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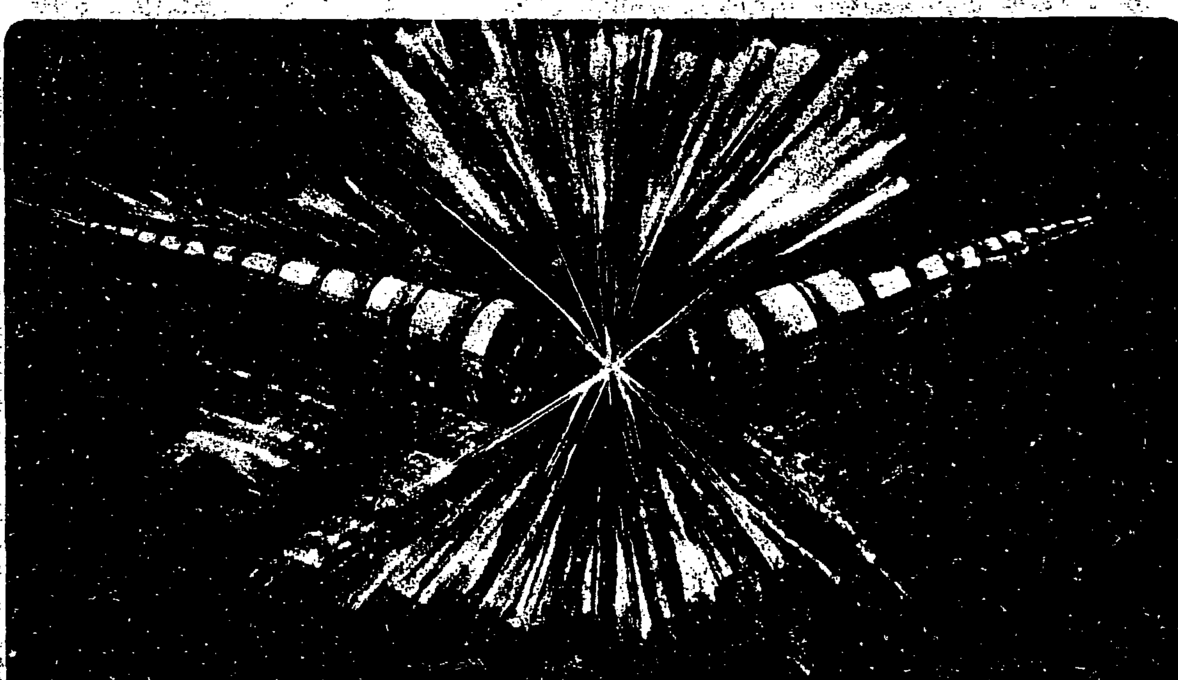

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ABSTRACT

A time-of-flight diagnostic for analysis of relatively low energy ion beams is described. The system incorporates several novel features which improve its performance in a number of ways. The technique is simple and can provide an alternative to magnetic analysis of ion beams for the determination of ion charge state and beam composition.

INTRODUCTION

Analysis of ion beams by time-of-flight (TOF) systems is a diagnostic method used in a variety of fields [1 3]. It provides a particularly simple alternative to magnetic analysis for the determination of the charge state distribution of the beam produced by an ion source. We have made extensive use of this kind of system in our work developing the MEVVA (metal vapor vacuum arc) high current metal ion source [4-6]. In our application we need to monitor the charge state distribution of beams of metal ions, from lithium up to uranium, extracted from the ion source at a voltage of from 10 kV to 100 kV and injected into a high vacuum test chamber. We describe here the system we've developed and the improvements we've made.

DESCRIPTION OF THE METHOD

Ions of mass number A and charge state Q are extracted from the ion source through a voltage drop V_{ext} and thus acquire a velocity

$$v = \left(\frac{2eV_{ext}}{m}\right)^{1/2} \left(\frac{Q}{A}\right)^{1/2} \tag{1}$$

where e is the electronic charge and m the nucleon mass. In the time-of-flight method, a short pulse is gated out of the main ion beam pulse for analysis. The short sampled pulse is caused to drift through a distance L adequate to allow separation of the various Q/A components in the beam, and the flight time of these components is measured by a detector located at the end of the drift region. In this application the method is a Q/A diagnostic, and since in our case the beam is composed almost entirely of a single mass ion, it provides a charge state analysis. The time in the main beam pulse at which the short time-of-flight pulse is gated out can of course be varied electronically, so allowing the charge state spectrum to be sampled as a function of time throughout the beam pulse.

The short ion pulse is produced by a gate typically a few tenths of a microsecond wide. The gating device is a set of electrostatic deflection plates arranged such that in the "off" condition no beam reaches the detector; the gated ion pulse is created by pulsing the deflection plates on so as to aim the deflected ion beam at the detector. The gate pulse is produced by the discharge of a suitable length of RG58 coaxial cable, charged to (twice) the required pulse voltage, through a 5C22 thyratron switching unit. To good approximation the beam angular deflection θ is given by

$$\theta = \frac{\ell V_p}{2sV_{ext}} \qquad (2)$$

where V_p is the voltage applied across the plates, ℓ is the length of the plates and s their separation. Note that the deflection is a function of only the extraction voltage and the deflection plates geometry and voltage, and is independent of the particle type, Q/A. In our set-up the plates are approximately 2 cm long, have a 1 cm separation, and we apply a voltage pulse of from 1 to 5 kV. For an extraction voltage of, say, 50 kV, the deflection is thus several degrees.

In the initial configuration, the gating plates were positioned off-axis with respect to the ion source and detector, and the direct line-of-sight path from the source to detector was blocked in order to stop intense light and uv generated by the source from striking the detector and producing a spurious signal. The signal amplitude, and thus the device sensitivity, was greatly increased by replacing this configuration with a nested set of annular gating plates. Figure 1 shows the simple gating plates configuration used initially (rear view), and the nested annular gating plates (front view). The central plate blocks the direct line-of-sight, as before, and also serves as a beam current monitor. The length of the plates increases with radius so as to increase the angular deflection of the beam at greater radii, as per equation (2). This annular gating plate array transmits a much greater fraction of the beam than the smaller, offset plates. The gated ion pulse is further focused onto the detector by a 10 cm diameter gridded Einzel lens midway between gating plates and detector.

The magnitude of the ion current in the beam pulse at the detector is small, and before we changed to the higher transmittance annular gate this signal was not measurable using a Faraday cup as detector. We instead used a photomultiplier with the front glass faceplate (photocathode) cut off so that ions could strike the first dynode directly. So long as this detector was shielded from seeing the ion source directly, clean and crisp signals were generated. We firstly used an RCA 7265 tube and this worked well; we replaced this with an RCA 4523, which has a larger diameter first dynode and so can monitor a greater fraction of the ion beam. A problem in using a photomultiplier structure for the detector, however, is in the unknown calibration of the sensitivity with respect to charge state, especially noting that in the present application the different charge state species have different energies. Also, one has to be careful to ensure that the input ion signal is sufficiently small that the photomultiplier is not near saturation; the spectrum can be distorted significantly and still appear "reasonable". In some cases, for example when using the annular gate array, we found it convenient to use a 100:1 (approximately) ion beam attenuator, fabricated from an aluminum plate with many small holes drilled in it and located immediately in front of the gate.

With the greater signal provided by the annular gating array, we were able to use a magnetically suppressed Faraday cup as detector. The 2 cm diameter cup was located within a metal box with a screened aperture on the front for transmission of the beam into the cup, to provide maximum shielding from electromagnetic pickup. Two samarium cobalt bar magnets were located just in front of the cup so as to produce a transverse magnetic field for the suppression of secondary electron current; an iron flux return path was provided. A custom-made x6.7 pre-amplifier with 10 Mhz bandwidth was located at the Faraday cup output. The amplifier has an input impedance of 1.5 KOhms and feeds into a 50 Ohm cable terminated with a 50 Ohm resistor at the oscilloscope. With this amplifier in place, the Faraday cup current is 100 microamperes per volt measured at the oscilloscope.

A schematic diagram of the pre-amplifier circuit is shown in Figure 2, and the complete time-of-flight configuration in Figure 3.

