Roger Brown

Quantum Interference and Light Polarization Effects in Unresolvable Atomic Lines: Application to a Precise Measurement of the Li-6, Li-7 D-2 Lines


We characterize the effect of quantum interference on the line shapes and measured line positions in atomic spectra. These effects, which occur when the excited-state splittings are of order of the natural line widths, represent an overlooked but significant systematic effect. We show that excited-state interference gives rise to non-Lorentzian line shapes that depend on excitation polarization, and we present expressions for the corrected line shapes. We present spectra of Li-6, Li-7 D lines taken at multiple excitation laser polarizations and show that failure to account for interference changes the inferred line strengths and shifts the line centers by as much as 1 MHz. Using the correct line shape, we determine absolute optical transition frequencies with an uncertainty of $< 25$ kHz and provide an improved determination of the difference in mean-square nuclear charge radii between Li-6 and Li-7. This analysis should be important for a number of high-resolution spectral measurements that include partially resolvable atomic lines.

Absolute Transition Frequencies and Quantum Interference in a Frequency Comb Based Measurement of the (6,7) Li D Lines


Optical frequencies of the D lines of Li-6, Li-7 were measured with a relative accuracy of $5 \times 10^{-11}$ using an optical comb synthesizer. Quantum interference in the laser induced fluorescence for the partially resolved D2 lines was found to produce polarization dependent shifts as large as 1 MHz. Our results resolve large discrepancies among previous experiments and between all experiments and theory. The fine-structure splittings for Li-6 and Li-7 are 10052.837(22) MHz and 10053.435(21) MHz. The splitting isotope shift is 0.599(30) MHz, in reasonable agreement with recent theoretical calculations.

Pulsed Sisyphus Scheme for Laser Cooling of Atomic (Anti) Hydrogen


We propose a laser cooling technique in which atoms are selectively excited to a dressed metastable state whose light shift and decay rate are spatially correlated for Sisyphus cooling. The case of cooling magnetically trapped (anti) hydrogen with the 1S-2S-3P transitions by using pulsed ultraviolet and
continuous-wave visible lasers is numerically simulated. We find a number of appealing features including rapid three-dimensional cooling from similar to 1 K to recoil-limited, millikelvin temperatures, as well as suppressed spin-flip loss and manageable photoionization loss.

Mesoscopic Effects in Quantum Phases of Ultracold Quantum Gases in Optical Lattices


We present a wide array of quantum measures on numerical solutions of one-dimensional Bose- and Fermi-Hubbard Hamiltonians for finite-size systems with open boundary conditions. Finite-size effects are highly relevant to ultracold quantum gases in optical lattices, where an external trap creates smaller effective regions in the form of the celebrated “wedding cake” structure and the local density approximation is often not applicable. Specifically, for the Bose-Hubbard Hamiltonian we calculate number, quantum depletion, local von Neumann entropy, generalized entanglement or Q measure, fidelity, and fidelity susceptibility; for the Fermi-Hubbard Hamiltonian we also calculate the pairing correlations, magnetization, charge-density correlations, and antiferromagnetic structure factor. Our numerical method is imaginary time propagation via time-evolving block decimation. As part of our study we provide a careful comparison of canonical versus grand canonical ensembles and Gutzwiller versus entangled simulations. The most striking effect of finite size occurs for bosons: we observe a strong blurring of the tips of the Mott lobes accompanied by higher depletion, and show how the location of the first Mott lobe tip approaches the thermodynamic value as a function of system size.

Multiphoton Magnetooptical Trap


We demonstrate a magnetooptical trap (MOT) configuration which employs optical forces due to light scattering between electronically excited states of the atom. With the standard MOT laser beams propagating along the x and y directions, the laser beams along the z direction are at a different wavelength that couples two sets of excited states. We demonstrate efficient cooling and trapping of cesium atoms in a vapor cell and sub-Doppler cooling on both the red and blue sides of the two-photon resonance. The technique demonstrated in this work may have applications in background-free detection of trapped atoms, and in assisting laser cooling and trapping of certain atomic species that require cooling lasers at inconvenient wavelengths.

