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DESCRIPTION AND OPERATION OF AN EXPERIMENTAL TUBE FOR A PULSED NEUTRON SOURCE

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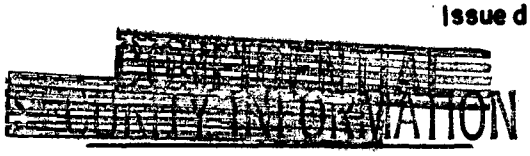

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DESCRIPTION AND OPERATION OF AN EXPERIMENTAL TUBE FOR A PULSED NEUTRON SOURCE

XR-1 Project
Radiation Laboratory, University of California
Berkeley, California

January 10, 1952

CLYDE WIEGAND

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I. INTRODUCTION

This report describes the construction and operation of an accelerator tube set up by the writer. The design of the tube is similar to those previously reported by J. D. Cow. The principal differences are in the ion source and the main insulator. Also an attempt was made to reduce the amount of contaminating organic materials in the tube.

The latest source design and operation are discussed.

II. DESCRIPTION

A schematic drawing of an experimental tube is shown in Fig. 1. The tube was used primarily to study the neutron yields from various ion sources and geometrical arrangements of the elements.

The main body of the tube was a piece of industrial Pyrex pipe of 4 inches inside diameter and 12 inches long. The ends of the pipe were clamped to brass plates with the clamps furnished with the pipe and were sealed with Teflon gaskets.

Two hollow cylinders of steel were used to shield the glass wall from the source and the deuteron beam. The shielding was necessary to minimize electrical breakdown over the glass insulator surface. Also the inner pipe around the source serves to focus or collimate the beam onto the target. The cylinders were made of steel, but could be made of any hard metal. Copper would be less suitable because spurious discharges between the two cylinders might tend to pit and roughen the smooth surface of such a soft metal and this would enhance the probability of breakdown discharges.

The glass pipe insulator was cleaned by washing with dilute HCl and rinsing with distilled water. Final cleaning of the insulator was done by a glow discharge at an air pressure of about 30 microns. After this treatment no difficulty was encountered in holding voltage pulses up to 400 kv.

The operating pressure of the tube as indicated by a VG-1A ion gauge located between the tube and liquid air trap was about 10^{-6} mm Hg.

The target used in this tube consisted of deuterized Ti metal melted into a thin layer on a Ta sheet backing. The preparation of such targets will be described in another project report.

III. VOLTAGE CALIBRATION

The potential between the source and target as a function of time during firing of the tube can be observed by means of the capacitance divider ring indicated in Fig. 1. The capacitance divider was calibrated by measuring the same high voltage pulse with a resistance divider made of fifty 2000 ohm 2 watt resistors plus one 50 ohm resistor all mounted in a lucite cylinder full of oil. The potential V_r across the 50 ohm resistor R_1 was assumed proportional to the total potential V_t. V_r was observed on a calibrated oscilloscope connected to R_1 by a coaxial cable. We have then:

$$V_t = \left(\frac{R_1+R_2}{R_1}\right) V_r = \left(\frac{R_1+R_2}{R_1}\right) S\, d$$

where R_1+R_2 is the total resistance, S is the sensitivity of the oscilloscope in volts cm^{-1} and d is the deflection in cm. The value of R_2 was 10^6 ohms and measured the same before and after periods of usage.

The capacitance divider was actually used because it was easy to install and will stand higher voltage than the resistor network. The same high voltage pulse appeared in shape quite similar on the two systems.

IV. YIELD CALIBRATION

The neutron yield per pulse was determined by slow neutron activation of Ag^{109} and subsequent counting of the induced β activity. The neutrons from the d-d reaction were slowed down in the insulating oil surrounding the tube. A thin aluminum wall Geiger counter surrounded by a silver foil was mounted directly in the oil. Calibration was accomplished by placing a standard Ra+Be neutron source at the target position and irradiating for a known time. The Ag activation was measured by counting for several half life periods after irradiation (usually 60 seconds).