RESULTS

We have used this system routinely for measurement of the charge state distribution of the beam produced by the MEVVA ion source with a wide range of cathode materials. An example of the spectra obtained with the photomultiplier structure and with the Faraday cup is shown in Figure 4. The two traces were obtained successively, since the Faraday cup has to be positioned far off-axis to allow the beam to propagate to the photomultiplier. In this oscillogram, the upper trace is the photomultiplier signal and the bottom trace is the Faraday cup signal; the sweep speed is 1 microsecond/cm, and the photomultiplier signal is delayed with respect to the Faraday cup signal because it is 35 cm further downstream. The ion species was tantalum and the extraction voltage from the MEVVA ion source was 50 kV. The charge states generated by the MEVVA source, and shown in the oscillogram, are Ta^{+}, Ta^{2+}, Ta^{3+}, Ta^{4+} and Ta^{5+}. The spectral compositions for the two detectors are similar but not identical, and this is because the Faraday cup reads electrical current (ema) while the photomultiplier reads a signal related to particle current (pma, equal to ema/Q). In fact, at least for this particular case, the normalized photomultiplier spectrum can be brought into agreement with the normalized Faraday cup spectrum by dividing the Faraday cup spectral peaks by the charge state, Q, (to convert to particle current), and dividing the photomultiplier spectral peaks by $\sqrt{Q}$, which would be as expected if the photomultiplier secondary emission signal is proportional to the number of ions striking it (particle current) multiplied by the ion velocity (proportional to $\sqrt{Q}$).

The radial distribution of the measured charge state distribution is of some importance. There are two concerns here - firstly whether the beam generated by the ion source has an inherent charge state radial distribution built into it, and secondly whether the charge state diagnostic selectively distorts the true distribution. Figure 5 shows the spectrum measured by the on-axis Faraday cup for the case when only the innermost annular gate was used (r = 2 cm) and for the case when only the outermost annular gate was used (r = 7.1 cm), upper and lower traces respectively. It is evident that the spectra are closely the same in shape, and thus that the MEVVA ion beam has no radial variation of charge state distribution. The ability to measure this beam characteristic is an interesting feature of the annular gating plate configuration. Figure 6 shows the radial distribution of the various charge states in the vicinity of the time-of-flight detectors, obtained by scanning the Faraday cup radially. It is clear that the distributions for the different charge states are all peaked at the same radial position, which in fact is close to the axis. Thus we conclude that no spectral distortion of this kind is introduced by the diagnostic itself.

A time-of-flight spectrum as obtained in normal operation is shown in Figure 7. Here the gating pulse is shown also; this is the pulse applied to the annular gate, and it provides a reference from which to measure the flight times of the various charge state bunches. Since the drift length is known (195 cm for this case, where the detector is the Faraday cup), the charge states can be determined through equation (1). The fit of the measured to the calculated delays is very good:

Charge state, Q	1	2	3	4	5	
Measured flight time	8.42	5.97	4.88	4.22	3.83	(microsec)
Calculated flight time	8.45	5.97	4.88	4.22	3.78	"

The fit is good to about 1%, which is better than we have reason to expect based on measurement uncertainties alone. Thus we have a high degree of confidence in the interpretation of the charge state spectra in this way.

CONCLUSION

A time-of-flight ion charge state diagnostic has been described. Several novel features have been incorporated into the system which improve the utility of the dagnostic, including a nested set of annular gating plates, greatly increasing the fraction of the beam that the diagnostic samples and allowing the radial structure of the beam charge state distribution to be studied easily. The system has been used to survey the ion charge state distribution of the beam produced by the MEVVA high current metal ion source for a wide variety of cathode materials and operating conditions. Excellent agreement was found between the measured and calculated time-of-flight spectra, and the data obtained are clean and unambiguous. The improvements in the scope, sensitivity and reliability of this diagnostic method may broaden the utility of the method to other fields of application.

