Optical Methods for Trapping Atoms and Making Cold Molecules
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Introduction
In its ground state, a krypton (Kr) atom has a full valence shell and so is unreactive. However, if two Kr atoms are in the metastable 1s\(_2\) state, they can be bound together briefly if they absorb laser photons with specific energies. This process of "photoassociation" (PA) is probable only at extremely low temperatures. We use a magneto-optical trap (MOT) to produce a cloud of Kr atoms at temperatures below 1 milli-Kelvin, and we illuminate the cloud with a tunable probe laser in an effort to find the photon energies at which PA occurs.

Theory
Atom’s journey:
- Sent through vacuum system down solenoid, travelling about 300 m/s.
- Magnetic field Zeeman shifts some energy levels of the atoms downward.
- Relative motion Doppler shifts slowing beams frequency upwards.
- Atom absorbs and scatters many photons, slowing it to less than 10 m/s.
- The atom is caught in a cloud at the center of the MOT; if it moves away from the center, a restoring force is applied. The cloud is cooled to < 1mK.
- At certain PA laser wavelengths, a photon may be absorbed by a pair of atoms as the collide. The two atoms then form a molecule, which falls out of the trap.

Procedure
Our project had three stages: the setup of the MOTs, data collection, and analysis.
Creating two traps:
- Lock lasers to an energy matching the difference between two atomic states
- Optimize magnetic field currents for overlapping traps, one larger and fluffier and the other smaller and denser
We were then able to add a third laser (our "PA laser") intended to initiate photoassociation.

Typical data run:
- Gather large atom cloud within two sets of overlapping trapping lasers
- Shut off one set of lasers, so remaining set compresses the cloud
- Flash PA laser on, record measurements of cloud fluorescence, ion rate, and PA laser wavelength, and turn PA laser off
- Repeat process from beginning with higher PA wavelength

After our data was collected, it needed to be formatted and analyzed.
Analysis:
- Compile all data, create graphs, and look for dips in the data; if any are found, repeat the scan for various cloud densities and with multiple lasers

Results
While we did find resonances in the trap fluorescence (see below), we are unable to confirm that these are molecular resonances caused by the PA process. The signals may be due to light produced by the PA laser at different wavelengths (in different laser modes).

Next Steps
- To complete our search, scan over all remaining wavelengths in our range
- To confirm our potential photoassociation wavelengths, verify with grating-stabilized PA laser and take careful density measurements

Fig. 2: Krypton atom cloud alone (left), and cloud with PA laser at a potential molecular resonance (right)

Fig. 1: Relevant atomic energy levels and transition energies of krypton. Of particular import to our research are the 1s\(_2\) to 2p\(_9\), 2p\(_9\) to 4d\(_5\), and 1s\(_2\) to 2p\(_9\) transitions.

Fig. 3: Diatomic energy potentials for krypton. Photoassociation occurs within the diatomic energy potential wells.

Fig. 4: Photoassociation potentials

Fig. 5: A magneto-optical trap

Fig. 6: MOT fluorescence produced by scanned PA laser

References

Goals
- Set up a system of two overlapping MOTs for trapping atoms
- Seek out wavelengths of krypton’s molecular interactions
- Analyze and explore nature of these molecular interactions as they relate to krypton’s quantum structure


Brightness vs. Wavelength


http://www.33rdsquare.com/2014/03/ultracold