The number of counts obtained is given by:

$$N_{cal} = g\,S \int_0^{T} e^{-\lambda(T-t)}\,dt = g\,S\,\frac{1}{\lambda}\left(1 - e^{-\lambda T}\right)$$

g is an efficiency factor which contains geometrical constants, the Ag cross section, Geiger counter efficiency, etc. It is common to the Ra+Be calibration and the d-d reaction and need not be known. S is the source strength in neutrons sec^{-1}, T is the time of irradiation and λ is the decay constant of Ag^{110}. The half lifetime of Ag^{110} is 24.5 sec. Its mean life time τ is then 36.4 sec and $\lambda = 0.028\ sec^{-1}$. It is convenient to irradiate for a time T equal to $T_{1/2}$. The above expression then becomes:

$$N_{cal} = \frac{g\,S}{2\lambda}$$

If now the Ag is activated by a pulse of the tube and we assume that the neutron energy spectrum of the Ra+Be source is the same as that of the d-d neutrons, we have for the number of Geiger counts N_{d-d} accumulated in 60 sec. after the pulse:

$$N_{d-d} = g\,N_n$$

where N_n is the number of neutrons emitted in the burst from the tube. Solving for N_n we have:

$$N_n = \frac{S}{2\lambda}\,\frac{N_{d-d}}{N_{cal}}$$

Most of the error in this determination probably results from assuming that the neutron energy spectra are equal. Also considerable care must be exercised in placing the Ra+Be source to imitate the d-d target. The absolute value of N_n may be considered to be known within about a factor of 2. The accuracy of relative yields using the same target,

moderator, and counter arrangement are dependent upon the counting statistics of N_{d-d}.

A typical set of values were:

$S = 7.4 \times 10^4$ neutrons sec^{-1}

N_{cal} = 400 counts obtained during 60 sec. after irradiation

N_{d-d} = 640 counts obtained during 60 sec. after firing

$N_n = 2.1 \times 10^6$ neutrons.

V. ION SOURCE

A. Description and Operation

The ion source is the crux of the tube and will likely present the most difficulties in developing a successful pulsed neutron source. Several types of sources were studied and were discussed in a previous project progress report.

The latest design involves a modification of the deuterized Ti globule and W-point gap type. It was apparent that the LiD crystal source fired more consistently than the metallic gap type and with the same voltage across it although the path between conductors was considerably longer for the LiD source. The principal difference was that the discharge took place over the insulating LiD surface whereas with the deuterized Ti and W point arrangement the original discharge started in vacuum. It is well known that dischargee are prevalent over insulating surfaces.

The thought occurred that perhaps this usually aggravating situation was responsible for stabilizing the discharge of the LiD crystal source and could possibly be used to favorably affect a deuterized Ti source.

Accordingly, a source was constructed as illustrated in Fig. 2. The deuterized Ti on Ta backing was a scrap trimmed from a target sheet and wrapped around the ceramic tubing. The W point was the usual .010" wire. The ceramic tubing provided a spacing of .018" between the wire and deuterized Ti.

This source operated satisfactorily with 5 kv on the 0.1 mfd capacitor of the source pulsing circuit. It was fired once every 5 to 10 seconds for a total of 3857 times in two periods of operation and was still usable when taken out of the tube for examination. With high voltage pulses of 350 kv the yield per firing was between 10^6 and 2×10^6 neutrons. Best results were obtained with "simultaneous" firing of the source and H.V. pulser.

The shape of the high voltage pulse is critically dependent upon the characteristics of the source. Clean appearing round bottomed pulses as shown by A in Fig. 3 are always associated with high neutron yields. When a source misbehaves the high voltage pulse is jagged and not symmetrical as illustrated by B. The operation of a tube can be determined rapidly and effectively by repeated firings at definite intervals. An automatic device was made to fire the triggering pulser at intervals adjustable in the range from 1 to 20 seconds and to register the number of firings. Of course, the activity of the silver foil around the Geiger counter builds up, but it reaches equilibrium in a few half lifetimes and then the average yield for each firing is readily determined. Perhaps a count rate indicator would serve better than an ordinary scaling circuit.

By observing the high voltage pulses and the neutron yield when the tube is firing at a constant repetition rate one can readily determine when a source is working properly. A LiD crystal source was fired 2300 times at intervals of 5 sec. The pulse shapes were clean and very similar. Several sources using deuterized Ti and W points only were likewise observed. The yield was lower and erratic and the pulse shapes were not constant. Sometimes there would be several clean pulses in succession and then some jagged ones and again clean ones, etc. The ceramic insulated source gave pulses whose uniformity was comparable with that of the LiD crystal source.

At the present time, we are constructing a source similar to the one of Fig. 2 except that the deuterized Ti will be replaced by a strip of Ti metal secured to electrical conductors at each end. The strip will be narrower at the place where it is in contact with the ceramic insulator. The whole source can then be placed in a deuterium atmosphere and the Ti treated in the usual manner. This arrangement should be suitable for use with tritium.

B. Source Contamination

A disturbing aspect of the operation of the tube is that the first pulse after an extended period of inactivity does not give a good neutron yield. If the tube has been operating satisfactorily and then is left idle for, say, an hour, the next pulse even though it appears good will not give a reasonable neutron yield. This situation probably arises from contaminants settling on the surface of the source. Foreign layers on the target are of secondary importance because the range of 300 Kev deuterons is of the order of 1 mg cm^{-2}.

Let us speculate for a moment on the time required for a mono-molecular layer of O_2 to settle on the deuterized Ti surface of the source. Assume that the pressure is 10^{-6} mm Hg (1.3×10^{-3} dynes cm^{-2}) and the temperature 300° K. The number of molecules which strike a surface per cm^2 x sec is:

$$n = \frac{p}{\sqrt{2\pi m k T}} = 3.5 \times 10^{14} \frac{O_2 \text{ molecules}}{cm^2 \times sec}$$

m is the mass of the molecule and k is Boltzmann's constant. If we take 3 angstroms as the diameter of O_2 molecules a mono-molecular layer would contain about 3.55×10^{14} molecules. Thus we see that a mono-molecular layer of O_2 will cover the surface in about 1 sec. We know that it takes about 10^{12} accelerated deuterons to yield 10^6 neutrons.* So it is clear that a mono-molecular layer of most any contaminant can overwhelm the deuteron current. Of course, not all of the molecules will stick to the surface so the claculation is pessimistic. However, the order of magnitude of the time for contamination is probably 10^6 times shorter than we would like. One can think of several possible solutions to the problem and it is certainly one that will have to be reckoned with.

Upon completion of our well-baffled mercury diffusion pumping system we shall try to obtain more data on the contamination effects.

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*Coon, Davis, Graves, Manley and Nobles in MDDC-206 give the ratio $n/d = 7 \times 10^{-7}$ at 300 Kev using a D_2O target.

C. Gas Emission and Ionization

The amount of gas released by a source can be roughly determined by closing off the tube from the pump and firing the source. When this is done we find that the ion gauge indicates between 10^{15} and 10^{16} molecules that get to the gauge past the liquid air trap. From the ratio $n/d = 7 \times 10^{-7}$ we find that the order of 10^{12} deuterons are accelerated to yield 10^{6} neutrons. Therefore the overall ionization efficiency of the source to produce deuterons which reach the target is between 10^{-8} and 10^{-4}.

VI. DEUTERON BEAM DISTRIBUTION AND SPACE CHARGE

An experiment was made to determine how the deuteron beam was distributed over the target. The spacing from the inner pipe to the target was set at 4 cm and with a target diameter of 7.5 cm, the neutron yield was found to be 2.5×10^{6}. The target was then masked by a Cu foil with a 2.5 cm diameter hole in the center and the yield was found to be about 0.6×10^{6}. The diameter of the hole was next increased to 5 cm and the yield again increased to 2.5×10^{6}. Since the yield increased about proportionally to the area of the target up to the point where the area of the inner pipe and target were equal we can conclude that the deuteron current density is uniform over the open end of the inner pipe.

It would be interesting to know if the deuteron current is limited by the space charge. If we consider the end of the inner pipe to be a uniform emitting deuteron surface, we can calculate the current density j from the well known relation:

$$j = \frac{1}{9\pi}\sqrt{\frac{2e}{m}}\,\frac{V^{3/2}}{d^2}$$

where e/m is the charge to mass ratio of deuterons, V is the potential and d the distance between the inner pipe and the target. When V is 300 kv and d is 4 cm, the current density j turns out to be 0.3 amps, making a maximum total current of 8 amps.

