Electron Spectroscopy at Storage Rings

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ATOMIC PHYSICS DIVISION

Scientific goals:

I reaction mechanisms
- excitation and decay channels (impact parameter dependence)
- correlated processes: (R)TE (sub shell population), DR (crossed beam)
- few electron systems in strong fields (high Z)
- Rydberg states, meta stable configurations
- Auger decay lines → QED contributions, FS-splitting, Breit−terms

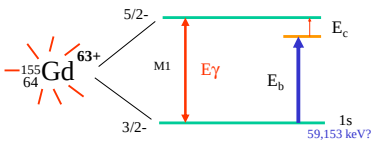
II interplay of nuclear and atomic structures:
- conversion electrons from H-, He-, Li- like ions after Coulomb excitation
- precision measurement of 1s binding energy
- conversion coefficients → e- wave function at nucleus
- HFS : nuclear magnetic moments from excited nuclei ($\tau \leq 1$ns)

Method

Excited nucleus (precision source) — Eγ — Crystal-spectrometer standards

precision transfer (internal conversion)

Error reduction ($E_c << E_b$) !



$\frac{\Delta E_c}{E_c}$ → $\frac{\Delta E_c}{E_b}$

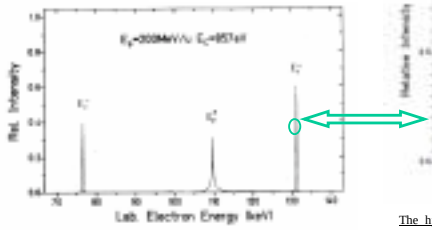
10^{-4} → 10^{-6}

10^{-4} accuracy of electron energy measurement correspond to 1eV or 1% of 1s- self-energy.

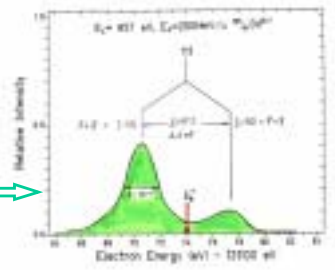
1s-self-energy (Gd) ~ 92 eV ~ 11% Ec ~ 0,16 % Eb

(1s ground state: no problems from natural line width)

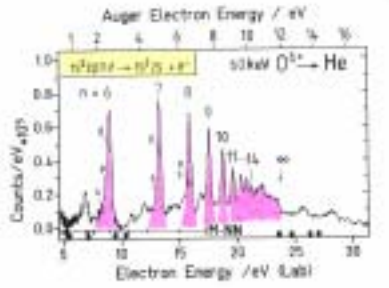
Nucleus	transition	E γ (keV)	τ (ns)	E_c (keV)
$^{195}Pt^{77+}$	3/2 – 1/2 (M1,E2)	98,86	0,16	5,4
$^{212}Bi^{82+}$	$2^- - 1^-$ (M1)	115,17	----	10,77
$^{228}Th^{89+}$	$4^+ - 2^+$ (E2)	129,1	0,16	3,45
$^{155}Gd^{63+}$	$5/2^- - 3/2^-$ (M1)	60,01	0,194	0,857



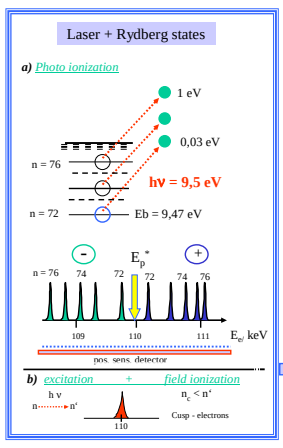
Synthetic spectrum of 857 eV electrons from internal conversion of H-like Gd^{63+} projectiles. Ep* denotes the cusp peak at projectile velocity. E_e^+ and E_e^- correspond to the kinematical shifts (forward - backward) observed at zero degree.



The hyperfine splitting of 1s-conversion electrons can be observed if an electron spectrometer with high resolution ($\Delta E/E < 6x10^{-5}$) is applied. It gives access to HFS of excited nuclear states with life times below nano seconds allowing determinations of magnetic momenta and nuclear g-factors. The intensities -besides the statistical weights- reflect state-dependent nuclear life-times within the spectrometer acceptance length.



Example of Coster-Kronig transitions ($1s^22pnl$)→$1s^22s$ +e^- (n = 6... ∞) from O^{4+} projectiles after electron capture from He in slow collisions measured at 0°. Such states can be studied at storage rings for high atomic numbers where the stretching of line-spacing is amplified due to the high V_p. Besides collisional generation-mechanisms (capture, excitation ...) information is obtained on QED, relativistic and magnetic electron interactions, similar to DR – experiments. Here Auger transitions are studied in situ without background from charge changing collisions or from disturbing magnetic and electric cooler fields.



