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FT-ICR Mass Spectrometry of Very Highly Charged Atomic Ions

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The electron beam ion trap (EBIT) at Livermore produces very highly charged atomic ions by successive ionization in collisions with an intense (>120 mA, 4000A/cm^{-2}), energetic (E < 200 kV) electron beam [1]. With the electron beam on, the ions are trapped radially in the electrostatic field of the beam and with the beam off the ions are trapped radially by a 3-T magnetic field produced by a pair of superconducting Helmholtz coils. Axially, the ions are trapped by a bias potential on the top and bottom electrodes (see Fig. 1). The central electrode is 4.2 cm long and has a diameter of 1 cm. EBIT was originally designed as an x-ray source [2], and six slots allow direct line-of-sight access to the trapping region for x-ray measurements.

For the present measurement, we made use of the access provided by the radial x-ray slots (see Fig. 2). We constructed two probes that could be inserted into the 2-mm wide slots. The probes each subtend only 25° and face each other 180° apart [3]. For most measurements we used only one probe for excitation and the other for detection. A typical transformed spectrum of highly charged ^{84}Kr ions obtained with this arrangement is shown in Fig. 3. The spectrum was obtained by exciting with a 300-μs sweep from 17.5 to 19.5 MHz [4]. The resonance peaks of $^{84}Kr^{34+}$, $^{84}Kr^{35+}$, and $^{84}Kr^{36+}$ are clearly seen.

Because the electrostatic field of the electron beam dominates the ion motion, it must be turned off during the ion cyclotron resonance measurement, that is during excitation and detection. We found that turning the electron beam off does not compromise the ion confinement needed for a successful measurement. Trapping times exceeding 1 s were found in the absence of the electron beam. We also found a decay time of 10 ms for the coherent ion motion after excitation. We estimate that there were as much as 10^5 Kr ions in the trap; in addition, there were at least as many ions from low-Z background gases such as hydrogen, carbon, nitrogen, and oxygen, as well as argon. The mass resolution we achieved in the measurement was limited by the number of digitization points we could include in the Fourier transform (50,000 points, as determined by the LeCroy 9314L digitizing scope used for the measurements) and by the large number of ions in the trap. Nevertheless, a single measurement achieved a resolution of 2×10^{-4}.

The use of the FT-ICR on an EBIT device holds several promises. First, we can detect and measure different charge states and isotopes simultaneously. Second, using segmented trap electrodes for excitation and detection we will be able to determine the number of ions. Third, it should be possible to detect a single highly charged atomic ion. Finally, many measurements can be performed more quickly with the FT-ICR technique than with conventional diagnostics. For example, we have been able to measure the relative abundance ratio of adjacent ionization stages twenty times faster with the ICR technique than with using conventional x-ray methods. The FT-ICR method thus is becoming one of the most important tools for studying highly charged atomic ions in an EBIT device.

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References

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Figures

FIG. 1. Schematic of the trap region (vertical cut). In the presence of the electron beam, ions are trapped in the space charge of the electron beam. In its absence, they are trapped axially by the potential applied to the top and bottom drift tubes and radially by the axial magnetic field.

FIG. 2. Schematic of the trap region (horizontal cut) showing the location of the two ICR probes as well as different x-ray instrumentation.

FIG. 3. Transformed spectrum showing the resonances of highly charged krypton ions.

