High Resolution Particle Spectroscopy of $^{208}\text{Pb}$ with the MLL Q3D Spectrograph

Andreas Heusler

Heidelberg, Germany
Experiments
at Maier-Leibnitz-Laboratorium Garching (2003-2013)

with the Q3D magnetic spectrograph

incoming beam
detector
The $^{208}$Pb(d, d') reaction

Peak shape is highly asymmetric

Half-width at half-maximum (HWHM) = 1.5 keV on low energy side

Total length of spectrum $3 < Ex < 8$ MeV – here 4 %

Mean spacing of states 10 keV

Total number of states > 300
Inelastic proton scattering via an *Isobaric Analog Resonance* is equivalent to a neutron pickup reaction on a *Target in an Excited State* or in the Ground State.

**Ten reactions were studied:**

- $^{207}$Pb(d,p) with $E_d=22, 24$ MeV
- $^{208}$Pb(d,d') with $E_d=22, 24$ MeV
- $^{208}$Pb(p,p') with $14 < E_p < 18$ MeV
- $^{208}$Pb(p,p') via d$^{3/2}$,
  - via g$^7/2$,
  - via s$^1/2$,
  - via d$^5/2$,
  - via j$^{15/2}$,
  - via i$^{11/2}$,
  - via g$^9/2$ IAR in $^{209}$Bi

![Graph showing excitation energies for various states in $^{209}$Pb](image)
Selective excitation of particle-hole states in 208Pb by the 208Pb(p,p') reaction via Isobaric Analog Resonances in 209Bi.
Satellites from the knockout of atomic electrons

(not fitted)
Satellites from knockout of atomic electrons to each peak

- **2** K-electrons = 88.000 keV
- **8** L-electrons = 13.066, 15.200, 15.861 keV
- **18** M-electrons = 2.484 ... 3.851 keV
  - mean = 2.9 keV
- **32** N-electrons = 0.5 keV
- **18** O- and 4 P-electrons = 0.1 keV
Pragmatic handling of the effect of the knockout of atomic electrons

knockout of atomic K-electrons with probability of 0.1% relevant

at peak-to-valley ratio > 1000 : 1

knockout of atomic L-electrons with probability of 1% relevant

at peak-to-valley ratio > 100 : 1

the instrumental resolution is about ~ 1.5 keV

distribution of atomic M-electrons adds ~ 2.9 keV
distribution of atomic L-electrons adds ~ 2.0 keV for 1st satellite
~ 4.0 keV for 2nd satellite etc

GAUSSIAN width for physical states ~ 3 keV

for 1st L-satellite ~ 5 keV
for 2nd L-satellite ~ 7 keV
for 3rd L-satellite ~ 10 keV

GASPAN may fit two peaks at the same position if the GAUSSIAN widths are different

Satellites and contaminations from light nuclei are tagged and ignored in subsequent analysis
Fit without seven levels

$\chi^2 / f = 0.98$

$\chi^2 / f = 1.37$
Correction for magneto-optical aberrations

Three successive fits with parabola of 2nd order:

1. Fit of spectrum
   \( d-Ex \sim 2 \text{ keV} \)

2. Fit with selected levels
   \( d-Ex \sim 1 \text{ keV} \)

3. Final fit
   \( d-Ex \sim 0.5 \text{ keV} \)

Check of magnetic field for 300 runs

\( \sqrt{E_p - E_x} \)
\( f(\text{NMR}) \)[r.u.]

\( 91 \) start of detector

\( 2/3 \) of detector

\( 95 \) end of detector
Resolving a doublet

Proton energy [MeV] in $^{209}$Bi

- 16.9 – 18.0 near $s_{1/2}$, $g_{7/2},d_{3/2}$
- 16.4 – 16.6 near $d_{5/2}$
- 16.2 – 16.4 near $j_{15/2}$
- 15.72 on $i_{11/2}$
- 14.92 on $g_{9/2}$

Excitation energy [keV]

Run number

400 eV

$1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14$
Distribution of uncertainties d-Ex of excitation energies

$3.7 < \text{Ex} < 6.2 \text{ MeV}$
Summary

Experiments with the Q3D magnetic spectrograph (2003 - 2013) at MLL (Garching)

Ten particle transfer reactions studied:
- $^{208}\text{Pb}(p,p')$ via the $g_{9/2}$, $i_{11/2}$, $j_{15/2}$, $d_{5/2}$, $s_{1/2}$, $g_{7/2}$, $d_{3/2}$ analog resonance
- $^{208}\text{Pb}(p,p')$ off-resonance at $14 < E_p < 18$ MeV
- $^{208}\text{Pb}(d,d')$ at $E_d=22$ and 24 MeV
- $^{207}\text{Pb}(d,p)$ at $E_d=22$ and 24 MeV

Scattering angles from $15^\circ$ to $138^\circ$

Energy resolution of 1.5 keV HWHM on low Ex-side

Interpretation of spectra limited by knockout of atomic electrons:
- M-electrons $2.5 < E_b < 3.8$ keV
- L-electrons $13.0 < E_b < 15.9$ keV

Excitation energies determined for 150 states in $^{208}\text{Pb}$ with a median precision of 100 eV for $3 < E_x < 6.2$ MeV
Thank you for your attention