

SODIUM VAPOR CHARGE EXCHANGE CELL^{*}

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Summary

An operational sequential charge-exchange ion source¹ yielding a 50 MeV H^- current of ~ 8 mA is planned for use with the Argonne 500 MeV booster synchrotron. We report on the progress for development of a sodium vapor charge-exchange cell as part of that planned effort. Design, fabrication, and operating results to date are presented and discussed.

Introduction

It has been pointed out² that the introduction in the 1960's of alkali vapor targets for more effective $H^+ \rightarrow H^-$ charge exchange than that provided by hydrogen gas has not as yet resulted in application to operational H^- injectors. The major problems are 1) the production of low energy, high intensity H^+ beams, and 2) the development of cells in which the alkali vapor contamination to the rest of the system is minimized. Regarding the latter point, it is not easily predicted just how much alkali metal contamination is injurious to a system. It would seem this could vary greatly depending on the nature of the application. The results of Dyachkov³ in the production of alkali vapor jets and of Dimov⁴ in the utilization of sodium jets for H^- production lend encouragement to the possibilities for developing cells with acceptable outstreaming.

For an operational design a recirculating or partially recirculating scheme for the alkali material is highly desired. Charge exchange cells of the reservoir type which utilize wicking methods for recirculation of the deposited material have been reported by Bacal *et al.*⁵ for cesium and by Lawrence *et al.*⁶ for cesium or sodium. The latter cell had an ID of 1 1/4 in and was about 14 in long, but operation with sodium and, specifically, measurements of end losses have not yet been reported. Consideration has been given to such a cell for our application. The design we present here is a nozzle with an end loss of ~ 20 mg/hr, both ends, and a target thickness of $\sim 2 \times 10^{15}$ atoms/cm. For the desired 2 in apertures, calculations indicate that these end losses for the reservoir type cell require a cell length of at least 22 in. This severely limits the solid angle of acceptance of the cell for the beam.

We have chosen sodium as the alkali metal for use in our system. From the results of studies

of Gruebler, *et al.*⁷ on the equilibrium charge yields of H^- fractions in the various alkali vapors, sodium appears to be the most viable candidate for our uses. The optimum (12% H^- yield) incident proton energy is relatively high (2.5 - 3.0 keV). Furthermore the broad maximum of the H^- yield with energy is such that for H^+ energies from 10 to 15 keV, for example, the H^- fraction falls only from 5% to 3%, still higher than that for hydrogen.

The proposed scheme for application to our situation is that commonly used in the cesium charge-exchange, Lamb-shift, polarized ion sources which utilize an accel-decel configuration. This allows extraction of the H^+ beam at high voltages to maximize the intensity and then deceleration to energies at or nearer those for optimum H^- charge-exchange. Initial stages of our planning take advantage of the broad maximum in the sodium H^- yield with energy by performing only mild decelerations, but still gaining factors of 2 or 3 in intensity over H^- production using hydrogen for the same extraction voltages.

Design

The concept of sequential charge exchange appears to have originated with Dawton⁸ and has been applied to H^- production in sodium by Dimov.⁴ In our source a low density hydrogen target will serve as a space charge neutralizer and a buffer between the positive ion source and a sodium vapor charge-exchange cell. We have utilized a planar de Laval nozzle to form a down jet of sodium vapor incident on a liquid sodium surface maintained just above melting so that the liquid may complete the recirculation loop. The cell through which beam passes was designed with 2 in apertures and as short as possible consistent with maintaining the minimum amount of vapor outstreaming. The length of the cell (12 in) has been determined by direct measurements on the sodium jet.

The sodium charge exchange apparatus is shown in Fig. 1. In operation, sodium travels from the vaporization region, through the nozzle to

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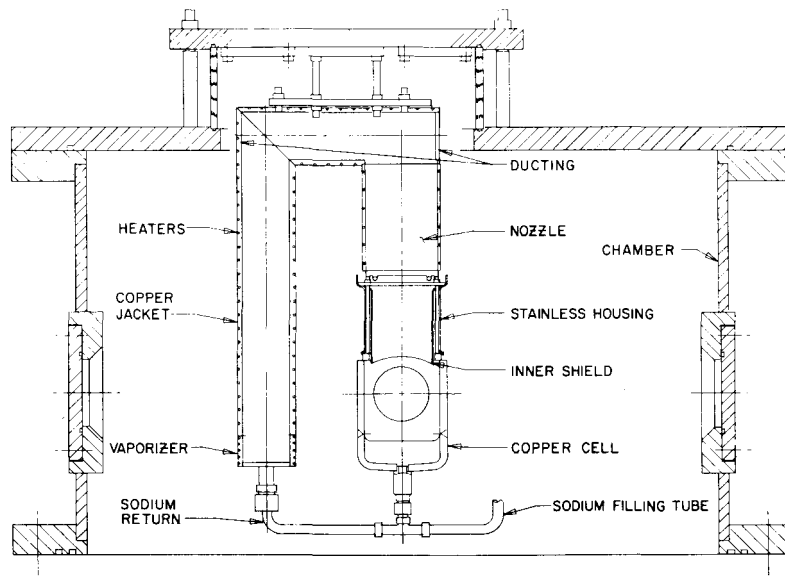
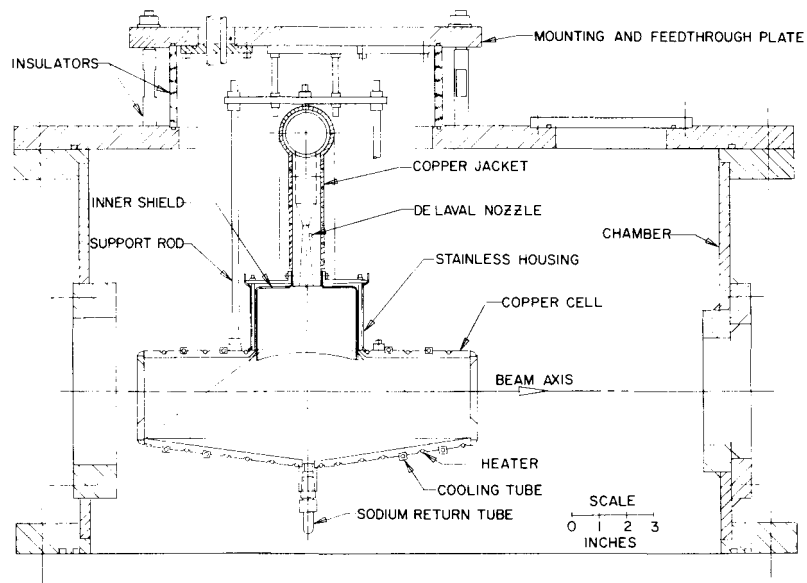


Figure 1 - Recirculating sodium charge exchange cell assembly, side and end views. Partial horizontal lines at the bottom of the cell and vaporizer indicate the proposed liquid level. The 15° expansion angle of the down jetting sodium is also shown.

form a jet which extends into the vapor collector or cell. The vaporization region is connected to the nozzle by means of stainless steel ducting of constant cross-sectional area. This area is that calculated to deliver the mass flow necessary for the nozzle to operate properly. The liquid sodium is heated to 430°C and vaporizes at the rate of about 50 mg/sec. The optimum operating temperature for the nozzle, which has a mach number of 2.7 for sodium, is also 430°C. The sodium jet has a calculated mass flow of 44.3 mg/sec. The vapor jet formed by the nozzle is incident upon a surface of liquid sodium contained in a copper cell 12 in long with 2 in apertures. The OFHC copper cell is maintained at 120°C-140°C by opposing heating and cooling elements. Liquid return to the vaporization region is by gravity feed through a 3/8 in stainless steel tube. The actual amount of sodium necessary to maintain the liquid levels in the vaporizer and cell as shown in Fig. 1 plus that adhering to surfaces has not been determined but is probably in the order of 100 g.

The temperature gradient between the nozzle exit and the copper cell is maintained over a 4 in length by a 0.018 in stainless sheet housing. An inner shield, also mechanically connected to the nozzle, but thermally floating, protects the housing from direct vapor from the jet. In theory, the inner shield is maintained at a high enough temperature to prevent sodium from the jet from condensing onto its surfaces.

The vaporization region, ducting and nozzle are all constructed of stainless steel and surrounded by copper jackets. Enclosed heating elements are imbedded in grooves in the copper and held in place with clamps. The heaters are composed of resistance wire embedded in MgO and contained in 1/16 in OD stainless steel jackets. They have an active length of 40 in and an inactive length of 30 in. They are used in conjunction with Swagelok connections for feedthrough from the vacuum. Power ratings are about 250 W, though in operation we limit the maximum power to ~50 W. (1 A @ 50 V). Each copper jacket contains one heater and one thermocouple (similar in construction to the heaters) which acts as the sensor for a temperature controlled feedback system. Six such units are used to heat the vaporizer-nozzle sections.

