
Electron-Impact Ionization of Lithium-like Ions

Presented to:
20 Years of Spectroscopy with EBIT
UCB Space Sciences Laboratory



Keith L. Wong
LLNL A-division
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Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551-0808

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Outline



- **Background**
- **Measurement Scheme**
- **Lithium-like Ionization Measurements**
 - **Ba⁵³⁺ (Ge detector)**
 - **Ti¹⁹⁺, V²⁰⁺, Cr²¹⁺, Mn²²⁺, Fe²³⁺ (Ge detector + Van Hamos crystal spectrometer)**
- **Model Comparisons**
- **Results**

Background

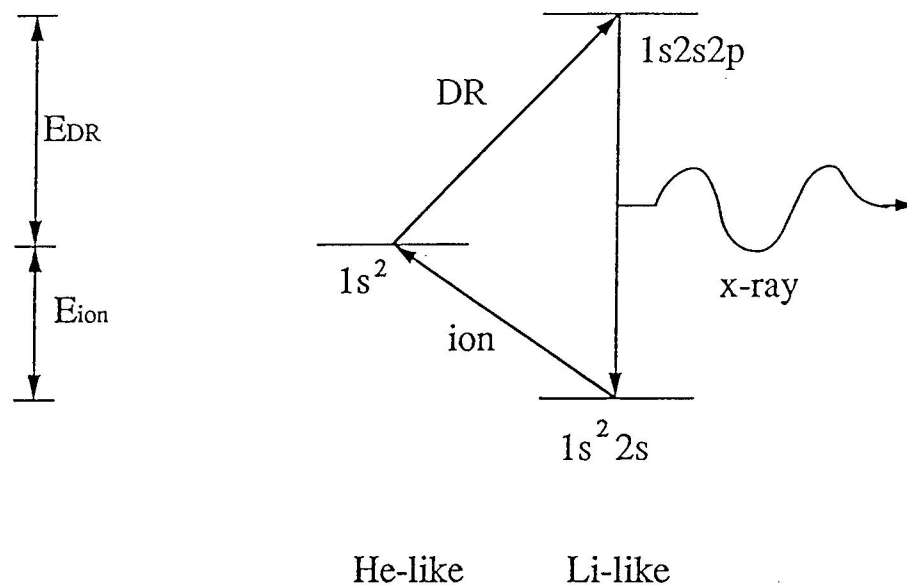


- **EBIT ~ 1988; Excitation, Dielectronic Recombination, Precision Wavelengths, and Polarization measurements were being made**
- **Missing Ionization measurements**
- **Previous Ionization measurements**
 - **Absolute cross sections, crossed beam (+15), 8-10% uncertainty**
 - **Ionization rates $\langle\sigma v\rangle$, tokamaks (+21), 20-40% accuracy**
- **Novel x-ray technique**

Measurement Scheme (Dec. 1988)



In steady-state with $E_{\text{beam}} = E_{\text{DR}}$ for Helium-like ions ($dn_{\text{He}}/dt = 0$):

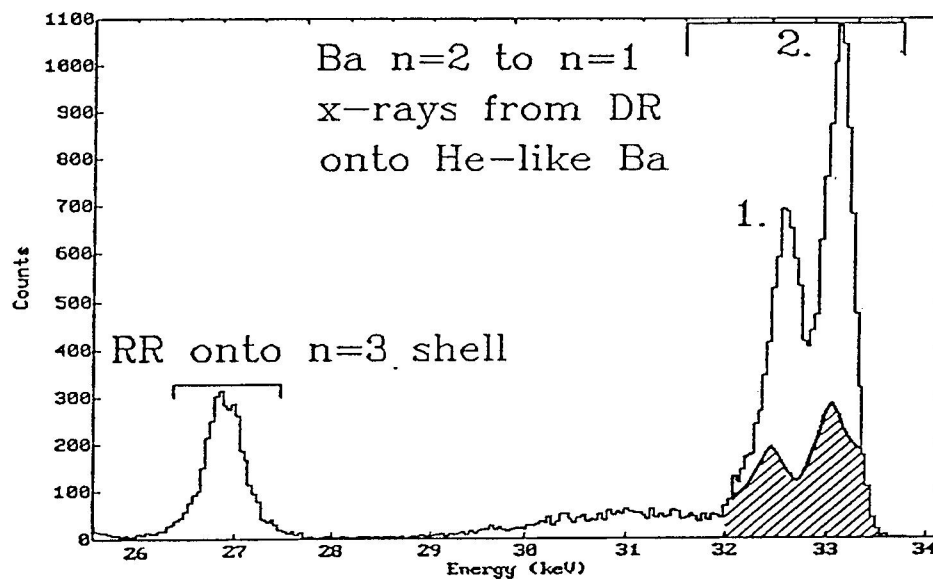


$$\sigma_{\text{ion}} \sim [(I_{\text{DR}}/I_{\text{RR}}(\text{Li}))] \sigma_{\text{RR}}(\text{Li})$$

