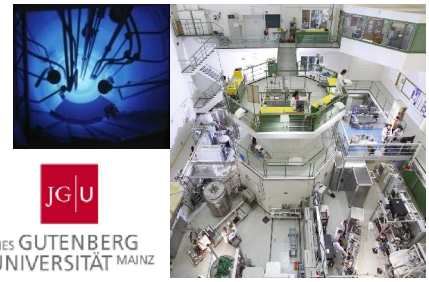
Collinear Laser Spectroscopy of Praseodymium at TRIGA-LASER and COLLAPS/ISOLDE

N. Frömmgen[1*], M.L. Bissel[2], K. Blaum[3], Ch. Geppert[1,4,5], M. Hammen[1], M. Kowalska[6], J. Krämer[1], K. Kreim[3], A. Krieger[1,3], Yu. A. Litvinov[3,4], R. Neugart[1], G. Neyens[2], W. Nörtershäuser[1,4,5], J. Papuga[2], R. Sánchez[4] and D.T. Yordanov[3]

[1]Institut für Kernchemie, Johannes Gutenberg-Universität, Mainz, Germany
[2]Instituut voor Kern- en Stralingsfysica, KU Leuven, Belgium
[3]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
[4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[5]HIM Helmholtz Institut Mainz, Germany
[6]CERN, Physics Department, Geneva, Switzerland

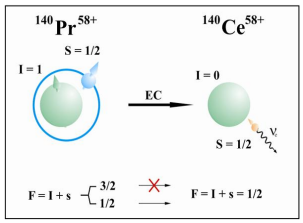


Motivation

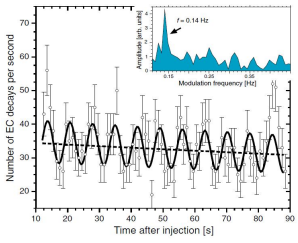
EC rate of H-like ^{140}Pr ions compared to He-like ^{140}Pr ions

The isotope ^{140}Pr (Z=59) decays to ^{140}Ce via an allowed Gamov-Teller decay ($\Delta\ell$=1, no parity change) [1]. Thereby a proton is converted into a neutron either via β^+ decay or via electron-capture decay ($p + e^- \rightarrow n + \nu_e$).

The measured electron-capture decay constant of hydrogen-like $^{140}Pr^{58+}$ ions in the ESR storage ring increases by a factor of 1.49(8) compared to helium-like $^{140}Pr^{57+}$ [2]. Taking the conservation of total angular momentum into account this can be explained if the nuclear magnetic moment of ^{140}Pr is positive (see the figure to the right [2]).
Moreover, $^{140}Pr^{58+}$ ions decay even faster than neutral ^{140}Pr atoms [2].
To verify the explanation of this counter-intuitive observation the sign of the nuclear magnetic moment needs to be confirmed. The magnetic moment μ_I of a nucleus can be determined from the hyperfine splitting using collinear laser spectroscopy.



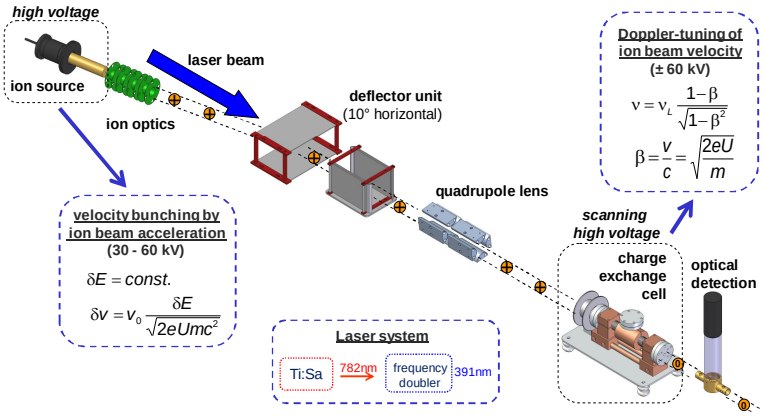
Electron-capture decay of H-like ^{140}Pr ions in the ESR storage ring at GSI



The figure to the left shows the number of electron-capture decays of hydrogen-like ^{140}Pr ions per second as a function of time after injection into the ESR storage ring [3]. Besides the expected exponential decay a periodic modulation is observed. A firm explanation of this phenomenon is still missing.
Due to its importance for the explanation of the observed modulation the nuclear magnetic moment of ^{140}Pr is of particular interest.