Let us make an estimate of the deuteron current from the measured neutron yield, target efficiency, and high voltage timing. Suppose that the tube yields 10^6 neutrons at 300 kv, during 0.5×10^{-6} sec. Assuming $n/d = 7 \times 10^{-7}$ at 300 Kev, the current during the pulse will be:

$$i = \frac{10^6}{7 \times 10^{-7} \times 6.3 \times 10^{18} \times 0.5 \times 10^{-6}} \simeq 0.5 \text{ amps}$$

Therefore, unless the deuterized Ti targets are less than 1/10 as efficient as D_2O targets, the tube is probably not space charge limited in the region between the inner pipe and target providing the deuteron beam is pure.

ADDED NOTE ON TARGET EFFICIENCY

If we assume the composition of the target to be TiD, an estimate of the target efficiency compared with that of D_2O can be made. Mr. M. Ruderman of the Theoretical Group of the Radiation Laboratory has made such an estimate based upon experimental values of proton stopping powers in the energy range of 100 kv to 500 kv. He found that the efficiency for producing neutrons at a deuteron energy of 300 kv for a TiD target should be about one-half that for a D_2O target. The reason is that even though the atomic number of T is 22/8 that of oxygen, the inner electrons of the higher Z elements are not very effective in stopping low energy deuterons.

Captions for Figures

Fig. 1: Schematic diagram of accelerator tube and associated components.

Fig. 2: Illustration of coaxial ceramic insulated source.

Fig. 3: Illustrations of potential across the tube as a function of time during firing. A is a clean pulse associated with high neutron yield. B is a typical pulse obtained when the source fires unsatisfactorily.