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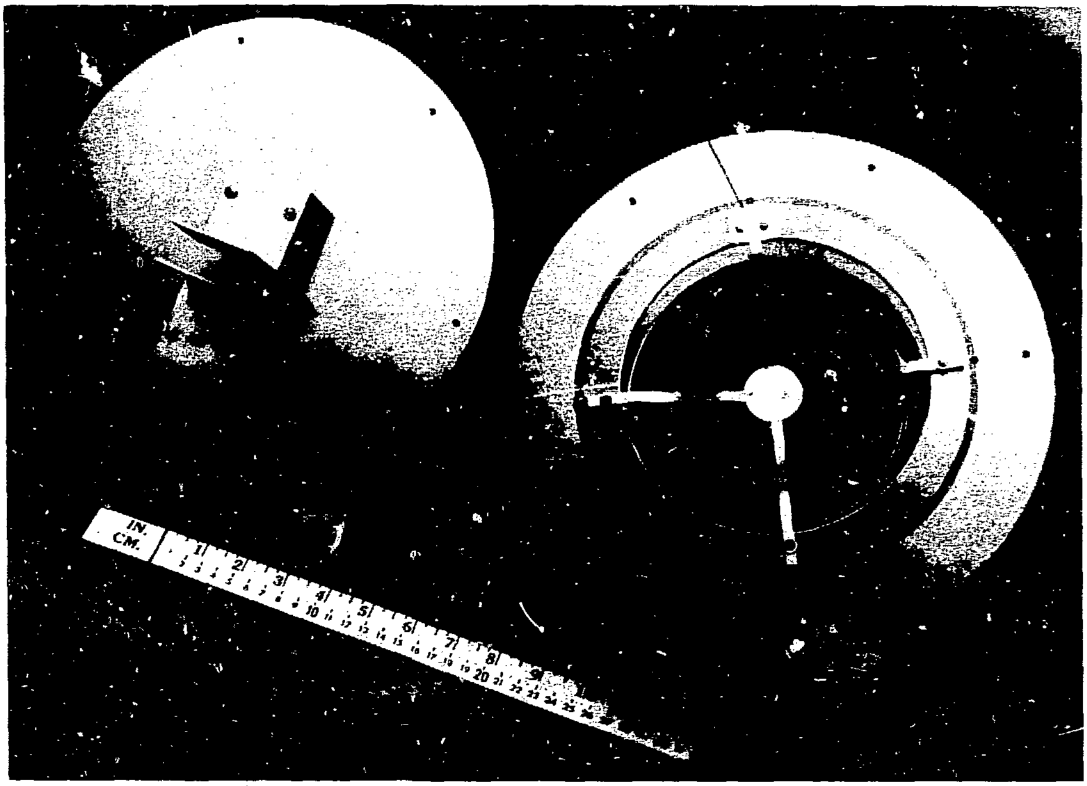

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Fig. 1 Photograph of the old and new gating plates. The original, small plate-pair is shown on the left (viewed from downstream); the higher transmission annular array is shown on the right (viewed from upstream).

