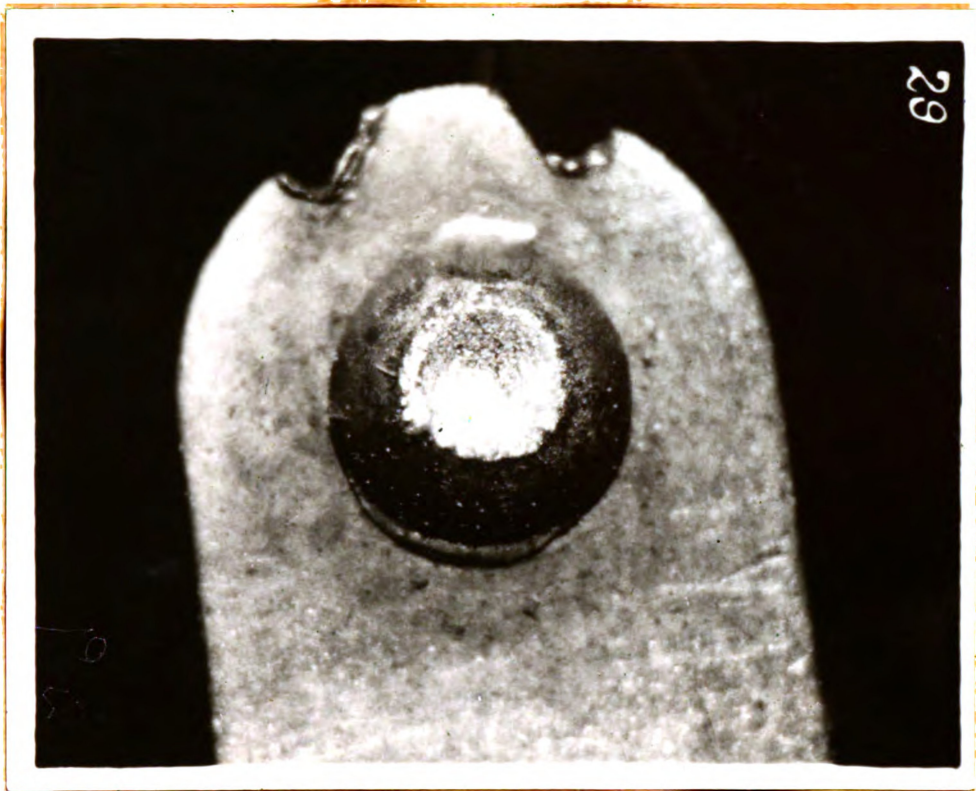




C27. Pt. #189a. 765520 impulses. Pos. Damper Spring.



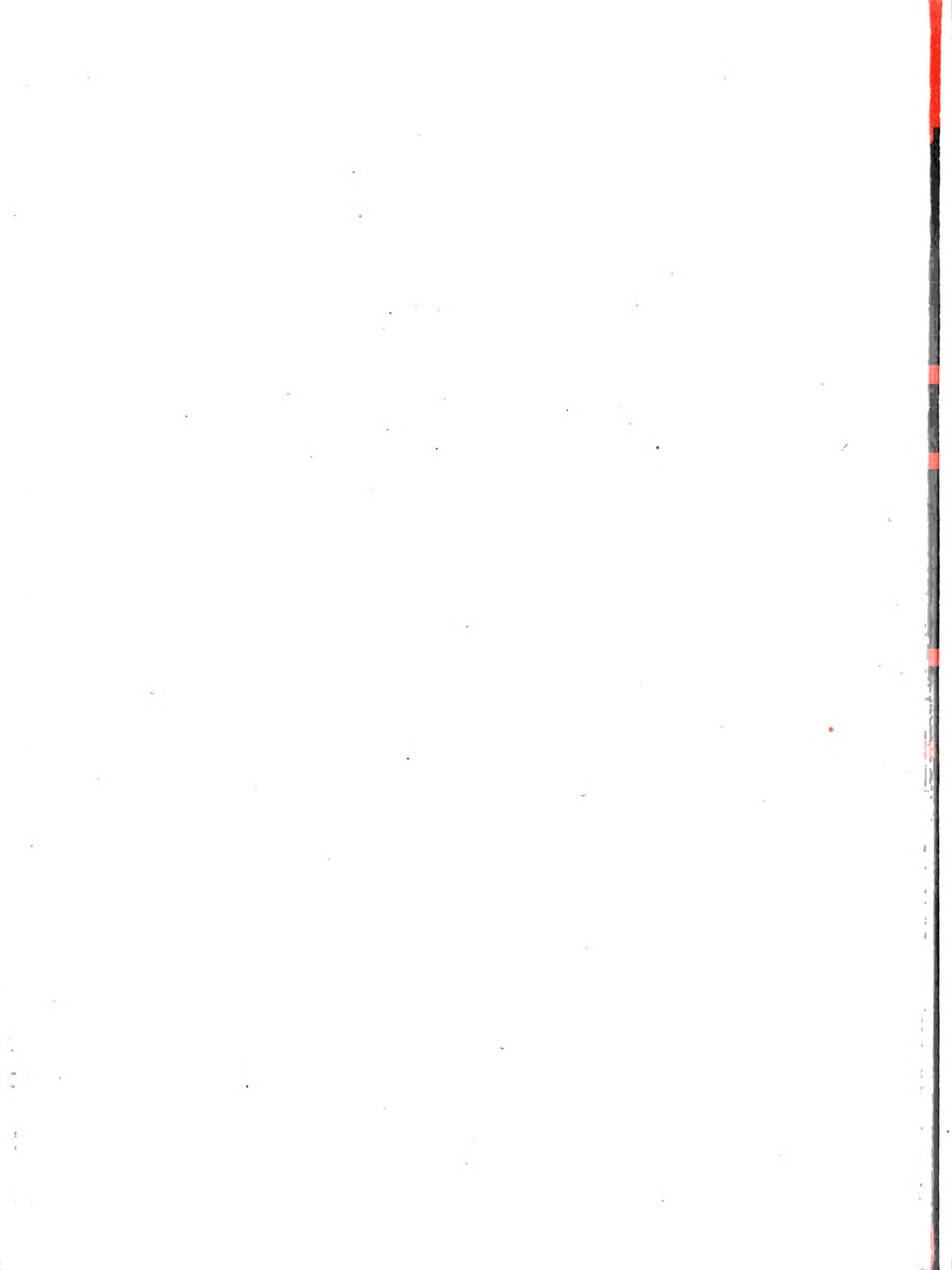
C28. Pt. #189a. 765520 impulses. Neg. Damper Spring.

