Outline:

• Motivation
  – Why highly charged, high-z ions?

• Experiment
  – GSI facility
  – Experimental set-up

• Results
  – REC
  – Ly-α alignment
  – Bremsstrahlung
Why spectroscopy with highly charged, heavy ions?

- Quantum Electro-Dynamics
  - \( \Delta E \approx 500 \text{ eV} \)
  - \( Z \alpha \approx 1 \)

- \( \Delta E \approx 10^{-6} \text{ eV} \)
  - \( Z \alpha \approx 10^{-2} \)
The GSI Facility

UNILAC
11.4 MeV/ u
U^{73+}

ESR
10 - 500 MeV/ u
U^{92+}

SIS
up to 1000 MeV/ u
U^{92+}
Internal Gasjet-Target

- Available Targets: H₂, N₂, Ar, Kr, Xe
- Typical density: \(10^{12}\) particles/cm³

Experimental Storage Ring (ESR)
The Experiment

U$^{92+}$ -> H$_2$ @ 96.6 MeV/u

Experimental Set-up

X-ray Spectra at 150°

a) raw data
Radiative Electron Recombination (REC)

Projectile

$U^{92+}$

Target

$H$

$e^-$

$v$

$\hbar \omega$

$X$ - ray energy

$\hbar \omega = E_B + E_{KIN}$
Results: REC lines

non-zero because of magnetic interactions (‘spin flip‘)
Lyman-α alignment

1s₁/₂ → 2p₃/₂ → Lyα₁ (E₁+M₂)

2s₁/₂ → Lyα₂ (E₁)

Electron capture

2p₁/₂

1s₁/₂

M₂ (1 %)

μ=+3/2
μ=+1/2
μ=-1/2
μ=-3/2
Results: Lyman-α alignment

Theory for Z=92: \( f = 1.28 \)

\[
W(\theta) \propto 1 + f \left( \frac{a_{M2}}{a_{E1}} \right) \beta_A \left[ 1 - \frac{3}{2} \sin^2 \theta \right]
\]

\[
f \left( \frac{a_{M2}}{a_{E1}} \right) \propto \left[ 1 + 2 \sqrt{3} \left\langle \frac{\langle M2 \rangle}{\langle E1 \rangle} \right\rangle \right]
\]
Electron Bremsstrahlung

\[ E_i = E_f + E_\gamma \]
Short wavelength limit of $e^{-}$ Bremsstrahlung

Relativistic QM calculation: Finite cross section at the high frequency limit

The short wavelength limit...

...shows the smooth transition from REC to capture into continuum states

...reflects details of the ions Coulomb potential
Thank you for your attention

... and many thanks to the working group!

Literature:

- **REC angular distribution**

- **Ly-α alignment**

- **Bremsstrahlung**
  T. Ludziejewski et al. 'Study of electron bremsstrahlung in strong Coulomb fields at the ESR storage ring'. Hyperfine Interactions Vol 144 (1998)
Atomic Physics in Strong Coulomb Fields

Structure Studies
- bound state quantum electrodynamics
- nuclear effects on the atomic structure
- effects of relativity on the atomic structure
- electron correlation in strong fields
- supercritical fields

Dynamics
- dynamically induced strong field effects
- correlated many body dynamics
- elementary atomic processes at high Z
- photon matter interaction, e.g. photon polarization correlation