Lithium-like Ba⁵³⁺ measurements (Jan. 1989) using a Ge detector



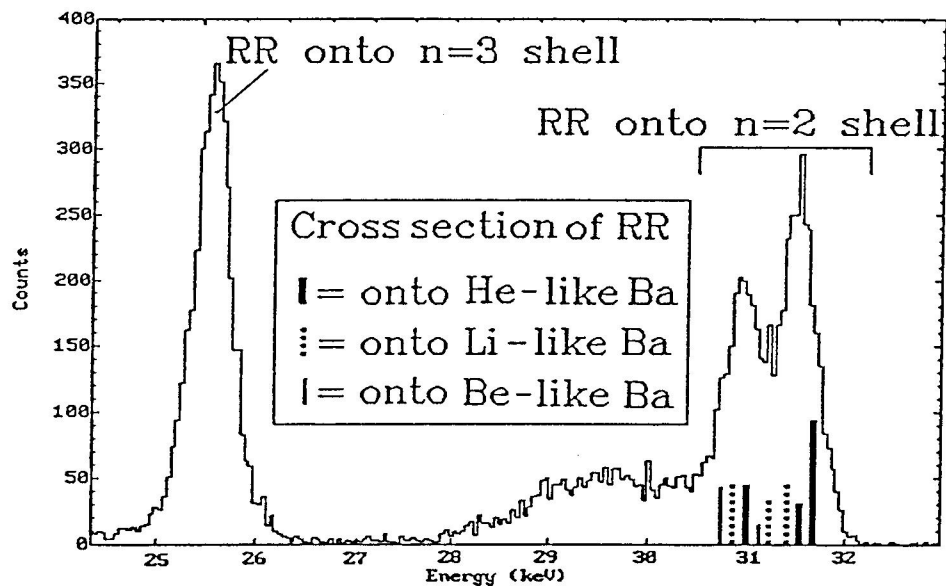
In steady-state with $E_{\text{beam}} = E_{\text{DR}} = 22.4$ keV for 40 ms/cycle:



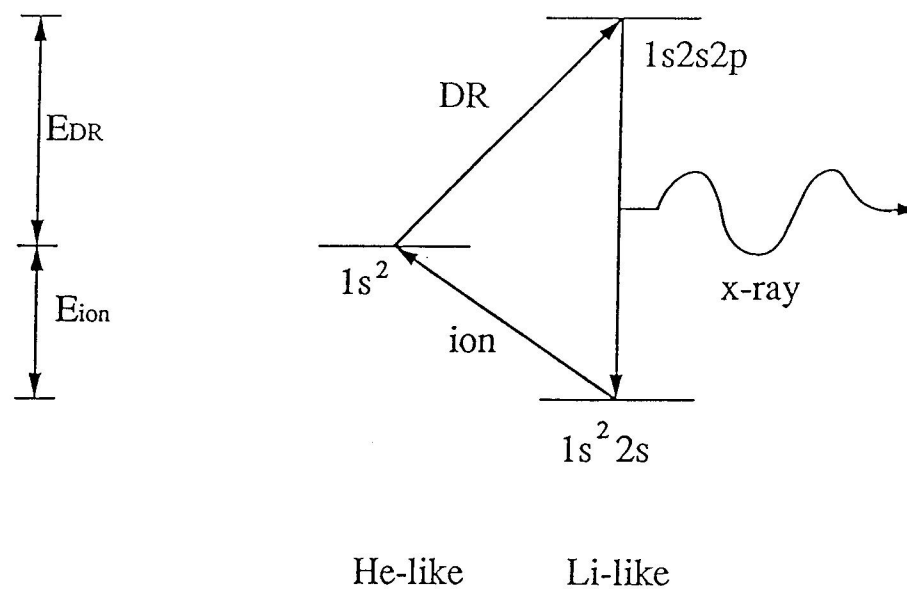
The charge state balance was probed to determine the amount of Lithium-like Ba⁵³⁺