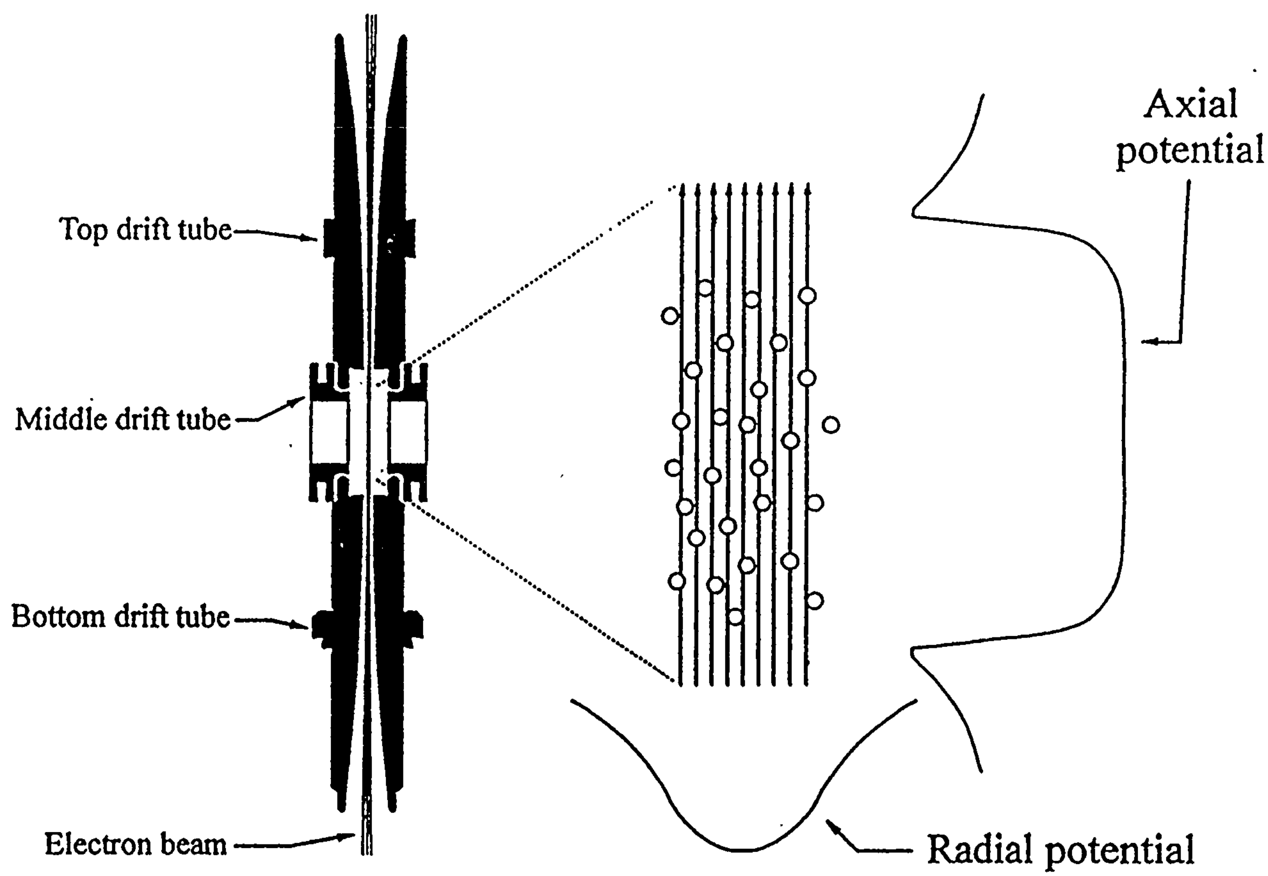
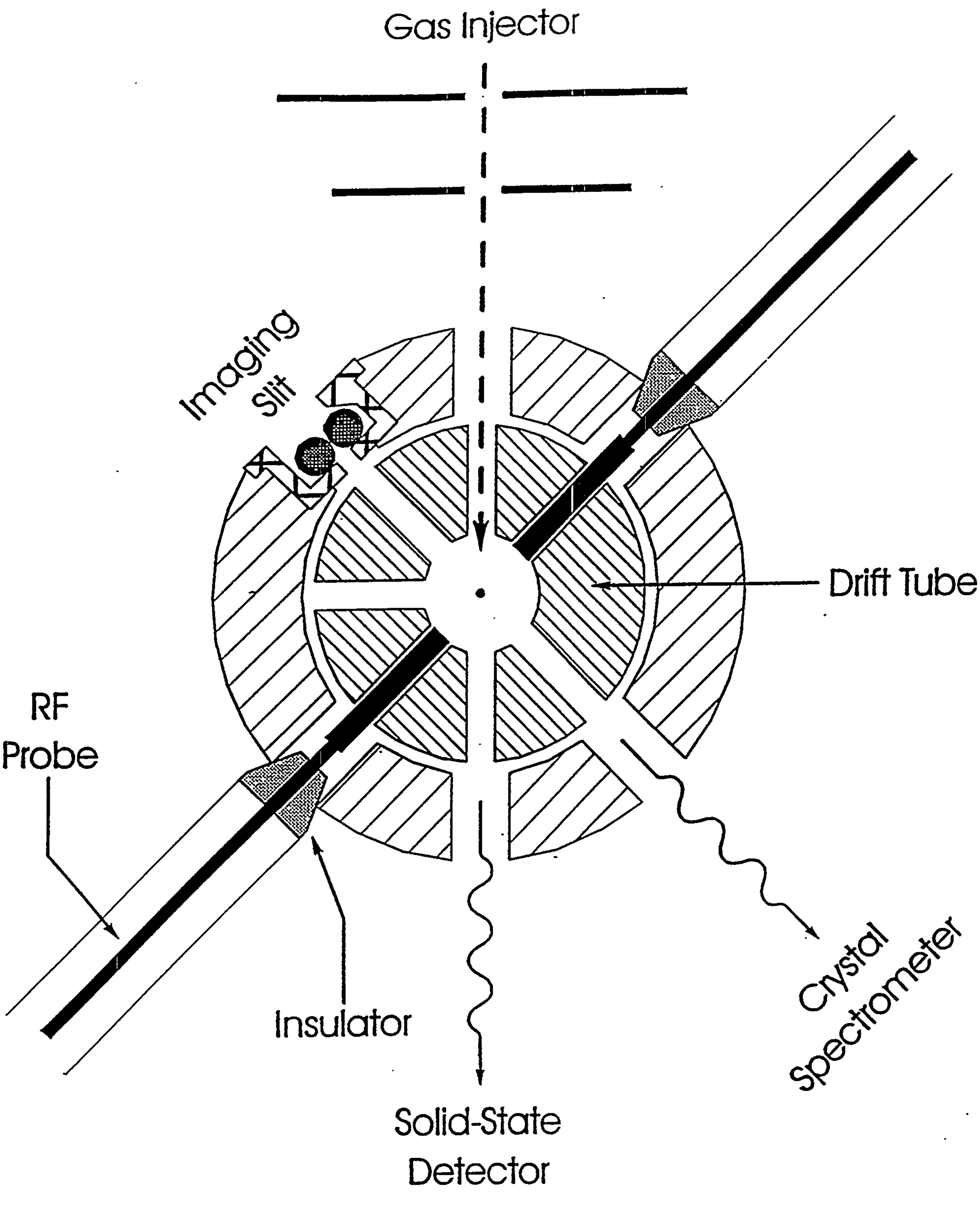

