Antiprotonic Atom Formation and Spectroscopy
- ASACUSA experiment at CERN-AD

LEAP’98, Sardinia, September 12, 1998

- ASACUSA collaboration
- Phase 1: AD beam @ 100 MeV/c: 1999
  - antiprotonic helium atomcules
    - higher precision for energy levels
    - 2-laser microwave triple resonance experiment to measure “hyperfine” structure
- Phase 2: RFQ beam @ 100-10 keV: 2000
  - antiprotonic helium atomcules
  - atomic collisions, dE/dx
- Phase 3: extraction of trapped antiprotons at 10 keV - 10 eV: 2000~
  - antiprotonic atom formation process
  - protonium
Atomic Spectroscopy And Collisions Using Slow Antiprotons

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by Utagawa Hiroshige (1797-1858)

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• CERN, Switzerland
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• PSI Villigen, Switzerland
• Ciril -Lab. Mixte CEA-CNRS, Caen Cedex, France
• GSI, Darmstadt, Germany
• St. Patrick's College, Maynooth, Ireland
ASACUSA overview

PS205
laser spectroscopy
of \( \bar{p}He^+ \) atoms

PS194
energy loss
ionization
atomic collisions

PS200(part)
atomic collisions
antiprotonic atom
formation

Approved in
fall 1997 as
AD-3

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<th>New apparatus</th>
<th>Physics study</th>
<th>Atomic Collisions</th>
<th>High Precision Spectroscopy</th>
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<td>1999</td>
<td>AD: 5.3 MeV/c</td>
<td>stopping power</td>
<td>( \bar{p}He ) spectroscopy: high resolution</td>
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<td>channeling</td>
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<td>2000</td>
<td>RFQ: ~100 keV</td>
<td>( \bar{p} ) atom formation in dilute targets</td>
<td>( \bar{p}He ) spectroscopy: primordial (n,l) distribution</td>
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<td>2000~</td>
<td>trap: 10 eV ~ 10 keV</td>
<td>Ionization in single collision</td>
<td>( \bar{p}p ) spectroscopy</td>
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possible interactions of magnetic moments:

- electron:
  \[ \vec{\mu}_e = g \mu_B \vec{s}_e \]
- pbar:
  \[ \vec{\mu}_p = \left[ g_s \frac{\vec{p}}{m_p} \vec{s}_p + g_1 \frac{\vec{l}}{m_p} \right] \mu_N \]

- "Finestructure":
  \[ \vec{l}_p \cdot \vec{s}_p \]
  - magnitude \(-10^{-7}\) eV (25 MHz) for \(l=37\)
  - negligible at current exp. precision

- "Hyperfinestructure":
  \[ \vec{\mu}_e \cdot \vec{\mu}_p \]
  - sizeable because of large \(l\) of pbar.

Level scheme:

\[
\begin{align*}
\text{F}_- &= l - 1/2 & \text{J} &= l \\
\text{F}_+ &= l + 1/2 & \text{J} &= l + 1
\end{align*}
\]

\[ \Delta \nu = 10 \ldots 15 \text{ GHz} \]

\[ \vec{l}_p \cdot \vec{s}_e \]

"HFS"

\[ \vec{j} = \vec{l}_p + \vec{s}_e \]

\[ \vec{J} = \vec{j} + \vec{s}_p = \vec{l}_p + \vec{s}_e + \vec{s}_p \]
"Hyperfine" splitting in a laser transition

- laser transitions proceed along $\Delta F=0$, i.e. without changing the electron spin direction:

F$^-$' = l' − 1/2

F$^+$ = l − 1/2

F$^+$' = l' + 1/2

F_+ = l + 1/2

unfavoured transition

First observation in an “unfavoured” transition

$(n,l)=(37,35)\rightarrow(38,34)$

laser BW: 1.2 GHz
(quadruplet not resolved, only doublet)
remain: 0.4 GHz
~Dopplerwidth

theoretical prediction: 1.77 GHz (Korobov, Bakalov, PR A 57, 1662 (1998))

$\Delta \lambda = 2.98 \pm 0.09$ pm

$\Delta \lambda = 1.70 \pm 0.05$ GHz

Peak to Total Ratio (%)
Phase 2: AD + RFQ (2000)

- ūHe+ atomcule studies
  - stop ū in low density gas (~ 1 torr and below)
  - primordial (n,l) distribution
  - trapping fraction and lifetime may be larger at low density

- Atomic collisions
  - Energy loss in thin films and gases
  - Channeling of slow antiprotons
  - Swarm experiments

- example: dE/dx: