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NEW YORK UNIVERSITY

COLLEGE OF ENGINEERING

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RESEARCH DIVISION

Project Report 141.03

GEIGER COUNTERS

Prepared for

OFFICE OF NAVAL RESEARCH
Nuclear Physics Branch, Washington, D.C.
Contract No. N6 ONR 279 T.O. 12

NEW YORK UNIVERSITY
COLLEGE OF ENGINEERING
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PROJECT REPORT 141.03

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QUANTITATIVE STUDY OF DECOMPOSITION OF QUENCHING CONSTITUENT IN GEIGER COUNTERS UNDER NORMAL COUNTING OR CONTINUOUS DISCHARGE

Project No. 141

Report No. 141.03

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ACKNOWLEDGEMENTS

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ABSTRACT

The effects on the plateau characteristics of Geiger-Mueller Counters containing organic quenching vapors was compared after passing equal amounts of charge at normal counting rates and in continuous discharge. The effect was found to be the same in both cases. Mass Spectrographic analysis also indicated that the decomposition of the quenching vapor was the same in both cases..Use of this result for the acceleration of life-time tests is discussed, as is the error in an accelerated life test recommended by the Institute of Radio Engineers.

INTRODUCTION

The useful lifetime of a self-quenching Geiger-Mueller Counter is usually of the order of 10^9 counts. The finite lifetime is well-known and is usually attributed to the decomposition of the quenching constituent of the filling mixture[1,2,3]. The effect of this decomposition is to render the counter non-self-quenching. This is a gradual effect and is observed in the well-known "plateau curve" (counting rate vs. voltage) by an increase in starting potential and an increase of plateau slope[4]. The decomposition is also seen in a mass-spectrographic analysis of the quenching vapor[3].

When the voltage of a counter is raised above that corresponding to the end of the plateau, there is a rapid increase in spurious counts and eventually the counter goes into a "continuous discharge". This discharge is not really continuous,but consists of a large number of multiple pulses[5]. Wiedenbeck and Crane[6] have indicated that the source of these multiple pulses is the delayed emission of electrons from the cathode which has been excited by a previous count.

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1. S.A.Korff & R.D.Present, Phys. Rev. <u>65</u>, 274 (1944)
2. W.D.B.Spatz, Phys. Rev. <u>64</u>, 236 (1943)
3. S.S.Friedland, Phys. Rev. <u>74</u>, 898 (1948)
4. S.A.Korff, <u>Electron and Nuclear Counters</u>, p.113, Van Nostrand,1946
5. S.A.Korff, Op. Cit., p.13
6. M.L.Wiedenbeck & H.R.Crane, Phys. Rev. <u>75</u>, 1268 (1949)

A relatively large amount of charge passes through the counter during a continuous discharge, due both to the large size of the pulses and to their rapid succession. This charge, all of which arrives at the cathode in the form of ionized products of the decomposed quenching gas, is equal to the charge in the pulses. Thus it would be expected that a continuous discharge for a relatively short time would seriously alter the operating characteristics of a counter due to decomposition of the quenching constituent[7].

It was the purpose of this experiment to determine whether the passage of equal amounts of charge through identical counters, in (1) normal operation or (2) continuous discharge, actually would have the same effects on the counter characteristics as indicated in the plateau curve, and on the quenching vapor as indicated in a mass-spectrographic analysis.

Chaudri and Fenton[8] have shown that an important effect of a continuous discharge was a rapid increase in photosensitivity. However, they did not compare the relative effects of normal running and continuous discharge, nor did they investigate the decomposition of the quenching vapor.

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7. S.A.Korff, Op. Cit., p.112
8. M.Chaudri & A.G.Fenton, Proc. Phys. Soc. 60, 183 (1948)

Wilkinson[9] has recommended running a "bad counter" in continuous discharge for a few moments to improve its characteristics. He believes the improvement may be due to the elimination of small quantities of impurity and indicates that care must be taken that the quenching gas is not completely decomposed[10].

The Institute of Radio Engineers has recommended an "accelerated life test" which utilizes continuous discharge[11]. This will be discussed in a subsequent part of this report.

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[9] D.H.Wilkinson, Ionization Chambers and Counters, p.240, Cambridge University Press, 1950

[10] D.H.Wilkinson, Private Communication

[11] Standards on Gas-Filled Radiation Counter Tubes: Methods of Testing, 1952, 52 IRE 7.S2, 7.3

EXPERIMENTAL TECHNIQUE

Description of Apparatus

Two types of counters were used. Type A were commercially manufactured and filled. The filling mixture was spectroscopic argon and anhydrous ethyl-ether. The cathode was aquadag. More complete specifications[12] are to be found in Table I. Type B were filled in our laboratory on the vacuum system shown in Figure 1. They had copper cathodes and were filled with a mixture of tank argon and ethyl-alcohol. More complete specifications are to be found in Table II. The type B counters were equipped with break-off tips for mass spectroscopic analysis.

The quantity of charge per pulse (average) was measured using a method originally devised by Stever[13]. He used a low-leakage condenser charged to operating voltage to supply the counter potential. Measuring the small change in voltage ΔV in time τ, the average charge per pulse q, is given by:

$$q = \frac{C\,\Delta V}{S\,\tau},$$

where: C = capacitance
S = counting rate.

The actual circuit used, as shown in Figure 2, is Simpson's[14] improvement of Stever's method. Switches A and B are low-leakage

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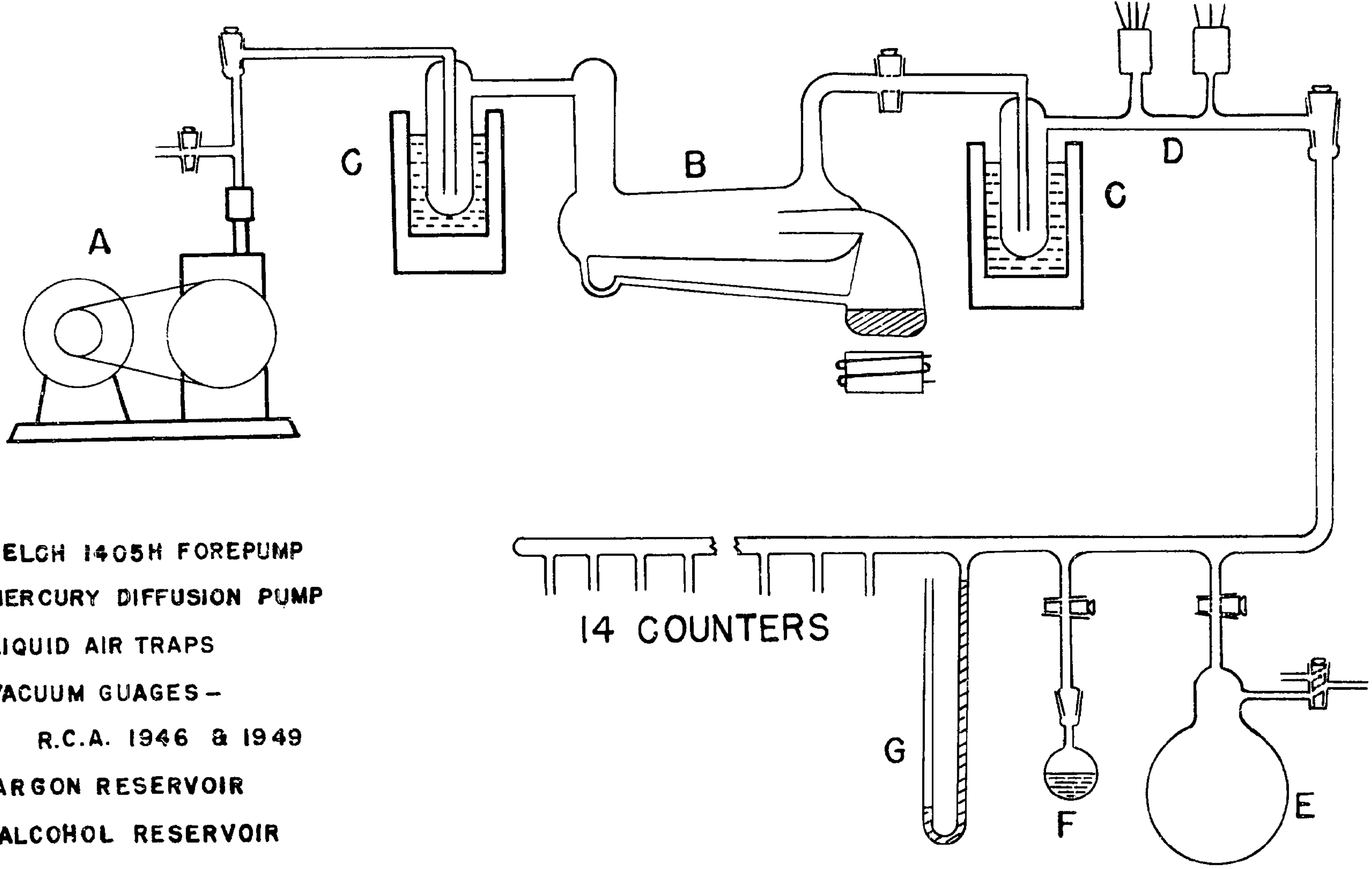
[12] Courtesy of Herbach & Rademan, Inc.
[13] H.G.Stever, Phys. Rev. 61, 38 (1942)
[14] J.A.Simpson, N.Y.U. Thesis (1946)

FIG. I
VACUUM SYSTEM



A. WELCH 1405H FOREPUMP
B. MERCURY DIFFUSION PUMP
C. LIQUID AIR TRAPS
D. VACUUM GUAGES –
R.C.A. 1946 & 1949
E. ARGON RESERVOIR
F. ALCOHOL RESERVOIR
G. MANOMETER

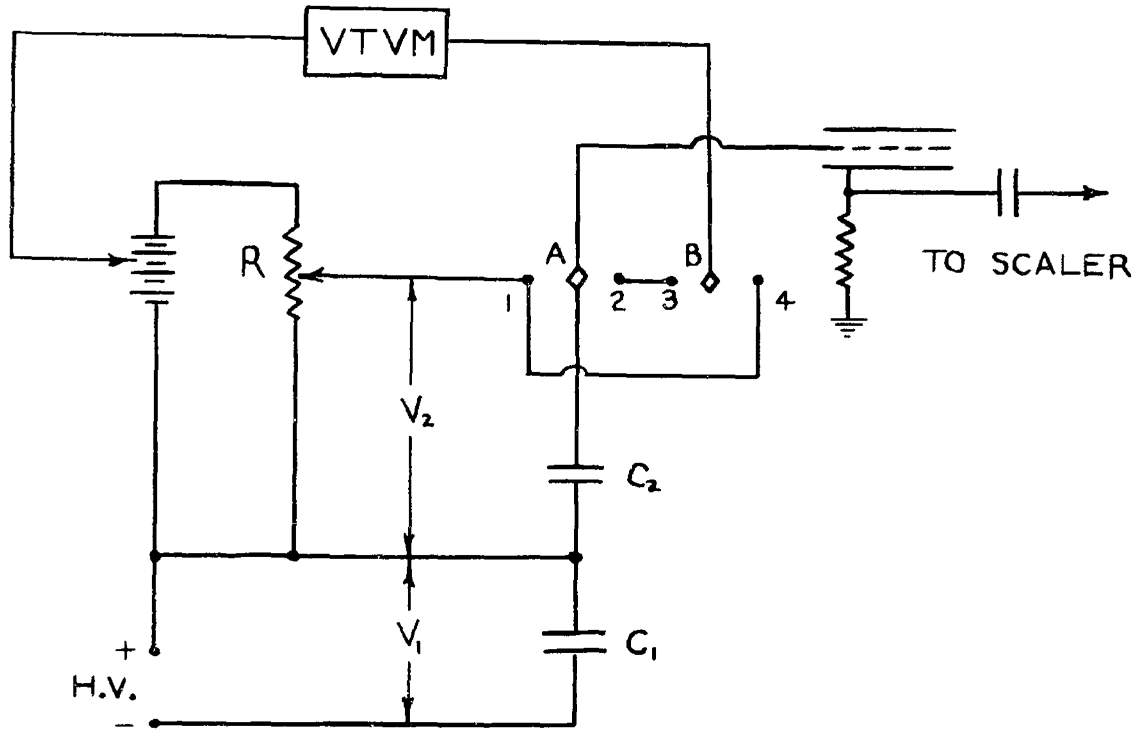


FIGURE 2

TABLE I

Type A* Counter Specifications

Overall length - 5"
Overall Diameter - 5/8"
Active cathode length - 2"
Glass Wall thickness - 0.065"
Counter Filling - Spectroscopic Argon - 7 cm.
Ethyl-Ether - 1.1 cm.
Cathode - Aquadag
Approximate Threshold - 800 volts
Plateau length - 250 volts
Plateau slope/100 volts - 2-4%
Deadtime - 75 microseconds
Line in counts - 5 x 10^8 to 10^9
Efficiency (electrons) - 99%
Time lag - less than 5 x 10^{-8} sec.
Pulse time rise - 0.1 microsecond

* Herbach & Rademan GM 400 A

TABLE II

Type B Counter Specifications

Overall length - 8"
Overall diameter - 7/8"
Cathode length - 3"
Cathode diameter - 5/8"
Counter Filling - Tank Argon - 9.4 cm.
Ethyl-Alcohol - 0.6 cm.
Cathode - Copper
Approximate Threshold - 800 volts
Plateau length - 100-150 volts
Plateau slope/100 volts - 5-10%

single pole double throw. Condenser C1 was a 4 mfd 2000 volt pyranol condenser. C2 was a special 1 mfd 100 volt polystyrene condenser manufactured by the General Radio Corporation. It had a leakage resistance of the order of 10^{11} ohms. Losses were therefore negligible and the condenser would stay charged to its original voltage for long periods of time. The operation of the circuit is as follows. V_1 is constant and supplies the greater percentage of the total voltage across the counter. R is adjusted to the proper value of V_2, to get the desired total voltage $V_1 + V_2$. Switch A is moved to 1, charging C2 to this desired value. Switch B is moved to 4 and the voltage V_2 is measured. Switch A is moved to 2 and the condenser C2 slowly discharges as pulses are counted. When a desired number of pulses are recorded, switch B is moved to 3 and the new value of V_2 measured. The charge per pulse is determined from:

$$q = \frac{(C2)(\Delta V_2)}{m}$$

where m is the number of counts.

Figure 3 shows a more complete diagram of the experimental arrangement. The condensers, switches, rheostat, and counter were mounted on a plexiglass base for insulation purposes. The scaler indicated was an A.E.C. model CGM-3B. It had a regulated high-voltage power supply and a scale of 64. Two separate cable taps were provided, one marked "H.V.Output" and the other "G.M. Input". The "H.V.Output" was used to supply voltage V_1. The

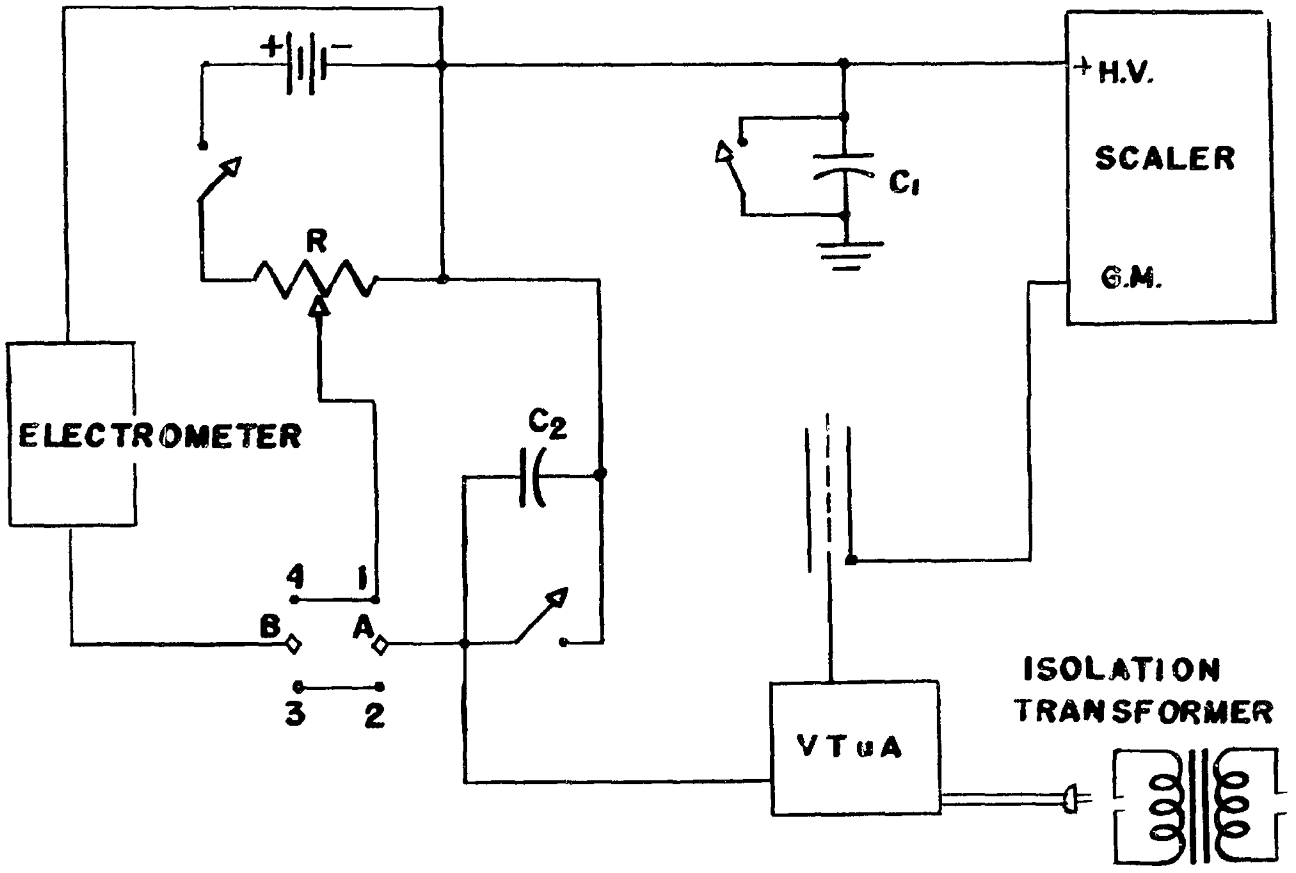

+
−
R
ELECTROMETER
4
1
B
A
3
2
C2
C1
+H.V.
SCALER
G.M.
V T u A
ISOLATION
TRANSFORMER

FIG. 3

"G.M.Input" originally combined a high voltage supply with the input to the scaling circuit. The high voltage was disconnected from this terminal through which the positive pulses from the counter cathode were to be introduced. Since the scaler was originally designed to accept negative pulses, modification was necessary. This was accomplished by adaptation of a published circuit[15] as shown in Figure 4. This is simply one stage of a pulse pre-amplifier and inverted the pulses as desired. The power for this circuit was obtained from the "quench" receptacle on the scaler. Careful shielding of the input and output leads was necessary to avoid feedback.

It was not possible to read the voltage V_2 using an ordinary Vacuum Tube Voltmeter. A usual VTVM having an input resistance of the order of ten megohms would discharge C2 too rapidly for accurate readings. For this reason, a published electrometer circuit[16] was modified for use as a high-impedance voltmeter (see Figure 5). This circuit has an input resistance of greater than 10^{11} ohms. Grid current leakage must be carefully avoided. For this reason, the switch used (a Mallory 161C ceramic) was painted with ceresin wax supplied by the Kuhne-Libby Co. The high-value resistors are manufactured by the S.S.White Dental Mfg. Co., Industrial Division. The warm-up switch is provided to protect the meter while

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15 W.C.Elmore & M.Sands, Electronics, p.161, McGraw Hill, 1948
16 W.C.Elmore & M.Sands, Op.Cit., p.186

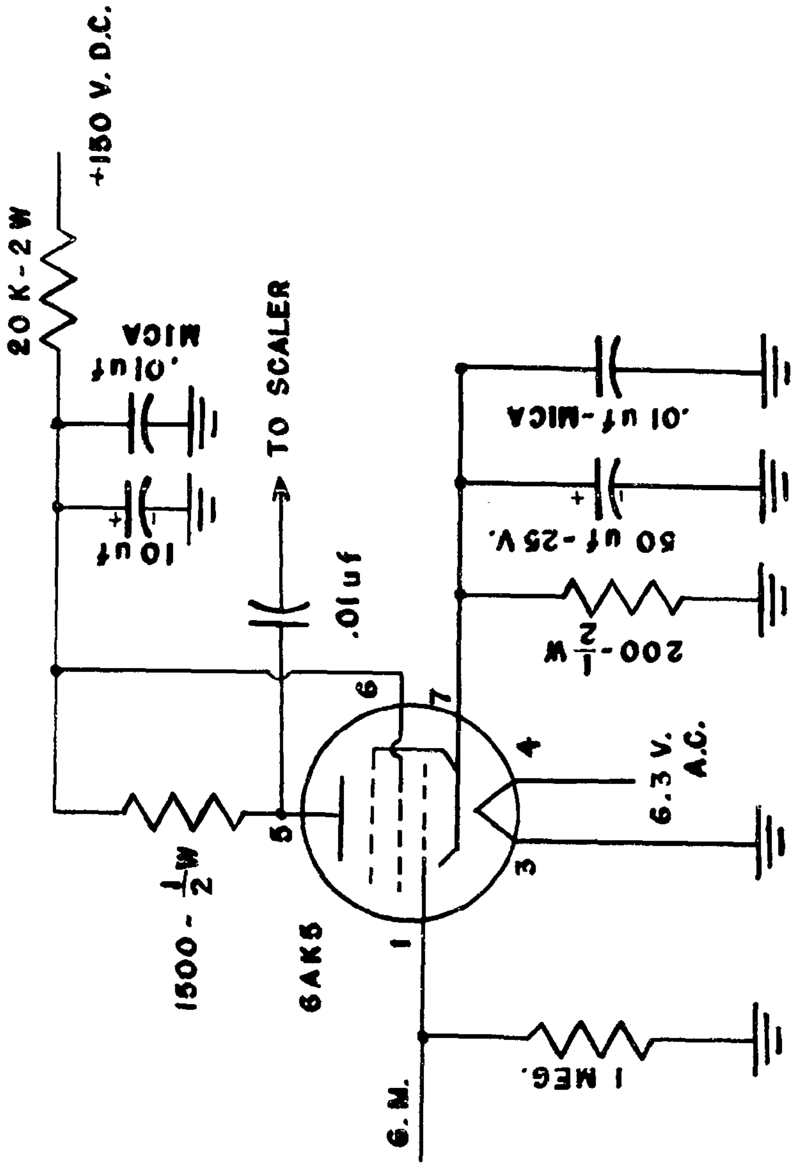
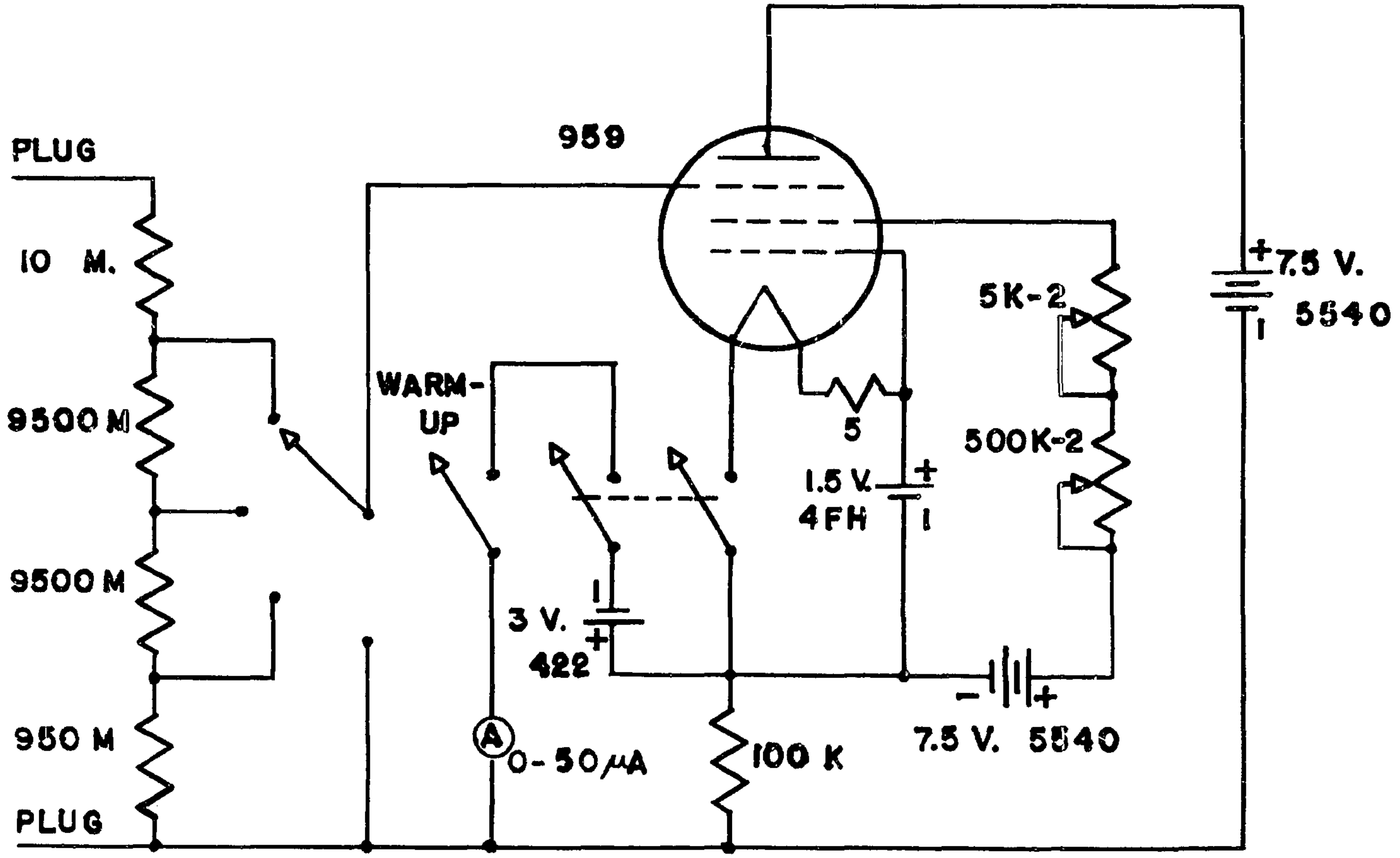