Instrumental Method: zero degree electron spectrometry:

I a dispersion free magnetic transport system (270° deflector, fig.1) transports electrons from the (gas) target in a forward cone out of the beam line. Large momentum ($\Delta P/P \sim 2,5/1$) and angle ($\Delta\theta = \pm 12°$, $\Delta\vartheta = \pm 8°$) acceptances enable the study of a large band of electron energies with high efficiency (fig.2).

II energy measurements are performed by
1) a window-less SI-detector covering the complete energy band with moderate energy resolution or by

2) a high-resolution iron-free magnetic analyzer ($r^{-1/2}$ −field) with high dispersion.

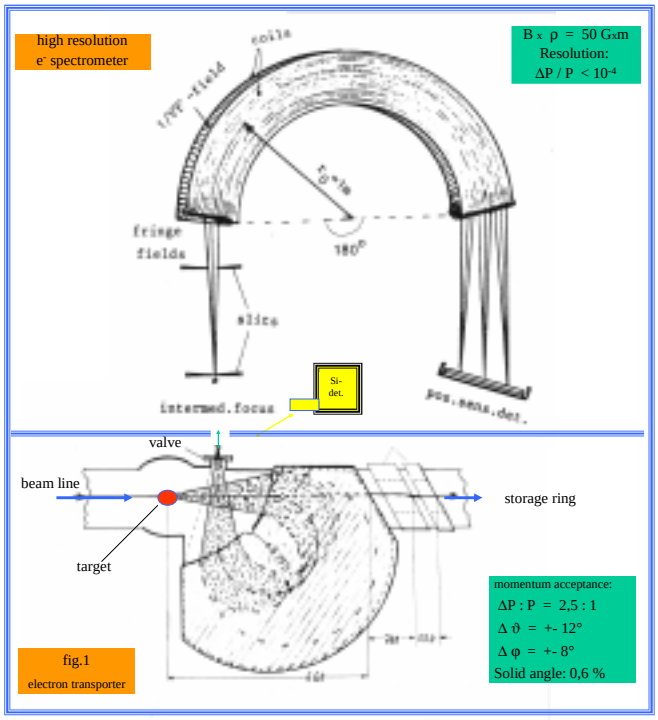
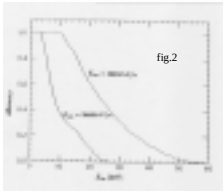
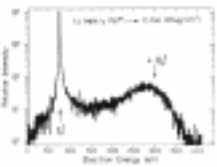


fig.1 electron transporter

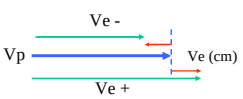


Calculated-efficiency of transport magnet for two projectile energies in dependence of electron energy in the projectile frame.



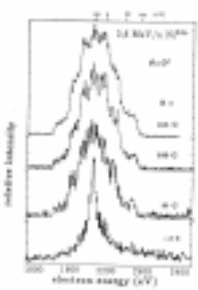
Typical electron spectrum obtained at 0° observation angle from an UNILAC – experiment. Intensity is not corrected for spectrometer transmission.

Concept of 0° – Electron Spectrometry



- energy shift: $(eV)_{cm}$ → $(keV)_{lab}$
- stretching of energy spectrum
- doubling of lines (Ve < Vp)
- acceptance: $\Delta\Omega_{cm} / \Delta\Omega_{lab} \sim Ve^2_{lab} / Ve^2_{cm}$

kinematical line broadening:
- minimum for $\vartheta = 0°$
- maximum for ΔEp → beam cooling required!



Example of „cusp-structures" demonstrating the existence of long living doubly excited projectile states based on metastable ion cores with spectator (Rydberg) electrons.

Ni – projectiles penetrating a 40 µg/cm² C-foil generate ($1s^22spnl$) → $1s^22s^2$ + e^- Coster-Kronig transitions (n>12). A variable short magnetic field between foil and spectrometer discriminates free „cusp"-electrons and field-ionises or quenches Rydberg states from critical shells $n_c \sim 44$ to 23.

The top scale refers to energies in the projectile frame.

Ions in storage rings are dressed with Rydberg electrons via different interactions with cooler- electrons. A certain class of n,l states are stable against field ionisation (quenching) in the ring magnets with life times $\tau > 0,2$ µs. They can be measured at the experimental area free from photon and electron noise of the cooler, providing they fall into the ring q- acceptance. Collisions with target atoms transfer Rydberg electrons to the cusp – continuum or generate (via isolated core excitations like $1s^22s \rightarrow 1s^22p_j$, ...) specific Auger decay lines which are fully received from the forward electron spectrometer. Alternatively photo ionisation and excitations can release these upper bound electrons more distinctively into the analyzer. The system represents a versatile tool for investigation of cooler induced recombination processes as well as for precise spectroscopic studies.