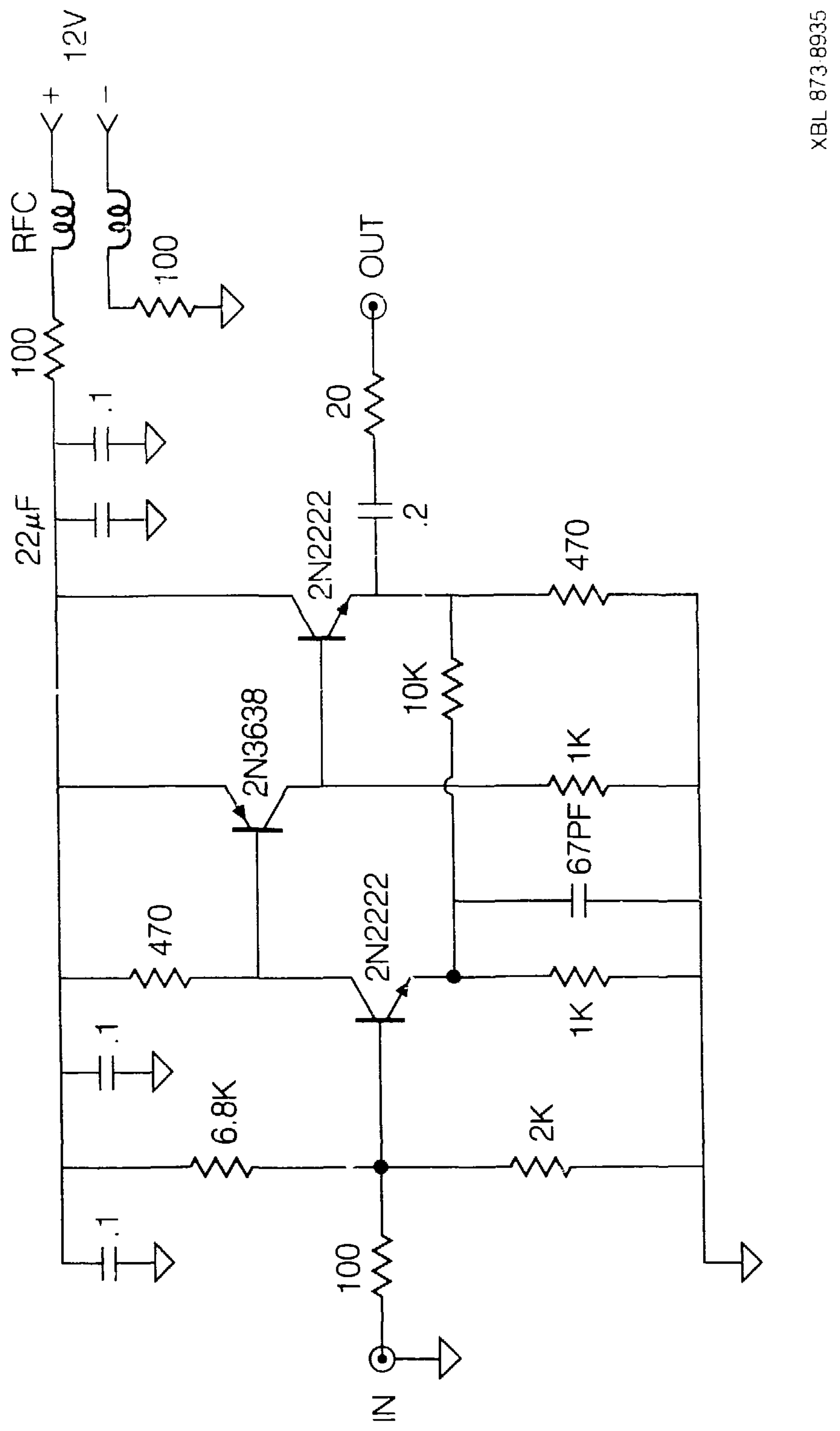

Fig. 2 Schematic of the pre-amplifier circuit. Gain is 6.7, bandwidth approximately 10 MHz.