20 K - 2 W
+150 V. D.C.
.01 uf MICA
10 uf
+
-
TO SCALER
.01 uf
6
7
5
4
3
1
1500 - ½ W
6AK5
G.M.
1 MEG.
6.3 V. A.C.
200 - ½ W
50 uf - 25 V.
.01 uf - MICA

FIG. 4



ALL BATTERIES BURGESS

FIG. 5

the circuit is warming up. Since the circuit is extremely sensitive to changes in capacitance in the grid circuit, the whole chassis is completely shielded by a box of wire screening. Three voltage ranges were available; 0-7, 0-12 and 0-150 volts. The calibration curve for the last range is indicated in Figure 6.

The vacuum-tube microammeter, also used to measure the pulse charge, had six ranges; 0.20, 1, 5, 20, 50, and 100 microamperes full scale. A 120 volt AC supply was needed for this meter. Since it was to be operated at about 1000 volts above ground, it was isolated from the supply through a Stancor P6160 isolation transformer.

A type 274 Dumont Oscilloscope was connected to the scaler to facilitate detection of pulses.

Procedure

Fourteen counters of type B were filled on the vacuum system using a standard procedure[17]. They were outgassed under vacuum by heating for about one hour with infra-red lamps while counters and lamps were surrounded by aluminum foil. The central wires were heated to incandescence by connecting their two exposed leads to a Variac. They were allowed to glow for over an hour. The purpose was

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[17] S.A.Korff, Op.Cit., pp. 131-3

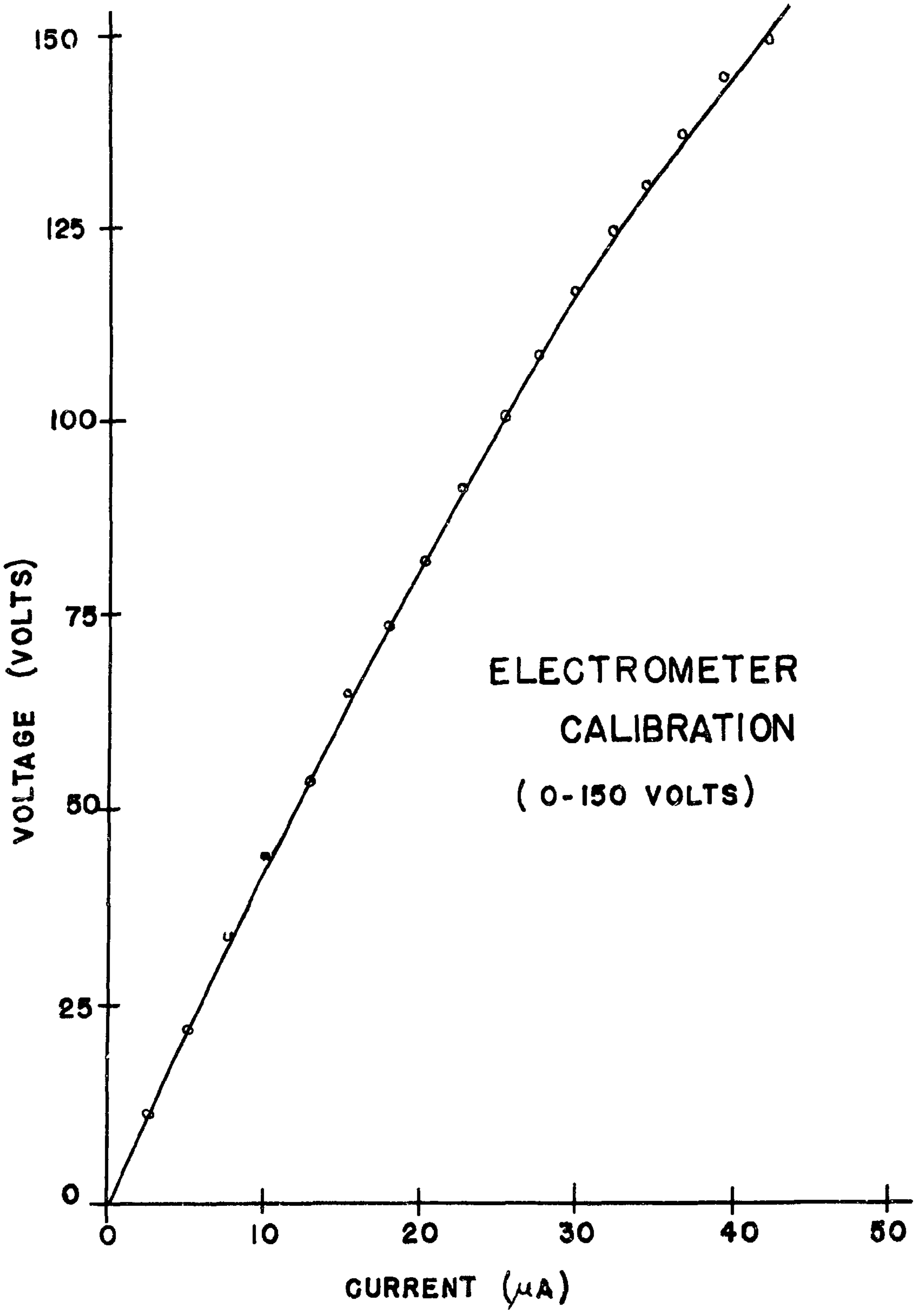
150
125
100
75
50
25
0
VOLTAGE (VOLTS)
0
10
20
30
40
50
CURRENT (μA)
ELECTROMETER
CALIBRATION
(0-150 VOLTS)

FIG. 6

twofold, to outgas the wires and to remove any microscopic "spikes" which may be the cause of sparking.

Before filling, the pressure as read on the ionization guage was 5 x 10^{-6} mm. of Hg. Alcohol vapor was admitted to the counter first until the pressure rose to 0.6 cm. After allowing the alcohol to diffuse for about an hour, argon was admitted until the total pressure rose to 10 cm. After diffusion for another hour, the counters were checked and sealed off.