“Flip”/switch to $E_{\text{beam}} = E_{\text{RR}} = 21.2 \text{ keV}$ for 20 ms/cycle:



Measurement Scheme for Lithium-like Ba⁵³⁺



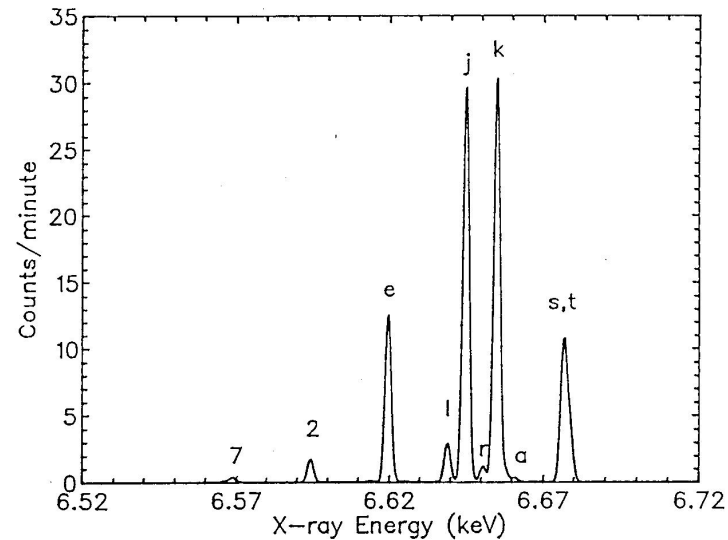
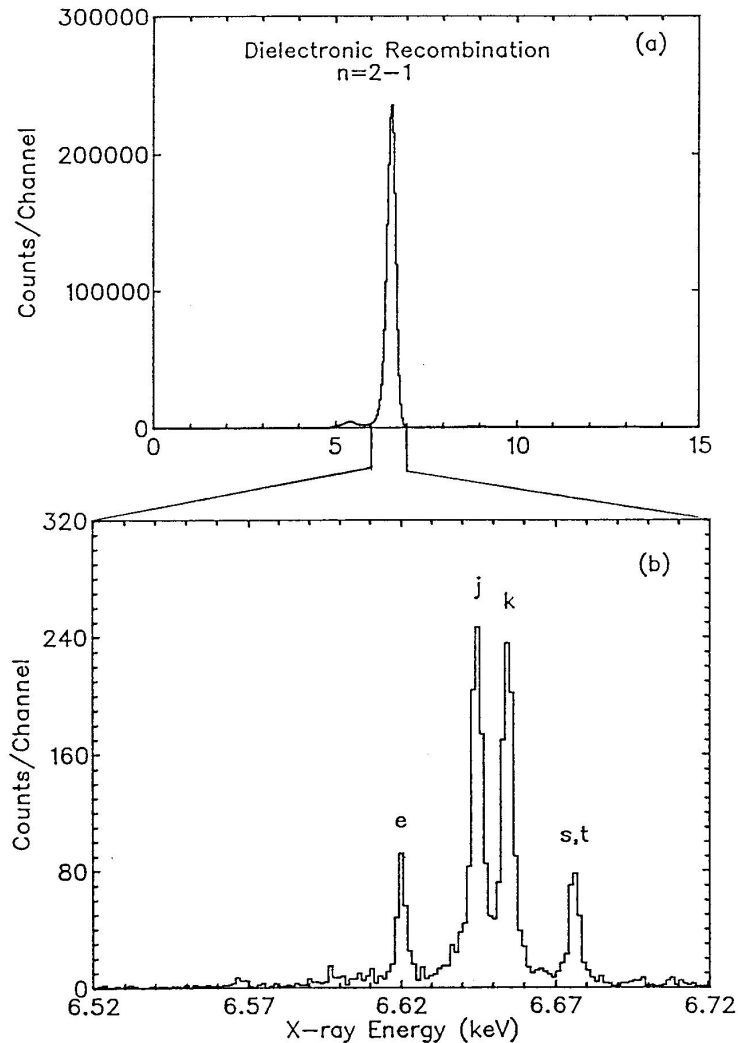
$$\sigma_{\text{ion}} \sim [(I_{\text{DR}} - I_{\text{RR}})/I_{\text{RR}}(\text{Li})] \sigma_{\text{RR}}(\text{Li}),$$

$$\sigma_{\text{ion}} = 0.25 \pm 0.13 \times 10^{-21} \text{ cm}^2 \text{ (no CX)}, \sigma_{\text{ion}}(\text{Zhang}) = 0.143 \times 10^{-21} \text{ cm}^2$$

