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[redacted] PRELIMINARY REPORT

J. D. Gow, Ed Seaman, Wing Pon, R. Brumbaugh

July, 1951

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[redacted] PRELIMINARY REPORT

J. D. Gow, Ed Seaman, Wing Pon, R. Brumbaugh

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

July, 1951

The problem of producing a pulsed source of neutrons of extremely high intensity having a duration of the order of 1 microsecond or less has been of interest for several years. A method for building such a device was proposed by one of the authors of this report in the fall of 1950 and subsequent work on this scheme resulted in a tube which does meet the requirements. Although the original scheme has been modified, the basic ideas are used in the present tube. The original proposal was to load a filament made of one of the hydrogen occluding metals (such as Zr, Ti, etc.) with deuterium, place a target of a similar metal loaded with tritium nearby, explode the filament electrically having provided a potential difference between the filament and the target of the order of 100 kv. The thought was that the filament would reach a temperature of 10 to 20 thousand degrees C which would ionize an appreciable amount of the deuterium in the filament. These ions would then be accelerated radially to the target by the high voltage supply. Calculations show that the D ions would reach the target in the order of 10^{-8} sec., while neutral gas liberated at the time of filament explosion would take of the order of microseconds to reach the target by thermal velocities, hence electrical breakdown of the vacuum would be sufficiently delayed to make the scheme work. An axial magnetic field was provided to return photo electrons to the target to prevent breakdown from this cause.

Fig. 1 shows a sketch of the scheme as originally proposed.

Positive Ion Emitting Filament

The first suprising discovery came about early in the work. This was that a titanium or zirconium filament which was loaded with deuterium could not be exploded with the expected voltage and reasonable size capacitors. In fact, to so explode such a wire it is necessary to have the order of 100 times as much energy as is required to explode the same wire which is not loaded with gas. Investigation disclosed that the gas is liberated from the filament so fast that there is a gas sheath at quite high pressures around the filament before the metal has been raised to incandescence. Since the voltage across the filament is high (5 - 15 kv) this gas sheath will ionize and carry the current which prevents further heating of the wire, the arc resistance being very low.

The arc formation time is undoubtedly a function of the rate of rise of current in the filament. With good fast capacitors, and a low inductance circuit dumping them into the filament, the arc seems to form in the order of 10^{-7} sec. The discharge from the capacitors becomes oscilliatory at the time of arc formation since the resistance of the circuit drops to an extremely low value, and the arc persists until the energy of the capacitors is dissipated in the circuit. With our typical operating values this takes of the order of 1 to 2 microseconds. It is also found that a small fraction of the total gas storage in the filament is used in any one pulse. Since no damage is done to the filament in the process described the filament can be pulsed many times before all of the gas is used up and it burns out like an unloaded wire.

The ion output of the filament consists of a mixture of D^+ and D_2^+ or molecular ions. A simple mass spectrometer was built in which the ions were accelerated through a slit in front of the filament and bent magnetically to form an image of the slit on a fluorescent screen. From this experiment it was found that the major portion of the ions were in the D_2^+ beam with less than 1/3 of the total current being D^+. There is some evidence that this measurement may be in serious error. To check this a carefully made 60° spectrometer is under construction. Data on this machine will begin to be taken around August 1.

The mechanical design of the filament for use in the tube was purely an experimental matter. Many schemes were tried before a satisfactory filament was developed. The filament is pulsed by connecting it across a capacitor of around 0.02 mfd which is charged to 10 - 15 kv using a 5C22 hydrogen thyratron as a switch. The current is of the order of 5000 amperes with a rise time of the order of 10^{-7} sec. With such currents considerable difficulty was met in providing contact between the filament and its support leads. Various clamping arrangements and Cu plating were tried but results were erratic due to contact resistance troubles. The solution consisted of using copper support rods which were drilled and then sweging the filament into the copper rod at each end (Fig. 2). This technique has provided filaments of good reliability. The metal totanium was finally selected as a filament material although there is little evidence that other occluding metals used the same way would not be as good. The filament is cut from 0.002 in. titanium sheet, is of the order of 0.020 - 0.030 in. wide and 1/8 in. to 3/16 in. in length. These dimensions provide a filament which will "go" with reasonably low electrical energy requirements and has reasonably good mechanical properties.