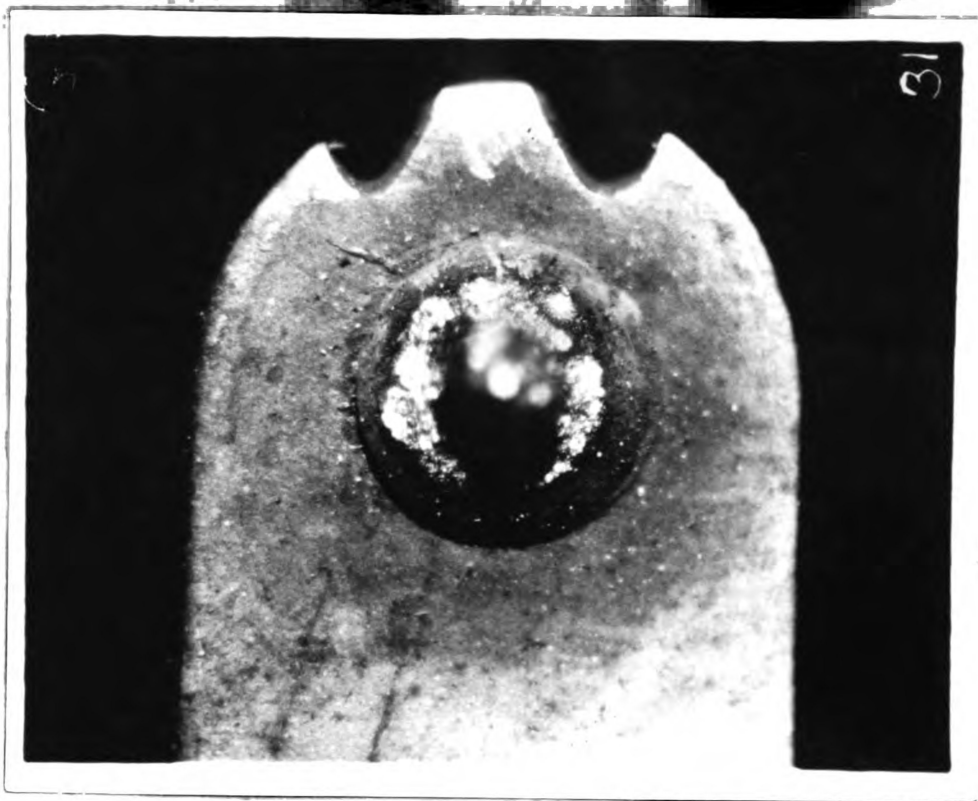


C29. Pt. #189a. 788960 impulses. Pos. Damper Spring.



C30. Pt. #189a. 788960 impulses. Neg. Damper Spring.