Top drift tube
Middle drift tube
Bottom drift tube
Electron beam
Axial potential
Radial potential

Figure 1.



Gas Injector
Imaging Slit
Drift Tube
RF Probe
Insulator
Solid-State Detector
Crystal Spectrometer

Figure 2.

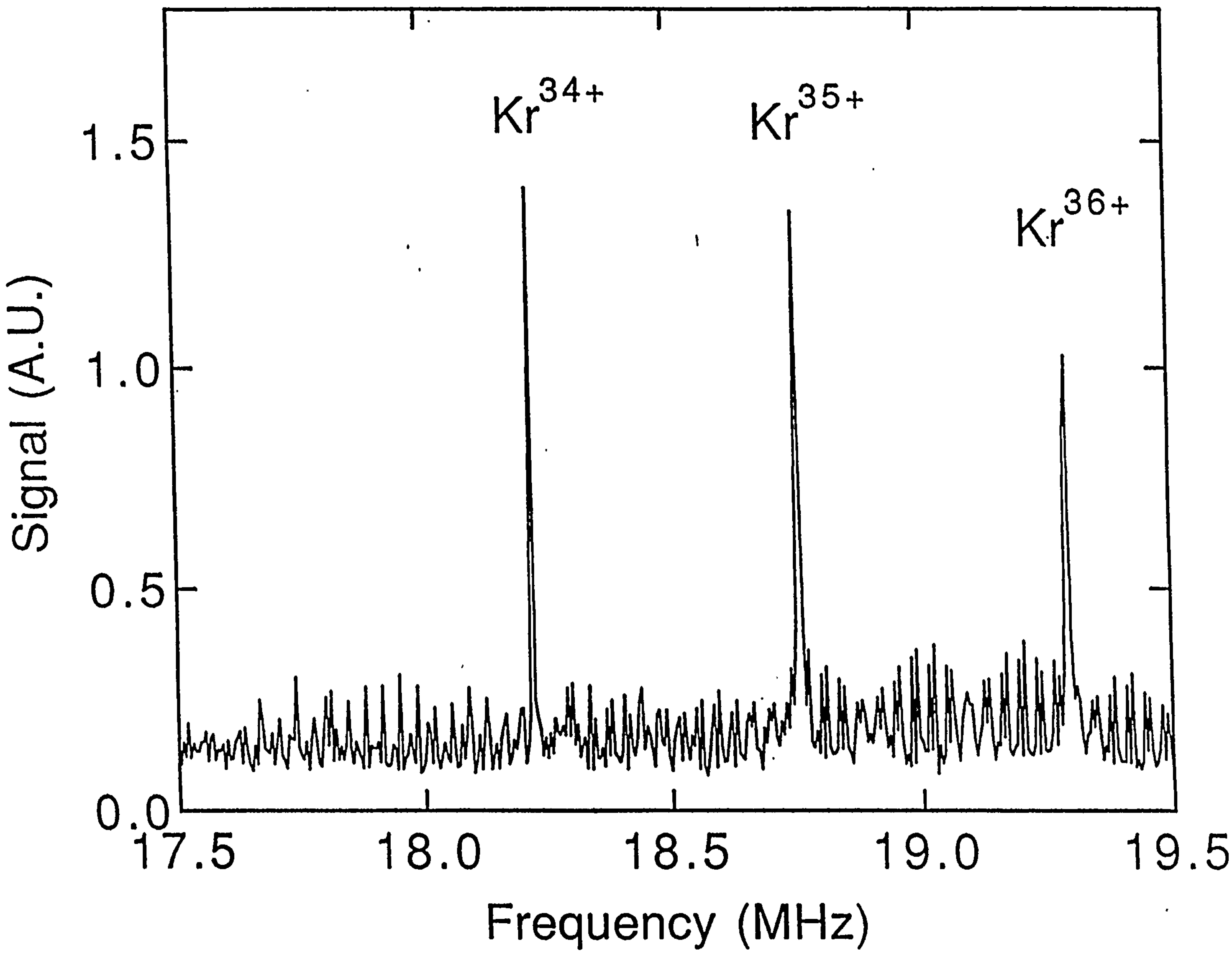

Kr34+
Kr35+
Kr36+
1.5
1.0
0.5
0.0
Signal (A.U.)
17.5
18.0
18.5
19.0
19.5
Frequency (MHz)

Figure 3.