After running for several times 10^6 counts, the counters became considerably photosensitive. For this reason, all characteristic curve data (counting rate vs. voltage) was taken with the counters in darkness. Voltage was varied in steps of 25 volts and the total counts in one-minute periods measured. The oscilloscope aided in detection of the starting potential and the Geiger Threshold.

After taking their original plateau data, three counters of type A and six of type B were run at normal rates of about 20,000 counts per minute. This was continued until 10^8 counts were completed on each counter. Plateau data was taken at the end of 10^6, 10^7 and 10^8 counts. The three type A counters were run at a voltage corresponding to an original overvoltage of 120 volts. Three each of the type B counters were run at voltages corresponding to original overvoltages of 90 and 60 volts respectively.

Frequently throughout the tests, the charge per pulse was measured using the previously described circuit. As both Stever[18] and Simpson[19] have shown, the charge per pulse varies linearly with the overvoltage. It was desired to measure the value of charge per pulse at the operating voltage used throughout the tests. For this reason, V_2 was allowed to range from a value above this to one below it while counting the pulses. In this way, the higher pulses while above the desired voltage would approximately make up for the lower pulses while below it.

The value of average charge per pulse was also determined by simultaneous measurements of current and counting rate as recommended by the Institute of Radio Engineers[20]. The current was unsteady but readable.

From the pulse data above, it was possible to calculate the total charge equivalent to 10^6, 10^7 and 10^8 counts at each of the overvoltages and for each corresponding type of counter.

Four counters of type A were run in continuous discharge for the same amount of charge as the previous counters run at 120 volts initial overvoltage. Five of type B were run in continuous discharge, three corresponding to the 90 volts overvoltage and two to

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[18] H.G.Stever, Loc.Cit.

[19] J.A.Simpson, Loc.Cit.

[20] Standards on Gas-Filled Radiation Counter Tubes: Methods of Testing, 1952, 52 IRE 7.S2, 3.1

the 60 volt overvoltage. Plateau data was taken at intervals corresponding to 10^6, 10^7 and 10^8 counts as well as initially. The "condenser method" of measuring charge passage was not possible in these tests due to the large quantities being passed. The microammeter reading was now steady enough for accurate readings and this was used alone.

The fillings of three of the type B counters were analyzed on the mass spectrometer at the University of Connecticut through the courtesy of Professor S.S. Friedland. These counters consisted of a control counter, a normally-run counter and a corresponding continuous discharged counter.

DISCUSSION OF RESULTS

Initially the type A counters had a starting potential of about 775 volts and a plateau length of 225 volts. The type B counters had a starting potential of about 810 volts and a plateau length of 100 - 150 volts. In figures 7a, 7b, 7c and 7d, we see the plateau characteristics of a typical type A counter initially and after 10^6, 10^7 and 10^8 counts respectively. Figure 8 shows a superposition of the initial characteristics and the characteristics after 10^8 counts. It is seen, as was expected from previous consideration of the decomposition of the quenching vapor, that the plateau length has shortened considerably (to about 50 volts) and the starting potential has increased about 80 volts. These type A counters had been run at a voltage corresponding to an original overvoltage of 120 volts.

Similar effects were found with the type B counters. Again after 10^8 counts, the plateau of the type B counters had shortened considerably and the starting potential increased. One important effect noted was that the deterioration in the counters run at an initial overvoltage of 60 volts was not as great as that in the counters run at the higher initial overvoltages. This was to be expected, for as we know, the amount of charge per pulse is pro-

FIG. 7

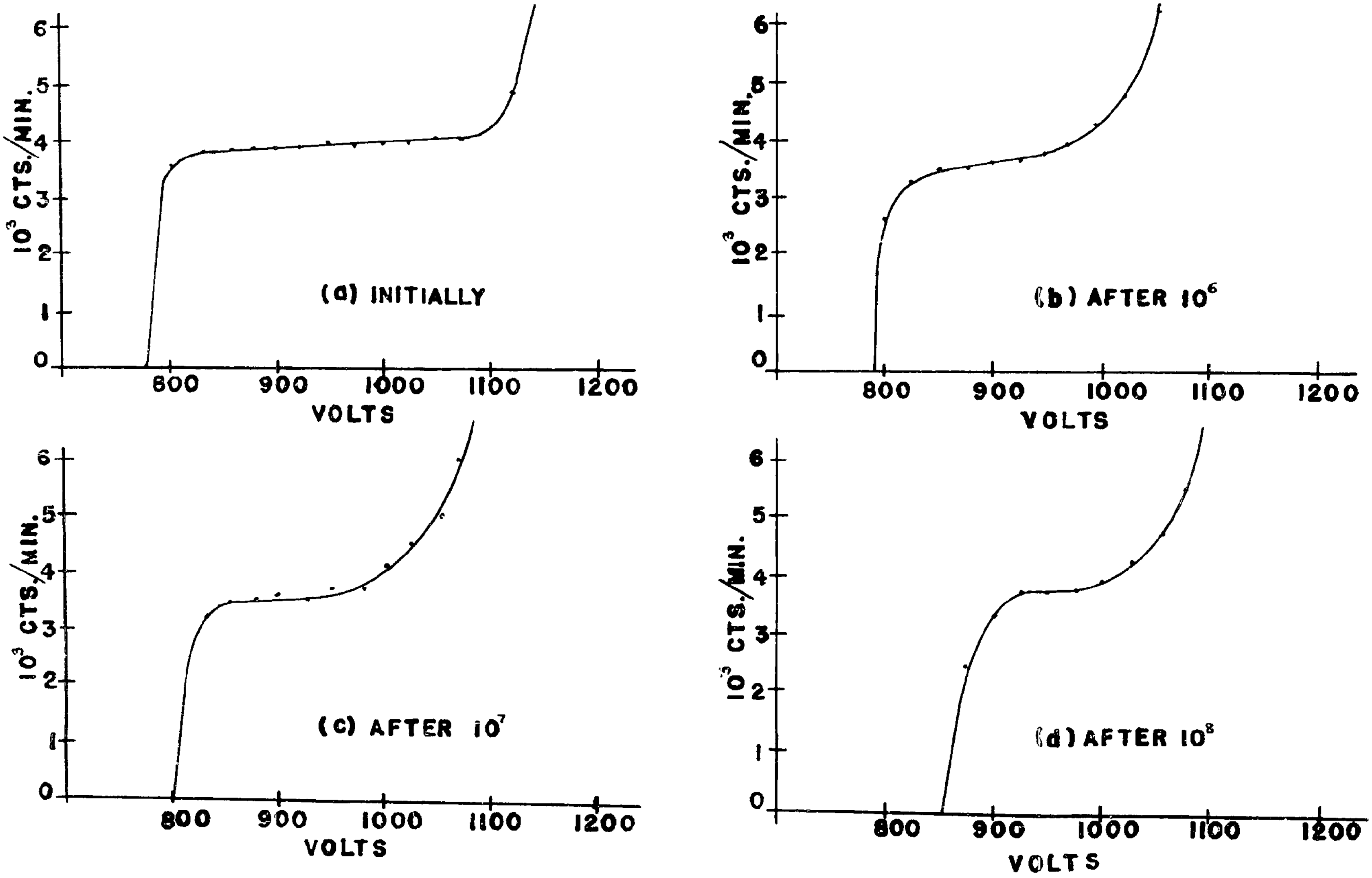
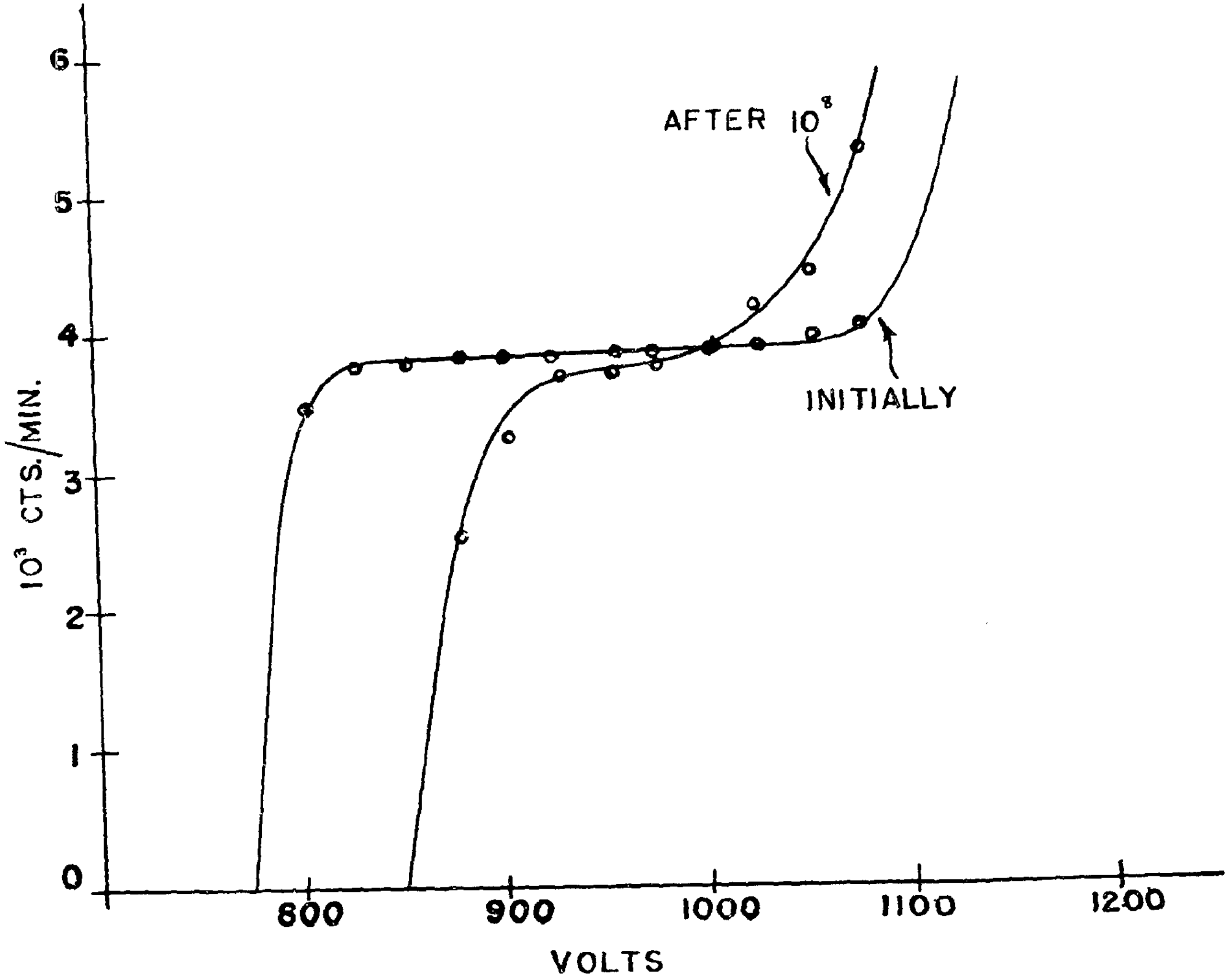

