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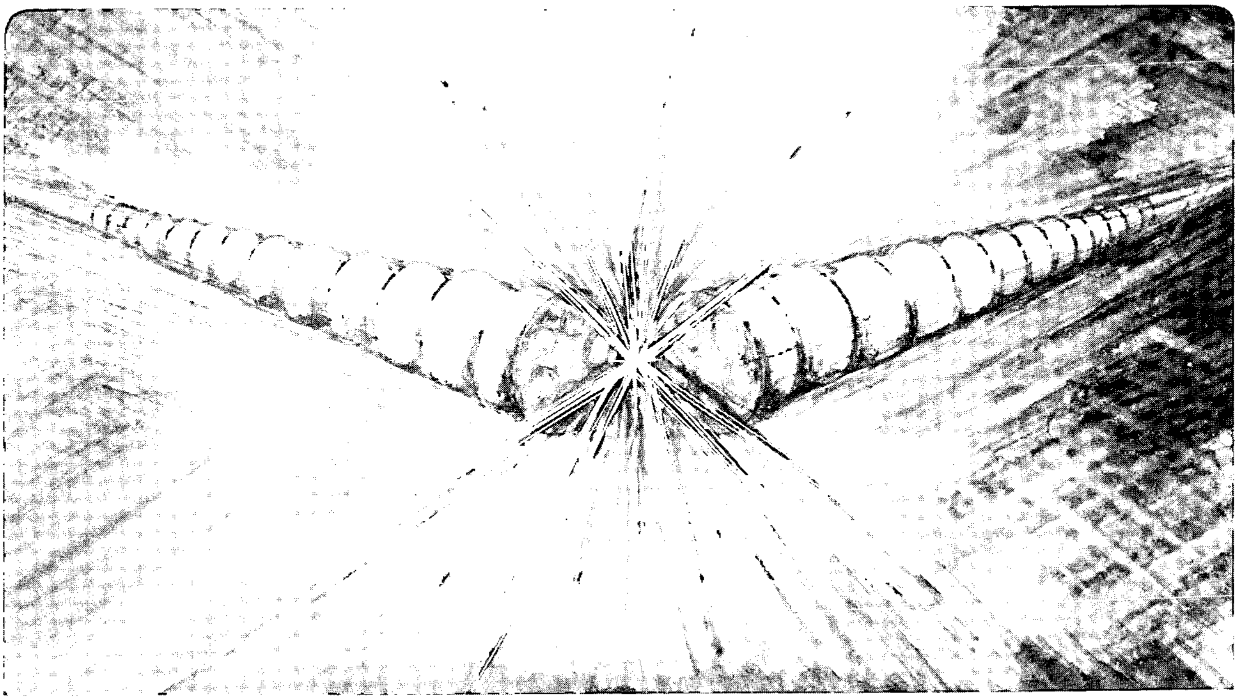

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CHARGE STATE DISTRIBUTION STUDIES OF THE METAL VAPOR VACUUM ARC ION SOURCE

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ABSTRACT

We have studied the charge state distribution of the ion beam produced by the MEVVA (metal vapor vacuum arc) high current metal ion source. Beams produced from a wide range of cathode materials have been examined and the charge state distributions have been measured as a function of many operational parameters. In this paper we review the charge state data we have accumulated, with particular emphasis on the time history of the distribution throughout the arc current pulse duration. We find that in general the spectra remain quite constant throughout most of the beam pulse, so long as the arc current is constant. There is an interesting early-time transient behavior when the arc is first initiated and the arc current is still rising, during which time the ion charge states produced are observed to be significantly higher than during the steady current region that follows.

I. INTRODUCTION

The charge state distributions of ions generated by the metal vapor vacuum arc ion source have been investigated for a variety of experimental conditions [1-4], and it is well recognized that the distributions in general contain a high fraction of multiply stripped species. Charge state spectra have been measured for a wide range of elemental cathode materials [1,2] as well as for cathodes that are composed of compound and alloy materials [3].

It is important for many applications of the source that the charge state distribution (CSD) be known as a function of time throughout the beam pulse history. Since the ion energy varies with the ion charge state, any variation of charge state distribution will affect the beam optics and hence transmission through magnetic systems (magnetic lenses, analysis magnetic fields, etc), as well as implantation profiles. We have measured the charge state distributions as a function of time throughout the arc current pulse for several different cathode materials and for two different shapes of arc current pulse. The measurements were made using a time-of-flight (TOF) charge state diagnostic in which the gating pulse time was scanned through the beam pulse.

