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EVIDENCE OF SHELL EFFECTS AND THE APPROACH TO EQUILIBRIUM IN THE CHARGE-STATE DISTRIBUTIONS FOR 15-160 MeV ^{79}Br AND ^{127}I IONS IN CARBON*

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Equilibrium charge distributions of ^{79}Br and ^{127}I ions have been obtained with an electrostatic analyzer. Influences of ionic shell structure upon the charge distributions have been found. Thin carbon foils (8-78 μg/cm^2) have been used to observe the approach to charge-state equilibrium.

Recent interest in very heavy ions from accelerators for studies of transuranic nuclear structure has emphasized the need for information about ionic charge states. The assumption that charge-state equilibrium is reached in the thinnest available carbon foils has been found to be incorrect even at energies as low as 100 MeV. The assumption that equilibrium charge-state distributions are approximately Gaussian has been found to be grossly incorrect in certain energy regions because of shell effects in the electronic structure of the ion.

Charge-state measurements were made with beams of ^{79}Br and ^{127}I ions (15-160 MeV) from the Oak Ridge tandem accelerator and a High Voltage Engineering Corporation Model MP tandem accelerator.[1] The beams were passed through various carbon foils (8-78 μg/cm^2), collimated to 0.02° in the forward direction, separated according to charge state by electrostatic deflection, and detected with a position-sensitive solid-state detector.[2] Simultaneous recording of all charge states eliminated normalization problems. Peak-to-valley ratios for the dominant charge groups were ≥ 1000. Typical spectra contained 15 000 counts, so that statistical errors in all charge fractions normally were ≤ 0.0037.

The dependence of the observed charge-state distributions upon carbon foil thickness is seen in Fig. 1. The carbon thickness required to reach equilibrium clearly exceeds 25 μg/cm^2 at these energies. The more gradual changes in the distributions for carbon thicknesses above 60 μg/cm^2 are explained by the decrease of ion energy with increasing carbon thickness (e.g., the 78-μg/cm^2 foil reduced the ion energy from 100 to 96 MeV). It can be seen that nonequilibrium effects are more pronounced at higher energies.

The shapes of the two equilibrium distributions in Fig. 1 are strikingly different at the two energies. At 100 MeV where most of the ions have partially filled M shells, the distribution is nearly Gaussian. In contrast, the distribution at 140 MeV is very distorted. We believe this distortion is caused by the difficulty of removing electrons from the L shell of the ion. At charge 25 the last M-shell electron has been removed and higher charge states can be reached only by removing L-shell electrons. The apparent success of this description in explaining the observations implies that excited states do not contribute significantly

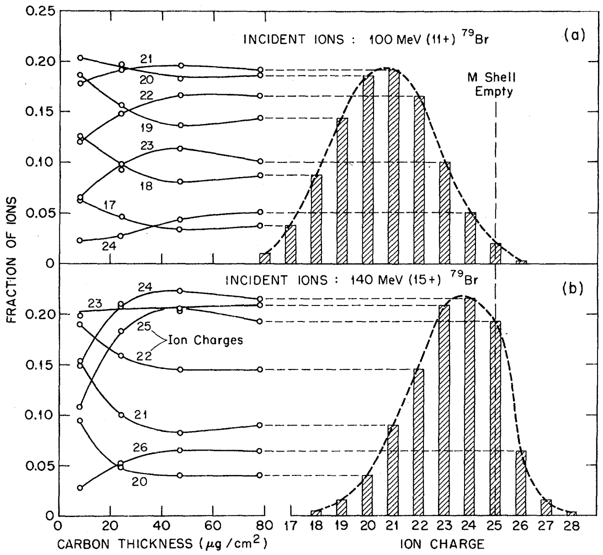

FIG. 1. Variation of charge-state fractions showing the approach to equilibrium with increasing carbon foil thickness for ^{79}Br ions at (a) 100 MeV and (b) 140 MeV. Equilibrium distributions are shown on the right.

toward smearing out the transition effects.

Figure 2 summarizes the measurements for ^{79}Br and ^{127}I ions in carbon foils at equilibrium. The values found for the most probable charge state agree fairly well with those found at Chalk River in the overlapping energy region but disagree somewhat with their extrapolations to higher energy.[3] The gross energy variation of the most probable charge does not appear to be linear with $E^{1/2}$ or $E^{1/4}$ but seems to follow the relation[4,5]

$$q/Z = 1 - A\exp(-CE^{1/2}). \qquad (1)$$

Superimposed on this gross dependence we have found departures which reflect the effect of a shell change as stripping proceeds in the ion. For example, as the energy of I ions is increased [Fig. 2(b)], the spacing of the positively sloping parts of the curves (indicated by arrows) suddenly becomes much larger at charge 25, where the N shell is emptied and M-shell electron removal becomes necessary. Furthermore,

