Title
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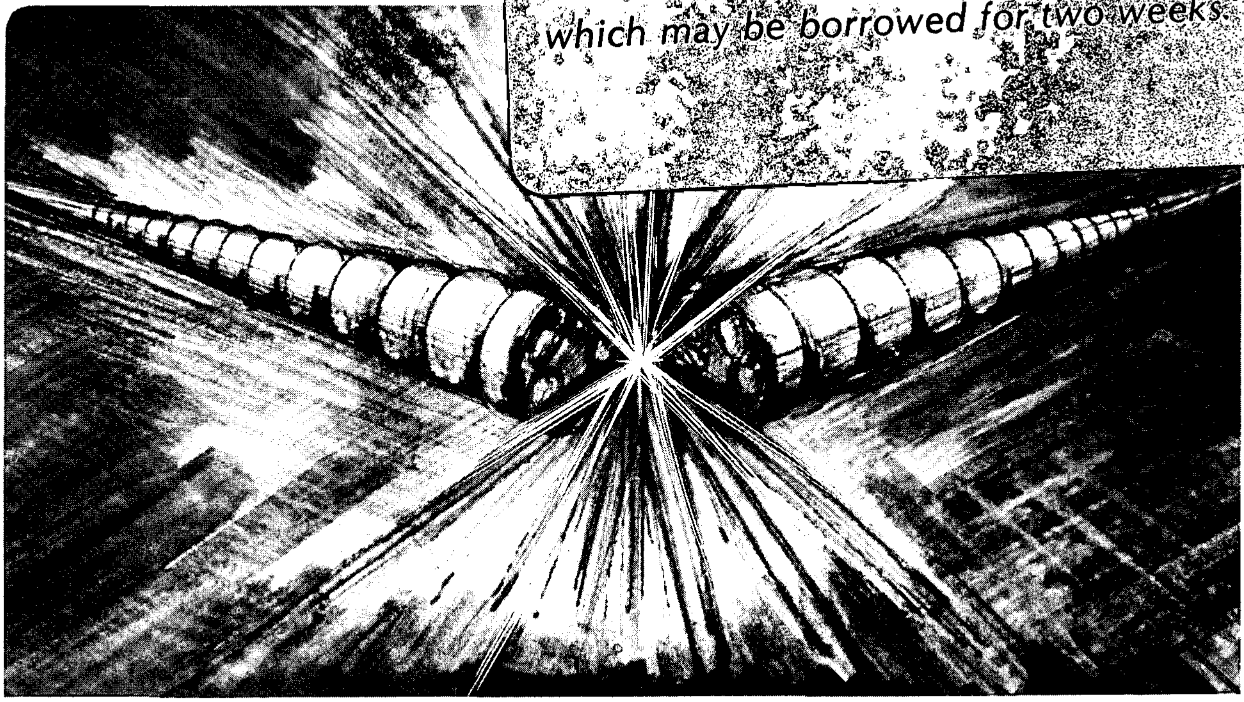

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DISCLAIMER

A CONTINUOUS LIQUID SHEET GENERATOR FOR ION STRIPPING*

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Many of the technical problems of generating a large thin liquid sheet from 0.02-0.20μm thick (3-40$\mu g/cm^2$) have been solved. It is shown that this perennial sheet is stable and consonant in dimension. Several ion beam species from the SuperHILAC have been used for evaluation; at 0.11 MeV/n. In one of three modes this sheet serves as an equivalent substitute for a carbon foil. The second mode is characterized by a solid-like charge state distribution but with a varying fraction of unstripped ions. The third mode gives stripping performance akin to a vapor stripping medium.

1. Description:

Two 8.6 cm diameter steel discs, radially flat on one side and with a razor sharp circumferential edge, free from any form of irregularity, are rotated in the same direction tangentially above one another and in the same plane at 7500 rpm. An unbroken continuous tubular flow of fluid is directed perpendicular to each disc close to the outer circumference. The nozzles are adjustable in radial (and tangential) direction for critical tuning of the sheets (See Figure 1). The fluid is filtered to eliminate holes, and pumped from sump to nozzle.

Surrounding each disc are critically shaped sheet terminators that serve to stabilize and stretch the thin sections of the sheet spun out from the disc. Terminator curvature, location, and pitch are critical for quiet draining. The location is set empirically. Without them, thin sheets cannot be achieved. The entire structure is capable of being rotated in a plane parallel to the accelerator axis. Further details regarding sheet generation are found in reference 1.

The hydrogen free large molecular makeup of the commercially available Fomblin (18/8), a fluorocarbon fluid, has the low surface tension needed for low film contraction velocity.[1] Fluid vapor pressure is 10^{-9}T at 20°c. Important, the fractionated components generated from radiation damage are volatile and therefore pumpable.

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The high 190 centistoke viscosity we use allows for large thin sections of sheet. At present thin areas exceed 40 cm^2. In general the sheet thickness at disc perimeter is fixed as a function of degree rotation from nozzle location, but the gradient of sheet thickness within the first centimeter of radial sheet displacement increases dramatically with rotation. High speed photographing of the sheet (200μs/frame) indicates a sheet velocity of ~3500 cm/sec, at ~270°.

Sheet thickness is conveniently measured with white light destructive interference of the first four orders. An Americium source of alpha particles (5.474 MeV) was used to assure the identification of the first order. Minimum surface densities are ~5μg/cm^2 (± 3μg/cm^2).

Thin sheet tuning is realized by visually bringing the higher orders of light interference close to the disc perimeter. High disc speed, low fluid flow rates (~0.4 gpm), and careful tuning of the fluid contact point are required. By rotating the plane of the sheets with respect to the beam line, the sheet thickness increases by the cosine of the rotation angle.

The material constants for fomblin will establish a beam current threshold for evaporative destruction of the sheet.[1] Unfortunately the specific heat of fomblin is low, as is the heat of vaporization. Further discussion follows.

2. Results at .113 MeV/amu:

The following tests were made with the SuperHILAC at Lawrence Berkeley Laboratory. A vapor stripper in close proximity allows comparison of sheet to vapor. We use an ion beam 2 ms. in length, at 36 pps. Charge state analysis is magnetic. Ions reported here are niobium and holmium. Given high current beams, 100 pμA peak or more to the stripper, the sheet vapor mode matches closely the charge state intensities usually encountered with the SuperHILAC fomblin gas stripper. As much as 14 pμA of Ho^{10+} has been produced in this mode, and 55 pμA of Nb^{6+} with either gas or sheet stripping.

Holes are formed on the sheet(s) at very low intensities; $\geq$ 10pμA/cm^2. The energy lost to the sheet per unit area is ~1/30 that required to vaporize.[1] Therefore we postulate that the non conductive nature of the sheet probably accounts for electrostatic puncture. The hole is first observed after some fraction of the pulsed ion beam has passed downstream. Once the hole is formed surface tension forces expand the hole into what appears as a tear on the sheet. Realize that this hole is continually being swept away by the inherent velocity of the sheet. The upstream circumference of the hole remains fixed (expanding slightly with high intensity beams). The large molecules of fomblin are readily available to the beam along this crescent even with the presence of a hole. In fact photon emission is readily observed exclusively in this interaction area. A DC beam should not alter this mode of stripping. Nevertheless 10pμA of niobium impinging upon a single sheet will generate a distribution closely approximating a 4μg/cm^2 carbon foil distribution. Collected currents differed by less than 15 pct. for all states greater than 8+ even with the hole.

As the beam intensity rises above ~50pμA/cm^2 the hole is visible at an earlier time in the pulse, and the sheet does pass an increasing fraction of unstripped ions, up to ~45 pct. the total collected particle current for a single sheet. The unstripped fraction varies with beam intensity, thickness of sheet and the number of sheets. As the flux continues to increase, the unstripped fraction drops now to a characteristic vapor like fractional distribution. A two sheet stripper does increase the collection efficiency, the uniformity of pulse shape, and also reduce at least by two, the unstripped fraction. The advantage of two sheets is that fluid for beam interaction is brought to the ion beam on opposite sides. It is disappointing that the higher charge states are not improved at least by two. A more modest 10 pct. gain is seen. Strobe lighting revealed that the downstream sheet was damaged about 1.7 ms. into the beam pulse, presumably by slow moving groups of fomblin molecules, > 30X the fluid molecular weight.