(a) INITIALLY
(b) AFTER 10^6
(c) AFTER 10^7
(d) AFTER 10^8
10^3 CTS./MIN.
0
1
2
3
4
5
6
VOLTS
800
900
1000
1100
1200

FIG. 8


6
5
4
3
2
1
0
10^3 CTS./MIN.
800
900
1000
1100
1200
VOLTS
AFTER 10^8
INITIALLY

portional to the overvoltage. This present experiment shows that the decomposition is proportional to this charge.

The values of charge per pulse as measured in counters of the same type running at the same overvoltage and after the same total number of counts checked within 5%. In Figure 9, we see how the pulse charge varies with the total number of counts for each of the initial overvoltages. The decrease in pulse size with life is due mainly to the decrease in overvoltage caused by the gradual increase in starting potential (as mentioned before, the counter voltage was constant throughout the tests).

The values of charge per pulse as measured using the microammeter agreed with those measured by the "condenser method". For example, when the "condenser method" yielded a value of 7.3×10^{-10} coulombs, the current was 0.4 microamps at a rate of 34,000 counts/min. Thus;

$$q = \frac{0.4 \times 10^{-6}\ \text{coul/sec.}}{565\ \text{counts/sec.}} = 7.2 \times 10^{-10}\ \frac{\text{coul.}}{\text{count}})$$

which shows the fairly good agreement. Throughout the tests, both methods of pulse charge measurement were used as a double check. It should be mentioned that the microammeter method was vastly simpler since it involved no complex

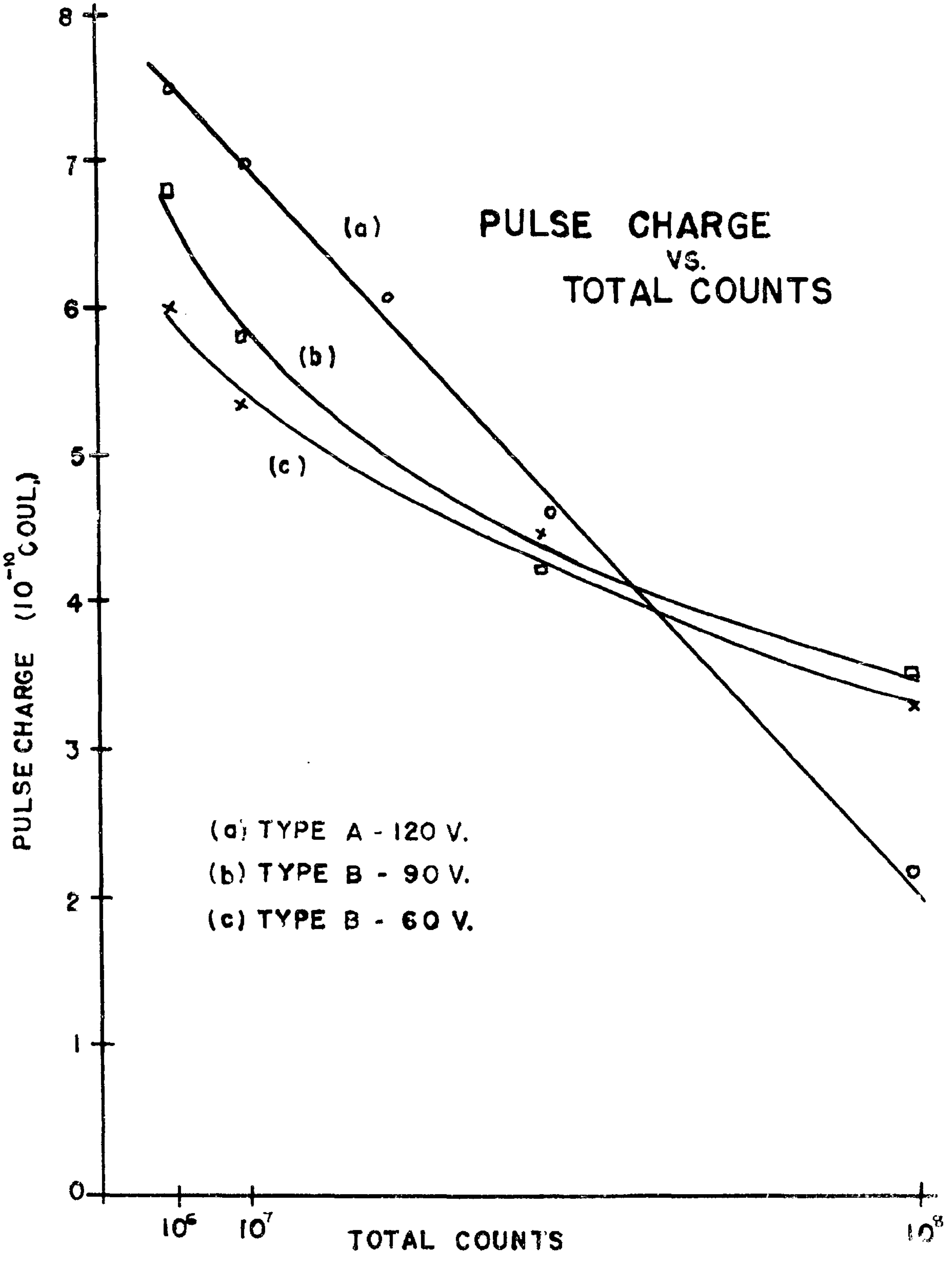

PULSE CHARGE
VS.
TOTAL COUNTS
PULSE CHARGE (10⁻¹⁰ COUL.)
0
1
2
3
4
5
6
7
8
TOTAL COUNTS
10⁶
10⁷
10⁸
(a)
(b)
(c)
(a) TYPE A - 120 V.
(b) TYPE B - 90 V.
(c) TYPE B - 60 V.