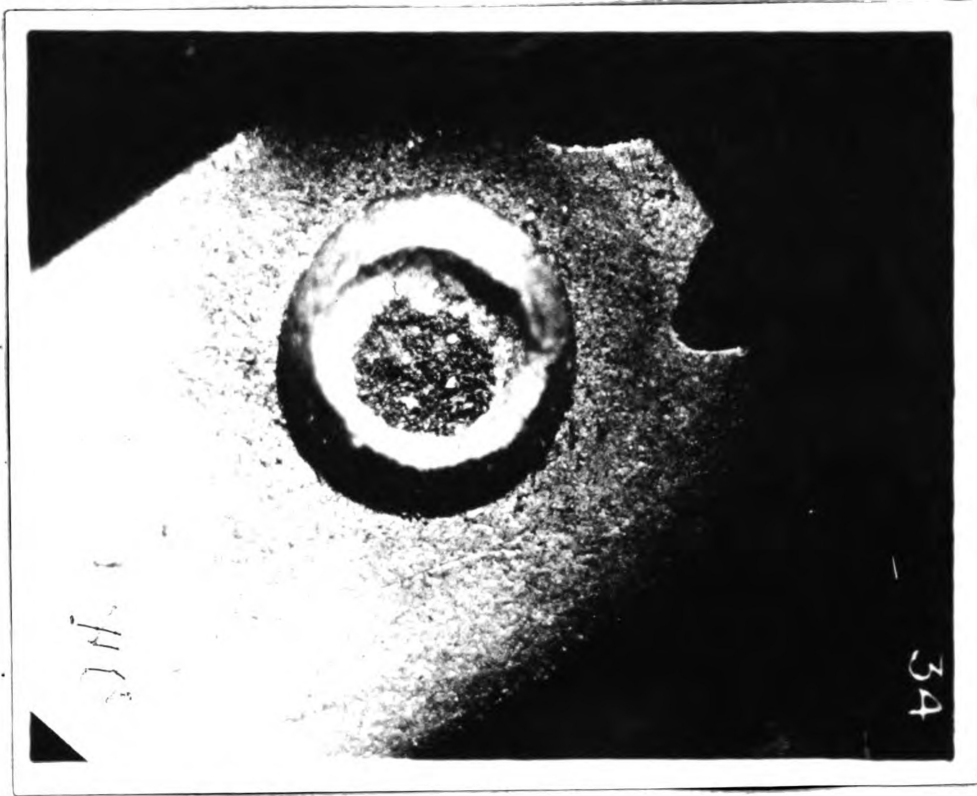




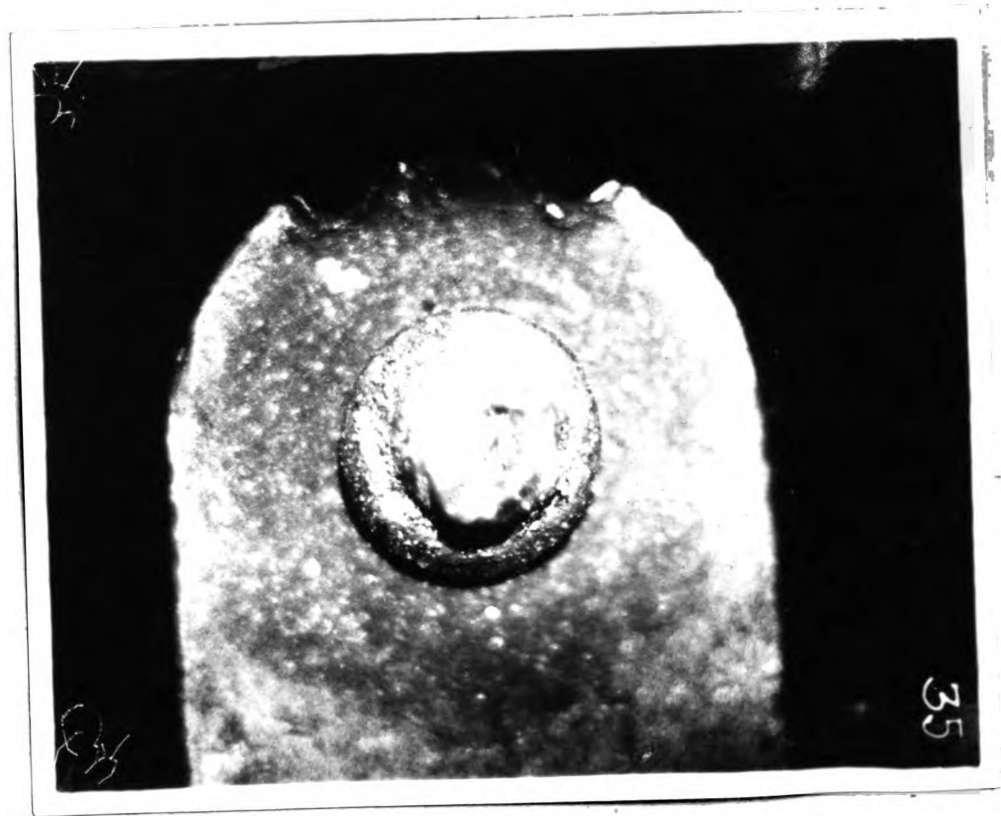
C31. Pt. #189a. 1515140 impulses. Pos.



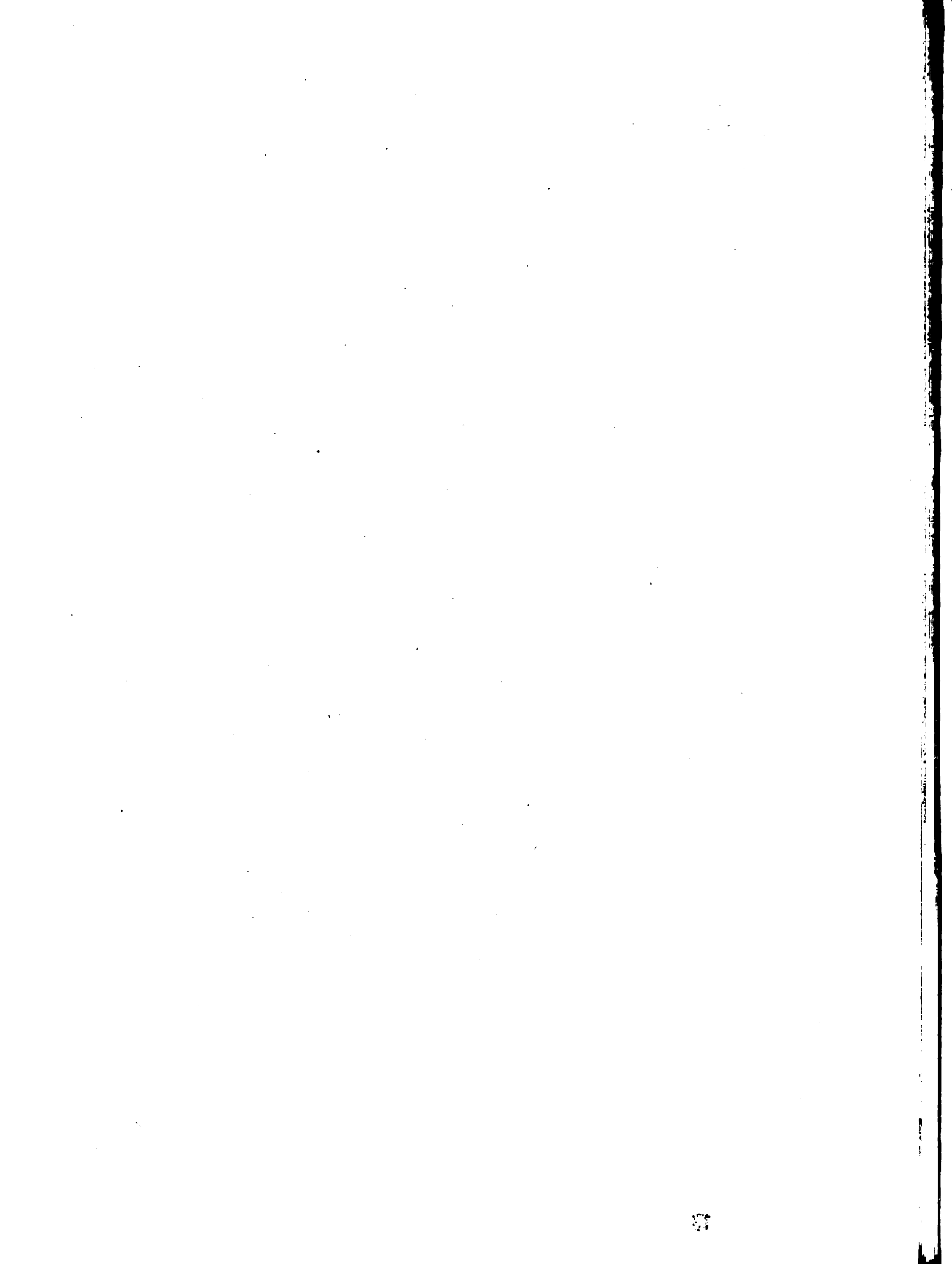
C32. Pt. #189a. 1515140 impulses. Neg.

