High-Precision Faraday Rotation Spectroscopy and Atomic Beam Polarizability Measurements in Lead

John H. Lacy, Abdullah Nasir ’20, Gabriel E. Patenotte ’21, and Protik K. Majumder
Department of Physics, Williams College, Williamstown, Massachusetts 01267 USA

Work supported by NSF grant #1912369

Background

- Heavy, multivalence elements are good testbeds for atomic theory; optical rotation scales with $Z^2$.
- Previous work with Group IIIA In [1] and Tl [2] tested ab initio multi-valence wavefunction models (Safronova group).
- New focus is on Group IV Pb. Extra valence electron complicates atomic wavefunction calculations. Pb also very important for PNC measurements and probing weak interaction with nucleus.
- Modest improvements $\rightarrow$ big impact.

Energy Levels of Pb

$6s^26p^2$ $6s^26p^7s$

$\uparrow \uparrow \uparrow$ $\uparrow \uparrow \uparrow$

$3P_0$ $3P_1$

$P \downarrow \downarrow \downarrow$

$1279$ nm, $M_1$

$368.5$ nm, $E_1$

$939$ nm, $E_2$

$\uparrow \uparrow \uparrow$ $\uparrow \uparrow \uparrow$

$\uparrow \downarrow \downarrow$

$\downarrow \uparrow \uparrow$

$\downarrow \uparrow \uparrow$

Recently: $3P_1 \rightarrow 3P_0$ (E2) transition amplitude relative to $M_1$ in a vapor cell [3].

Currently: $3P_0 \rightarrow 3P_1$ (M1) in an atomic beam unit $\rightarrow$ use polarimetry with $\mu$rad resolution, measure atomic polarizabilities, stark-induced M1 transition due to mixing of P states with S and D levels.

Future: two-step spectroscopy to $6s^26p^7$ states with atomic beam apparatus.

Faraday Rotation Spectroscopy (FRS)

- Applied B field splits $m_J$ sublevels for $3P_1$.
- Refractive indices for $\sigma^-$ and $\sigma^+$ are now different.
- Lock-in signal is proportional to this difference $\Phi = \text{Re}(n_s(f)) - \text{Re}(n_\sigma(f))$.
- Actual signal depends on Doppler broadening.

Atomic Beam Unit (ABU) for Pb

- Doppler broadening 20 times smaller compared with vapor cell at same temp.
- Isotopes resolvable.

Preliminary results in vapor cell

- Reduction in systematic thermal effects from heating of Quartz cell.
- Optical depth with ABU 2500 times smaller than in vapor cell at same temperature.
- Rotation signals of 30 $\mu$rad are still resolvable!

Pb Spectroscopy in UV

- Limit of existing laser diodes $\sim 369$ nm – too long for $6s^26p^23P_0 \rightarrow 6s^6p^73P_1$ (E1) transition.
- Lasing frequency $\uparrow$ as diode temperature $\downarrow$. Need $\sim 2$ $\mu$W.
- $H_2$ condensation avoided by flushing box with $N_2$.
- Lasing power $\sim 368$ nm $\sim 15$ mW.
- FRS feasible $\sim 368$ nm $\sim$ use CeF$_3$ Faraday glass.

Future Goals

- Low vapor pressure (Sn $\sim 900^\circ$C $\sim$ Pb $\sim 540^\circ$C).
- 7 stable even isotopes ($^{112}$Sn, $^{114}$Sn, $^{116}$Sn, $^{118}$Sn, $^{120}$Sn, $^{122}$Sn, $^{124}$Sn) $\rightarrow$ King plot linearity test.
- Several transitions at accessible wavelengths.

Isotope shifts and hyperfine splitting in Pb

Sn isotopes

[4] Data from Cry-Link, www.crylink.com/search/fields/5c9808d4-72a6-4c01-8d2b-878b9f7ad4e7