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Lawrence Ruby

April 1954

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Progress Report to February 1, 1954

Lawrence Ruby

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

April 1954

ABSTRACT

Progress in developing a high-output pulsed proton source is reported. The XR1 ion source has been examined to determine the factors influencing its operation. The manner of pulsing this source and measuring the beam current is described. Disadvantages of the XR1 source are discussed together with the characteristics of improved versions developed during the period covered by this report. Representative output data are presented and the future experimental program is outlined.

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SPECIAL DEVELOPMENTS PROJECT
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This project was initiated in the fall of 1953 for the purpose of developing, for a special application, a proton source that would produce several amperes of current over about 10 microseconds and with a high ratio of ions to neutrals. In the XR1 project[1], a successful pulsed source was made using the ability of the transition metals to dissolve hydrogen in very large quantities at low temperatures (Table 1). This absorption is accompanied by large volume expansions (10 to 15%) and by embrittlement. The evidence[3] is quite conclusive that in this class of metals, the hydrogen is not only found in lattice rifts, as is the case in other hydrogen-absorbing substances, but also is distributed regularly within the lattice structure. This hydrogen is contained in the atomic form, at least partially ionized, and, in fact, probably in the metallic state[4]. This last conclusion is suggested by the fact that although the size of the hydrogen atom is small enough to require no expansion of the Pd lattice to contain it, the observed expansion is 11%. It has been calculated that metallic hydrogen would be stable relative to covalent hydrogen at pressures not less than 2.5×10^5 atmospheres, and such an internal pressure in Pd would require a volume increase of about 10%.

Titanium at low temperatures has the largest known capacity to dissolve hydrogen (Table 1). In fact, the volume concentration of hydrogen in it is greater than in any other form in which hydrogen is known to exist. In addition, titanium is available as a metal in several forms, and thus it was the logical choice for the XR1 experiments.

The original intention was to release the absorbed gas at a high temperature by electrically exploding a Ti wire. However, it was found that before sufficient energy was absorbed to vaporize the metals an arc was

formed, which shunted the source and prevented further heating. The resulting high ion current and the advantage of reusing one source several hundred times made the arc-forming mechanism appear entirely unobjectionable. Various arrangements of Ti wires and ribbons were tried, but the most successful source was made by evaporating the metal in vacuum onto a quartz rod about a millimeter in diameter and two centimeters long. The amount of the deposited material was a few tenths of a milligram. The coated quartz was then banded with Ni or Ti bands spot-welded to support rods. The source was loaded by heating it by conduction or by radiation to the activation temperature,[3] which is just under red hot, and then allowing it to cool slowly in the presence of hydrogen at a few cm pressure. In later models the metal coating was put on in a spiral layer in order to increase the path length. This was done by using a wire mask, which was subsequently removed. Careful precleaning of the quartz was necessary to prevent the titanium from flaking after being deposited. The resistance of a completed source was in the neighborhood of a few ohms. This was the source used as a starting point in the present study.

To obtain pulses of a definite duration, a pulse line was constructed to fire the source. When matched with 10 ohms, this line produced 15-microsecond pulses with short rise and decay times (Fig. 2). Positive pulses were chosen for any additional acceleration they might provide. The early geometry for measuring beam output consisted of a grounded shield around the source, an accel electrode at negative DC potential, and a long cup that was also at accel potential but which could be partially discharged by the beam (Fig. 2). The capacitor C_1 was selected so that the voltage change across it due to the beam was small relative to the accel voltage. The capacitor C_2 was chosen to make the discharge of the accel due to beam loading small. In the course of the first four months of operation, collection current was measured as a function of source and accel voltages and of changes in the spacings of the electrodes. The 1/2-inch-diameter hole in the accel electrode was not varied initially, as this dimension was prescribed by the application for which the source was eventually intended.

The source-charging voltage was varied from 2 to 15 kv, and in order to get reasonably consistent data, i.e. ±50%, it was necessary to wait for at least one minute between shots. Some data were taken initially with pulses of about one μsec, obtained by using a 0.2 μf capacitor in place of the pulse line. With C_1 = 2 μf and C_2 = 15 μf it was usual to collect from 4 to 8 v, i.e. from 8 to 16 amp, for one μsec. The collected current was a sensitive function of charging-line voltage but an insensitive function of accel voltage above 50 v. Accel-voltage measurements were limited to values below 200 v by a breakdown phenomenon characterized by an appreciable discharge of the accel capacitor, collection of up to 10 times the usual current, and a large gas kick. Nevertheless, the identification of breakdown was not unambiguous. In order to maintain the accel voltage in the presence of breakdowns, the accel capacitor C_2 was increased to 250 μf.

After a few hundred shots, the source output would become erratic and require progressively higher line voltages. Examination then showed that in places the Ti had been flaked away, especially near the band on the high voltage side. Also, a greyish metallic deposit was always to be found covering the band and adjacent Ti on the ground side. This deposit had a high resistance and it was sometimes necessary to reband an otherwise good source in order to restore a low-resistance contact to the Ti. X-ray diffraction analysis could not identify this substance as any known compound of Ti or Ni with O, N, or H.

With the XR1 source, the only apparent difference in going from 1- to 15-μsec pulses was the onset of breakdown at lower accel voltages, i.e. 80 v and above. The requirements of our source application now made it desirable to have a 1-7/8-inch-diameter hole in the accel electrode and a 2-inch-diameter hole in the collector cup. With the consequent increase in the collected beam, the capacitor C_1 was changed to 2000 μf and C_2 to 575 μf. Collected current ranged up to 250 amp at 65 v accel. When C_2 was increased to 1575 μf, the current often amounted to several thousand amp. The data were erratic, but there seemed to be a definite correlation between the stored energy in the accel system and the apparent magnitude of the beam. This indicated that the breakdowns were contributing a spurious fraction of the measured beam.

In order to increase the area of the source, Ti was evaporated onto a 1-1/2-inch-diameter spiral made of 2 mm quartz tubing wound with about 2 mm between turns. These sources gave about 5 or 6 times as much gas kick per shot as the straight XR1 type but still exhibited all the failings previously described.

In an effort to hold higher accel voltages, an attempt was made to pulse the accel. This resulted in the collected beam's dropping by about a factor of 10 owing to the smaller stored energy of the pulse line. However, with the pulsed accel and charging voltages up to 5 kv, some measurements were made with an analysing magnet to check the energy of the accelerated beam. A peak was found in approximately the expected position as a function of magnet current. The attenuation through the analyser was 10^6, due at least in part to vertical defocusing. No indication was found of an H_2^+ peak.

A significant improvement in the reliability of identifying breakdowns came about with the adoption of the current-pickup monitor. This device was a current transformer made by winding about 20 turns of No. 18 wire around a Ferroxcube core. This comprised the secondary of the transformer and was terminated at the scope with 5 ohms. By slipping the lead to the accel capacitor through the core, it was possible to observe the accel current drain. Breakdown was unmistakably identifiable as a rapid (i.e. about 3 μsec) discharge of the accel lasting from 30 to 100 μsec. The arc thus formed extinguished itself when the accel capacitor had been bled down to about 60 v, and this value seemed to be independent of the initial voltage. It was also observed that nearly all breakdowns occurred after the source pulse was over, and furthermore, that the collection pulse corresponded in time to the breakdown pulse and not the source pulse. This explained the extraordinary values of collection current that had been observed, and also suggested that breakdown could be effectively suppressed by putting a "crowbar" across the accel right after the source pulse. A circuit was arranged for this purpose using a 5C22 hydrogen thyratron triggered through a delay line. This tube extinguished at too high a voltage to prevent breakdown in the test system, and a 3D22 mercury thyratron was substituted. With the consequent lower extinction voltage of this tube, the circuit performed as desired.

Some work was done with grids and multiple accel electrodes, but it was found that a breakdown could penetrate a grid and be detected in a supposedly field-free region. Also, the problem of holding accel voltages became acute in the presence of grids.

It was believed that appreciable ohmic resistance was necessary for initial gas evolution from the metal as a result of current heating. Some very thin-walled Ti tubing in 27 mm lengths was obtained from the Superior Tube Co. of Norristown, Penn. This was approximately 0.040-inch o.d. with a 0.002-inch wall. A quartz rod was slipped through a piece of this tubing for mechanical support and the assembly was loaded in the usual way. The resistance measured less than one ohm. When the source was fired at 10 kv charging voltage, initially no beam was observed and there was no flashing of the Ti. After several shots, a flashing of the source was observed at the high-voltage band accompanied by considerable beam current. Examination showed that the tubing had completely ruptured at the high-voltage bands. From then on, the source operated consistently well for several hundred shots. Furthermore, it produced a good output at 2-1/2 kv, whereas the evaporated sources produced well at from 10 to 15 kv. With this lower charging-line voltage and with the aid of the "crowbar" circuit, it was possible to hold up to 1 kv accel.

A source was made in which two intentional gaps were formed by not making a direct connection between the bands and the Ti tubing. Considerable data were taken with this source in the geometry shown in Fig. 3. The average output currents as a function of charging voltage at 500 v accel are given below. Repeated shots under the same conditions would show about a ±10% variation. Following this, a source with 10 gaps was made by slicing the Ti tubing into rings and making butt joints between adjacent pieces. The resultant increased output is also shown below for comparison. Finally, an assembly was prepared which incorporated three of these multiple-gap sources in series. This unit produced 200 amp for 15 μsec with 700 v accel.

Charging voltage	Current with 2 gaps	10 gaps
2-1/2 kv	7 amp	22
4	16	42
6	32	62
8	44	75
10	58	90

In the future several problems will be studied:

1. The performance of the source with longer pulses and continuous pulsing will be investigated with a view to possible application to accelerator source design.

2. A source which may be continuously reloaded by diffusion will be constructed. Calculation of diffusion rates[2] indicates that this is feasible, at least for low pulse rates.

3. The energy distribution of the ions will be investigated to determine the effectiveness of the accel in view of the apparently large degree of neutralization in the beam.

4. More will be learned about the mechanism of producing the ion beam. The XR1 sources exhibited high resistance only in scattered "thin" places, and in these regions local heating caused gas evolution. Then, if and only if the voltage was high enough to initiate a hydrogen arc, a large beam current was produced. This was evidenced by the appearance of several flashes at various points on the surface of the metal. These conclusions have been already partially verified.

5. Granting the validity of the preceding argument, hen what is essential is not the total absorptive capacity of a metal at room temperature but the rate of change of the solubility with heating. In this respect vanadium considerably exceeds titanium (Fig. 1) for temperatures up to 600°C. Sources made of vanadium as well as of several other materials will be tested.

This work has been performed with the able assistance of Richard Crawford and Wing Pon, and has been under the direction of James D. Gow.

References

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2. Smithells, C. J., Metals Reference Book, Interscience, 1949.

3. Smith, D. P., Hydrogen in Metals, University of Chicago Press, 1948.

4. Ubbelohde, A. R., Some Properties of the Metallic State, Proc. Royal Soc. A159, 295 (1937).

Hydrogen Solubility in cc STP per 100 g of metal. [2]

Temp°C		Ce	La	Nb	Pd	Ta	Th	Ti	V	Zr
20		------	------	10,400	------	------	12,500	40,300	15,000	24,000
150		------	------	------	------	------	-------	------	8,200	24,000
300		18,400	19,200	8,800	164	3,400	10,700	40,000	6,000	23,700
400		17,600	18,200	7,680	126	2,400	9,700	38,400	3,800	23,400
500		16,800	17,200	4,740	103	1,300	9,100	35,400	1,840	23,000
600		16,000	16,300	2,500	92.7	630	8,800	32,000	1,000	22,000
700		15,200	15,300	1,200	87.0	450	8,450	22,000	640	21,000
800		14,500	14,300	610	84.0	320	8,100	14,000	450	19,600
900		13,800	13,400	400	81.0	260	7,700	9,000	320	13,000
1000		13,000	12,300	------	78.5	230	2,600	6,500	240	------
1100		11,300	11,100	------	76.5	210	1,900	4,000	200	------
1200		5,300	4,100	------	------	------	1,750	------	------	------

TABLE I

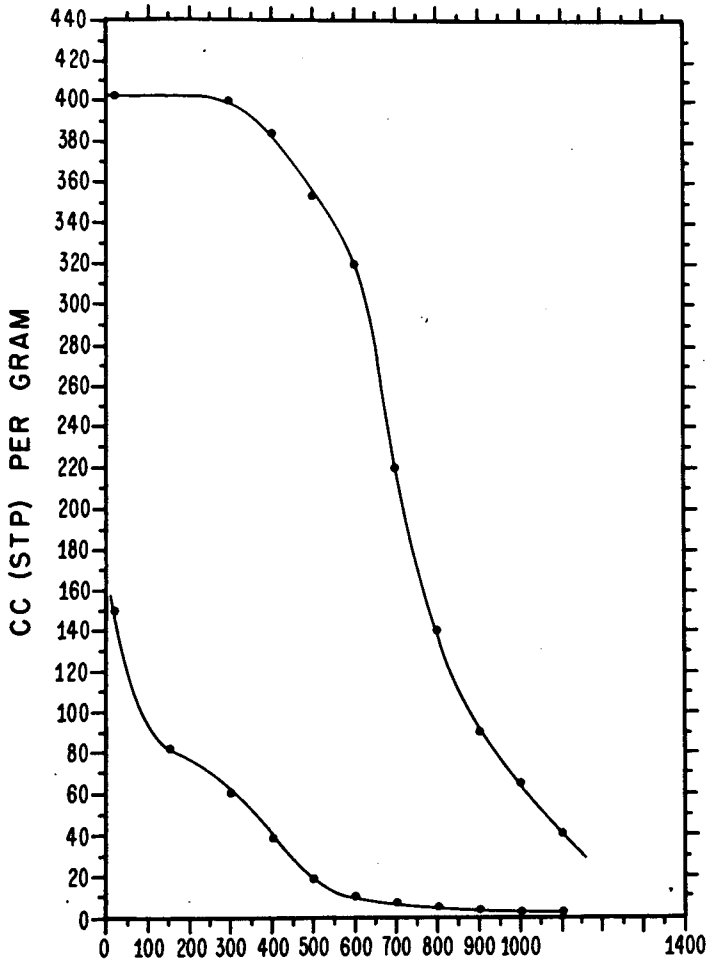

Figure 1

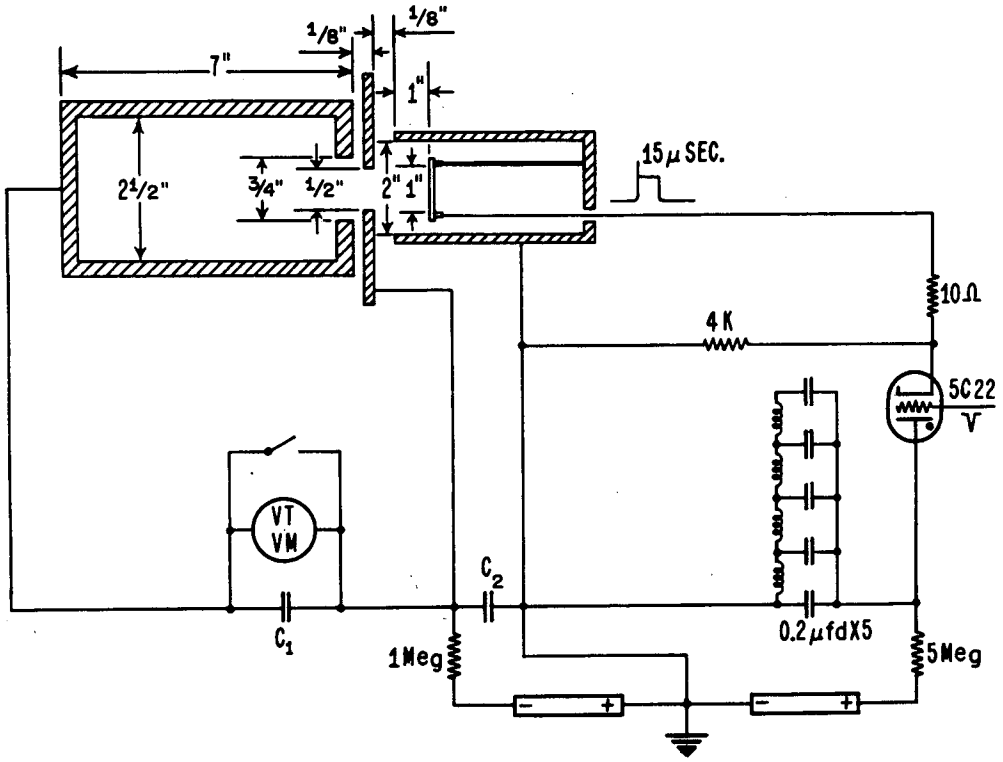

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Figure 2

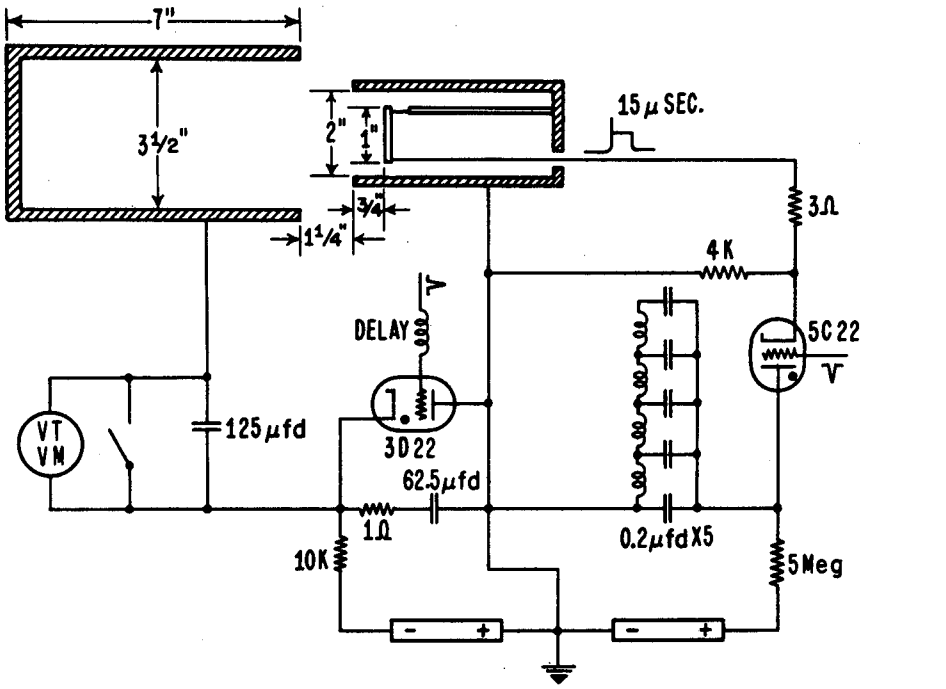

Figure 3

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