II. EXPERIMENTAL SET-UP

The MEVVA (metal vapor vacuum arc) ion sources developed at the Lawrence Berkeley Laboratory have been described in a number of previous publications [5-8] as well as in several companion papers [9-11].

For the present work the arc was driven by either of two LC pulse lines, each of impedance 1.5Ω and pulse length 250 μs, one being a low-loss line and having a very flat pulse shape ('flat pulse') and the other being quite lossy and having a pulse shape more similar to a damped half sinusoid ('half-sinusoid pulse'). The flat pulse was of magnitude 100 A and the half-sinusoid pulse had a peak current of 400 A. An oscillogram showing the arc current pulse shape and the ion beam current monitored by a central collector plate on the TOF gating plates is shown in Figure 1(a) for the flat pulse and in 1(b) for the half-sinusoid pulse. The ion beam extraction voltage was either 30 or 60 kV. The source was operated on a test-stand equipped with various diagnostics to monitor the source performance and the parameters of the extracted beam. A time-of-flight diagnostic was used for measurement of the ion charge state spectrum, and this instrument and its performance have been described previously [11]. A schematic of the experimental configuration is shown in Figure 2. The background pressure in the vacuum vessel was maintained at about 1×10^{-6} Torr.

In measuring the current of multiply charged ions it is important to distinguish between electrical current and particle current. For ions of charge state Q, the electrical current is greater than the particle current by the factor Q: $I_{elec} = QI_{part}$. Depending on the application one might be interested in either the electrical current or the particle current. Here the detector is a Faraday cup and the signal measured is electrical current.

III. RESULTS

Some General Observations

Cathode materials whose charge state distributions have been measured over the course of our investigations include: Li, C, Mg, Al, Si, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Rh, Pd, Ag, In, Sn, Gd, Ho, Ta, W, Pt, Au, Pb, Th, and U; these observations have been reported previously [1]. In another study the ion spectra obtained from cathodes composed of alloys and compounds have been investigated [3]. No special preparation of the cathode material was done; the cathodes were simply "as-machined". We have observed that the spectra may initially show some contamination (eg, C, N, O, Al), but in general become quite clean after around 100 or so shots, then showing only ion components belonging to the cathode material. For one case (uranium) we prepared a well-outgassed cathode by a 24-hour vacuum bake at 600C, and found no difference in the charge state spectra between this cathode and an unbaked cathode. The measured charge state spectra are influenced by the magnitude of the arc current. In general the dependence is rather weak over the range investigated, about $50 < I_{arc} < 1200$ A. This is consistent with a picture in which the main effect of increasing the arc current is simply the creation of more cathode spots, rather than a change in the plasma parameters within the spots. There is a shift to slightly higher charge states as the current is increased, but this trend often reverses for sufficiently high arc current. We have also discovered a pronounced effect on the charge state distribution of a strong axial magnetic field; the mean charge state increases with field strength, and new highly-stripped components are produced [2].

Charge State Distribution Time History

By scanning the time-of-flight gating pulse, the charge state distribution can be determined as a function of time throughout the arc pulse duration. We have carried out this kind of measurement for the two different arc current pulse shapes and for three different cathode materials (Ti, Cu and Ta). A set of oscillograms showing the TOF spectral variation for the case of a titanium cathode with the flat arc current pulse is shown in Figure 3. From data such as these the CSD time evolution can be obtained, and these results are shown in Figures 4 and 5. The charge state fractions plotted in Figures 4 and 5 are normalized particle current fractions, and have been obtained from data like that in Figure 3 by using $f_p(Q) = (i_e/Q)/\Sigma(i_e/Q)$, where $f_p(Q)$ is the fraction of the total beam particle current in charge state Q, and ie(Q) is the amplitude of the Q'th peak of the TOF spectra (which is an electrical current). Figure 4 shows the CSDs for the case of the constant-current arc pulse shape for (a) Ti and (b) Ta cathodes, and Figure 5 for the half-sinusoid arc current pulse shape for Ti. It can be seen that the charge state distributions contain higher charge state components at early times. The CSD time history for the copper cathode showed similar general behavior.

A possible reason for the 'early time effect' could be associated with the higher voltage that is then present across the anode-cathode gap, as the voltage falls from its pre-breakdown value of typically 200 V to its burning value of typically 20 V. Higher energy electrons that are then presumably present in the discharge could give rise to more highly stripped ion species. However, the voltage falls to its steady value in about 25 μs or so, while the CSD remains high for a time roughly twice this. This tends to imply that the elevated arc voltage is at most only partially responsible for the high charge states at early times.