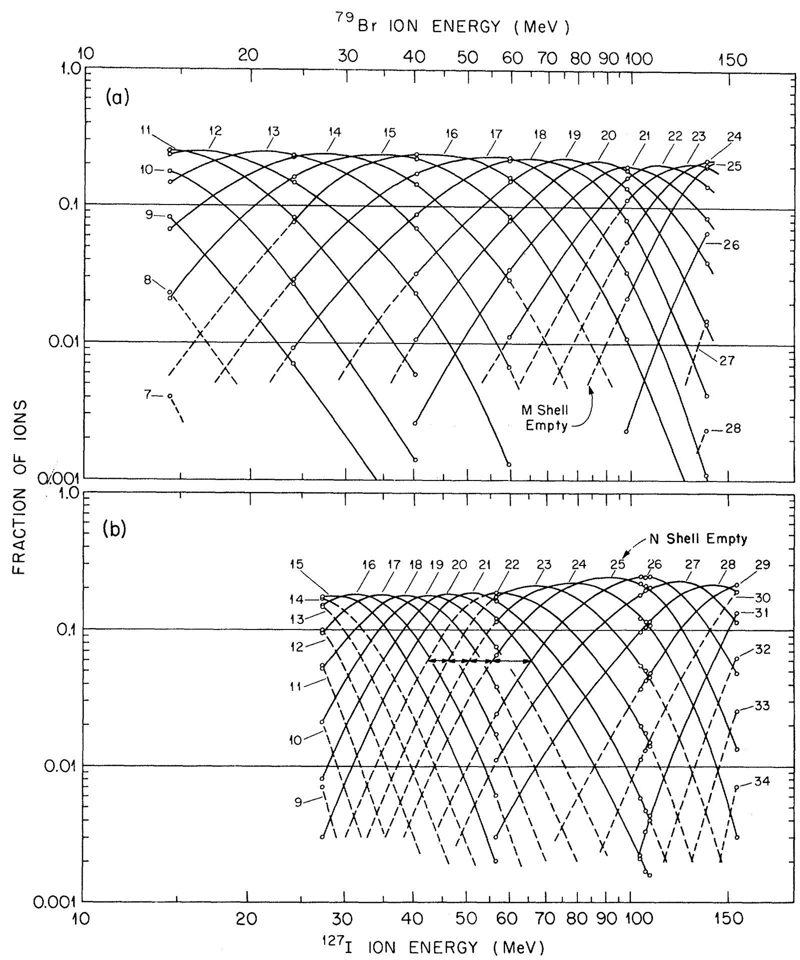

FIG. 2. Variation of charge-state fractions with energy for (a) ^{79}Br and (b) ^{127}I ions in carbon.

the peaks in the curves become higher as the N shell is emptied. These shell effects as well as departures from equilibrium have also been observed with other stripping materials and will be reported elsewhere.

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[2]Nuclear Diodes, Inc., Highland Park, Illinois.

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USE OF POINT CONTACTS TO OBTAIN DIRECT EVIDENCE OF FLUX MOTION IN SUPERCONDUCTORS*

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Recently, a number of experiments[1-3] have claimed to provide evidence that the resistive state of superconductors is a dynamic one, in the sense that the regions of normal material (domains containing one or more flux quanta) are supposed to be set into continuous motion by the transport current. Further, in a related experiment, Pearl[4] has attempted to establish that domain motion is associated with a potential difference in the case that it is produced by a changing magnetic field, rather than a steady transport current. Unfortunately, the potentials observed in Pearl's experiment are not necessarily connected with domain motion, as shown by Meincke,[5] so that, apart from the resistive evidence,[6,7] the only support we have at present for the dynamic model comes from thin-film experiments[1,2] and the point contact method. Using the latter, Sharvin[3] observed oscillations of the resistance of a small area of a superconducting tin disk and inferred that normal domains were in continuous motion across his sample. We have made an experimental study of this effect and find that oscillations such as Sharvin observed can occur very generally when current is passed via a point contact into a superconductor. The phenomena are complex and the application of a magnetic field further complicates the spectrum of oscillations obtainable, but is not a necessary condition for their appearance. From this fact, and others which are discussed below, we conclude that oscillations can arise from an instability of the normal-superconducting interface in the region of the contact and so do not necessarily involve domain motion as envisaged by Sharvin.

The inset of Fig. 1 shows schematically a simple point-contact configuration which we have found to exhibit oscillations. S is a (superconducting) tantalum wire, 0.007 cm diameter, 99.9% purity, with a point affixed by sparking to a (normal) tin plate. Current I is obtained from a constant-current supply. A V-I characteristic for such a point at $T = 4.2°K$ is shown on Fig. 1. (The voltage drop due to the normal tin has been subtracted from the observed V.) Recorder traces of the voltage fluctuations are shown with increased gain at a number of points on the characteristic. At high currents the fluctuations observed appear completely irregular, but at low currents there is a certain limited current range over which the amplitude and frequency are relatively constant. The actual shape of the fluctuations, as well as the current range over which they are uniform, varies according to the character of the contact, which can be modified by discharging a capacitor through it during the experiment. Resistance fluctuations in the current-induced intermediate state are well known and have been observed on many occasions (see, e.g., Weber[8] and Lalevic[9]), but this appears to be the first observation that they can be made regular by injecting the current at a point.

If the superconductor and normal metal ex-