"ORIZO" experiment

Nuclear laser spectroscopy in superfluid helium for measurements of spins and moments in exotic nuclei

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Contents

• What is “OROCHI”?  
  Nuclear laser spectroscopy in superfluid helium  
  For the measurement of rare isotopes  
  not a precision but sensitive to detect photons

• Present status  
  off-line development  
  with Rb, Cs, Ag, and Au stable isotopes

• Future prospect  
  on-line experiment with Rb beam @ RIKEN  
  off-line development for In and Tl isotopes

DESIR Workshop, 5/26-28, T. Furukawa
New Laser Spectroscopy

to measure the nuclear spins & moments in exotic nuclei...

“laser spectroscopy for radioisotope (RI) atoms in superfluid helium (He II)”

“OROCHI”

Optical RI-atom Observation in Condensed Helium as Ion-catcher

This is Japanese “OROCHI” snake

from “DRAEMON” vol. 22, by FUJIKO, F. Fujio
Advantage in He II

We use He II to reduce the b.g. photons.

Atomic absorption line in He II

\[ ^{133}\text{Cs D1 atomic spectra in He II} \]

① largely blue-shifted

② widely broadened

We use He II atomic absorption line in He II to reduce the b.g. photons.

Excited with pushing away the surrounding He atom

\[ \text{Laser} \]

Detector

wavelength: \( \lambda_{\text{LIF}} \neq \lambda_{\text{laser}} \)

Suppress background count

Reduction: \( 10^{-10} \sim 10^{-13} \)
Double resonance spectroscopy

measurement of atomic sublevel structure

In the case of Zeeman splitting in alkali atoms

In the case of Zeeman splitting in alkali atoms

2nd step: optical pumping

expected spectrum

No level

mission photons in optical pumping
(Laser Induced Fluorescence, LIF)

decreased gradually

\[ I_{\text{LIF}} \propto 1 - P_z \]
**Off-line development**

To confirm the feasibility of OROCHI with stable isotope: Rb, Cs, Ag, Au, ....

Atoms introduced with laser sputtering

Sputtering laser → sample

pumping laser → atom

He II

Optical pumping

Double resonance

Photons detection

[Image of experimental setup with Rb and Cs atoms indicated]
Optical pumping in He II

Produce the polarization in stable Rb, Cs in He II

Polarization: increased
LIF intensity: decreased

Polarization switched

Optical pumping in He II


Polarization: ~90% (Cs)
~50% (Rb)

Polarization switched

Linearly polarized

Circularly polarized

Polarization

LIF intensity:

decreased

photon counts

Time (ms)

5 ms

5 ms
Nuclear spin & moment determination

Zeeman resonance

- Magnetic field \( B = 4.0(1) \) Gauss
- \( ^{85}\text{Rb} \):
  - \( I_{^{85}\text{Rb}} = 2.6(1) \rightarrow 5/2 \)
  - \( \nu = 1.8203(2) \) MHz
- \( ^{87}\text{Rb} \):
  - \( I_{^{87}\text{Rb}} = 1.55(5) \rightarrow 3/2 \)
  - \( \nu = 2.7357(6) \) MHz

Hyperfine resonance

- \( \Delta \nu_{Zmn} = g_F m_B B / \hbar \)
- \( \nu = 2.8(\text{MHz}) \times B(\text{Gauss}) \)
- \( (2I+1) \) Nuclear spin

Pressure effect of He II:
- Indicates interesting phenomena of atoms in He II
- Both different from free space

Hyperfine interaction
- Hyperfine anomaly (Bohr-Weisskopf effect)

Pressure effect of He II:
- This work (from \( A_{\text{HeII}} \))
  - \( \mu = 1.35783(7) \mu_N \)
- Previous (from \( A_{\text{vacuum}} \))
  - \( \mu = 1.358071(1) \mu_N \)
- Literature value (NMR)
  - \( \mu = 1.3533515 \mu_N \)

On-line test with Rb beam

All the devices were mounted on RIKEN RIPS beam line!!

But Rb beam has not accelerated due to machine trouble...

Next MT is scheduled in this September. The result will be shown next time...

Remaining uncertainty: photo-detection efficiency confirmed with on-line experiment

Oh, my god......

Photo-detection system
lens x 3, slit x1, filter x 2
PMT (Peltier cooled) x1
Laser spectroscopy of Ag and Au

T. Furukawa, K. Fujikake et al., to be published...

Apply to noble metal Ag and Au atoms

Broadened absorption spectra in He II.

→ feasible to optically pumping various atomic species

(less limitation of laser wavelength)

polarization: \( \sim 80\% (\text{Ag}), \sim 60\% (\text{Au}) \)

incomplete polarization is due to imperfect circular polarization of laser

Zeeman splitting of stable \(^{107,109}\text{Ag}\) isotopes (both \(I=1/2\))

Nuclear spin \(I=1/2\) can be deduced clearly.
**Feasible elements in periodic table**

**Next attempt**
Optical pumping of In and Tl

<table>
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<th>Periodic Table</th>
<th>Feasible</th>
<th>succeeded</th>
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<tr>
<td>[L] La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu</td>
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<tr>
<td>[A] Ac Th Pa U Np Pu Am C Bk Cf Es Fm Md No Lr</td>
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</table>
1st goal: exotic N=Z nucleus $^{94}$Ag
$I, \mu$ of g.s. and isomer state (21+)
expected yield: < 1 pps (with BigRIPS)

RI (total): 0.1 pps
Isomer ratio: 5%
(from RIBF facility)
1 day measurement

Stable line

N. J. Stone, At. Nucl. Data Tab. 90, 75 (2005)
Conclusion

"OROCHI" Project

Optical Radioisotope-atom Observation in Condensed Helium as Ion-catcher

- We developed the new laser spectroscopy method "OROCHI" for determining nuclear spins and moments of exotic RI far from stability by using superfluid helium (He II) as a stopper of RI beam and host matrix of laser spectroscopy.

- Atomic spectra in He II (largely blue-shifted and broadened) enable us to measure for the extremely low yield RI whose yield is less than 1 pps. It is also useful to optical pumping of various atomic species.

- In our off-line development using stable Rb and Cs isotopes, we have successfully demonstrated the determination of nuclear spins and moments from the measured Zeeman and hyperfine splitting respectively. We have also demonstrated the optical pumping and double resonance of stable Ag and Au isotopes in recently.

- Preparation of setups for online experiment is almost finished.

We hope This OROCHI will open the door to measure nuclear spins and moments of exotic nuclei, particularly proton drip-line, $N=Z$ nucleus $^{94}$Ag.
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We feel OROCHI can be useful not only for nuclear laser spectroscopy, but also β-NMR, decay spectroscopy, and so on.

In 1980’s, some groups reported that the low energy atomic or molecular beams can be introduced into He II with electric field.

If you have some interests or ideas to use OROCHI for DESIR, please contact us, and collaborate with us if you prefer!

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Thank you for your attention.