Another mechanism that might play a role could be associated with the non-steady arc current at early times. This hypothesis is not completely supported by the data for the two different arc current pulse shapes, since the CSD time histories are quite similar in spite of the quite different arc current time histories. We have also carried out some experiments in which the arc current was modulated by a superimposed ringing current on top of the flat current pulse, and found that the charge states were higher when the current was increasing. We attempted to "harness" this effect by fabricating a split-cathode configuration - a cylindrical cathode split into two halves, with each half electrically connected separately and configured so as to encourage the arc to oscillate between the two halves; in this way the arc current would always be increasing as it switched from one half to the other. Although this set-up did not oscillate steadily, we did observe that in those cases where the discharge switched from one half of the cathode to the other, the charge state distribution was indeed elevated.

IV. CONCLUSION

The charge state distributions of ions generated in the metal vapor vacuum arc ion source have been measured as a function of time throughout the arc current pulse, both for flat and varying current pulse shapes and for several different cathode materials. The distributions contain a higher fraction of high charge state ions at early times, for both arc current pulse shapes. At the present time we do not have a good understanding of the early-time high charge state behavior, although the higher arc voltage and non-steady arc current at early times may both play a role. For the time in the arc pulse over which the current is steady, so also is the ion beam charge state distribution.

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FIGURE CAPTIONS

Fig. 1 Oscillogram of arc current and ion beam current. Upper trace is the ion beam current monitored by the central beam stop on the TOF gate, and the lower trace is the arc current. Sweep speed is 50 µs/cm. (a) flat current pulse; (b) half-sinusoid pulse shape.

Fig. 2 Schematic of the experimental configuration.

Fig. 3 TOF spectra as a function of time throughout the arc current pulse. Flat arc current pulse shape; Ti cathode; vertical scale is approx 2 mA/cm; sweep speed 0.5 µs/cm.

Fig. 4 Time history of the charge state spectrum (normalized particle fractions) throughout the arc current pulse, for the case of the flat arc current pulse shape. (a) Ti; (b) Ta.

Fig. 5 Time history of the charge state spectrum (normalized particle fractions) throughout the arc current pulse, for the case of the half-sinusoid arc current pulse shape, for Ti.

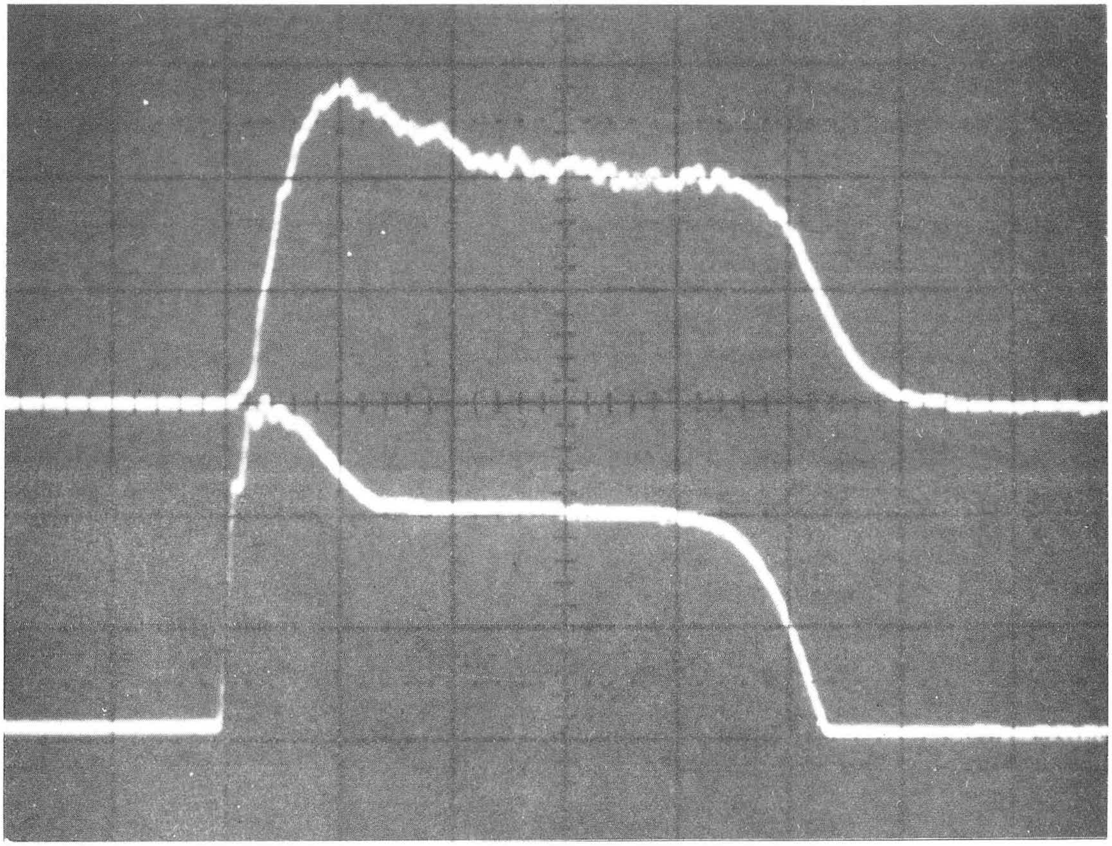

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Figure la

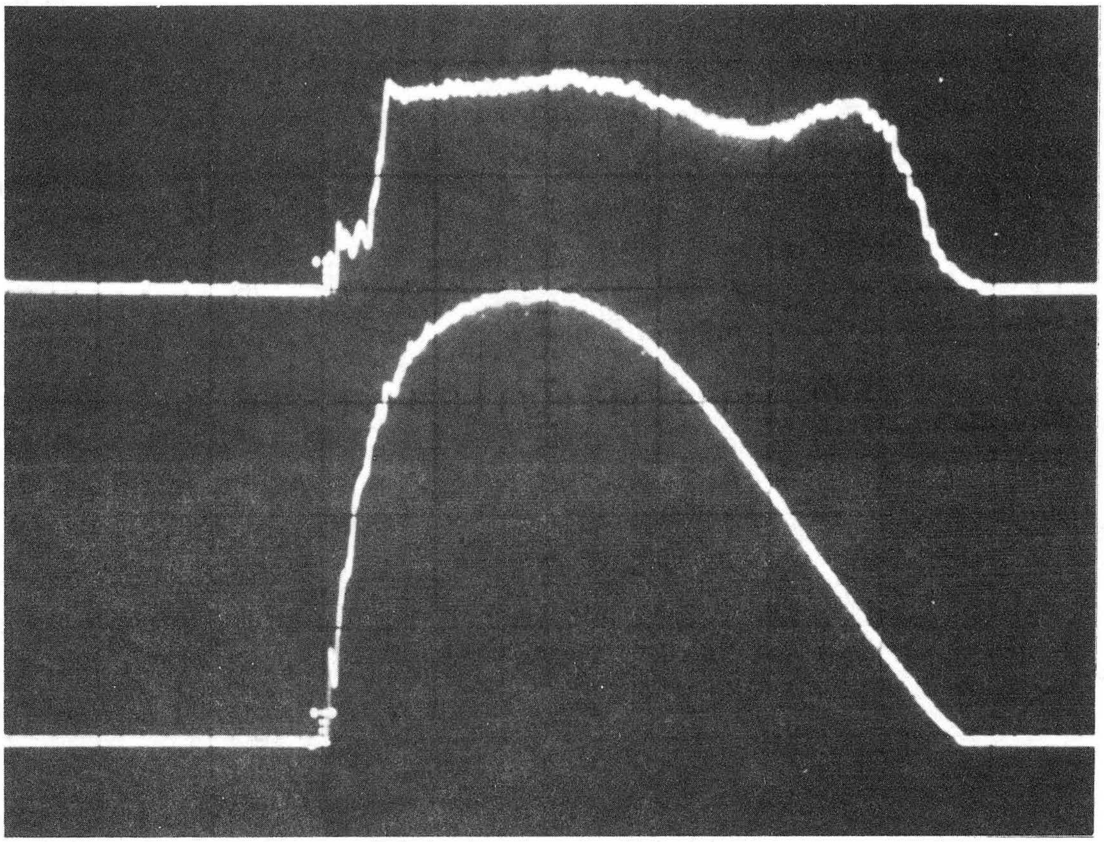

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Figure 1b

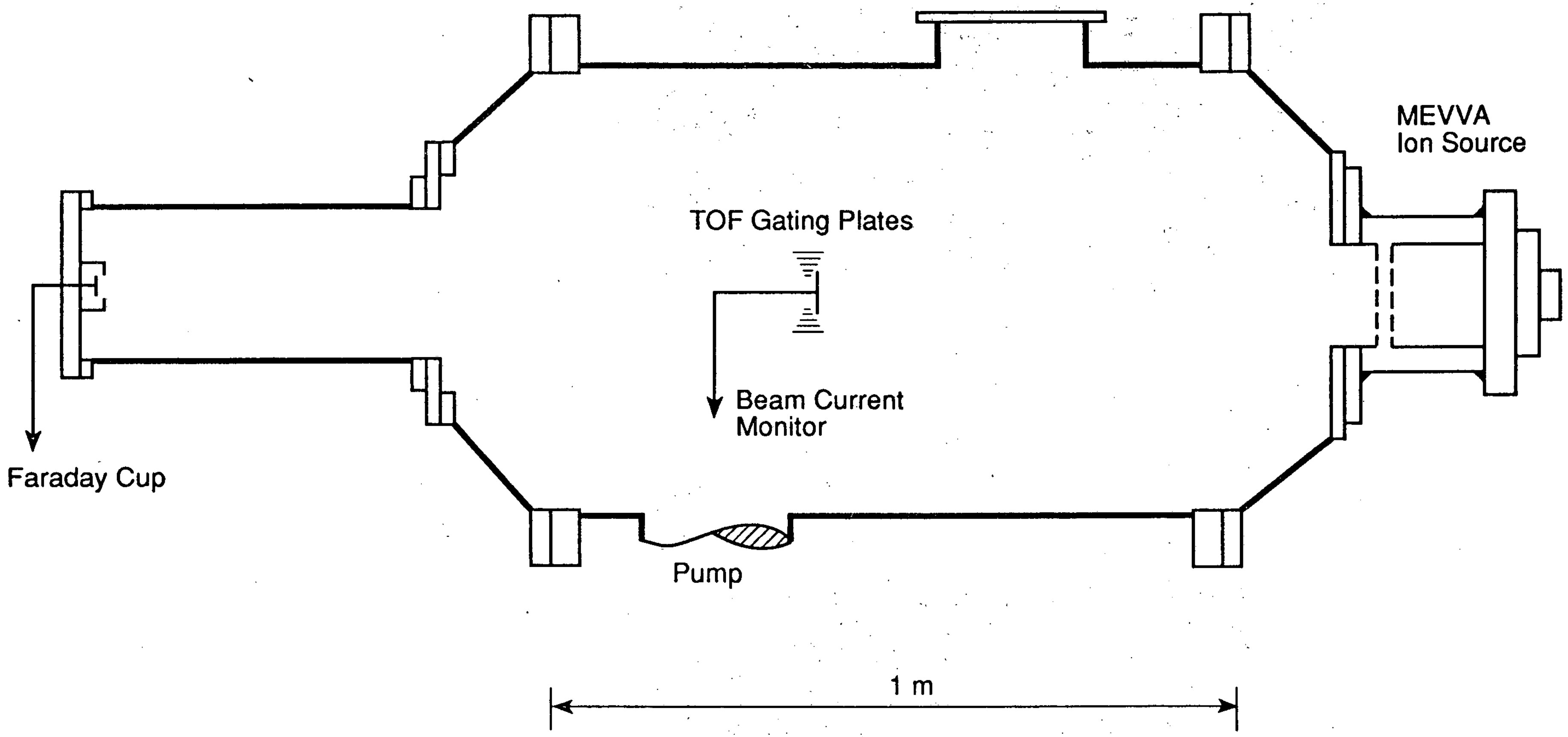