FIG. 9

switching procedure as previously described for the other method.

The values of charge per pulse are seen to be of the order of 10^{-10} to 10^{-9} coulombs. This order of magnitude is consistent with the results of Simpson[21] and Ramsey[22].

Taking the mean value of pulse charge over the intervals, the total charge equivalent to 10^6, 10^7 and 10^8 counts was calculated. The values are shown in Table III.

TABLE III

COUNTS	TYPE A - 120 v.		TYPE B - 90 v.		TYPE C - 60 v.	
	Avg. q/n	Total Q	Avg. q/n	Total Q	Avg. q/n	Total Q
10^6	.00076	760	.000701	701	.000568	568
9×10^6	.000725	6530	.000629	5660	.000503	4530
10^7		7290		6360		5100
9×10^7	.000480	43200	.000455	41000	.000417	37500
10^8		50490		47400		42600

Note : All values in microcoulombs.
Voltages indicated are initial overvoltages.

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[21] J.A. Simpson, Loc. Cit.
[22] W.E. Ramsey, Phys. Rev. 57, 1022 (1940)

In continuous discharge, the microammeter gave a steady reading of the order of tens of microamperes (about 100 times the current at normal counting rates. It was thus possible to duplicate 10^6 counts in less than a minute, 10^7 counts in about five minutes and 10^8 counts in forty minutes. The current decreased slowly during the tests. This was consistent with the expected decrease in pulse size as noted before.

Of the continuous discharged counters, two of type A and all five of type B showed the same plateau deterioration as had their normally-run counterparts. That is, their plateau changed in the same manner indicated in Figure 7. Again, those whose total charge passage corresponded to an original overvoltage of 60 volts showed a lesser deterioration than those whose total charge passage corresponded to the higher original overvoltages. This would indicate that the passage of equal quantities of charge in either normal counting or continuous discharge has the same effect on counter characteristics.

The other two type A counters became unstable and went into continuous discharge at low voltages. However, both of these counters had sparked at least once (as had one of the type A counters which gave good results). Several tests with different types of counters showed that this type of instability is very often caused by sparking. The instability is thought to be due to damage to the cathode by the spark. As was seen, this damage does not necessarily always occur. This explanation of instability is further justified by the fact that the unstable counters do not become stable even after several weeks rest.

The results of the mass spectrographic analysis of a control counter, a normelly-run counter, and a corresponding continuous-discharged counter are shown in Figures 10, 11, and 12 respectively. The abcissa gives the mass number and the ordinate is expressed in arbitrary units of positive ion current as detected by the mass spectrometer. The mass peaks for the three counters were normalized by setting the argon peak in each equal to 100 on the assumption that the amount of argon in each counter was a constant (they were filled at the same time on the same manifold). The horizontal cross lines in **Figures** 11 and 12 indicate the corresponding mass peaks of Figure 10. Comparison of Figures 11 and 12 indicates that the change of the mass peaks is approximately the same in both cases. Thus the normal-running and the continuous discharge had the same effects on the quenching vapor.

No attempt is made to justify the increase of certain peaks and the decrease of others. All that was desired was a comparison of the two effects.