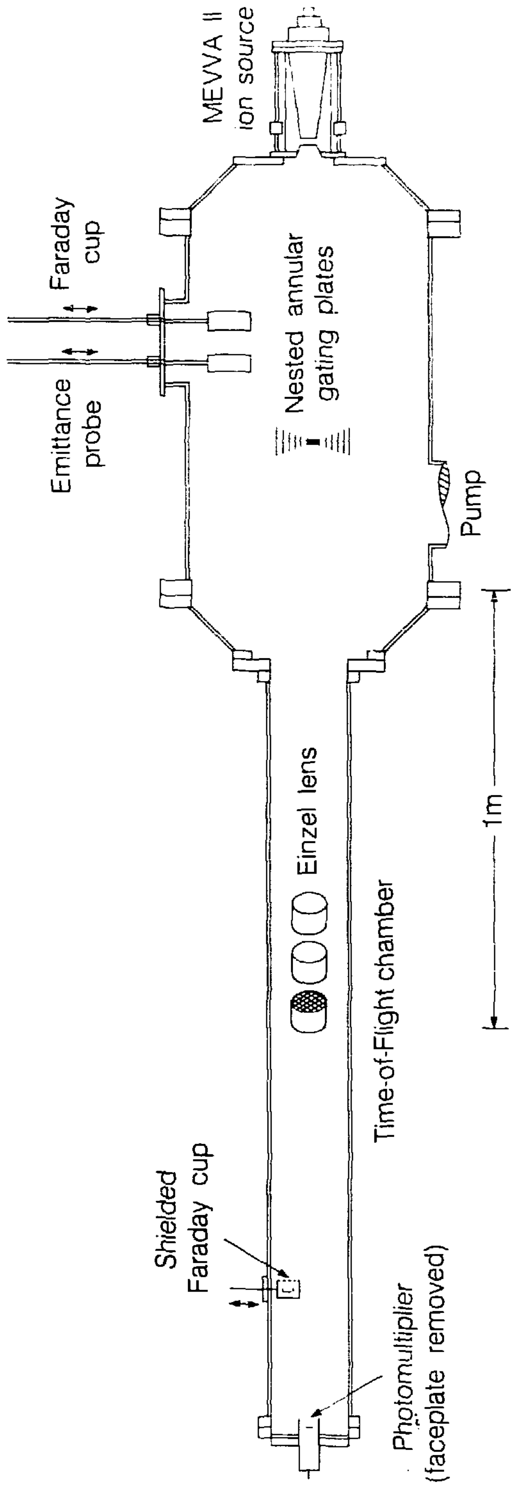

Fig. 3 Schematic of the experimental configuration.

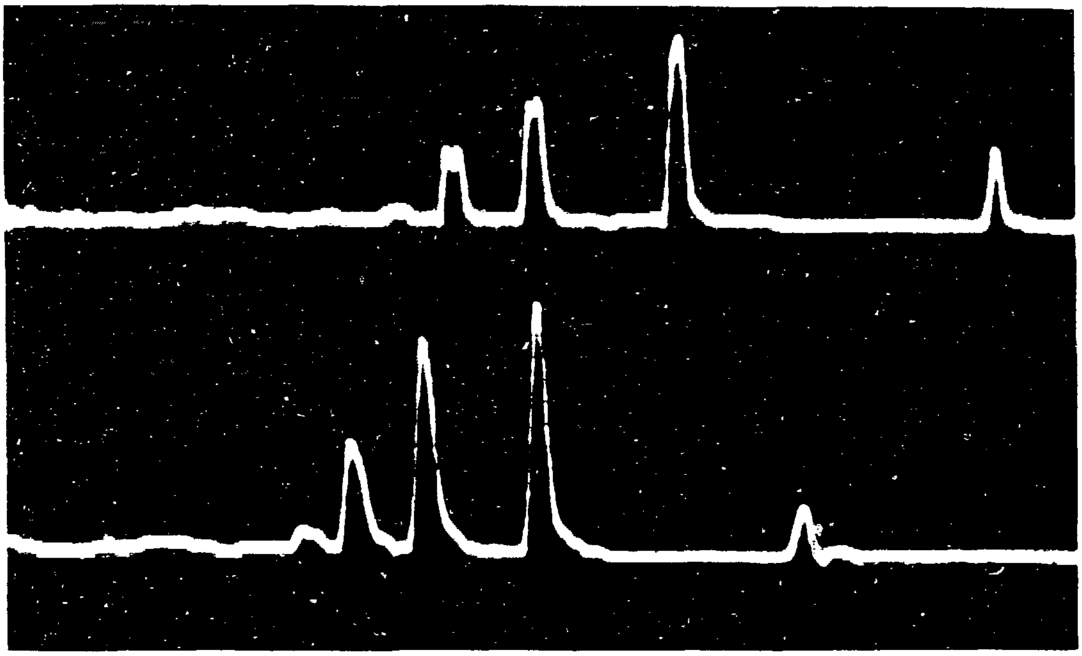

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Fig. 4 Time-of-flight signal measured by the photomultiplier structure (faceplate removed) (upper trace), and by the Faraday cup (lower trace). Tantalum, charge states 1 through 5 (right to left). Sweep speed is 1 microsecond/cm.