Figure 2

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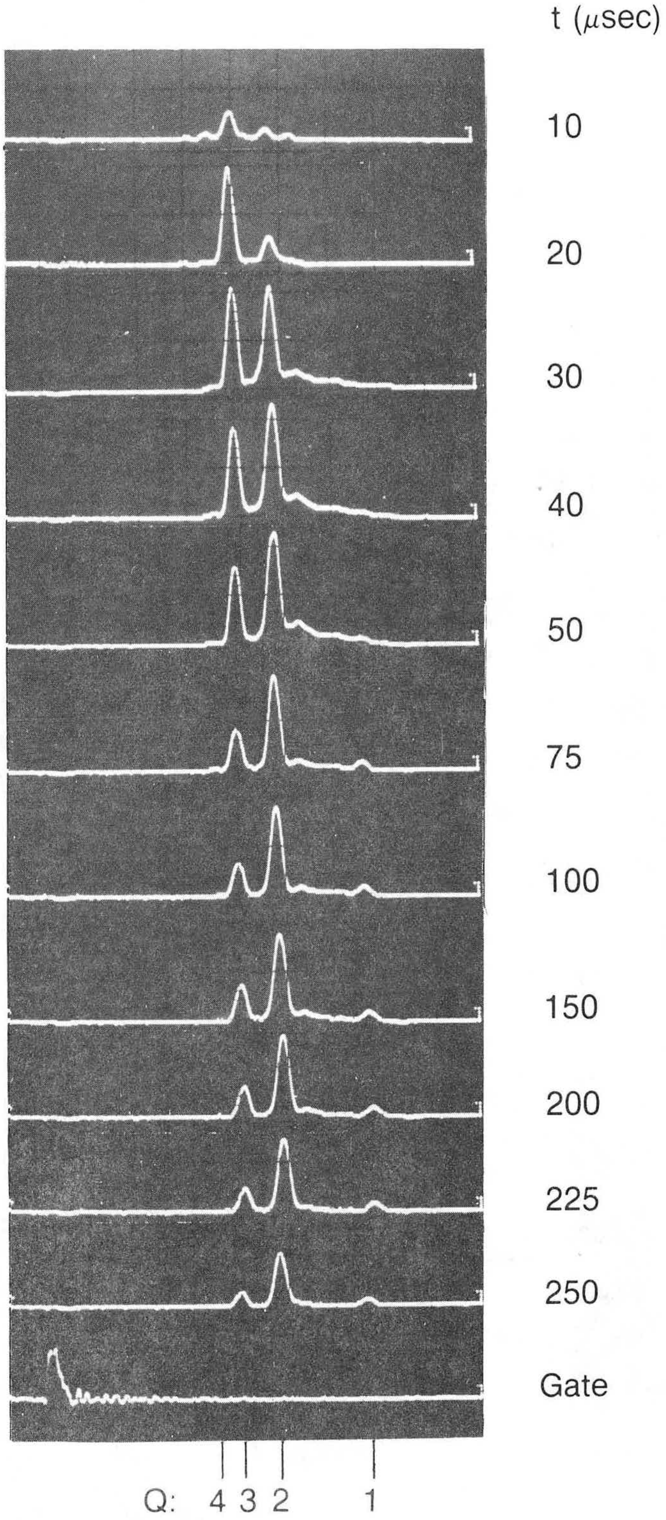

