3rd Order Nonlinear Susceptibility Calculations of Kr for Lyman-α Laser

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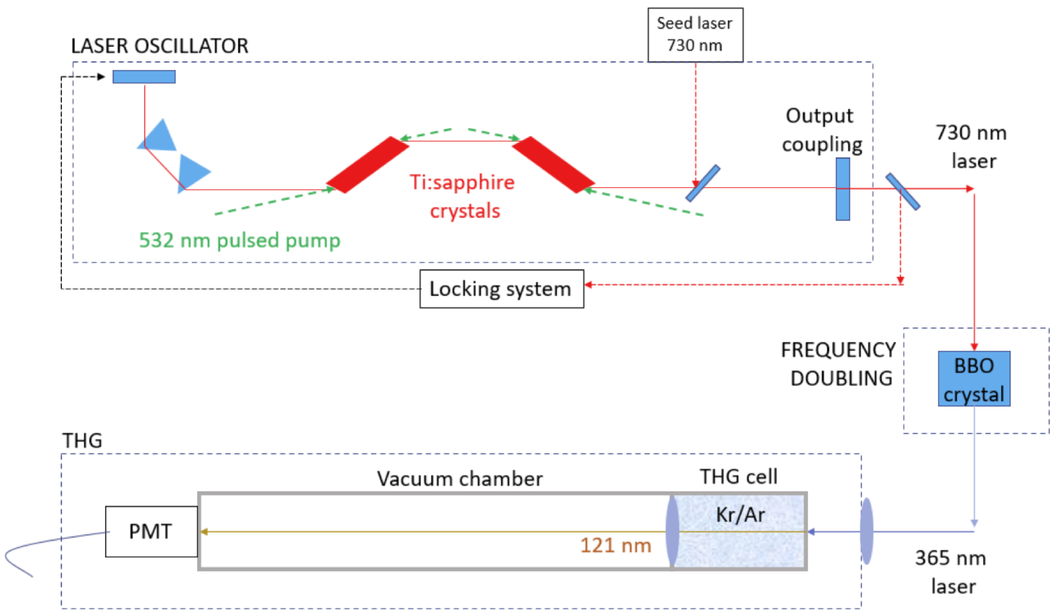
The ALPHA-g Collaboration at CERN

Antihydrogen Laser PHysics Apparatus

At ALPHA-g, the trajectories of antihydrogen atoms as they leave a magnetic trap in order to investigate the gravitational behaviour of the anti-atom. A Lyman-α (121 nm) laser is needed to cool the atoms to approximately 50 mK. My work involved calculating 3rd-order χ for the laser set-up.

Laser Set-Up



Nonlinear Optical Processes

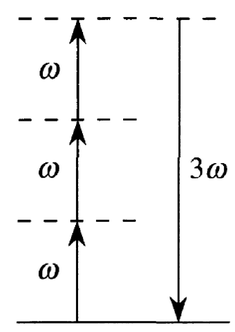
When light hits certain materials, the response of the system is not linear in relation to the magnitude of the applied electric field. Each χ term represents the nth-order nonlinear susceptibility.

$$\tilde{P}(t) = \epsilon_0[\chi^{(1)}\tilde{E}(t) + \chi^{(2)}\tilde{E}^2(t) + \chi^{(3)}\tilde{E}^3(t) + ...]$$

We focus on the third-order nonlinear processes $\chi^{(3)}$ which involve 3 different incident waves to interact.

Triple Harmonic Generation

3 photons of frequency ω are destroyed, and 1 photon of frequency 3ω is created.



Calculations

$\chi^{(3)}$ is a tensor where the indices k,m, and n represent three transitions that correspond to the new energy level when an ω is absorbed (ω, 2ω, and 3ω). $\chi^{(3)}$ is a summation of all allowed paths.

$$\chi^{(3)} \alpha \frac{\text{dipole moments}}{\text{resonances}}$$

- Wigner-Eckart Theorem separates dipole moment into corresponding Clebsch-Gordan coefficient and reduced matrix element
- Reduced matrix element calculated using oscillator strength and transition probability
- 3ω close to resonance to yield a higher nonlinear susceptibility without high chance of absorption