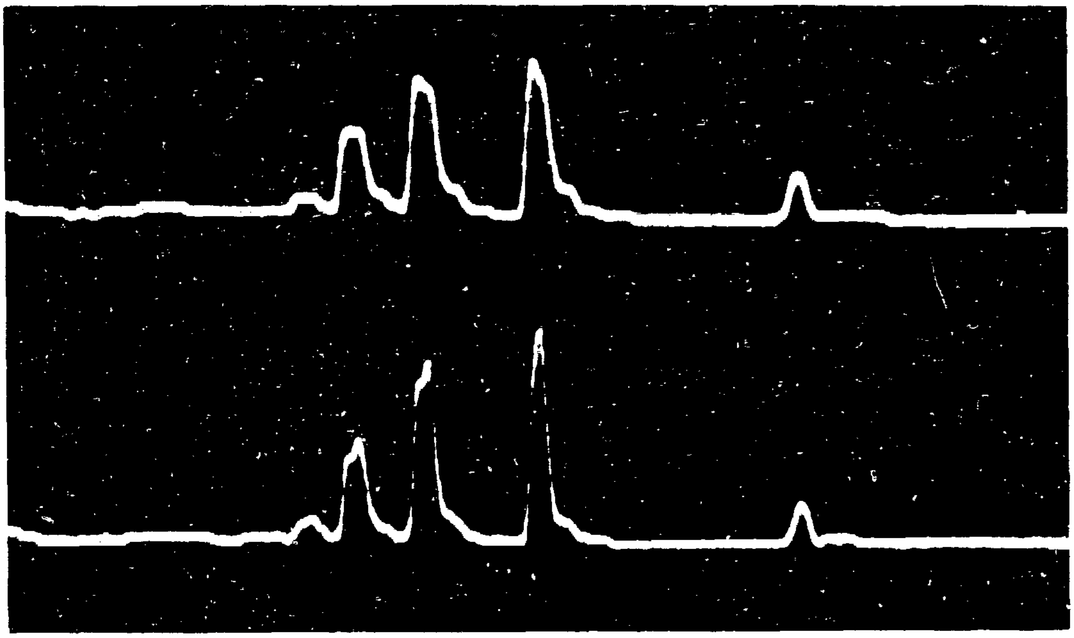

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Fig. 5 Signal measured by on-axis Faraday cup,

(a). Upper trace, only the innermost annular gate used (r = 2 cm);

(b). Lower trace, only the outermost annular gate used (r = 7.1 cm).

Vertical scale is 0.2 V/cm, or 20 microamperes/cm into the Faraday cup.