Figures 2 and 3 show the percentage particle current for each charge state of two ions and at several intensities to the stripper. Typically ~75 pct. of the ions are collected after analysis. As the intensity is increased so does the distribution shift to a gaseous type. Charge states less than the impinging ion were too rigid to be analyzed. Beam amplitude into any one charge state may be read by noting the particle current to the stripper, collection efficiency and the percent fraction. Of interest, the higher charge states appear to reach a rough upper limit of one to two pμA. Transition from solid to vapor is noted with greater clarity by plotting particle current against pμA current into any one charge state. In figure 4 one can see the gradual transition from solid to vapor stripping when the particle current to the stripper is increased. Single and double sheet stripping data have been merged for lack of significant difference. Also data gathered with lower charge state beams of higher intensity are included. For example: Nb^{13+} appears to steadily drop from a 8 pct. yield to ~5 pct. before halting gain to analyzed intensity. Ion fluxes are ~75pμA/cm^2. Already the effects of hole puncture can account for this disproportionate increase. As the current is further increased, we note a change from 5 pct. collection to ~2 pct., now without further increase in yield. One could postulate that an increase in incident ion current is not available in the outer portions of the ion beam where solid stripping is occurring. Why then do we not see a factor of two increase when two sheets are used? We can suggest that the increase in incident beam power is destroying the orderly location of the sheet molecules, that large chunks of sheet are probably charged and are being driven away from areas of interaction. If so, the chunks of sheet are released from the film at one fourth power expected for vaporization. Given a beam diameter of 0.5 cm, one calculates that at ~75pμA (400pμA/cm^2) the fomblin is vaporized, about where the solid and vapor curves are seen to merge, and, is independent of sheet thickness.[1]

Figure 4 also shows the degradation of the sheet by a rapidly increasing yield of the Nb^{7+}. Note that the vapor yields appear to increase linearly with input current. It should be mentioned that a visual inspection of the sheet interaction areas show a crescent like source of light on either one or two sides of the beam for currents below the solid-vapor merge value to be replaced by a general glow spreading along the beam line for higher intensities.

Relevant, the vaporization of fomblin will bring about a beam line pressure rise into the 10^{-5} torr range. Vacuum pumping should be improved with an upgrade to our LN trapping. D.C. ion beam operation will require further testing of vacuum system performance. While it is true that fluorine will be one of the volatile components, no problems were encountered.

3. Summary:

A minimum stable thickness of ~5μg/cm^2 (260Å) is routine. Thicker sheets are either tuneable or generated with rotation to the ion axis. The fluid is non-conductive. A charged ion beam will damage a sheet with a flux in excess of ~10pμA/cm^2. Large portions of the sheet appear to explode, perhaps from electrostatic forces, generating a hole that effectively strips electrons only from the circumference of the hole. The unstripped fraction of incident ions is reduced at least by two, to ~10 pct. (±10 pct.), when directing the moving sheets to collide on opposite sides of the ion beam. Two sheets do not increase significantly the yield in any one charge state. Rotation of the sheets will not eliminate the formation of holes. At approximately 75pμA/cm^2, the ions tested appear to reach an upper limit of current yield into any one charge state of 1 to 2pμA. A vaporization mode occurs when holmium or niobium ion beams are 70 pμA or more in intensity. The ion flux is in the vicinity of 400pμA/cm^2. The yield in any one charge state now will scale linearly with increasing incident ion intensity. It should be noted that a sheet stripper will require substantially lower accelerator ion currents to produce equal amounts of the higher charge state ions than with vapor stripping. Figure 3 indicates we need ten times the flux with vapor stripping to match the sheet yield of Ho^{15+}. As intensity increases, this gain will decrease. (See Fig. 4)

Further testing is planned at higher energies where sheet rotation will be more appropriate. Greater sheet separation or collimation between sheets will be mandatory for high duty factor operation.

Thanks are extended to J. Alonso for his encouragement and guidance, and also to H. Gould and R. McDonald for their helpful suggestions.