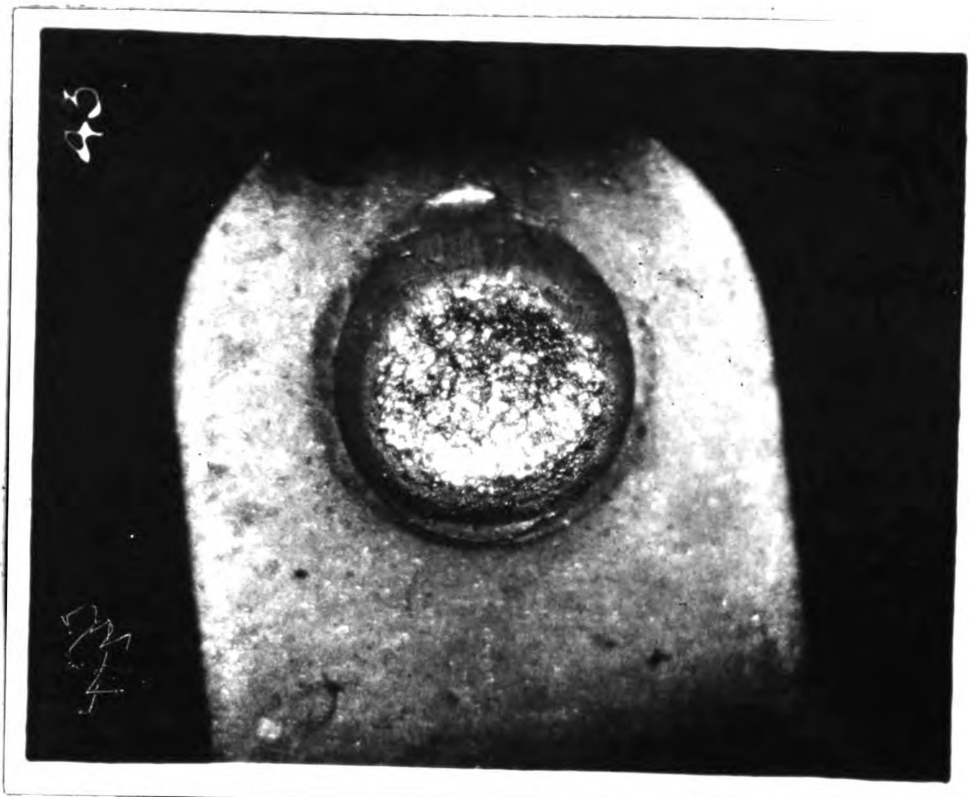


C34. Pt. #189a. 5 years. Honolulu Hawaii H.T. Neg.



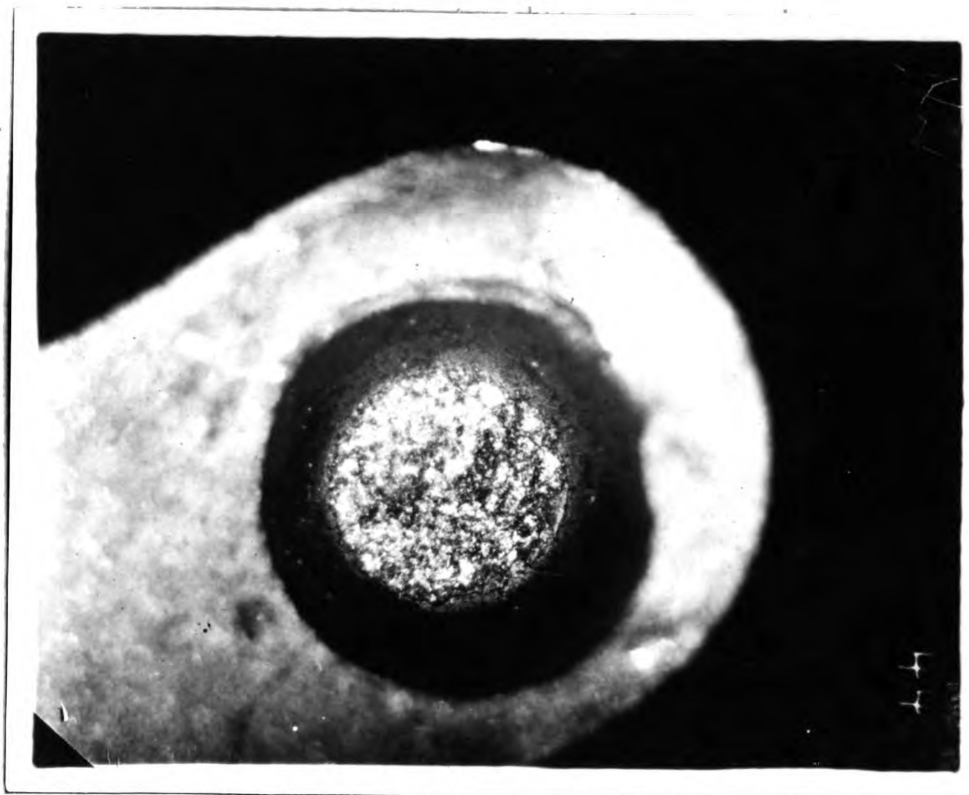
C35. Pt. #189a. 5 years. Honolulu, Hawaii, H.T. Pos.





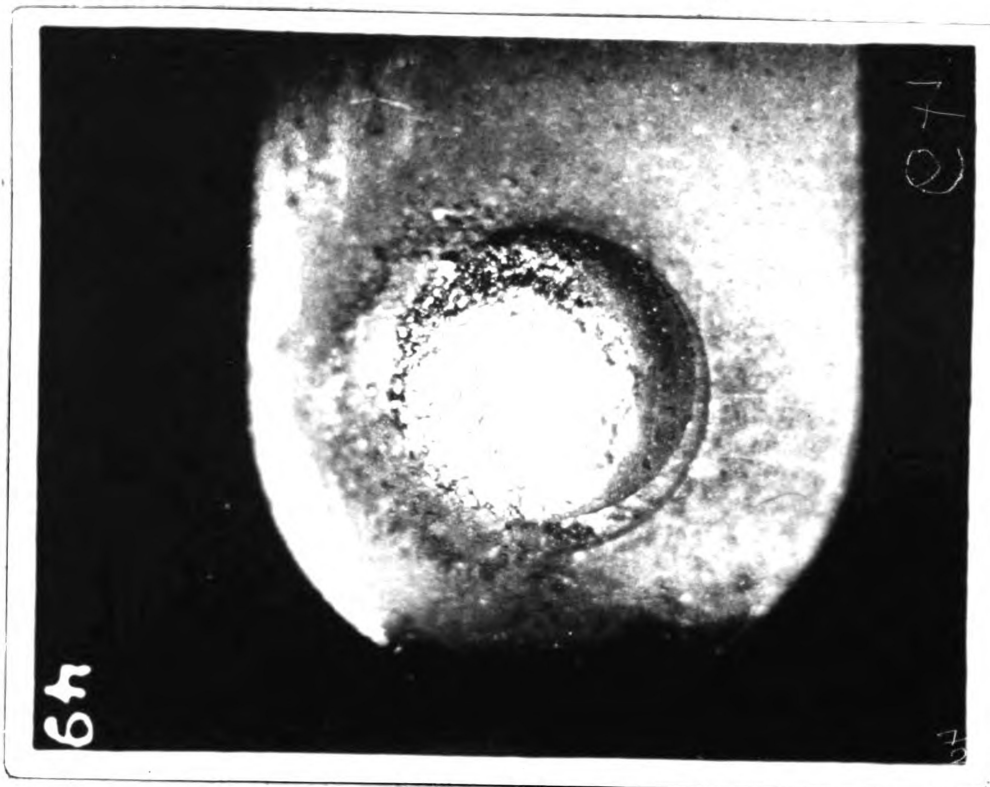
C43. Pt. #189a. 3028540 impulses.

