Towards Laser Cooling of Negative Ions

Elena Jordan*, Giovanni Cerchiari, Aurélien Chevaleyrias, Alban Kellerbauer Max Planck Institute for Nuclear Physics, Heidelberg



3/7/2014 EGAS46 conference, Lille



Motivation

Key technique for cooling of positive ions and atoms

- Positive ions (1978 by Wineland and Dehmelt)
- Neutral atoms (1985 by Chu)
- **Negative Ions**?

Until today, no technique to cool negative ions below a few K

Need:

- Two level system
- High spontaneous emission rate





2

Detuned laser

Negative Ions e Neutral Negative Atom on Energy Excited state Ground State Ground

State

- Bound mainly by correlation and by polarization effects
- Few, if any, bound excited states
- Even when there are excited states, there are generally no optical transitions



Negative Ions

¹ H 0.75		Known exceptions with electric dipole															² He <0
³ Li 0.62	⁴ Be <0	tra	ans	itio	ns:	La	⁵ B 0.28	⁶ C 1.26	⁷ N <0	⁸ O 1.46	⁹ F 3.40	¹⁰ Ne <0					
¹¹ Na 0.55	¹² Mg <0												¹⁴ Si 1.39	¹⁵ P 0.75	¹⁶ S 2.08	¹⁷ CI 3.61	¹⁸ Ar <0
¹⁹ K 0.50	²⁰ Ca 0.02	²¹ Sc 0.19	²² Ti 0.08	²³ V 0.53	²⁴ Cr 0.68	²⁵ Mn <0	²⁶ Fe 0.15	²⁷ Co 0.66	²⁸ Ni 1.16	²⁹ Cu 1.24	³⁰ Zn <0	³¹ Ga 0.41	³² Ge 1.23	³³ As 0.81	³⁴ Se 2.02	³⁵ Br 3.36	³⁶ Kr <0
³⁷ Rb 0.49	³⁸ Sr 0.05	³⁹ Y 0.31	⁴⁰ Zr 0.43	⁴¹ Nb 0.89	⁴² Mo 0.75	⁴³ Tc 0.55	⁴⁴ Ru 1.05	⁴⁵ Rh 1.14	⁴⁶ Pd 0.56	⁴⁷ Ag 1.30	⁴⁸ Cd <0	⁴⁹ In 0.40	⁵⁰ Sn 1.11	⁵¹ Sb 1.05	⁵² Te 1.97	⁵³ 3.06	⁵⁴ Xe <0
⁵⁵ Cs	⁵⁶ Ba	57	Hf	⁷³ Ta	⁷⁴ W	⁷⁵ Re	76	lr	⁷⁸ Pt	⁷⁹ Au	⁸⁰ Hg	⁸¹ TI	⁸² Pb	⁸³ Bi	⁸⁴ Po	⁸⁵ At	⁸⁶ Rn
0.47	0.14	La	3	0.52	0.02	0.15	Os	1.50	2.10	2.01	-0	0.30	0.30	0.94	1.9	2.0	-0





Max-Planck-Institut Für Kernphysik

Predictions for La⁻

5

- RCI calculations predict:
 - Transition rate 100 times
 higher than for Os⁻
- Closed transition (decays back >99.98%)



[S.M. O'Malley and D.R. Beck, Phys.Rev. A 81,032503 ³[(2010)] [L.Pan and D.R. Beck, Phys.Rev. A 82,014501 (2010)]

- Nuclear spin 7/2
- \rightarrow 9 Hyperfine transitions



Experimental Setup

- Middleton type ion sputtering source
- Mass separator magnet
- 1-100 pA La⁻ in spectroscopy part
- Laser bandwidth <1 MHz



Collinear Spectroscopy Setup



7

Measurement principle:

- Superimpose ion beam and laser beam
- Scan laser frequency
- Detect neutralized atoms



Measurements on Os⁻

8

Os⁻

- Transition frequencies measured and confirmed
- Measurements outcome
 - Low cooling rate:
 Einstein coefficient
 ≈ 330 s⁻¹ equivalent
 to 3 min from 4K
 - Metastable "dark" states
 - 2 additional lasers required



[U. Warring et al., Phys. Rev. Lett. 102 (2007) 043001]

Spectroscopic Results for La-

La

- Counts of neutral atoms on detector
- Background:
 - Dark counts
 - Stripping on apertures
 - Thermal excitation in ion source



Fig.: Transition of La⁻ at 7kV beam energy with 5 MHz binning



Spectroscopic Results

- Fit with Gaussian
- Hyperfine structure mostly resolved
- 8 of 9 expected peaks
- Transition width
 ≈ 2.3 GHz
- Peak width
 - ≈ 70±25 MHz



v-v₀



Doppler Correction

- Measure at various beam energies
- Extrapolation to 0 eV \rightarrow Doppler free transition energy



Doppler Correction





- Data analysis ongoing
- Doppler free transition frequency with Doppler correction:

$$f = f_0 \frac{\sqrt{1 + \frac{\nu}{c}}}{\sqrt{1 - \frac{\nu}{c}}}$$

Transition wavelength
 3.1 µm



Summary

Collinear ion beam spectroscopy

- Determined transition frequency between two bound states in negative La
- Partially resolved hyperfine splitting



Outlook

- Cross section measurement for the resonant transition
- Measure Zeemann splitting
- If possible: Laser cooling in Penning trap
- Sympathetic cooling of other negative species

Thanks to



Erc European Research Council



Alban Kellerbauer

Giovanni Cerchiari



15

Thank you for your attention!