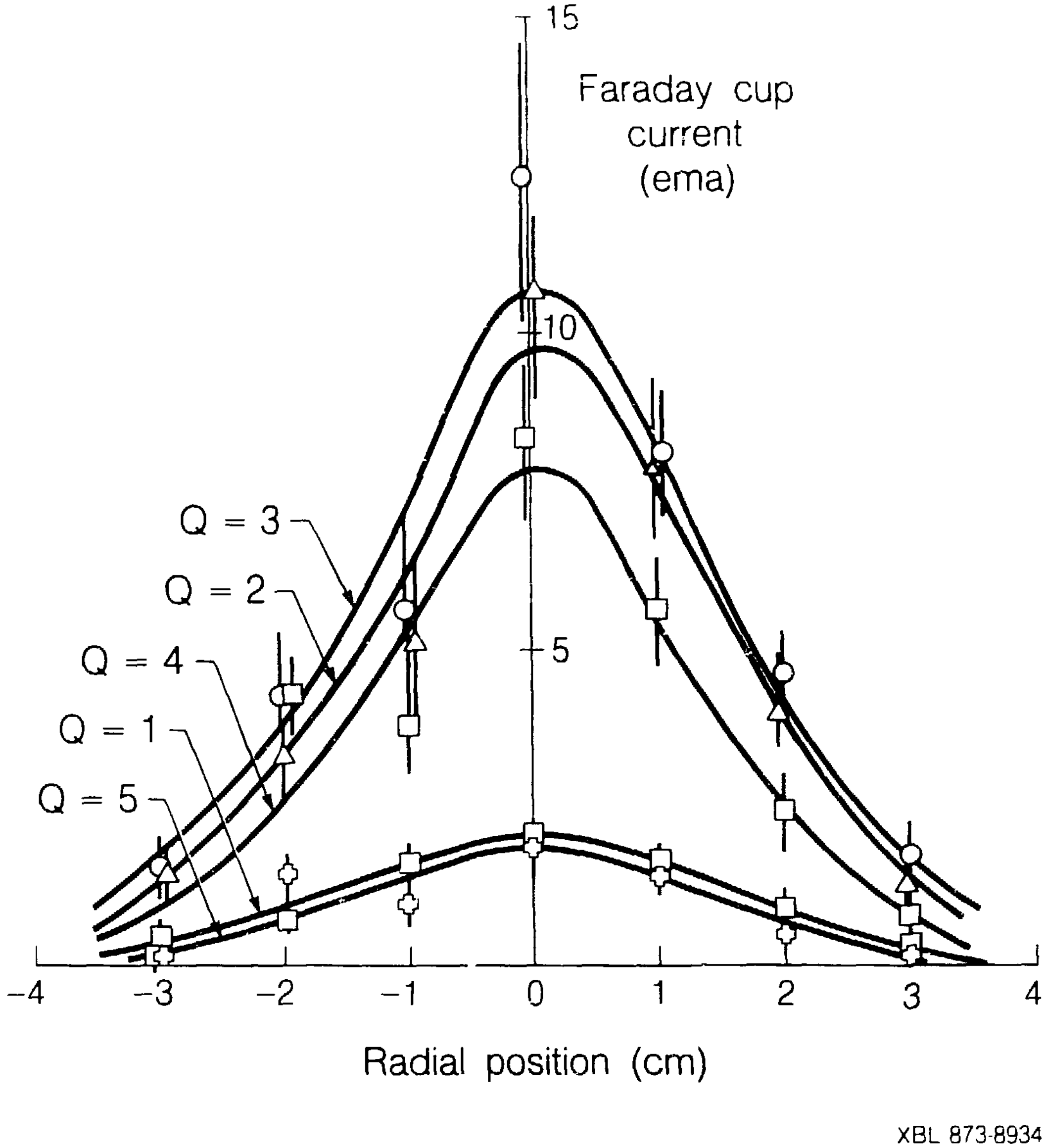

Fig. 6 Radial distribution of the charge state components, measured by scanning the Faraday cup radially.

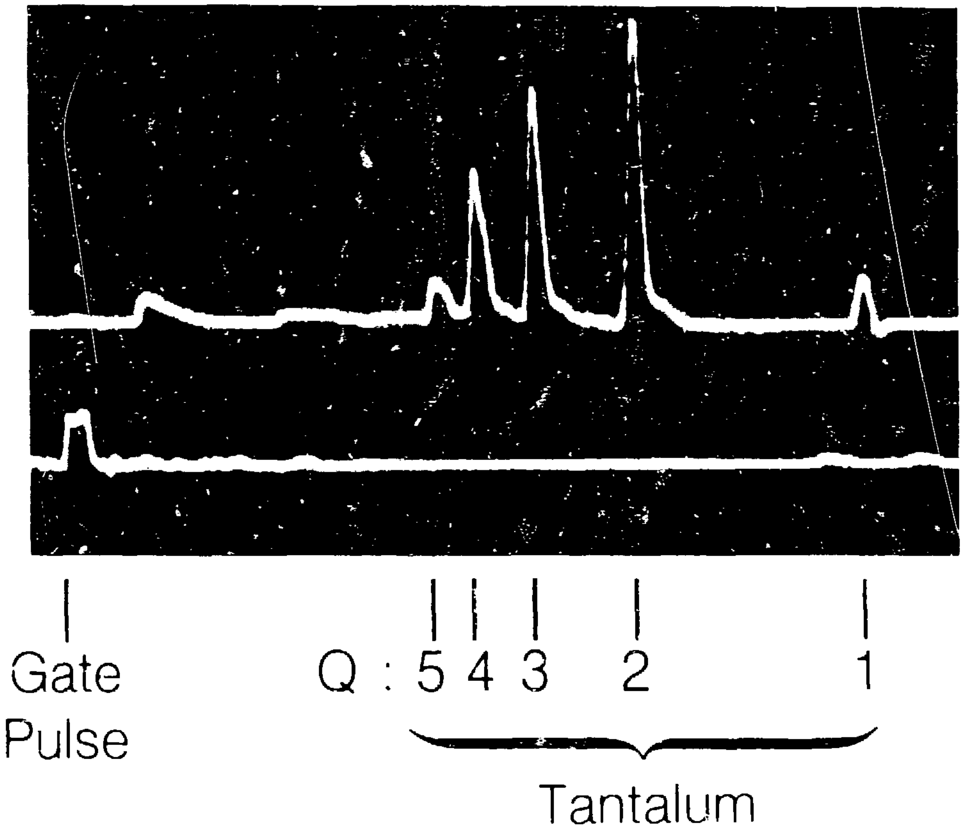

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Fig. 7 Time-of-flight spectrum measured by the Faraday cup, showing the gating pulse for a time reference. Sweep speed is 1 microsecond/cm.