Laser polarization setup at ISOLDE, CERN: $^{35}$Ar results and achievements

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Motivation

$^{35}\text{Ar}$ is a mirror nucleus $\rightarrow$ measurement of $\beta$-asymmetry can be used to calculate $V_{ud}$

Determined from $\beta$-asymmetry

Currently $\Delta V_{ud}: 2.2\times10^{-4}$ (all measurements combined)

With 0.5% relative precision on asymmetry: $4\times10^{-4}$ (single measurement!) $\rightarrow$ asymmetry of 20% needed for a reasonable measurement time
Location
Laser Polarization: mechanism

Optical pumping with $\sigma^\pm$ polarized laser light in a 2m long interaction region ($\sim \mu$s interaction time):

$\sigma^\pm$: induces $\Delta m_F = \pm 1$ transitions, $\sigma^+$ was used for $^{35}\text{Ar}$

Figure: Keim M, 1996, Messung der Kernquadrupolmomente neutronenreicher Natriumisotope, PhD Thesis
Multi-frequency pumping

- **Goal:** enhance the polarization for $^{35}\text{Ar}$
- **Closed cycle found at 811 nm in Ar atom. But high spins result in many HFS levels → reduces the amount of polarization per level
- **Solution:** multi-frequency pumping

811 nm

J=3

I=3/2

J=2

F=9/2

F=7/2

F=5/2

F=3/2

F=7/2

F=5/2

F=3/2

F=1/2

7/2 state: 60% of the population

Add population from 5/2 and 3/2: ≈100%
Measure laser-induced nuclear polarization: via the asymmetry in $\beta$-decay

$$P(\theta) \sim 1 + AP \cos \theta$$

$$A_{exp} = \frac{N(0^\circ) - N(180^\circ)}{N(0^\circ) + N(180^\circ)} = AP$$
Implantation setup

- Closed cycle He cold head: cools down to 10 K (~1.5 hours)
- Several hosts tested: Si, KBr, KCl, NaCl, Pt
Typical data

Hyperfine scan

Contains information about the environment of the implanted Ar

Relaxation curve
Polarization succes

- Transition was fully saturated with all beams
- Signal gain of factor 1.7 by pumping 3 hyperfine transitions
- Signal itself: 1.5-2%
**β-intensity**

- Arrhenius-like behavior of implanted radioactivity \( \rightarrow \) Activation energy in order of magnitude for diffusion in similar crystals [1]

\[ \beta \sim \exp\left(-\frac{Q}{RT}\right) \]

Relaxation time trend

Upward trend/phase transition visible: possible freezing of Ar used to vent the beamline
Conclusion

**Achieved**

- Maximal signal of 2% was seen in KCl at 10 K in one spectrum, average of 1.5% at 10 K
- Polarization optimization with multi-frequency pumping worked as expected from simulations

**Outlook**

- Observed asymmetry is ~5 times less than expected, factor 10 less than needed $\rightarrow$ project on hold until we find an explanation
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² Georgetown University
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⁶ Max-Planck-Institut für Kernphysik, Germany
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⁸ KU Leuven, Belgium
⁹ University of Copenhagen, Denmark
¹⁰ Democritus University of Thrace, Greece
¹¹ Poznan University of Technology, Poland
¹² Nuclear Physics Institute, Czech Republic
Fresh results

See poster by Rob Harding (#22)
Questions?
Backup slides
Doppler shifting the frequency

\[ f_{\text{beam}} = f_{\text{laser}} \sqrt{\frac{1 - \beta}{1 + \beta}}, \beta = \frac{v}{c} \]
Magnetic field

- Polarization is created along the beamaxis, magnet has field perpendicular → configure field to rotate polarization

- Blue: perpendicular, green: along, orange: total
Light characteristics

- $\lambda/4$ after $\lambda/2$ waveplate creates $\sigma^\pm$

- High power is crucial for inducing many optical pumping cycles!
AOM Setup

Factory efficiency: 85%
Measured efficiency: ~80%
Simulation results

- Classical rate equations adopted for multiple laser frequencies

- Expectation of ~2 times larger signal and addition of extra peaks
- Frequency shifts of 378 and 325 MHz needed: Acousto-Optic Modulators (AA Opto-Electronic MT325, MT378 with associated RF amplifier)
- Technical difficulty: overlap needs to happen with beam splitters instead of polarizing beam splitters due to need for the same σ polarization
Simulation results

\[
\text{Ratio} \quad 1.70^{+0.19}_{-0.17}(1.39)
\]
Saturation curve

\[ \text{Asym} = \text{Amp} \frac{P/P_0}{1 + P/P_0} \]
Asymmetry Results

NaCl
Asymmetry Results

KCl

![Graphs showing asymmetry results](image-url)
Optical detection

Cooled PMTs

Focusing lenses
Estimated Isotope Shift

Estimated $^{35}\text{Ar IS: } -531.478 +/- 1.193 \text{ MHz}$

Modified isotope shift of 811 nm line [Measured in April]

Modified isotope shift of 763 nm line [Klein et al.]