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Figure 3

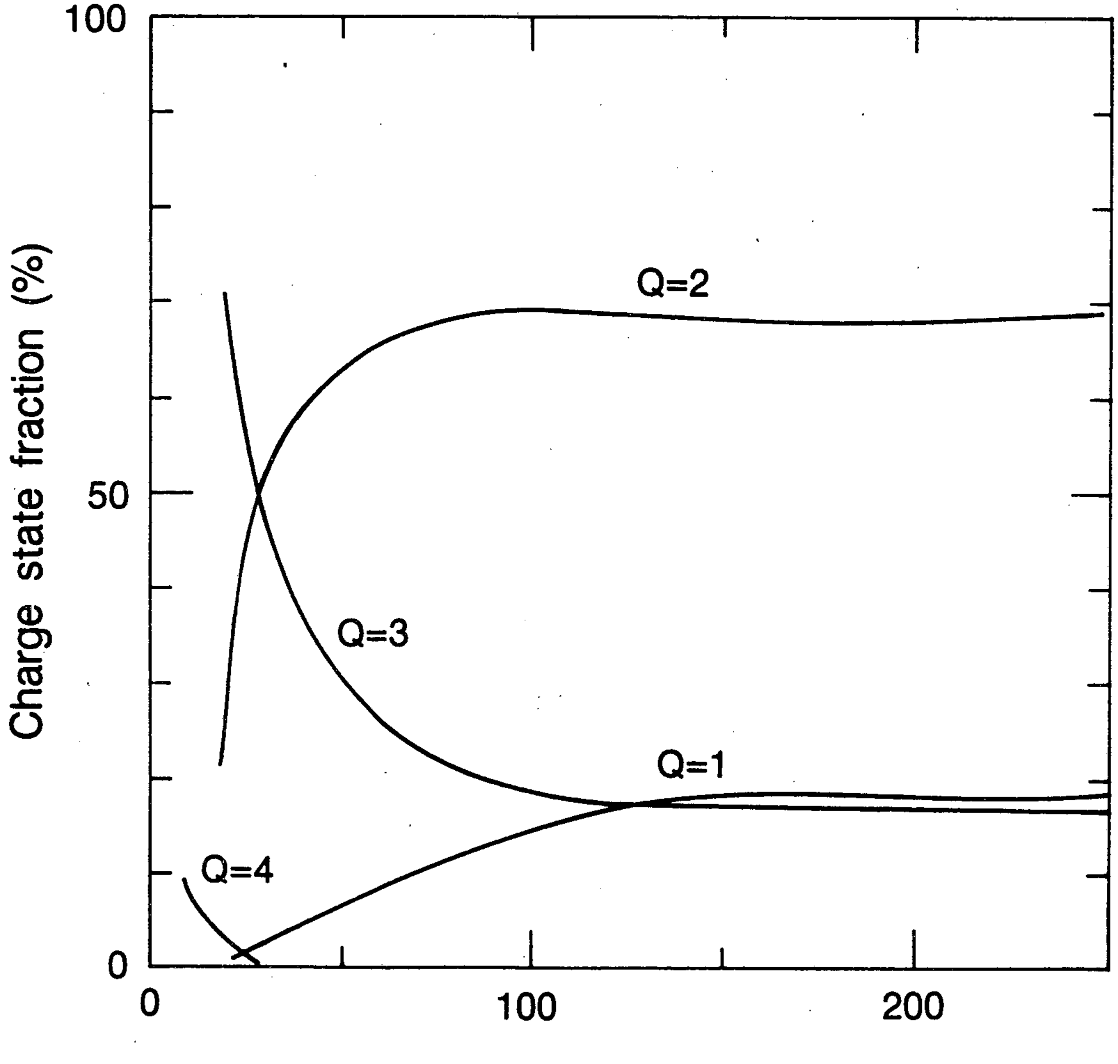

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Figure 4a