Target

In the first of the tubes a stainless steel cylindrical target which surrounded the filament was used. This target was coated with a thin layer of titanium and could be loaded with either deuterium or tritium depending on the desired reaction. Using the yield values given by Taschek and Williams (Rev. Mod. Phys., Oct., 1949) adequate numbers of neutrons should be available from such a target. It was later found that their number as given by their D-D yield curve is high by a factor of approximately 20. For the experimental tubes a coating of deutero wax is used which has a low enough vapor pressure to permit its use in a continuously pumped tube, and has a higher deuteron to electron ratio which gives larger yield than the TiD_2 targets. For sealed off tubes it is planned to use LiD or some similar hydride, its metallic member having low Z.

Linear Geometry Tube

Due to troubles with electrical breakdown which were experienced with the cylindrical geometry tube a linear tube was built as shown in Fig. 3. The target is a flat disk approximately 3 in. in diamter, coated with deutero wax. This was the first successful tube from a standpoint of yield and reliability. The tube consists of a four inch industrial glass tee gasketed to a flange on a porcelain insulator. The filament rods extend downward from the top of the tube, projecting a short distance into the porcelain high voltage insulator. In this tube 2 filaments were so mounted. The vacuum pump is connected to the side arm of the T, the lower arm of the tee being connected to the grounded flange of the high voltage insulator.

The target is supported from the lower end of this insulator and is recessed up into the insulator such that the target to filament distance is around 2 in.

Measurement of Yield

The entire tube (as shown in Fig. 3) is mounted on a paraffin moderator. A channel through this moderator permits a silver foil to be inserted. In measurement of yield the silver is placed in the moderator, the tube is fired and the silver is quickly tranferred to a Geiger counter. The decay of the 23 sec. Ag^{110} formed in the reaction $AG^{109}(n,\gamma)AG^{110}$ is counted. Normally this is counted for one minute. Typical induced activities are from 100 to 1000 counts in one minute, depending on the details of the geometry, with a background of 20 counts per minute. Since geometrical factors which would be difficult to evaluate are present the yield is not calculated directly from the geometry and the activity. Instead a calibration is made using a Ra - Be source of known strength which is placed in the target position for a known length of time. The silver is irradiated in the same position as it is during a tube run, then counted in the same way. The number of neutrons/sec. for the source was determined by comparison with a source calibrated at Los Alamos.

To produce reasonable activity in the foil and to minimize errors in time of exposure the time of irradiation of the foil during calibration must be reasonably long. For convenience it is chosen to be 23 sec. or one half-life of the Ag^{108} activity. A mathematical correction must be applied to arrive at the equivalent "instantaneous" yield corresponding to a given total number of neutrons supplied by the source. With the geometry as shown in Fig. 3 one count/min. corresponds to approximately 1.7×10^4

neutrons emitted from the target, or 60 counts above background corresponds to roughly 10^6 neutrons.

For reasons of convenience all work to date has been done with the D-D reaction. Since eventually either the target or the filament will be loaded with tritium the yield with the D-T reaction is of greater interest. The ratio of the thick target yield going from the D-D reaction to the T-D reaction is given by Tuck as 77 at 100 kv which we take as out effective energy. This ratio is not too sensitive a function of energy in the region of interest varying smoothly from 77 to 100 kv to a maximum of $\sim$ 110 at 200 kv and then falling slowly. Since we have a mixture of D^+ and D_2^+ ions striking the target the effective value of this ratio will be somewhere between that for the applied voltage and for 1/2 the applied voltage.