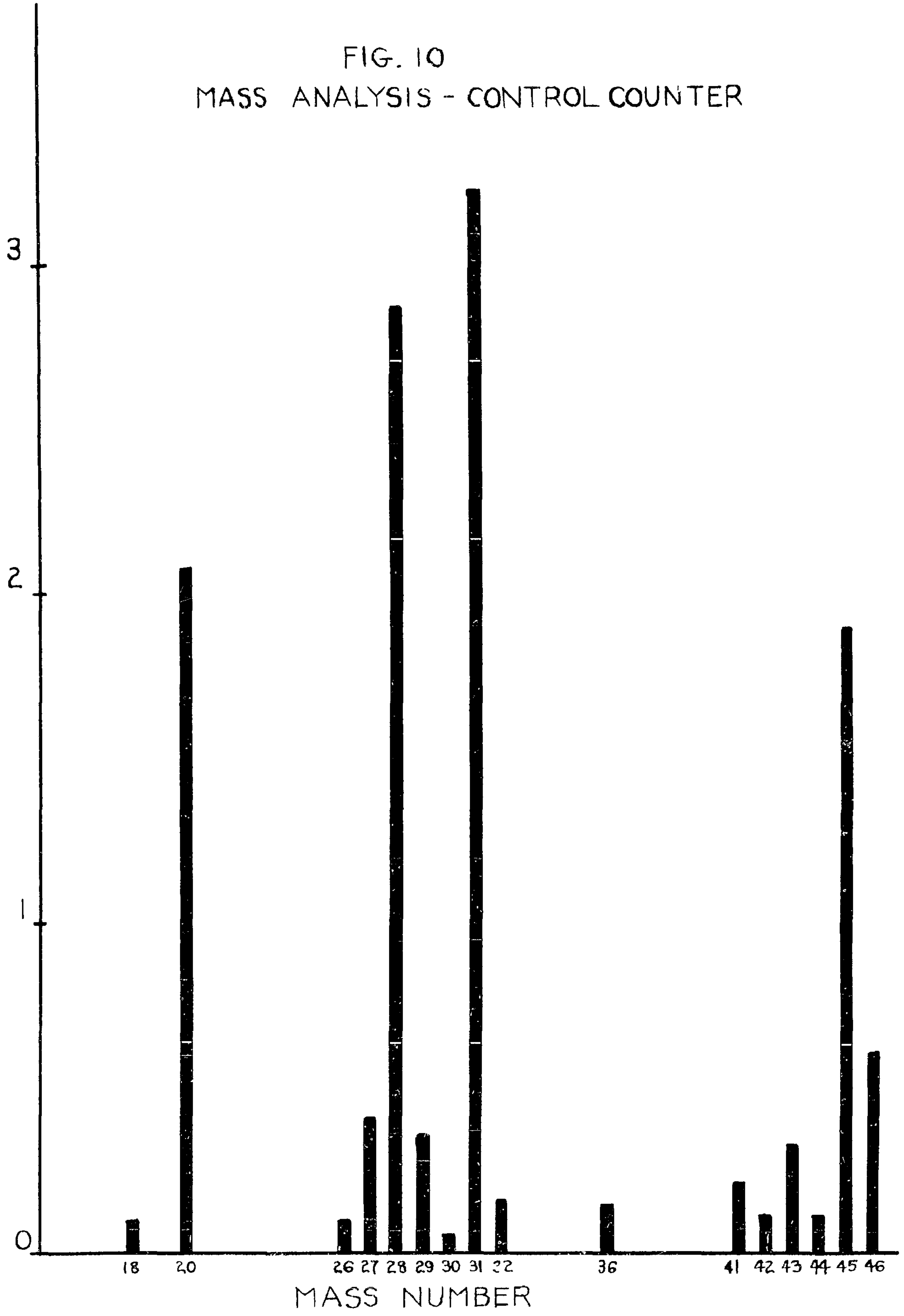


FIG. 10

MASS ANALYSIS - CONTROL COUNTER

FIG. 11 – MASS ANALYSIS
NORMALLY-RUN COUNTER

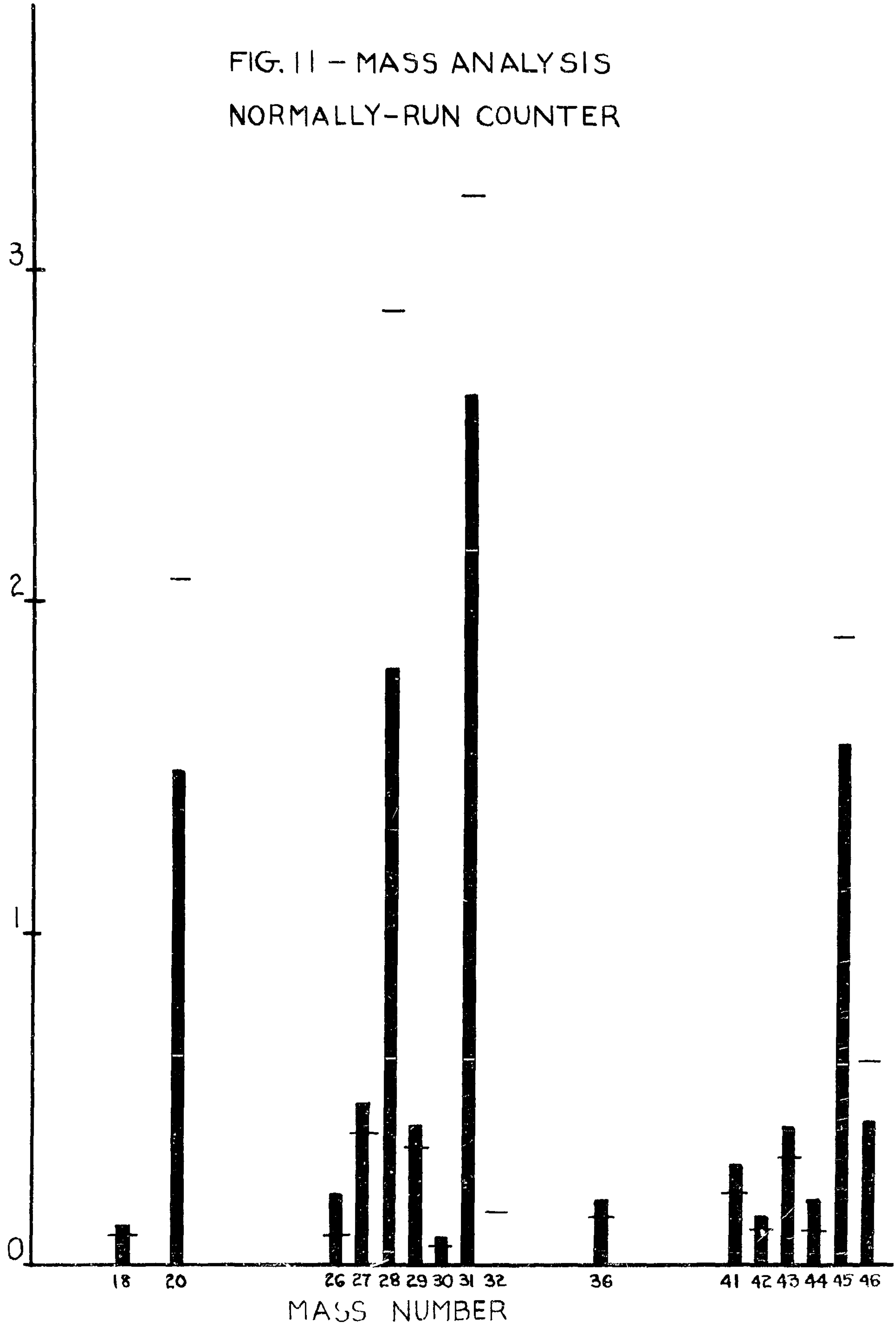
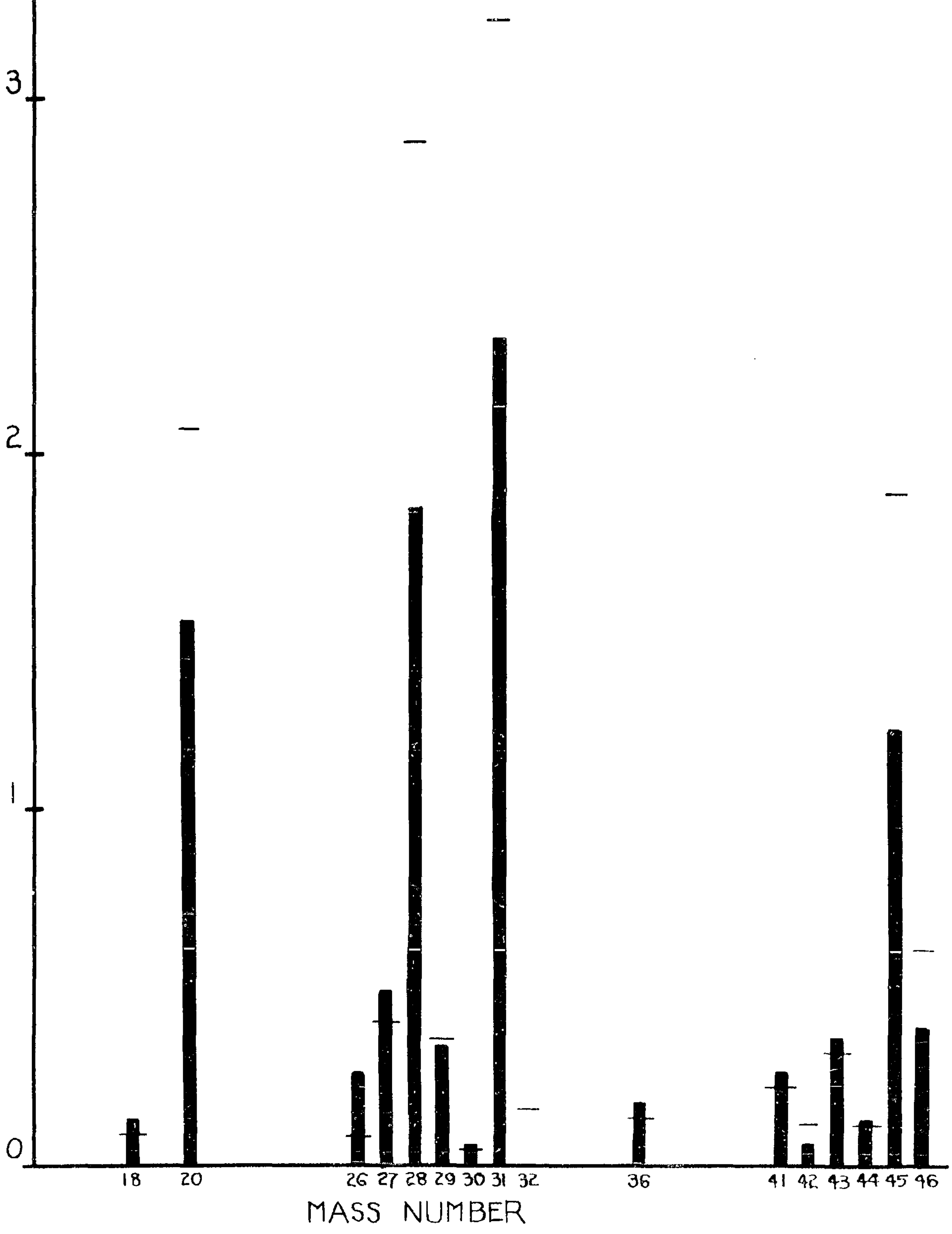


FIG. 12 - MASS ANALYSIS

CONTINUOUS-DISCHARGED COUNTER



CONCLUSION

Results indicate that the passage of equal amounts of charge through a self-quenching counter, in either normal-counting or continuous discharge, has the same effect. This is seen both in the changes of the characteristic curves and of the mass spectrographic analysis of the quenching vapor.

A possible use of this is for the acceleration of life-time tests which normally take a considerable length of time. The effect of a large number of counts can be quickly duplicated by passing an equivalent amount of charge in continuous discharge. In order to do this, correlation data with normal running (in regard to pulse charge) is necessary. Care must be taken when raising the voltage that the counter does not spark as we get above the plateau. As we have seen, this sparking may damage the cathode, invalidating any further results.

The Institute of Radio Engineers has recommended a method of life-test acceleration which is apparently based on the same principle:

> Accelerated Life Test[23]
>
> The tube is operated in the corona discharge region with enough series resistance to limit the tube current to a

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[23] Standards on Gas-Filled Radiation Counter Tubes: Methods of Testing, 1952, 52 IRE 7.S2, 7.3

> value equal to that which would be obtained at a given counting rate at the desired operating voltage. The counting-rate voltage characteristic is measured at intervals during the test. This test should not be used unless correlation data with normal life test are available.

We see that they "limit the tube current to a value equal to that which would be obtained at a given counting rate at the desired operating voltage". If such a procedure were followed, the rate of charge passage would be the same in continuous discharge as in normal counting. Thus it would take the same length of time to pass the same total charge. Thus the test would not actually be accelerated, for, as we have shown, it is the total charge which determines the plateau deterioration and the gas decomposition.

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