The crystal spectrometer improves the measurement of the charge state balance



In steady-state for Fe^{23+} $E_{\text{beam}} = E_{\text{DR}} = 4.64$ keV for 24 ms/cycle:

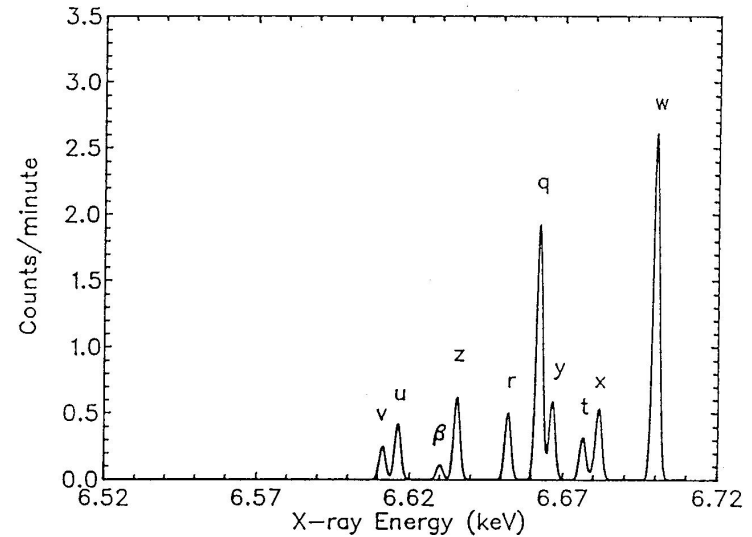
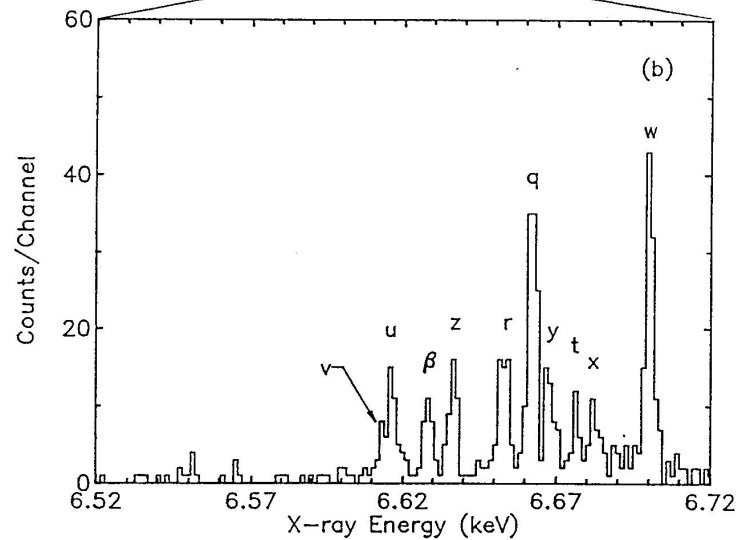
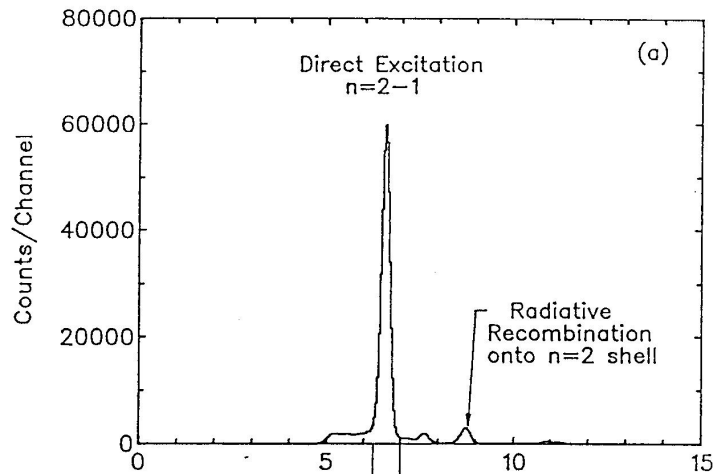


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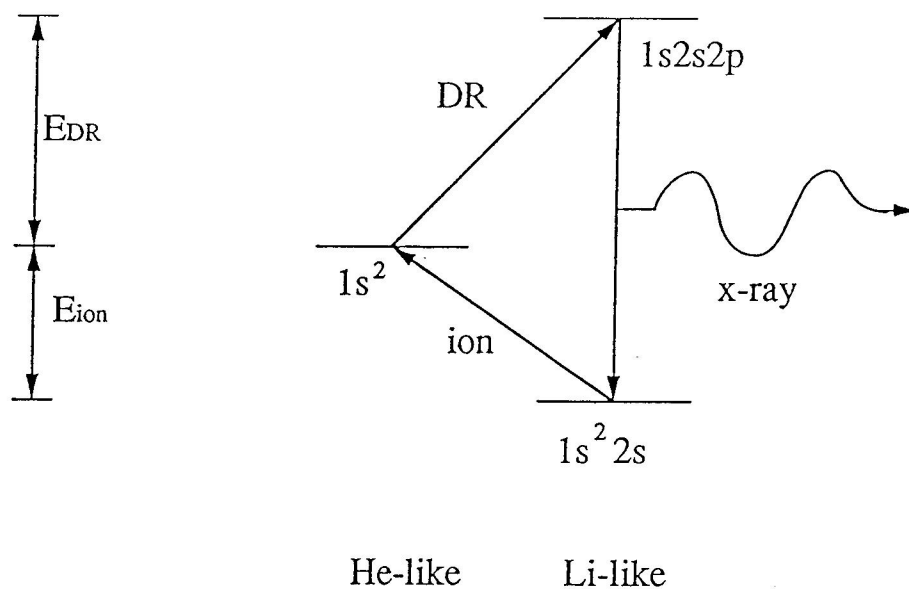
The $n = 2 - 1$ excitation spectrum was measured to determine the relative charge state balance



“Flip”/switch up to $E_{\text{beam}} = E_{\text{RR}} = 6.8 \text{ keV}$ for 6 ms/cycle:

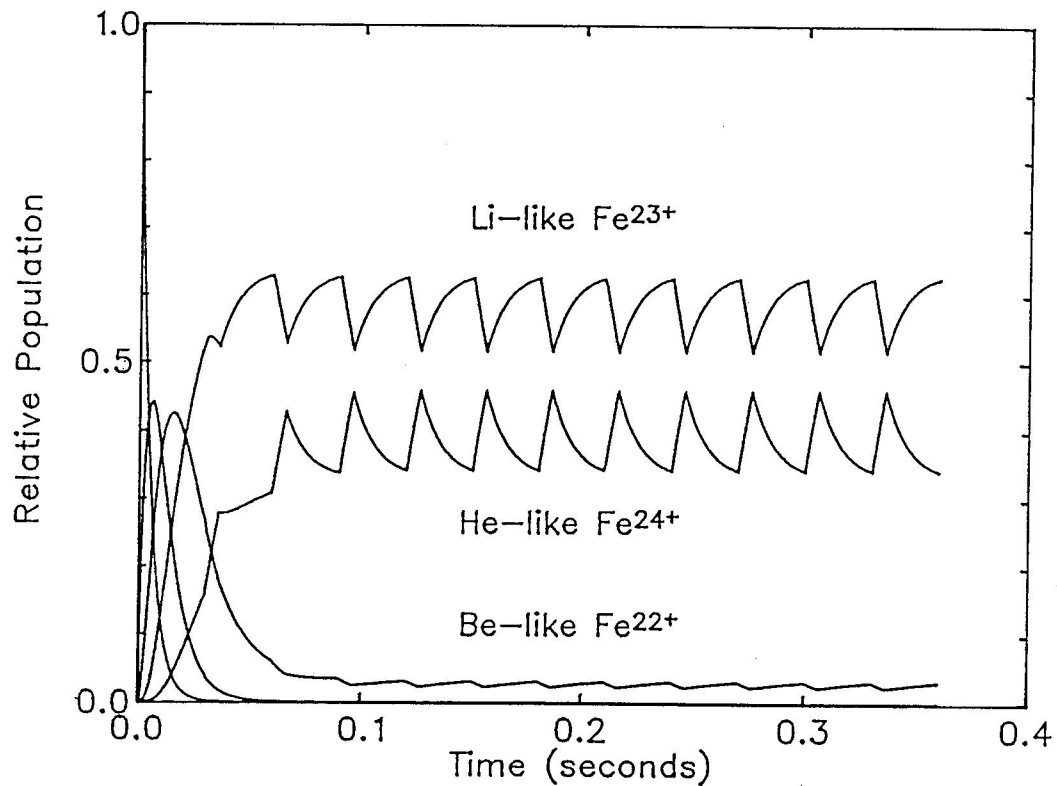


Measurement Scheme for Lithium-like Fe²³⁺

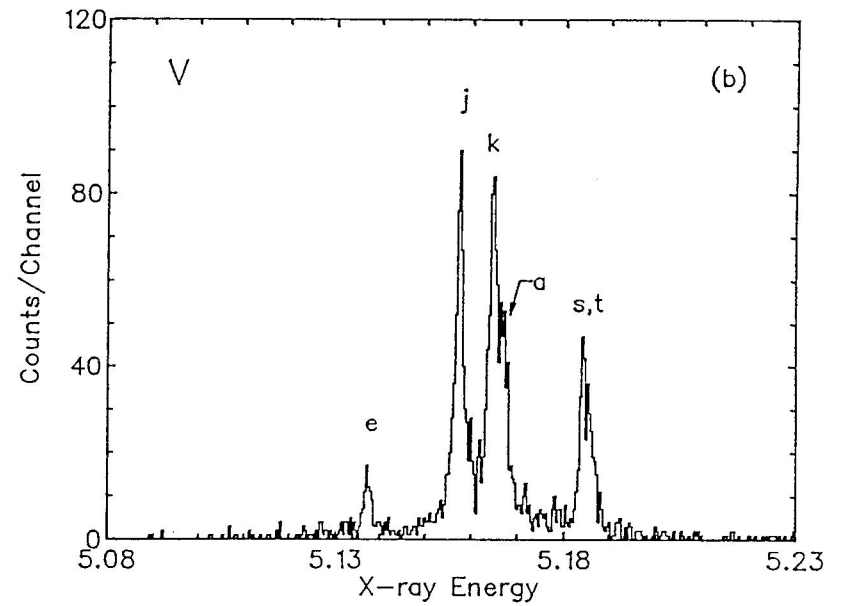
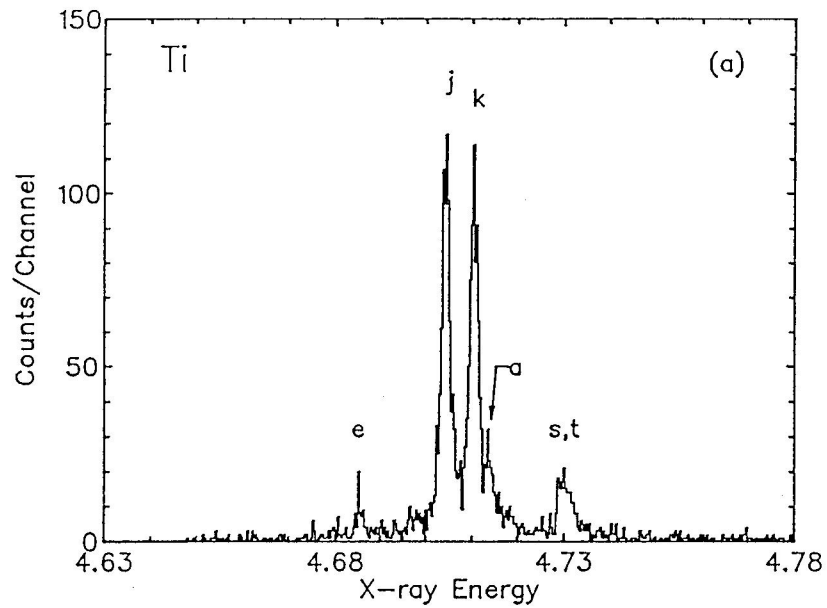


$$\sigma_{\text{ion}}(\text{Ge}) \sim [I_{\text{DR}}/I_{\text{RR}}(\text{Li})] \sigma_{\text{RR}}(\text{Li}), \quad \sigma_{\text{ion}}(\text{Cr}) \sim [I_{\text{DR}}/I_{\text{q}}] \sigma_{\text{q}}$$

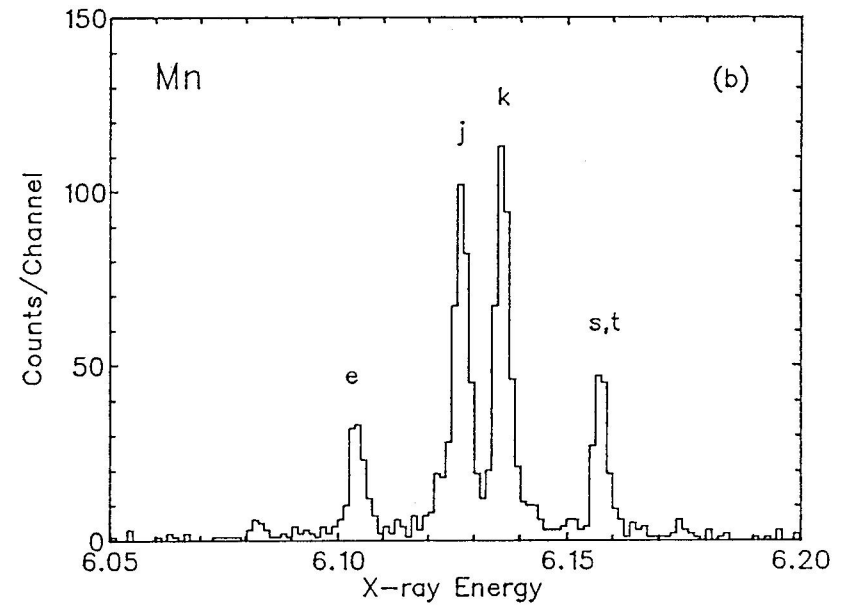
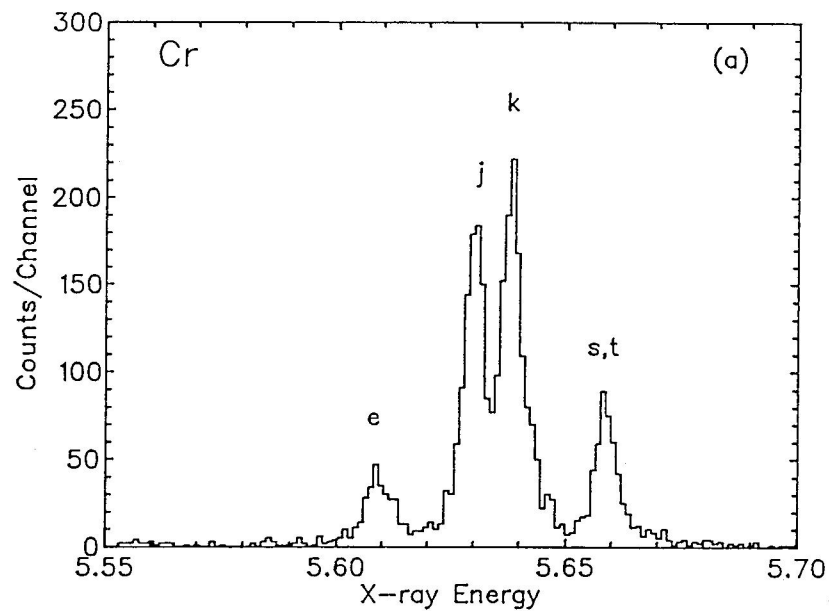
Computed relative charge state balance of Fe at $E_{\text{beam}} = 4.64 \text{ keV}$ for 24 ms and 6.8 keV for 6 ms



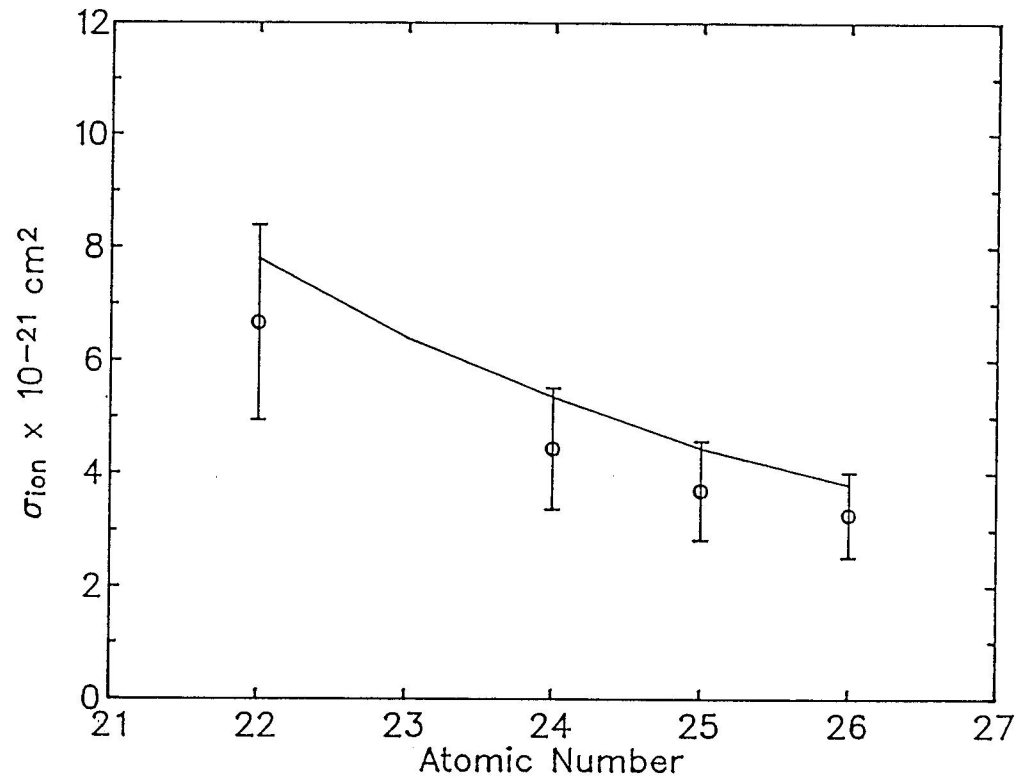
High Resolution DR spectra of Ti^{19+} at 3.31 keV and V^{20+} at 3.61 keV