The vapor collection takes place in the copper cell. Although copper alloys slightly with sodium at elevated temperatures (800°C), no alloy formations are reported at temperatures below this. Two heaters of the type described above, controlled by one TC are run in opposition to cooling coils circulating chilled oil to control the cell temperature. A 1/4 in stainless steel tubing line is used for filling the apparatus from an external reservoir and is also wrapped with a 40 in jacketed heating element.

To minimize the radiation of heat to other parts of the system and to increase the efficiency of the heating, heat shields were utilized around the parts of the apparatus to be maintained at 430°C. The heat shields were constructed of 4 layers of 0.001 in stainless steel shim stock, each layer separated from the next with fiberglass cloth and the total sandwich spot welded together on the edges. Several sections of laminate were then wrapped around the ducting and nozzle and held in position with wires. Without the heat shields, 300 W total power for all heaters raised the temperature to no higher than 290°C and took about 3 hrs. After adding the shields, the same temperature was achieved in less than one hour. The power was cut to ~200 W and full operating temperature (430°C) was reached in 3 hrs. Furthermore, the power was then cut back to a maintaining level of about 100 W total.

The entire assembly was mounted on a 12 in aluminum plate which is in turn mounted via a standoff ceramic ring to the lid of a 28 in diam aluminum chamber. The chamber is 15 in high and the axis of the cell is 6 in from the bottom. In operation this chamber will sit on top of a large gate valve which is mounted on top of a sublimator pumping vessel (~100,000 g/s).

In order to minimize damage to the aluminum surfaces of the chamber, valves, and beam lines, they will be lined where possible with disposable foil (probably aluminum foil). Although the sodium does not attack the aluminum directly, on exposure to normal humidity atmosphere, the reaction with the moisture in the air forms a NaOH paste which will etch the aluminum quite markedly.

Operation

For operation of the assembly, sodium is transferred in batches 10-30 g at a time by means of valving and an intermediate transfer vessel. Conducting wires at different levels in this vessel are monitored for make and break contact with the sodium surface. The desired amount of sodium is transferred in this way usually after the entire assembly is at operating temperature. Some splashing has been noted on the initial introduction of sodium into the system, possibly caused by the cover gas (Argon) used to insure that the sodium will flow during the filling.

Before attempting operation in the recirculating mode, tests were made with the vaporizer-nozzle part of the assembly by freezing out the sodium from the jet. An oil cooled copper cylinder of diameter 4 in with a 2 in neck to simulate the cell aperture was used as a collector. The neck was at right angles to the downward direction of the jet and to the plane of the nozzle. The distance from the bottom of the nozzle to the center

of the 2 in neck was 4 in. A mechanically operated shutter was interposed between the nozzle and the collector so that timed measurements could be made of the sodium collected. Measurements were made in the 2 in arm at distances of 4, 6, 8, and 10 in from the plane of the nozzle. These were interpreted to represent the end losses for operation of the jet into a cell of twice these lengths (end symmetry is assumed). This did not take into account however any vapor due to liquid sodium in the subsequently designed cell since we were freezing out the sodium in these tests. Measurements were also made at various positions along the sides and bottom of the 4 in cylinder, and with the proper geometric factors were used to determine the plane mass-flow angular distribution.

The technique for these measurements was to collect the sodium on samples of aluminum foil of previously determined mass and then to quickly transfer them under inert atmosphere (nitrogen) to an analytical balance for determining their total masses. This process was found to be not at all difficult and by either vaporizing a known mass of sodium through the nozzle or by controlling the time for the deposition with the shutter we were able to measure absolute values. The results of the end loss measurements are shown in Fig. 2. Using 6 in as the essential cut off point for the jet, and the actual geometry used, it was determined that the expansion of the jet around the corner of the 2 in neck is about 15° , and is also shown in Fig. 1. These measurements resulted in the design parameters of the actual cell, i. e. 2 in apertures with axis 4 in below the nozzle and total length of the cell of 12 in. The expected end losses then are 10 mg/hr (each end) or 20 mg/hr total.

The results of the angular distribution of the sodium are shown in a polar plot in Fig. 3. The solid line represents our data. The dashed line is derived from a figure in reference 3, measured for an almost identical nozzle. The units are relative and were arbitrarily normalized to the maximum. The total mass flow determined from the graph and the known geometry is 42 mg/sec in excellent agreement with the calculated value.