Pos.

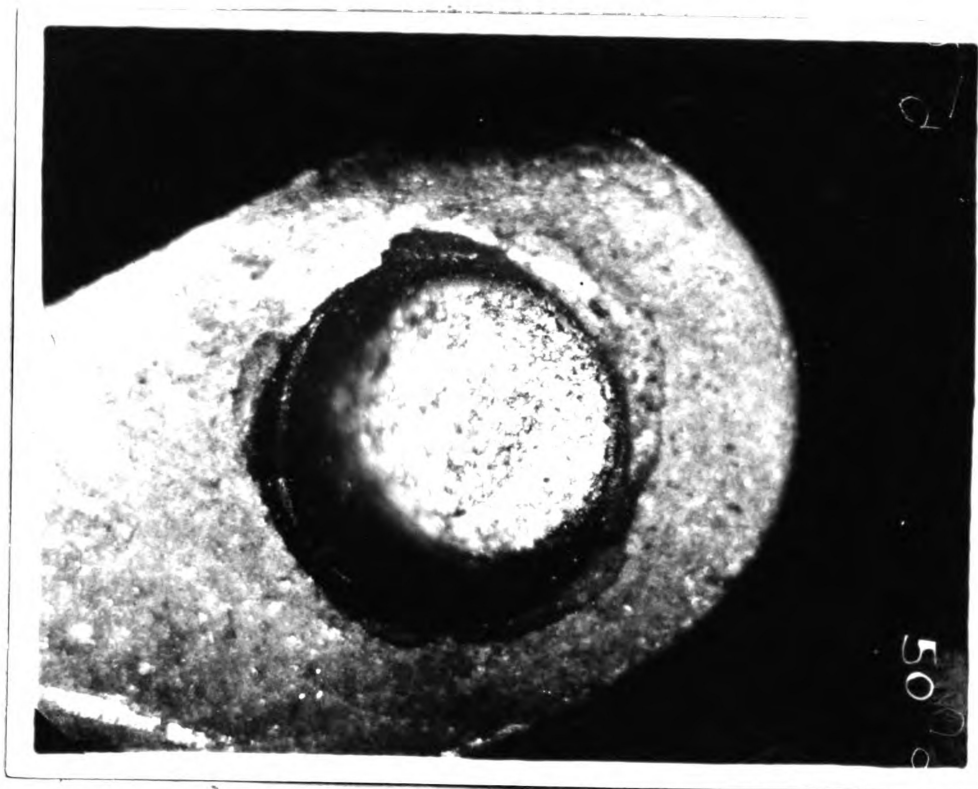


C44. Qg. #149a. 3028540 impulses.

Neg.



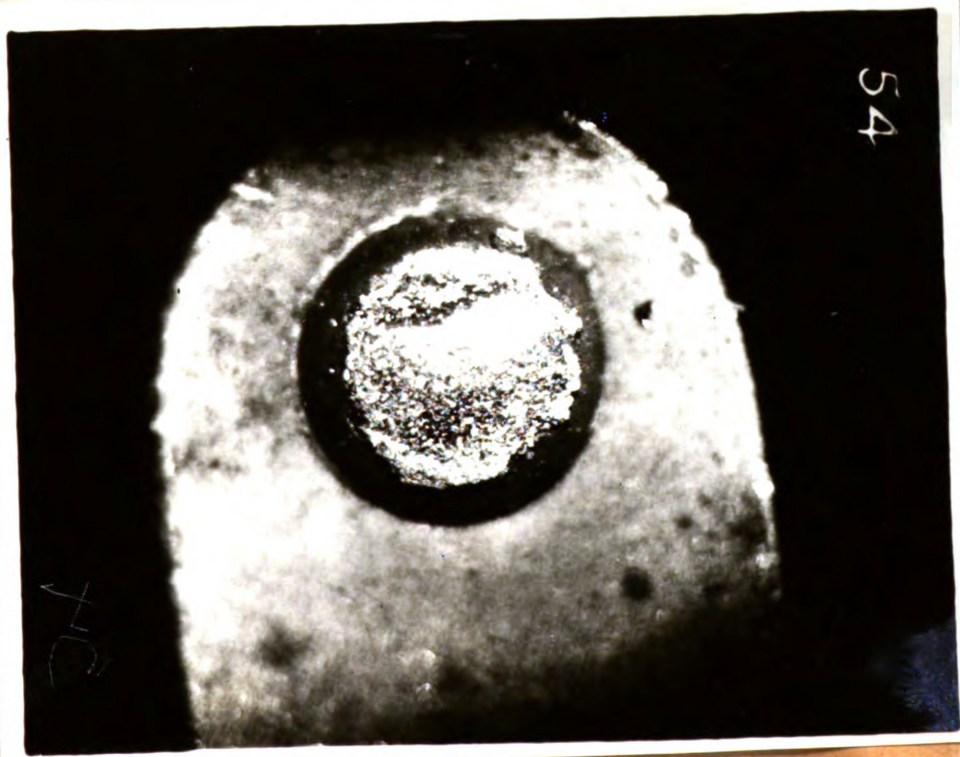
C49. Pt. #18qa. 2887800 impulses. Pos.