Reference

1 B. Gavin, et al, "LBL-17996", Lawrence Berkeley Laboratory Sept. '84.

FIGURE CAPTIONS

Fig. 1 The apparatus for sheet generation. The ion beam axis is indicated by a cross.

Fig. 2 Incident beam intensity to stripper indicated. 54pμA with vapor 89 and 41 pμA with 1 sheet 38 and 17 pμA with 2 sheets.

Fig. 3 Incident beam intensity to stripper indicated. 15 pμA with vapor. 13 pμA with sheets, 6 pμA with 2 sheets.

Fig. 4 Incident beam intensity vs. pμA yield in 1 charge state as indicated. 'V' stands for vapor, other curves with sheets. Dashed curves show a constant indicated percent fraction for reference.

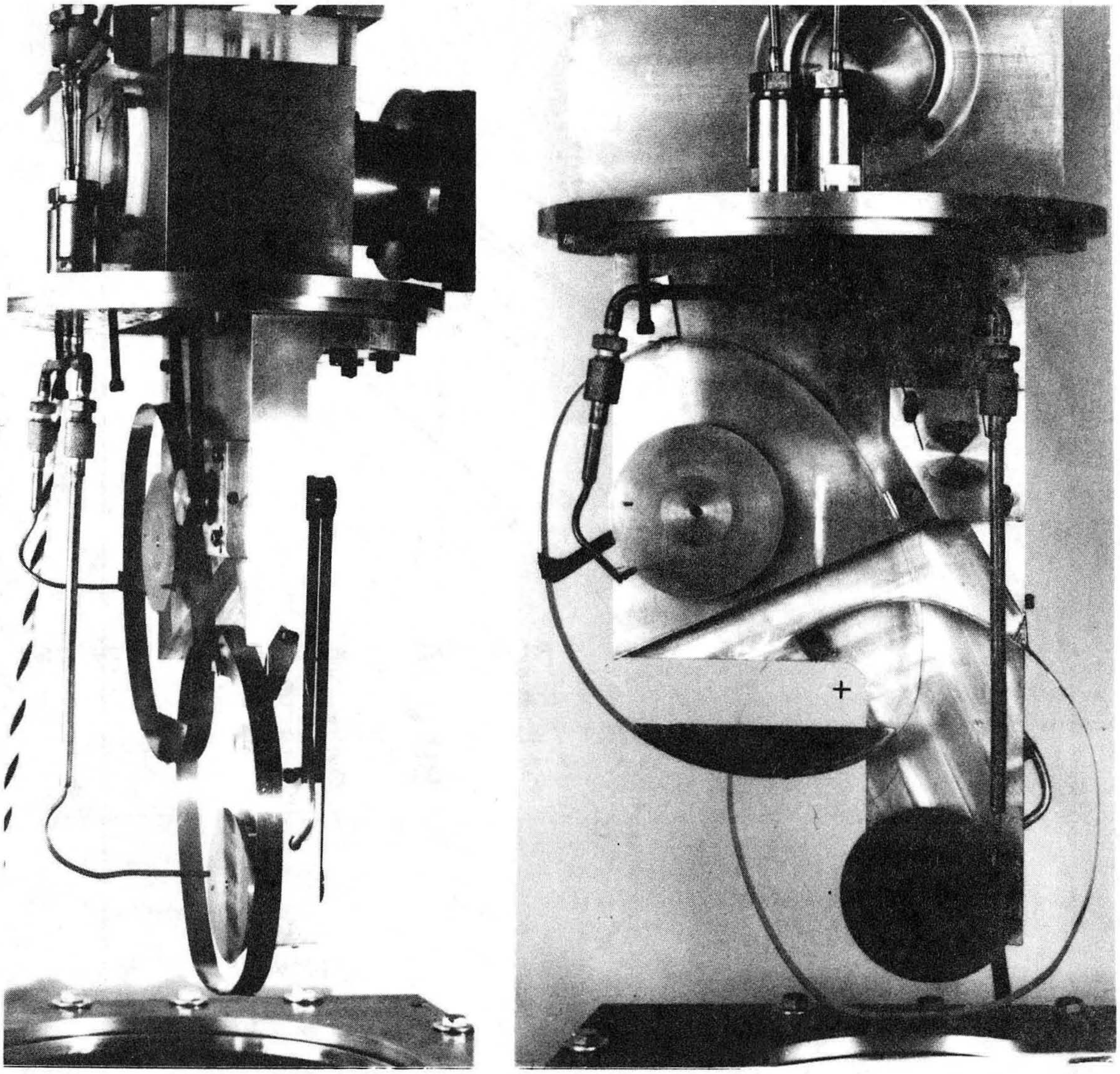

Fig. 1 XBB 848-6168

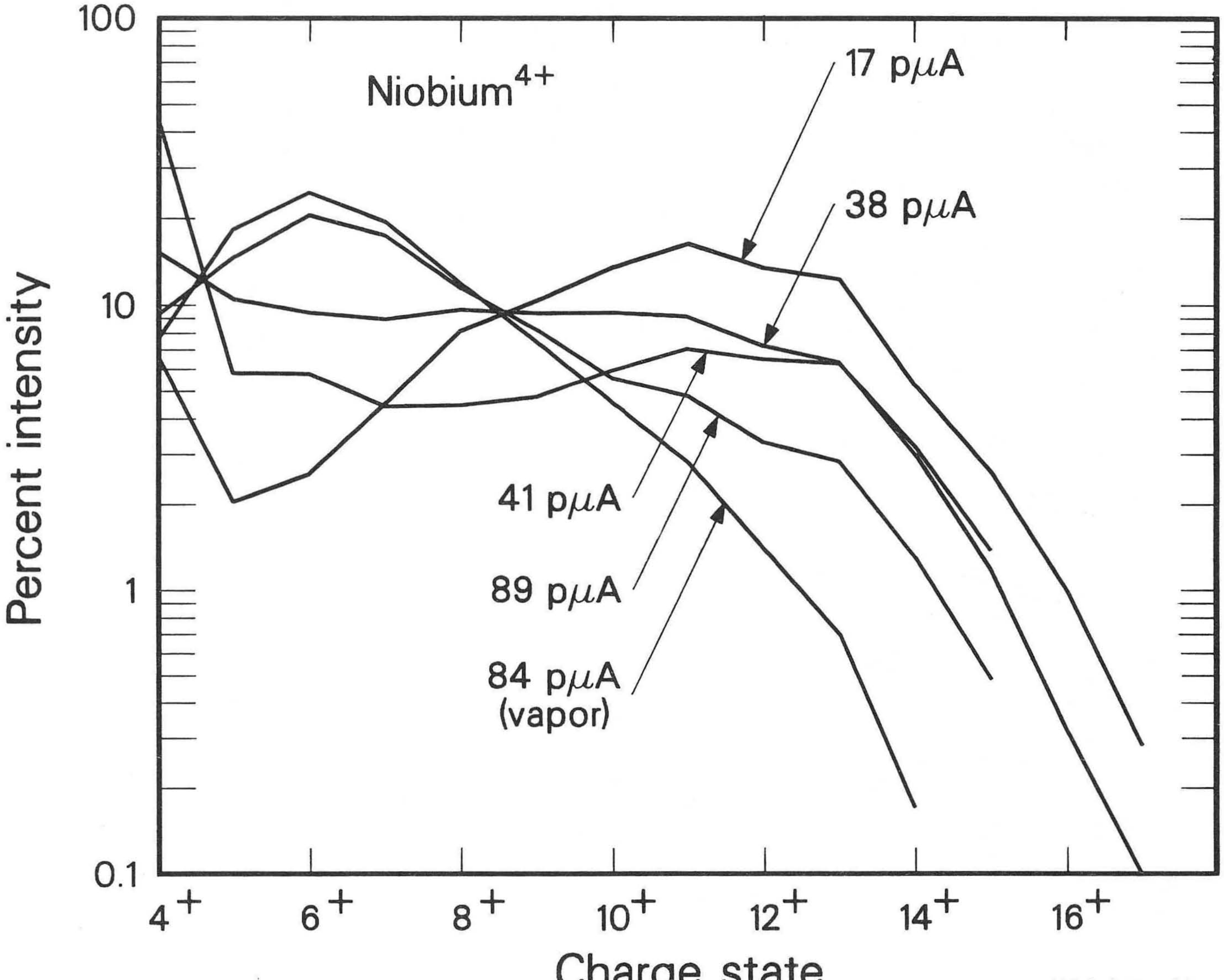

Fig. 2

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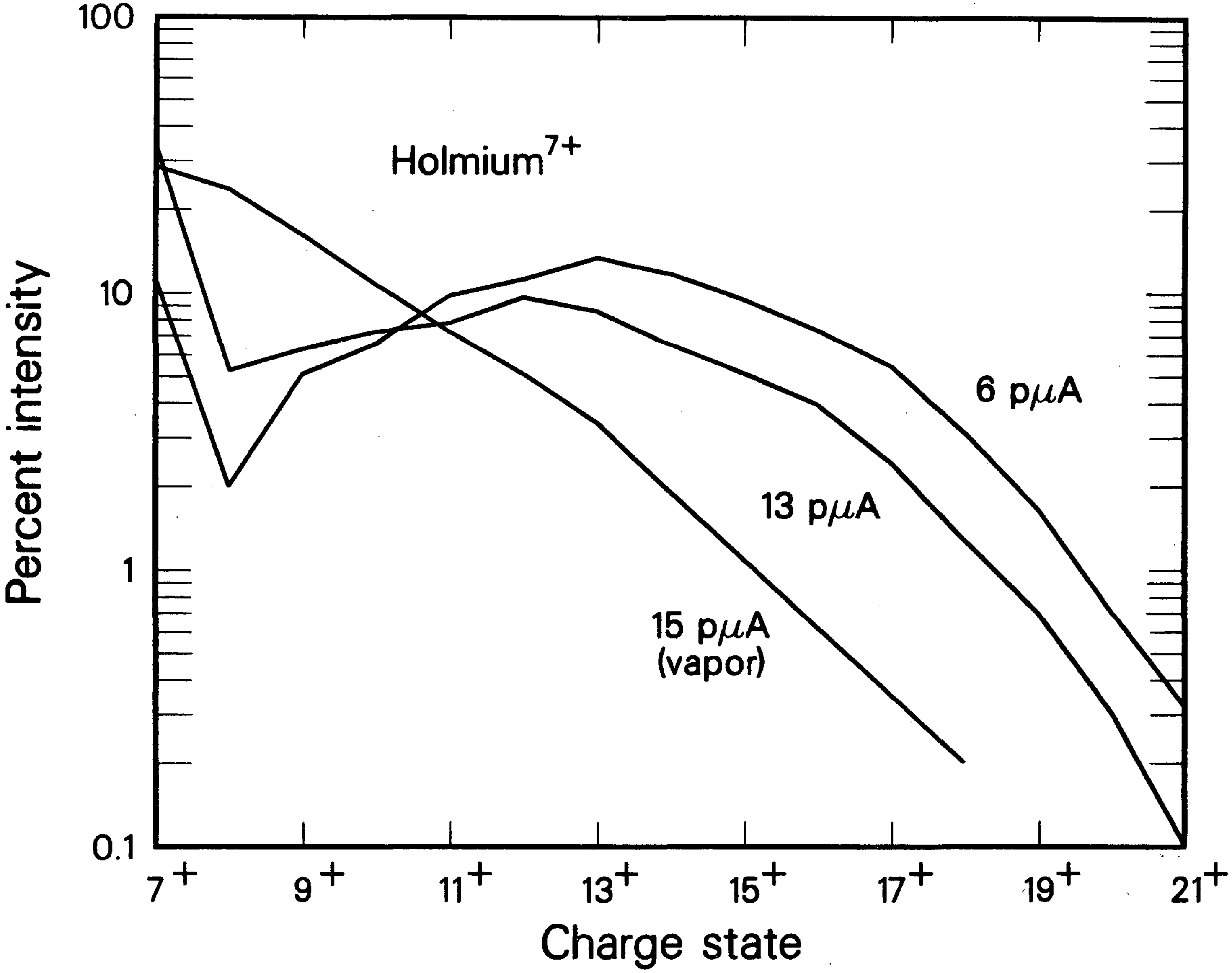