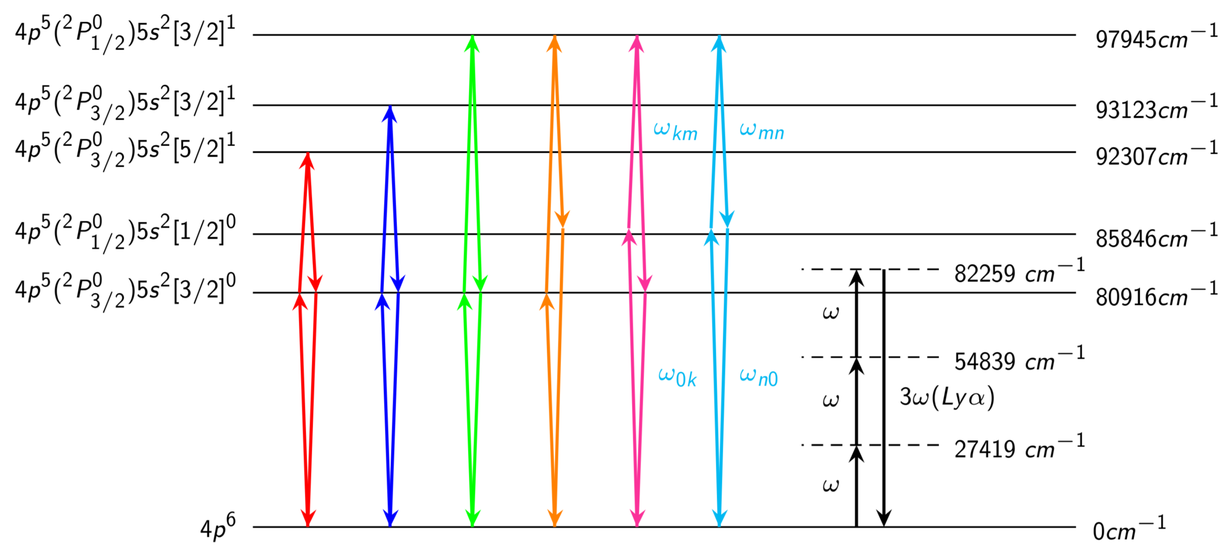


Figure: Energy Level Diagram to show allowed Transitions in Kr, and THG

Results and Conclusion

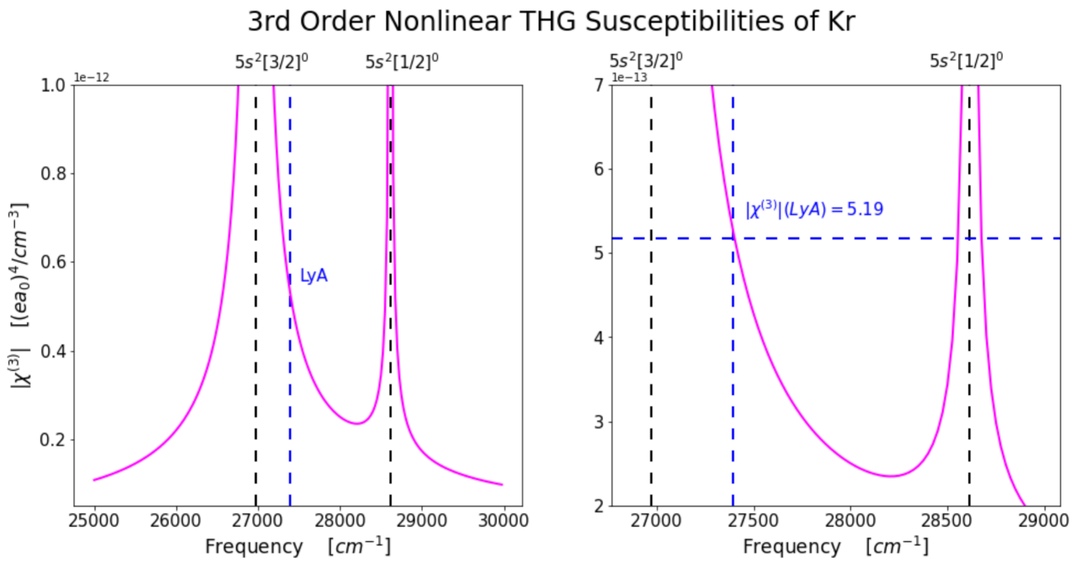


Figure: $\chi^{(3)}$ values for Kr where ω ranges from 25000 to 30000 cm^{-1} or approximately 330-400 nm. $\chi^{(3)}$ at LyA is approximately $9.2 * 10^{-37} esu/cm^{-3}$ with 20 percent uncertainty.

Results: 9.2 * 10^{-37} esu/cm^{-3}

Mahon et al. (1979): 11 * 10^{-37} esu/cm^{-3}

- Since our values are on the same magnitude as values found in literature, our method is verified
- Discrepancy comes from more significant digits to transition probabilities and oscillator strengths

TRIUMF

Discovery, accelerated