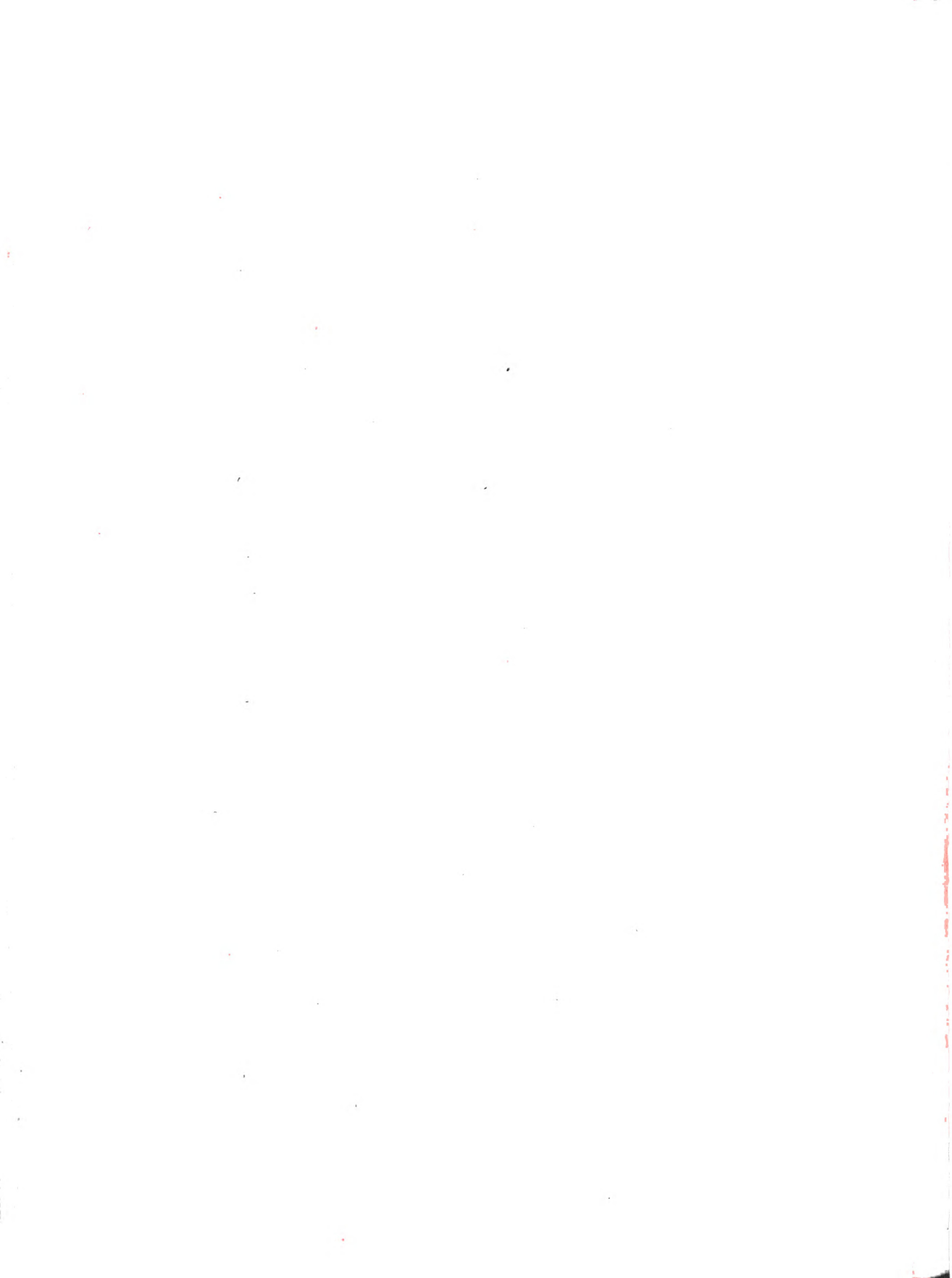
C50. Au. #14qa. 2887800 impulses. Neg.

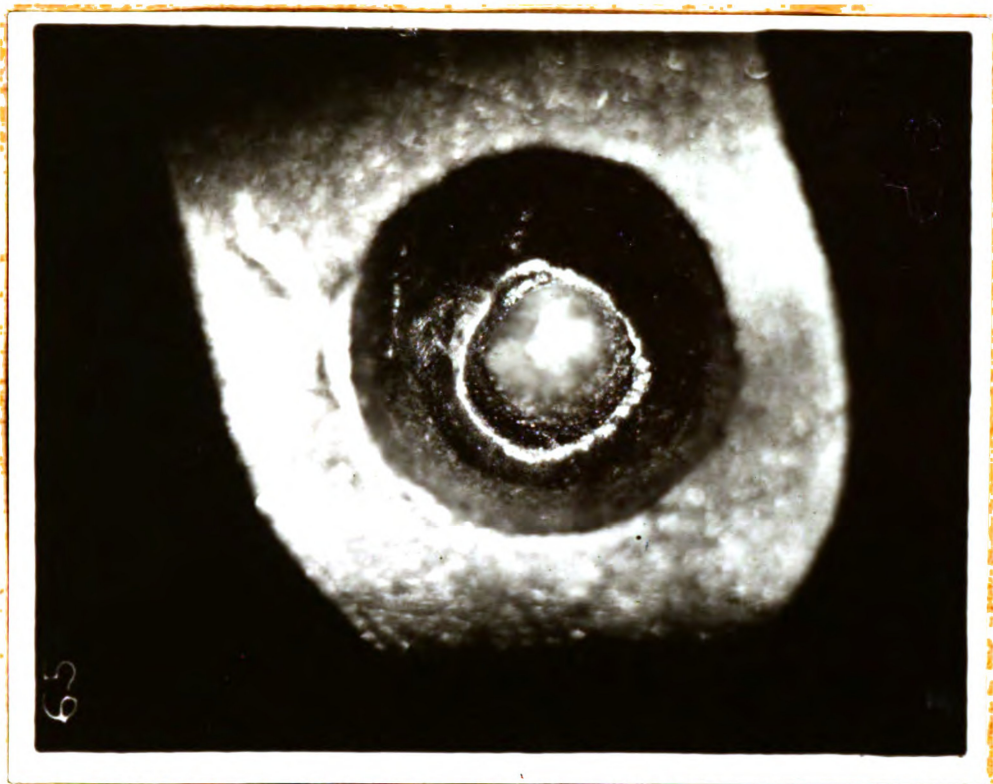


R53. Ag. #149a 5296275 impulses. Neg.