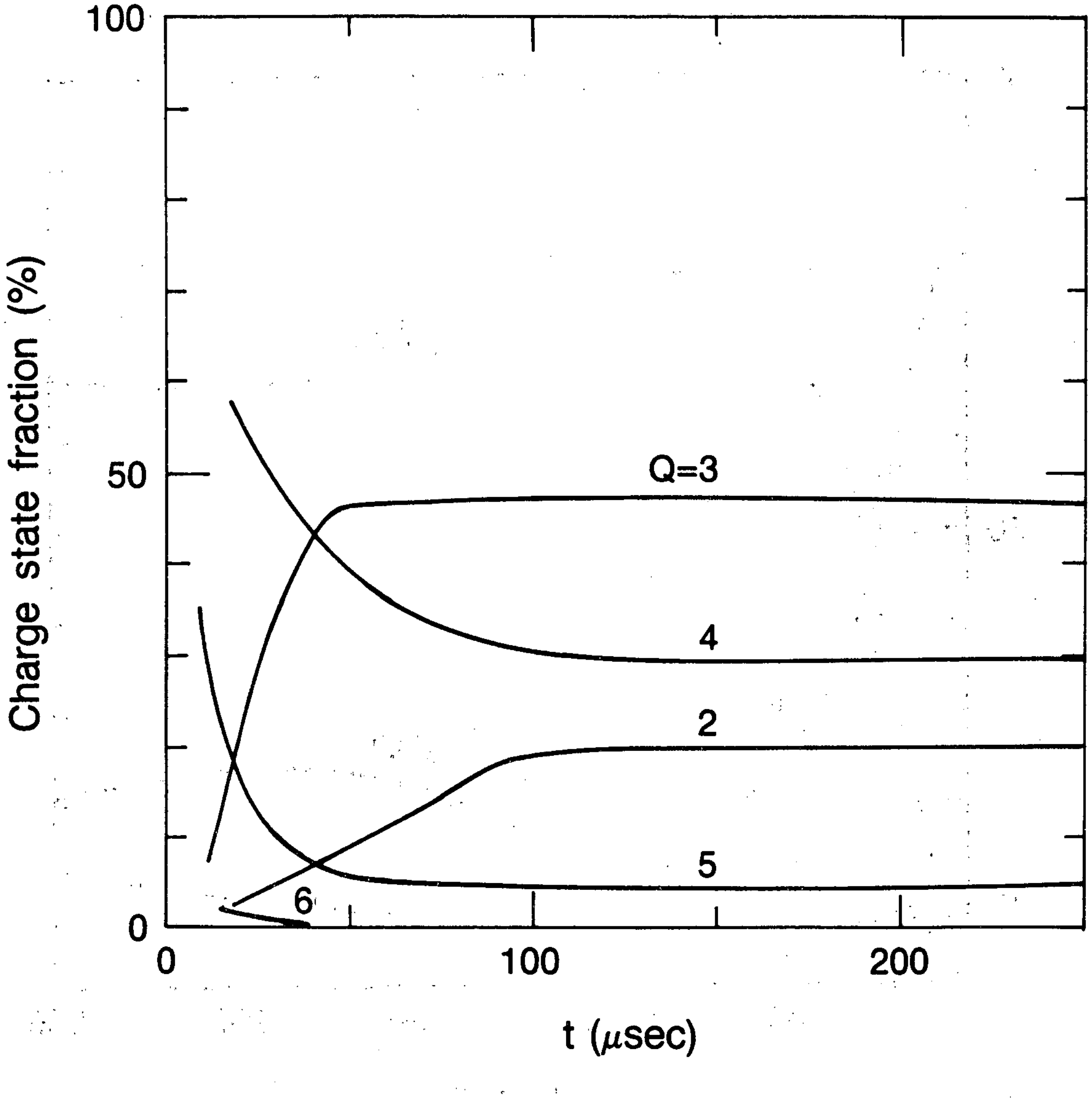

Figure 4b

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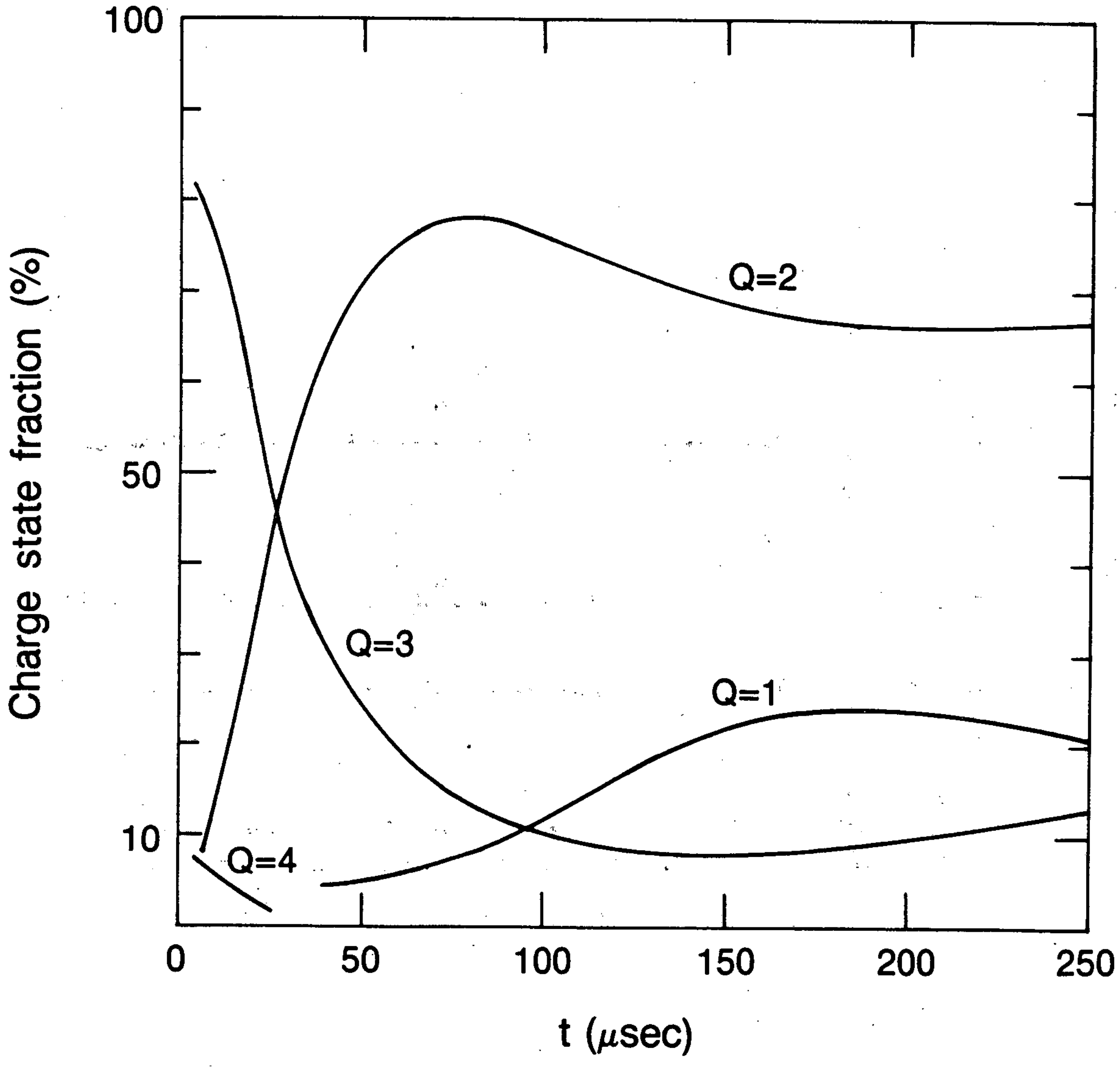

Figure 5

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