Fig. 3

XCG 849-13268

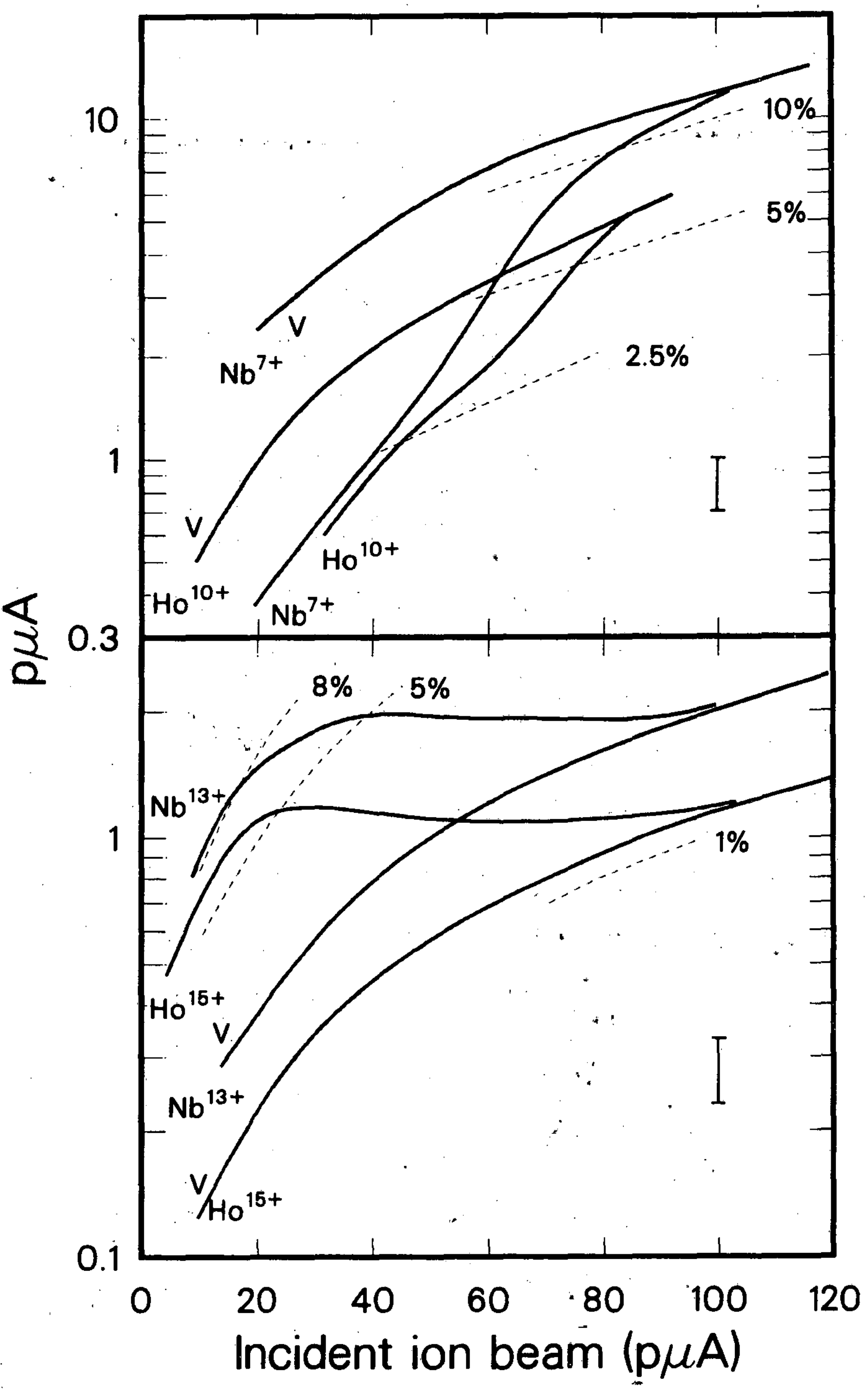

Fig. 4

XCG 849-13267