Measurements for the entire recirculating cell assembly are still in preliminary stages. Approximately 30 g of sodium was transferred into the vaporizer assembly and the operation was observed from a glass viewing port located about 12 in from one end of the cell. The vaporizer-nozzle section had been preheated to the operating temperature of 430°C but the cell itself was at only 80 or 90°C and still warming. The pattern of sodium vapor condensing on the copper was observed to be fairly uniform and as the cell temperature reached the melting point, the sodium liquified and immediately wet the surface of the

copper. Silvery globules of sodium could also be seen adhering to the sides of the inner shield, contrary to expectations. After about 5 min of operation, the glass became opaque and no further observations could be made.

After cooling, the system was filled with ultra high purity nitrogen and a shutter was added over the viewing port. The cell was reheated but with no additional sodium added. It was observed now that the sodium no longer wet the copper surface but seemed to adhere to it in lumps. Also, the sodium no longer exhibited the shiny silvery surface of before. Some contamination of the sodium is evident, possibly due to oxygen. The total time in vacuum for the sodium was about 3 days although heated only about 12 hrs of that time. Typical pressures were $8-10 \times 10^{-7}$ Torr.

Cleaning

There are several methods of cleaning alkali metal systems⁹⁾ and we shall describe briefly what has worked well for us. We are dealing with small amounts of sodium (~ 100 g) and we utilize the method by which the entire apparatus is immersed in 95% ethyl alcohol. This serves to dissolve the sodium slowly and with the amount of alcohol used (~ 15 gal) does not heat the alcohol appreciably. Nevertheless, a purging gas is recommended to minimize the possibility of the alcohol igniting. Experience has shown that if the alcohol is allowed to stand for prolonged periods it can obtain enough moisture from the air to increase the reaction rate sufficiently to self ignite with the introduction of the sodium. Care must also be taken to allow sodium in tubing and lines to completely dissolve. In our case the tubing is disconnected and cleaned separately as previous experience has shown that a 2 ft length of 1/4 in tubing took several days to clean out.

The next step is to immerse the apparatus in an 80% alcohol 20% water solution. This serves to dissolve the Na OH crust which can form in corners, cracks, etc. which is not soluble in alcohol but which may cover small amounts of still active sodium. A purging gas is also used in this step.

The final rinse is in distilled water and should be performed with some sort of agitation to dissolve all the Na OH. If any active sodium is left in the system at this point it will react violently with the water and although sodium and water cannot react fast enough to explode, the hydrogen gas evolution in a confined area can build up high pressures very quickly. This is the reason the sodium delivery tube is removed. A fourth step, a mild cleaning acid dip is sometimes used and may be necessary with copper if the sodium is to wet the surface.