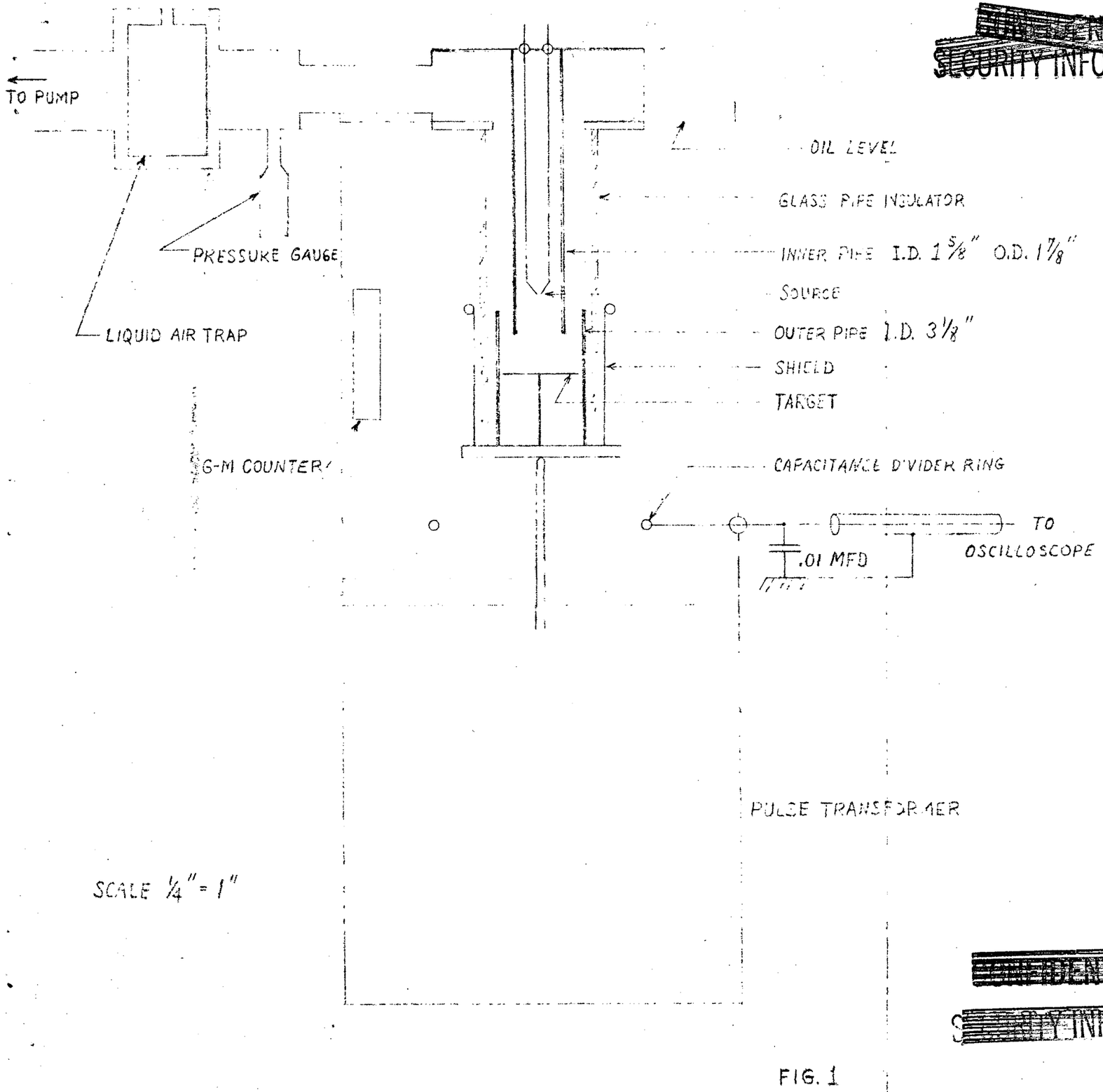

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FIG. 1

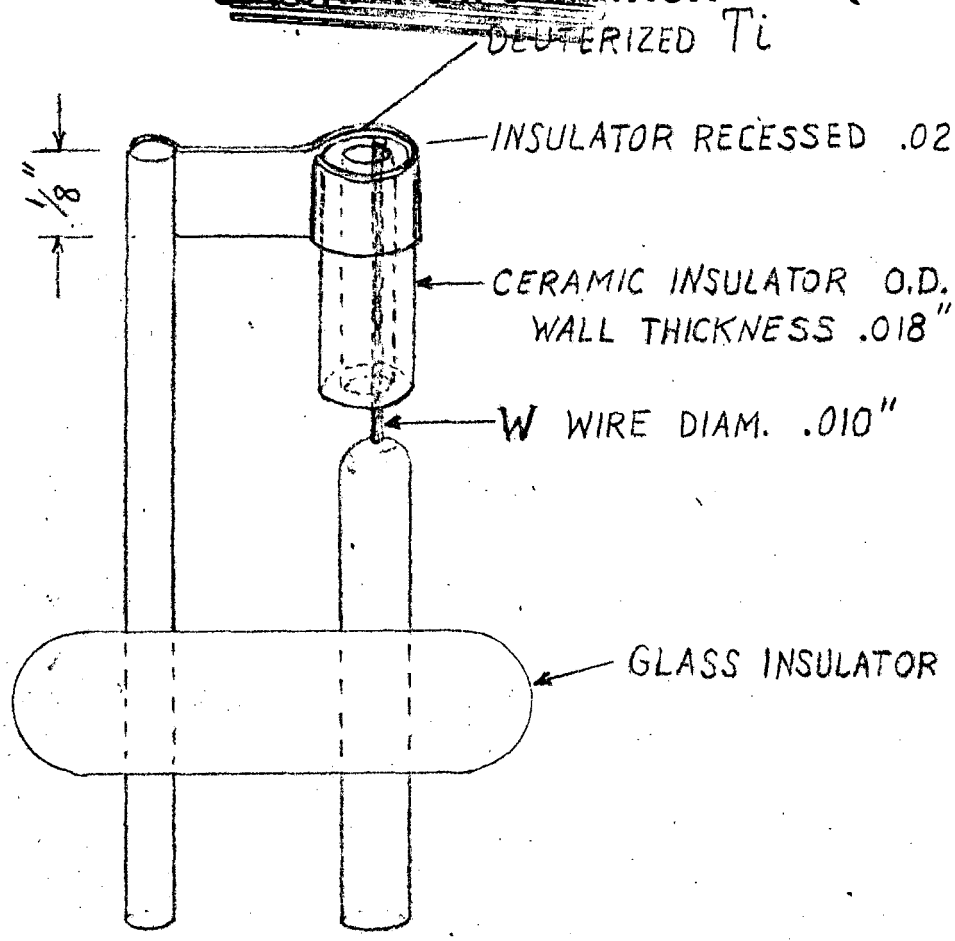
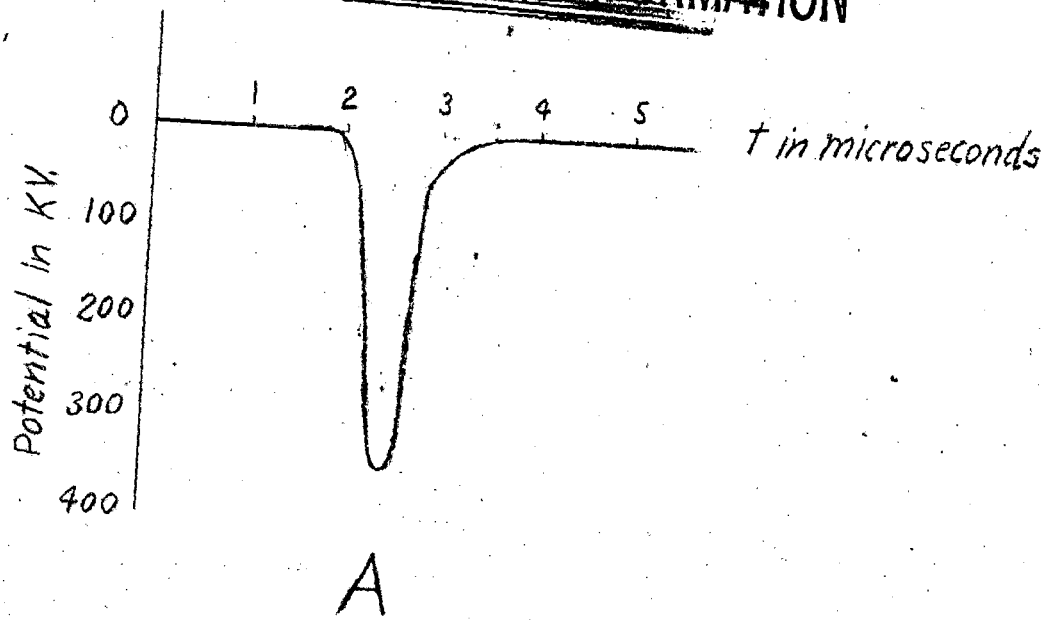
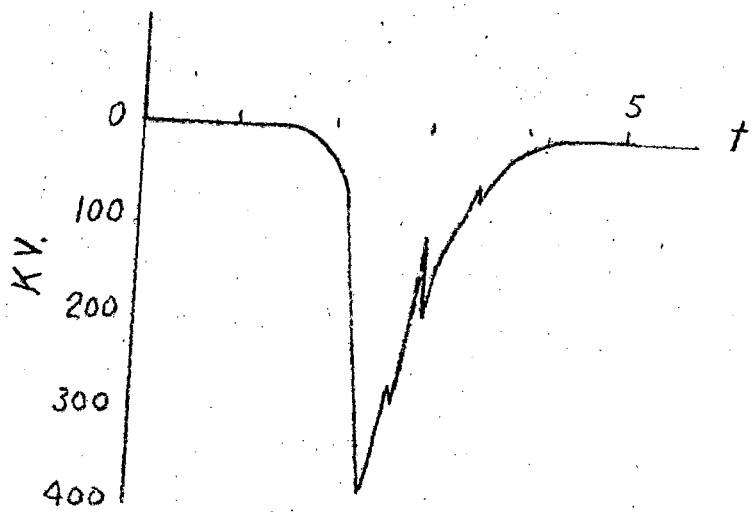


FIG. 2



A



B

FIG. 3