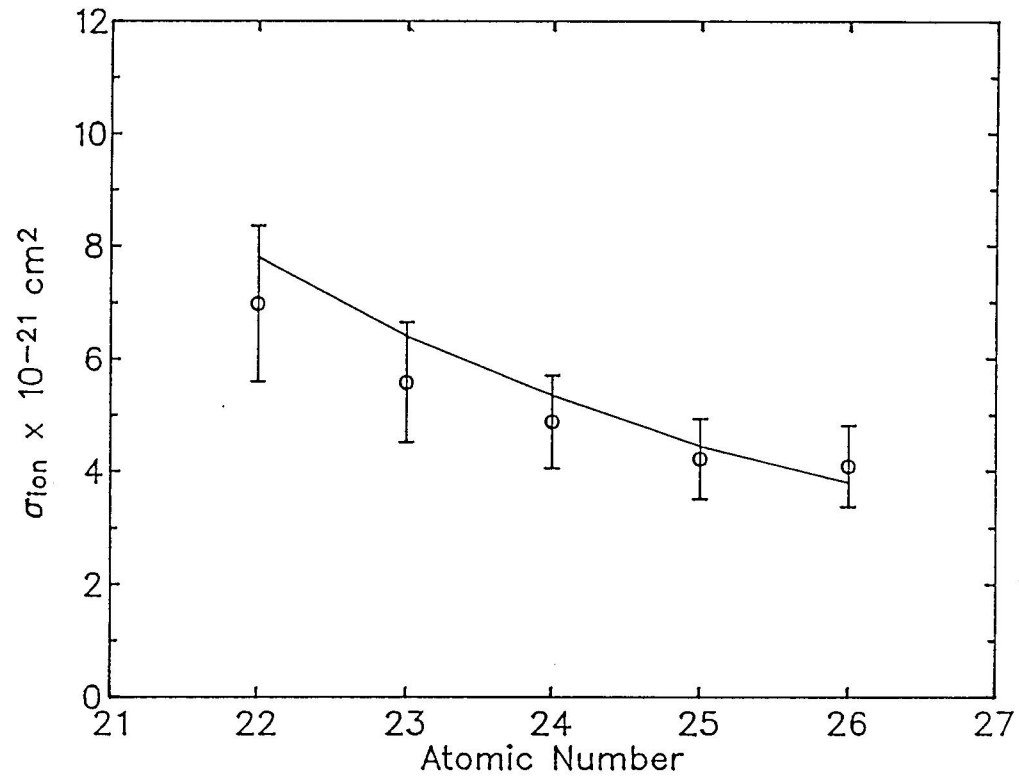
High Resolution DR spectra of Cr^{21+} at 3.95 keV and Mn^{22+} at 4.28 keV



Ge detector and relativistic distorted-wave (DW) results vs. atomic number



Crystal spectrometer and DW results vs. atomic number



Summary



- **The results for the ionization cross sections of Lithium-like Ti, V, Cr, Mn, and Fe at 2.3 x threshold agrees within the error bars (~10-20%) with the distorted-wave calculations of Zhang and Sampson.**
- **The Lithium-like Ba measurement was larger than theory, but has a large experimental uncertainty mainly due to the charge-state balance determination.**
- **Additional papers: excitation cross sections of Helium- and Lithium-like lines, charge state balance**