High-Precision Measurements and Theoretical Calculations of Indium Excited-State Polarizabilities

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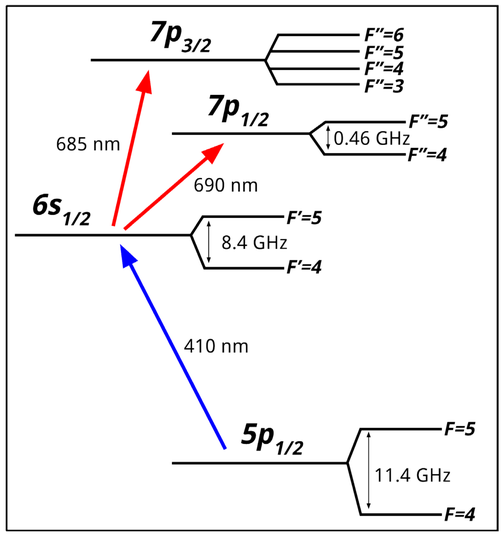
Background



Scalar and tensor polarizability measurements were performed for the $7p_{1/2}$ and $7p_{3/2}$ states of ^{115}In using two-step spectroscopy.

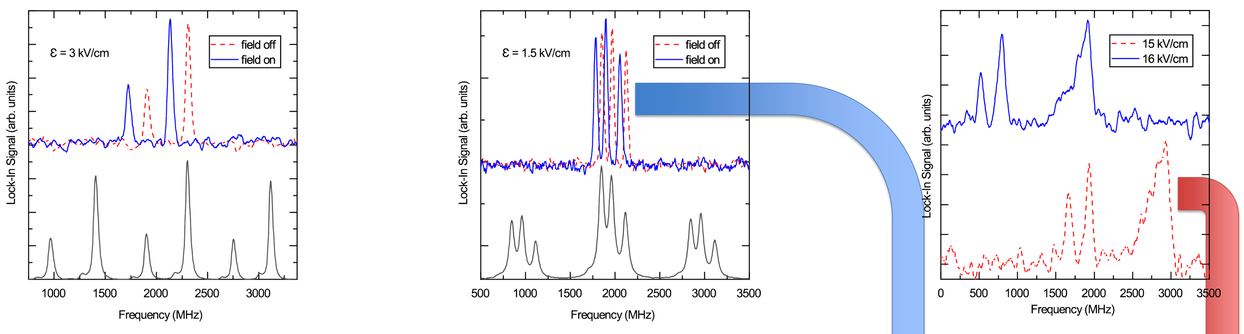
Why is this important?

Accurate modeling of multi-valence heavy atoms improves testing of fundamental particle physics in atomic physics experiments.

- Polarizability is an effective means to make a precise measurement that can be calculated *ab initio* by theorists in order to test models.

Experimental Results

Stark shift data shown for $7p_{1/2}$ at low field (left), $7p_{3/2}$ (F = 3, 4, 5) at low field (middle), and $7p_{3/2}$ (F = 3, 4, 5) at high field (right)



unshifted vapor cell data shown at bottom (with EOM sidebands) used for calibration

Analysis

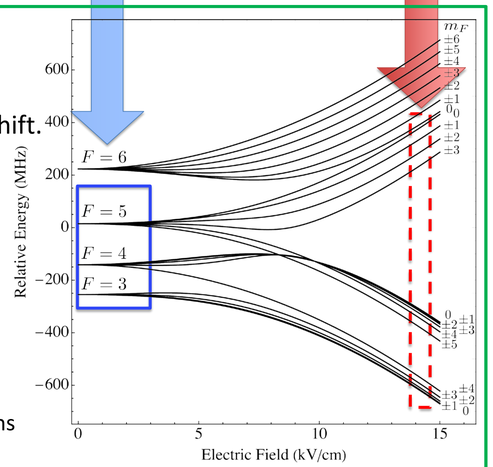
$\Delta E = -\frac{1}{2}\alpha_0 \varepsilon^2$ for $7p_{1/2}$, where ε is the applied electric field, and

$\Delta\nu = -\frac{1}{2h}\left[\alpha_0\left(7p_{1/2}\right) - \alpha_0\left(6s_{1/2}\right)\right]\varepsilon^2 \equiv k_0\varepsilon^2$ is its measured Stark shift.

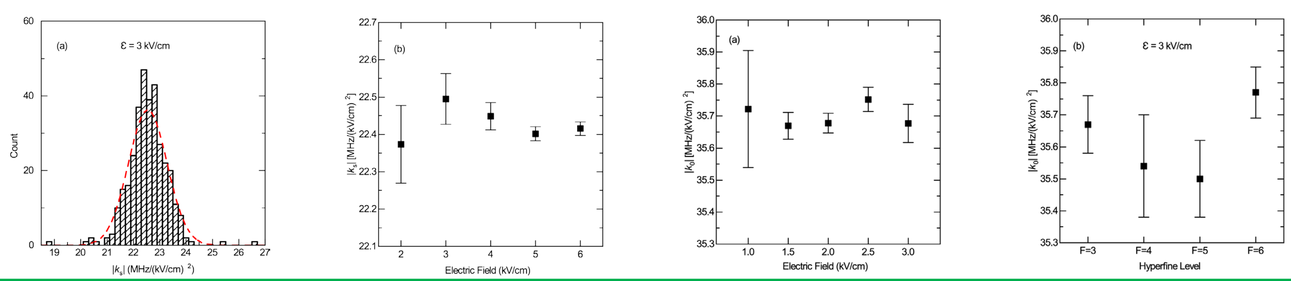
$7p_{3/2}$ features both a scalar and tensor component as well:

$k_{\text{eff}} = k_0 + c(F, m_F)k_2$ where $k_0 = -\frac{1}{2h}\left[\alpha_0\left(7p_{3/2}\right) - \alpha_0\left(6s_{1/2}\right)\right]$

(scalar) and $k_2 = -\frac{1}{2h}\alpha_2\left(7p_{3/2}\right)$ (tensor)



top right: modeled tensor component of $7p_{3/2}$ (F, m_F) states
bottom left: $7p_{1/2}$ (a) distribution of calculated $|k_s|$, (b) $|k_s|$ at five field strengths
bottom right: $7p_{3/2}$ (a) $|k_0|$ at five field strengths, (b) $|k_0|$ for all F values



References:

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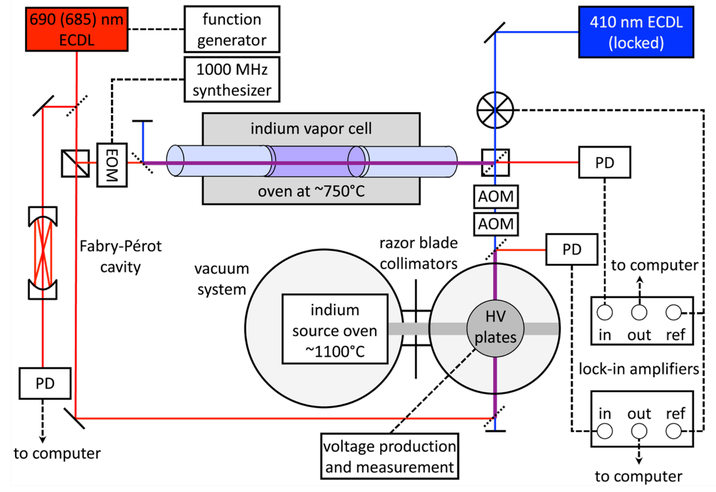
Experimental Setup

PD: photodiode
EOM: electro-optic modulator
ECDL: external cavity diode laser

(Blue is locked to first-step transition using the same vapor cell, not shown.)



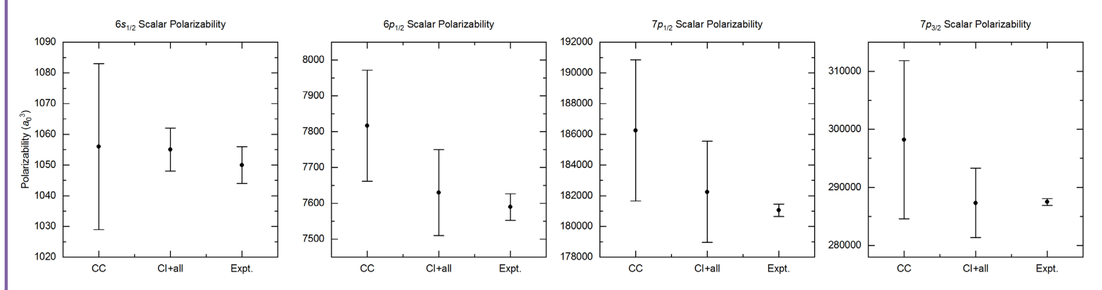
Theoretical Results

Indium can be treated in one of two ways:

- **one valence electron** ($5p$) with a [Kr]$4d^{10}5s^2$ core
- **trivalent system** with a $5s^2$ open shell and a [Kr]$4d^{10}$ core

- the single valence electron treatment is modeled using "coupled-cluster" (CC)
- the trivalent system is modeled using "configuration interaction" with all-order CC methods ("CI+all")

Method	$\alpha_0(6s)$	$\alpha_0(5p_{1/2})$	$\Delta\alpha_0$	$\alpha_0(6p_{1/2})$	$\alpha_0(6p_{3/2})$	$\alpha_2(6p_{3/2})$	$\alpha_0(7p_{1/2})$	$\alpha_0(7p_{3/2})$	$\alpha_2(7p_{3/2})$
CC	1056(27)	61.5(5.6)	995(28)	7817(155)	10506(180)	−1432(42)	1.863(46)×10^5	2.98(14)×10^5	−1.75(29)×10^4
CI+all	1055(7)	62.5(2.0)	992(7)	7630(120)	10259(230)	−1407(40)	1.823(33)×10^5	2.87(6)×10^5	−1.62(16)×10^4
Expt.	1050(6)		988.0(2.7)	7590(37)			1.811(04)×10^5	2.876(06)×10^5	−1.43(18)×10^4



CI+all in better agreement with experiment (to < 0.5%): importance of configuration mixing

Conclusions

- precise polarizability measurements are able to distinguish between accuracies of theoretical models of trivalent systems
  - CI+all-order, originally designed for low-lying states, works for high excited states
- major step in testing fundamental physics using trivalent atoms
- next: extend measurements of excited-state polarizabilities to thallium (also Group IIIA, but heavier)

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