An additional factor which affects the yields favorably is that we plan to use the D-T reaction rather than the T-D reaction. This gives an increased yield from the greater penetration of the deuterons and the greater energy available in the center of mass with the lighter particle accelerated. Putting in these corrections the ratio of the D-T to D-D yield will be above two hundred.

Electrical Circuitry

In order to produce neutrons with the present tube two basic electrical requirements must be met. The filament current must be switched on through a low inductance path from the capacitors, and sometime during the filament pulse there must be a voltage of around 200 kv appearing between the filament and the target. The first of these requirements is met by a coaxial pulser using type 5C22 hydrogen thyratron to discharge two "Glass mike" 0.05 mfd capacitors in series into the filaments. The pulser circuit is as shown in Fig. 4. Filaments have been run in parallel connection, series connection, and separately, successfully. Series connection is the preferred arrangement. The condensers are charged to 10 - 15 kv before firing. The choice of capacity is relatively noncritical.

In the early experiments a fixed d.c. potential of around 100 kv was used between target and filament for accelerating the ions. The troubles encountered with electrical breakdown in the vacuum coupled with the need for 200 kv to produce an effective deuteron energy of 100 kv for the D_2^+ beam led to the use of pulse transformers of the Baker-Kerns type which were developed in this laboratory (see UCRL-357). These transformers provide an excellent source of high voltage pulses in the 10^{-7} to 10^{-5} seconds range with fully adequate rise time for our application. The present transformer will deliver a pulse with around 3 or 4 x 10^{-7} second rise and an open circuit voltage of over 300 kv. Measurements indicated a pulse generator impedance of the transformer output of around 3000 ohms. Since the total current of the tube is around 30 amperes the voltage applied during a neutron producing pulse is around 200 kv. The pulse shape is smooth having half voltage points separated something like 0.3 to 0.4 microseconds. Since the yield vs. voltage of D-D or D-T reaction is a steep function of the energy of the incident particles and an additional factor of $E^{3/2}$ comes in due to the ion currents probably being space charge limited, practically all of the output is within 0.2 μsec.

The transformer primary is pulsed by switching 3 .03 15 kv capacitors across it using a 5C22 hydrogen thyratron. Although from a standpoint of current both thyratrons are grossly overloaded, due to the extremely low duty cycle, no trouble has been experienced. Normally both the filament and the high voltage thyratrons are triggered simultaneously, the rise time of the transformer providing sufficient delay in the high voltage to allow the filament to reach its operating condition. The timing is relatively noncritical. Delays of the order of 0.1 microsecond to the filament or 0.5 microsecond to the high voltage produced little if any reduction in output.

Vacuum

The tubes have been continuously pumped using an MC 500 pump with a liquid air trap to catch any oil between the pump and the tube. In general operating pressures were maintained at 2 to 5 x 10^{-6} mm Hg on a trapped gauge. A series of experiments were run to determine the effect of higher pressures using air, H_2 and D_2. In all cases no effect of pressure was observed up to 5 x 10^{-4} mm. At around 10^{-3} mm appreciable loading of the pulse transformer began to be noticed. The only vacuum precaution required is to keep the trap full to prevent the release of large amounts of oil vapor which if allowed to condense on the target can seriously degrade the energy of the impinging ions before they reach the target.

Mark II Tube

The above data refer to the Mark I tube which was in operation early in June. During the last week of June a new deisgn was developed which out performs the first tube in every respect. This tube has considerably more yield at some slight increase in complexity. The basic change stemmed from an attempt to shield the discharge region from the insulator. It proved that the insulator seeing the discharge was a bad thing from a standpoint of holding voltage and the changes enabled smooth operation of the tube at 200-250 kv. This also improved the space charge problem and the available output seems entirely limited by the impedance of the pulse generator. A sketch of this tube is shown in Fig. 5. The changes from the Mark I geometry consist of placing a copper piece around the filaments extending down to within 2 1/2 inches of the target, and bringing a copper pipe up from the target outside of and concentric with the filament shield pipe.