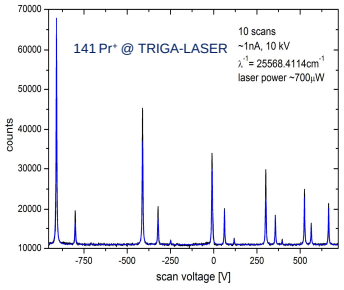
Experimental setup

Principle of collinear laser spectroscopy



Laser Spectroscopy probing nuclear structure

Hyperfine structure splitting



$$\Delta E_{HFS} = \frac{A}{2}C + B\frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2I(2I-1)J(2J-1)}$$

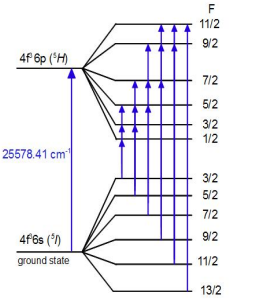
with $C = F(F+1) - I(I+1) - J(J+1)$

$$A = \frac{\mu_I \cdot H(0)}{I \cdot J} \qquad B = e \cdot Q \cdot V_{zz}(0)$$

Laser Spectroscopy of neutron-deficient Praseodymium Isotopes

@ TRIGA-LASER MAINZ

As a preparation for the measurements of the radioactive isotopes we investigated the $4f^3\ 6s\ ^5I_4 \rightarrow 4f^3\ 6p\ ^5H_3$ transition in $^{141}Pr^+$ at the TRIGA-LASER experiment. This is a transition from the ground state to the excited 25578.41cm^{-1} [4] state of the ion. The figure above shows the corresponding measured hyperfine spectra. All of the expected 15 lines could be observed. Thus the studied transition is perfectly suitable for the online measurements. The extracted hyperfine splitting parameters of the stable isotope are compared to the literature values in the table.



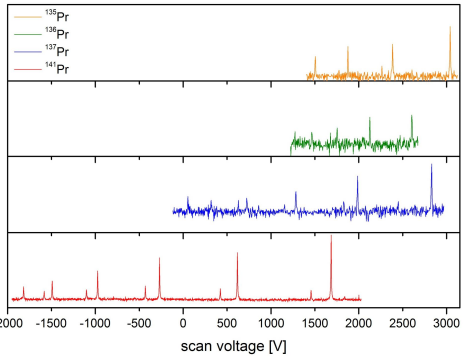
A [MHz]	B[MHz]	Reference
Ground state		
-239.8 (5)*	-5.4 (10)*	TRIGA-LASER
-218.8 (7)		[4]
25578.41 cm^{-1}		
1030.2 (5)*	-5.1 – -18.4*	TRIGA-LASER
891 (17)		[4]
1031.6 (2.2)	12.2 (6.6)	[6]
1030.9 (1.8)	14 (10)	[7]

* Theoretical uncertainness still under evaluation

^{141}Pr I=5/2 μ_I=4.2754(5)μ_N Q=-0.077 [5]

@ COLLAPS/ISOLDE

isotope	I	μ [μ_N]
135 Pr	3/2	2.0(3)
136 Pr	2	1.6(3)
137 Pr	5/2	3.5(3)



In a first try at the COLLAPS experiment at ISOLDE/CERN the interesting isotope ^{140}Pr could not be measured. However, the hyperfine spectra of the neutron-deficient isotopes $^{135,136,137}Pr^+$ could be recorded. The extracted nuclear magnetic moments μ_I are presented in the table above. Unfortunately, due to problems with the linearity of our power amplifier the uncertainty is larger than usually in a collinear laser spectroscopy experiment. It was the first time that the magnetic moment of these isotopes could be measured.

Summary / Outlook

The determination of the nuclear magnetic moment of the neutron-deficient isotope ^{140}Pr using collinear laser spectroscopy is planned. The magnetic moment is required for the explanation of the observed modulated EC decay of H-like ^{140}Pr in the ESR storage ring at GSI. As a preparation for the spectroscopy of the radioactive isotope we have performed collinear laser spectroscopy of the stable isotope $^{141}Pr^+$ at the TRIGA-LASER experiment in Mainz. The studied transition is perfectly suitable for the measurements but in a beamtime at the COLLAPS experiment at ISOLDE/CERN the interesting isotope could not be measured. However, the magnetic moment of the neutron-deficient isotopes ^{135,136,137}Pr were determined.

References

[1] N. Nica, *Nuclear Data Sheets* **108** (2007) 1287
[2] Yu. A. Litvinov et al., *PRL* **99** (2007) 262501
[3] Yu. A. Litvinov et al., *Phys. Lett* **B 664** (2008) 162
[4] A. Ginibre, *Phys. Script* **39** (1989) 694-709
[5] J. K. Tuli et al. *Nuclear Data Sheets* **92** (2001) 277
[6] Li Maosheng et al. , *Phys. Rev* **A 62** (2000) 052504
[7] B. Furmann et al., *Eur. Phys. J.* **D 17** (2001) 275-284

* nadja.froemmgen@uni-mainz.de

Acknowledgements

VH-NG-148
N. Frömmgen DFG/GRK 1581 Symmetry Breaking
A. Krieger B. AZ:21-0563-2.8/197/1