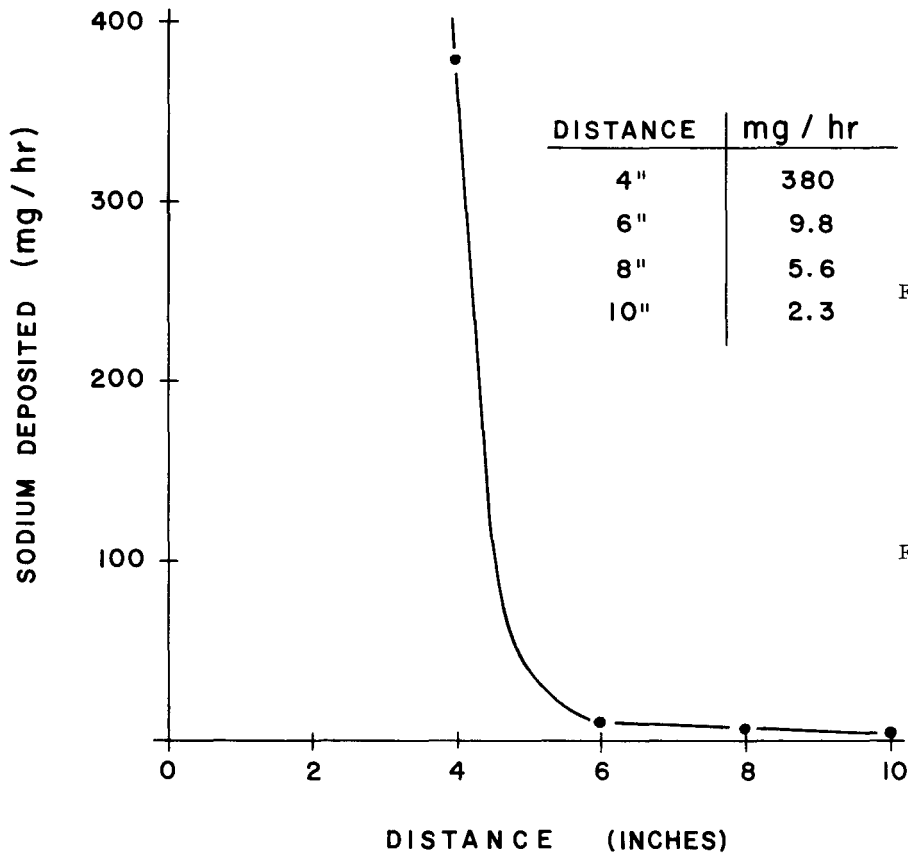
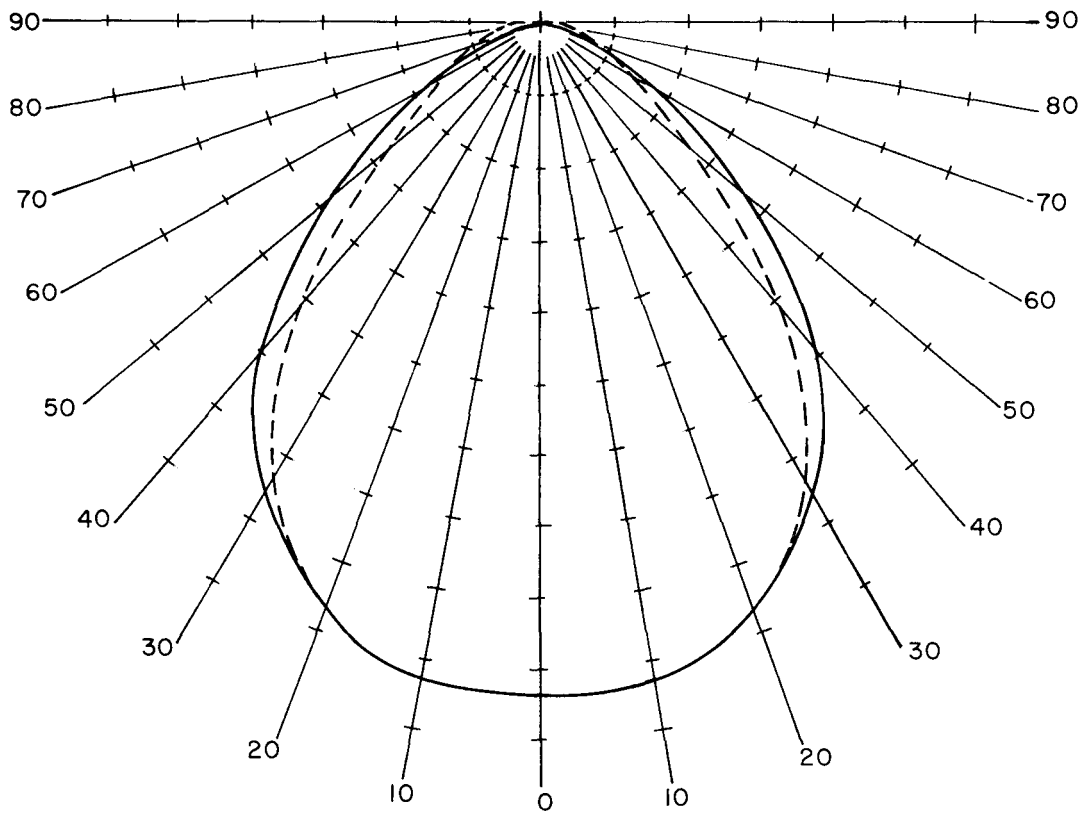


Figure 2 - End losses vs. distance

Figure 3 - Mass flow angular distribution



Future Considerations

Quantitative measurements of end losses for the recirculating apparatus are next to be made. The sodium inventory and length of time between refills must also be determined. Effects of contaminants in the sodium may necessitate the addition of a filter and electromagnetic pump to maintain circulation. In addition, the inclusion of several important safety features, such as an automatic inert gas pressurizing system in case of loss of vacuum, are necessary before the system can become operational.

After the engineering problems associated with the sodium operation have been resolved, operation with the 30 Hz multiaperture, multigrad source attached will be investigated. The operating parameters of the accel-decel configuration must also be optimized. It should be interesting to note the effects of outstreaming sodium on the grids and grid life, including the breakdown problems encountered by Lawrence et al.⁶

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