Operation of this tube is somewhat different than that experienced with the Mark I tube. First, it is no longer permissible to fire the high voltage and the filament simultaneously. Instead a delay of the order of 1 microsecond is required which apparently permits the upper pipe to become filled with ions. When the high voltage is pulsed the current which will be drawn depends on how much energy was dumped into the filament circuit and how much delay is used. Since the current is now being drawn from a large surface the space charge limitations have dropped from sight and the currents can be made as large as the pulse transformer will take. With this geometry pulses of 3×10^6 neutrons on the D-D reaction are normal and at optimum operation 5×10^6 is not infrequent. Lower impedance pulse transformers are under way which should materially increase the above figure.

Another interesting feature of the Mark II tube is that the filament life is extended greatly. It is suspected that this results from the filaments being recessed in the shield which prevents the high voltage pulse from striking arcs to the filaments. The upper limit on filament life with this geometry is at present unknown. One set of filaments were operated for over 600 shots with no evidence of potential failure.

Conclusions

At the present state of the project it is possible to say that pulsed neutron source tubes of the type discussed can be constructed which will give yields of 10^9 neutrons in a time of the order of 0.2 μsecond. There is no apparent reason why such tubes can not be made in a sealed off form and supplied with highly portable power supply equipment. It further appears likely that with a somewhat more bulky power supply and a somewhat larger tube neutron pulses of over 10^{10} in 0.2 μsecond can be produced. Such a simple device with this output should prove useful in neutron physics.

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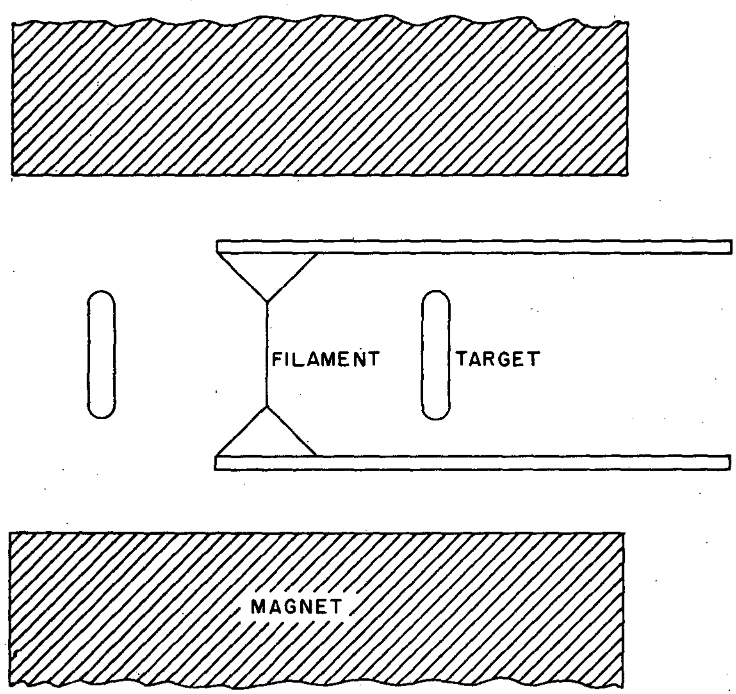

FIG. 1

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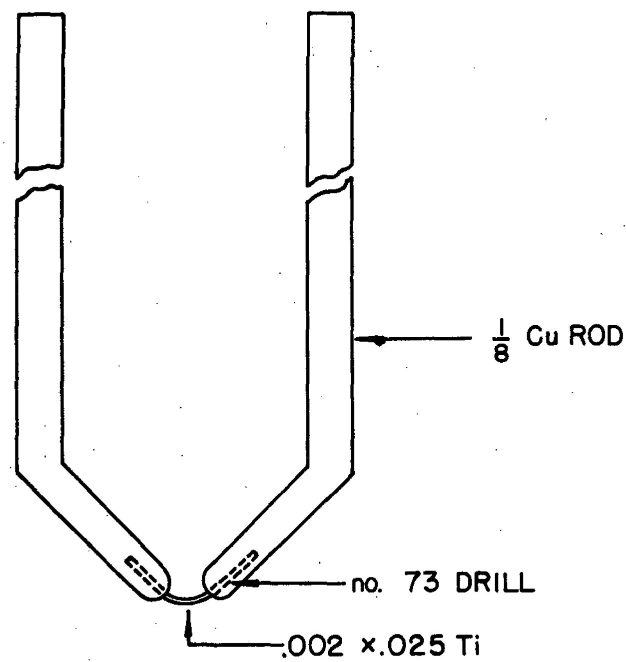

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FIG. 2

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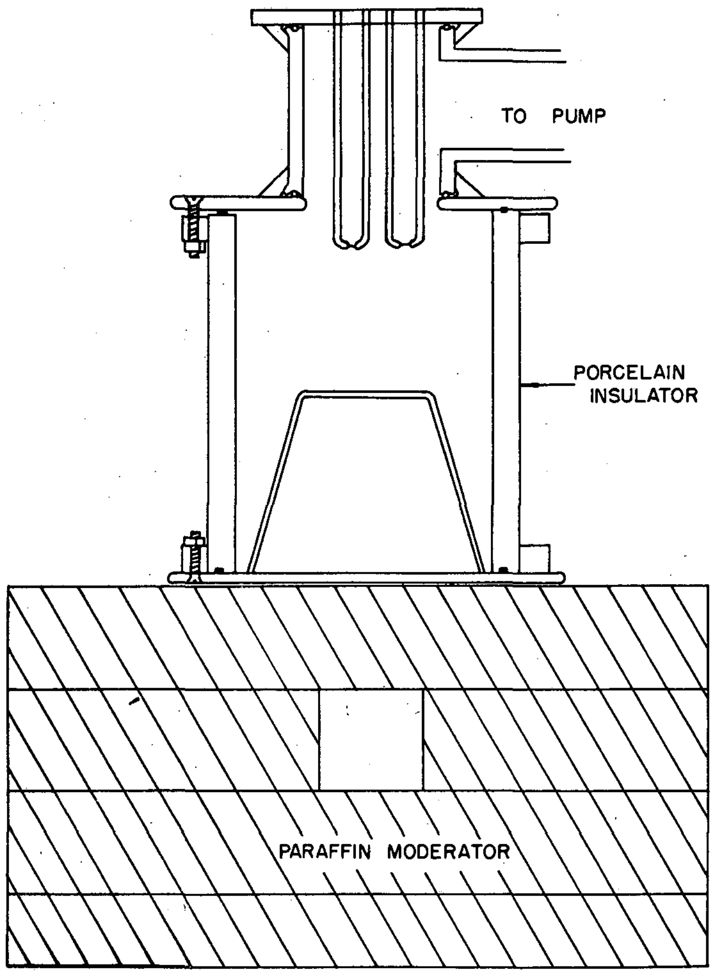

FIG. 3

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FIL PULSER

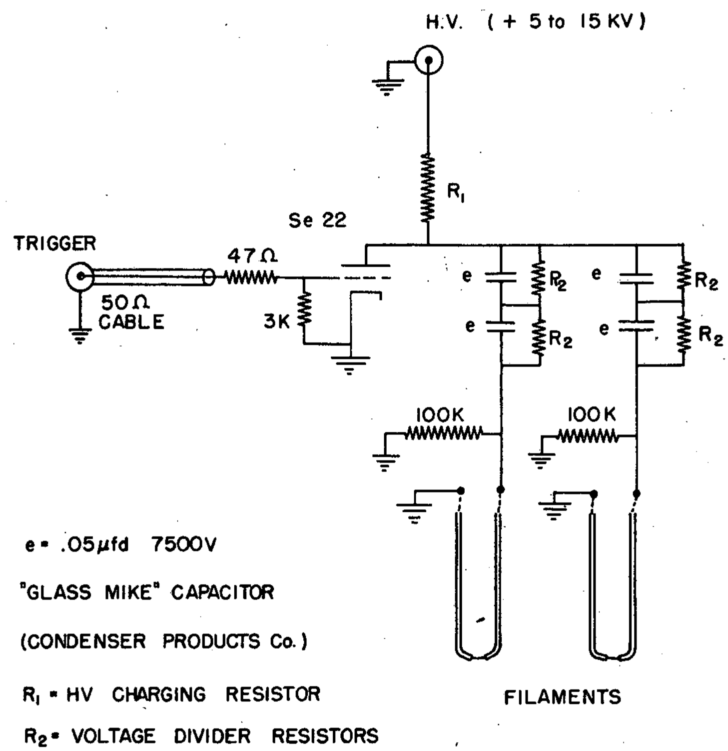

FIG. 4 MU2364

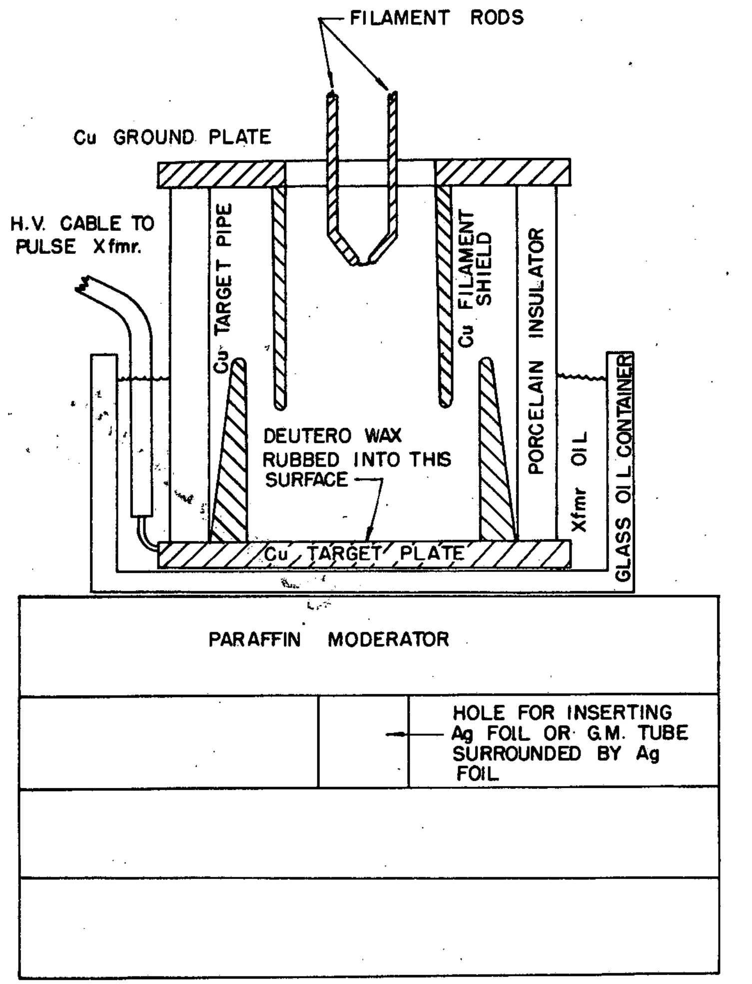
FILAMENT RODS
Cu GROUND PLATE
H.V. CABLE TO PULSE Xfmr.
Cu TARGET PIPE
Cu FILAMENT SHIELD
PORCELAIN INSULATOR
GLASS OIL CONTAINER
Xfmr OIL
DEUTERO WAX RUBBED INTO THIS SURFACE
Cu TARGET PLATE
PARAFFIN MODERATOR
HOLE FOR INSERTING Ag FOIL OR G.M. TUBE SURROUNDED BY Ag FOIL

FIG. 5

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