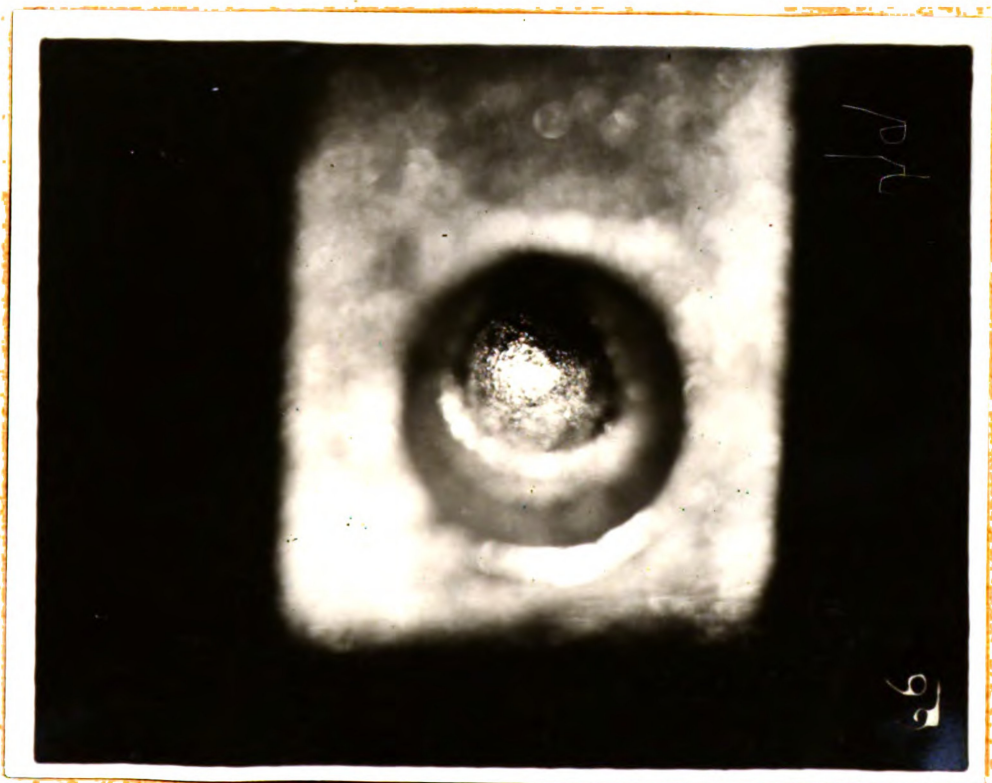


R54. Pt #189a. 5296275 impulses. Pos.





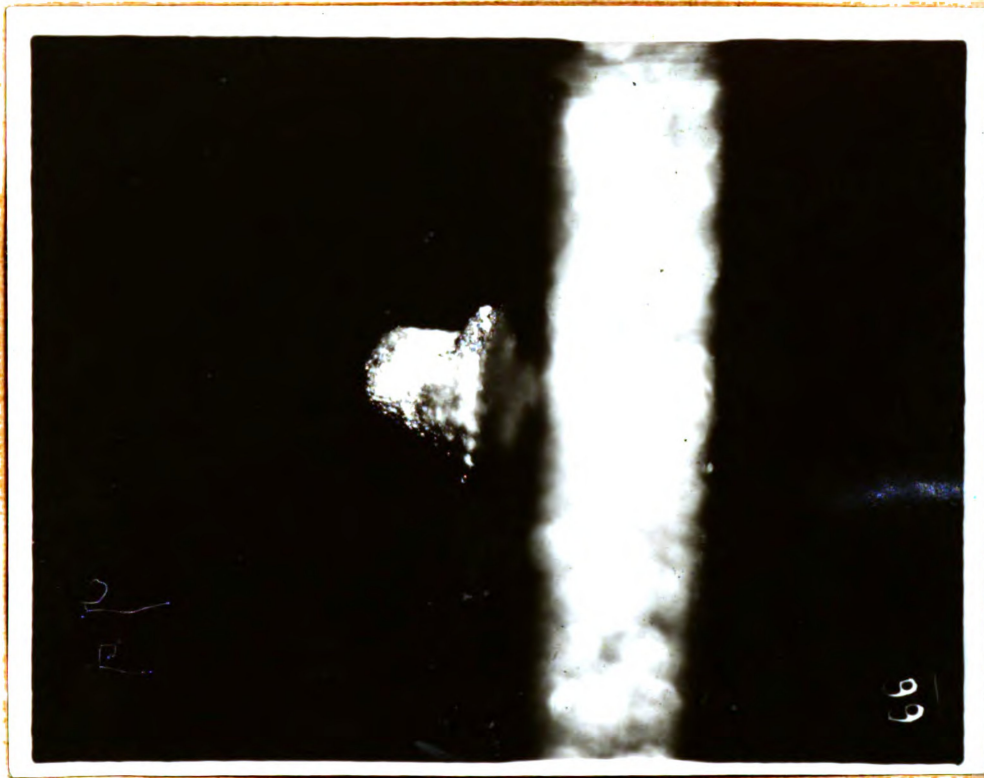
R65 Aq. #149a. 3508175 impulses. Pos.



R66. Pt. #189a. 3508175 impulses. Neg.



