Laser spectroscopy to test accuracy, guide refinement of 
ab initio theory calculations for Group IIIA (\(n^2P_{1/2}\)) atoms

Such theory essential for tests of fundamental physics and sym-
metry violations in these systems (PNC, EDM, etc.)

Energy shift scales quadratically with applied electric field:

\[ \Delta E \propto E^2 \]

Produces ‘Doppler-free’ spectra

Lock 410 nm diode laser to first-step transition, scan overlap-
ings ECDL through second-step transition

2016 two-step measurement of \(\alpha_0\) (Safronova 2016)

Two theory approaches:
1. Coupled-Cluster (CC) perturbative, hydrogenic approach –
   consistently overestimates experiment (green, above)
2. Configuration Interaction + All Order (CI+All) three-valence –
   consistently underestimates experiment (blue, above – not calcu-
   lated for \(7P_{1/2}\) states)

Scalar Polarizability

\[ \alpha_0 \] theory value – at 15% level – from Safronova (2016)

Requires more data acquisition and systematic error analysis

Recap: Comparisons with Theory

410 nm Laser Locking

- Lock to \(5P_{1/2} \rightarrow 6S_{1/2}\) resonance in auxiliary vapor cell using FM spec-
troscopy method (yields dispersive locking signal)
- Adjust lock to Stark-shifted resonance using AOM technique

Atomic Beam Lineshape Simulations

- Diagonalize \(60 \times 60\) Hamiltonian describing generalized three-level
  system in the presence of two near-
  resonant laser fields
- Near \(E \sim 15\) kHz/cm: fully res-
  olved \(4, 4\) sublevel, ‘composite peak’ \((5, 5-4)\) and \((4, 3-0)\)
  sublevels, and \(P = 5, 6\) feature

Scalar Polarizability Extraction

- Extract \(\alpha_0\) by measuring shift of resolved \(4, 4\) sublevel
- Use \(\alpha_2\) theory value – at 15 level – from Safronova (2016)
- \(\alpha_2\) uncertainty leads to \(\sim 1\%\) theory uncertainty in \(\alpha_0\)
  \(\alpha_2/\alpha_0 \sim 0.06\)

\[ \Delta E_{1/2}(E) = -\frac{1}{2}\alpha_0 E^2 - f_{\text{lock}}(\alpha_2, E) \]

Preliminary Results

\(7P_{3/2}\) Scalar Polarizability

- Preliminary result \(\alpha_0(7P_{3/2}) = 1.8064(32)\times10^{-11}\)
- Dominated by contribution from nearby \(6D_{3/2}\) state – allows indirect, 
  precise measurement of \(\Delta(6D_{3/2}/6P_{3/2}) = 23.16(4)\) a.u.
- Contains statistical and systematic error contributions
- Requires further data acquisition and systematic error analysis

\(7P_{1/2}\) Scalar Polarizability

- Very preliminary result \(\alpha_0(7P_{1/2}) = 2.852(30)\times10^{-11}\)
- Dominated by \(\alpha_2\) theory error bar at \(\sim 1\%\) level
- Requires more data acquisition and systematic error analysis

Future Work

Indium Work
- Collect more \(7P_{1/2}\) data and analyze further systematics
- Collect much more \(7P_{3/2}\) data and begin analyzing systematics
- Pursue further theory work towards tensor polarizability ex-
  traction

Long-Term Goals
- Begin thallium and or lead work in the atomic beam

\[ \frac{\alpha_3}{\alpha_0} = 0.06 \]

\[ \Delta E = -\frac{1}{2}\alpha_0 E^2 \]