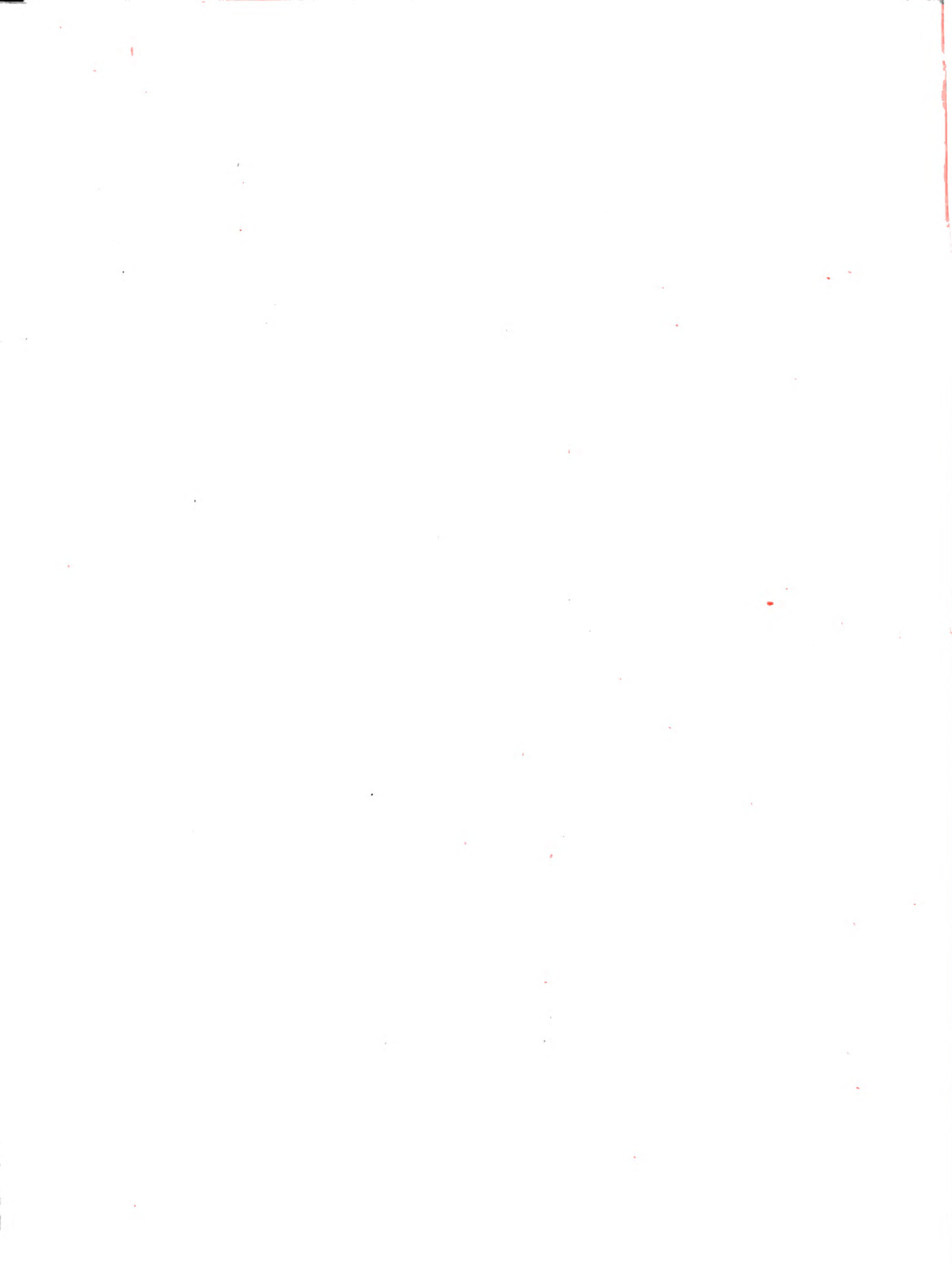
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R66. Pt. #18qa. 3508175 impulses.

Neq.

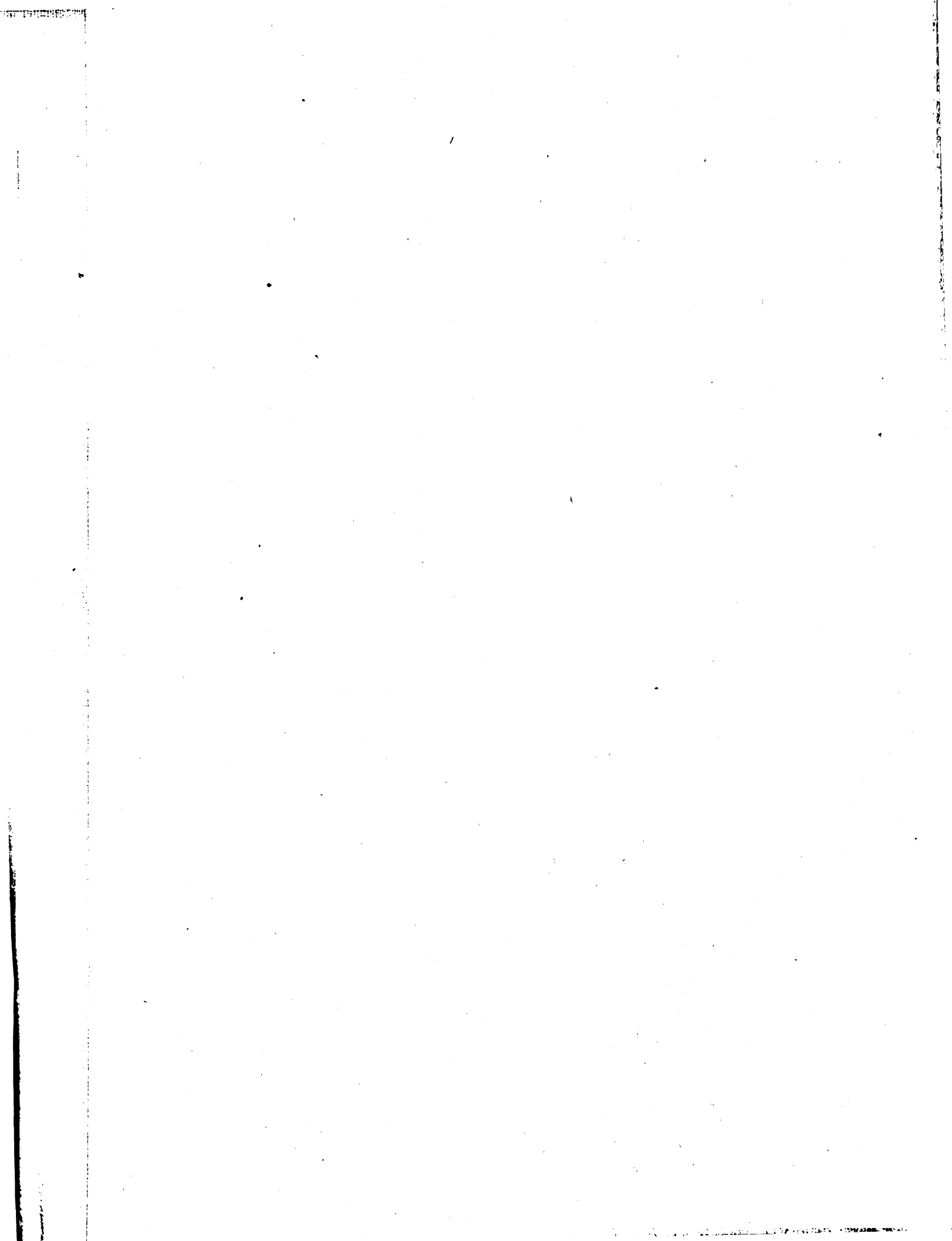
Side View.



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