PRESENTATIONS

Quantum Interference and Polarization Effects in a Precise Measurement of the Li D Lines

Roger Brown, NIST Division Seminar (joint w/ C.J. sanaonetti), NIST Gaithersburg, April 17 2013

By combining precise observations of isotope shifts in the Li D lines with results of the most accurate calculations of atomic theory, it is possible to probe the relative nuclear charge radii of lithium isotopes.
This method is particularly useful for short lived exotic isotopes, which have halo nuclei of interest for nuclear theory. Reported observations of the Li D lines, however, have been highly inconsistent and produce relative nuclear charge radii that disagree with electron scattering results for the stable isotopes $^6\text{Li}$ and $^7\text{Li}$.

Our new observations have revealed that the apparent positions of the Li D2 lines shift far outside the uncertainty of the measurements when the polarization of the laser light used in the experiment is rotated. This effect is due to previously unrecognized quantum interference that produces non-Lorentzian line shapes when light is scattered from hyperfine substates whose separation is of the order of the natural line width. We have derived corrected line shapes taking account of the polarization dependence of this interference. Using these corrected line shapes, we determine the absolute transition frequencies of the D lines with an uncertainty of 25 kHz and provide an improved determination of the difference in mean-square nuclear charge radii between $^6\text{Li}$ and $^7\text{Li}$.

### Absolute Transition Frequencies and Quantum Interference in a Frequency Comb Based Measurement of the D Lines of Lithium-6 and Lithium-7

**Roger Brown**, Qibec seminar (Quantum Information, Bose-Einstein condensation), NIST Gaithersburg
June 29 2011

### Quantum Interference and the Magic Angle in the Observation of Lithium D-Lines

**Roger Brown**, DAMOP (American Physical Society, Division of Atomic Molecular and Optical Physics), Atlanta, BAPS.2011.DAMOP.J5.3

The spectroscopy of the hyperfine components in the D-lines in atomic lithium represents a realization of the double-(or triple-) slit experiment in the frequency domain. Since the spacing between hyperfine components is less than the natural line width it is impossible to determine which component scattered a given photon. We analyze data collected from a frequency comb based precision spectroscopic measurement of the 6,7Li D-lines as a function of laser polarization [1]. Data fitted using a superposition of Voigt functions shows apparent frequency shifts which depend on the angle between the laser polarization and the direction of fluorescence collection. When restricted fluorescence collection direction and quantum interference terms are accounted for in the fitted line shape, spectra observed at all polarizations yield consistent results. At the so called ``magic angle'' of 54.7 degrees these additional quantum interference terms go to zero in analogy with the disappearance of quantum beats in the time domain.~ This may explain discrepancies between previous measurements. \[\text{[4pt]}\] \[\text{[1]}\] C.E. Simien et al. Can. J. Phys. \textbf{89}, 1, (2011)

### A Pulsed Sisyphus Scheme for Laser Cooling of Atomic Hydrogen

**Roger Brown**, DAMOP (In place of S. J. Wu), Huston BAPS.2010.DAMOP.W5.9

We discuss a 3-level laser cooling scheme and its application to cooling atomic Hydrogen. In this scheme, ground state atoms are repetitively excited to a meta-stable state that is shifted and quenched by a standing wave laser, and are subsequently cooled by a Sisyphus effect. We demonstrate numerically that this cooling scheme can have a large capture velocity and can have sub-Doppler equilibrium temperatures. The scheme may be particularly useful for cooling of atomic species that require deep-UV lasers for electronic excitations. In particular, we discuss the possibility of cooling magnetically trapped hydrogen.
atoms from a Kelvin down to 10's of milli-Kelvin temperatures with manageable photo-ionization and spin-flip losses, using high-power 2S-3P laser light (at 656 nm) and pulsed 1S-2S 2-photon excitation (at 243 nm).

**Multi-Photon Magneto-Optical Trapping**

**Roger Brown, DAMOP, Huston BAPS.2010.DAMOP.W5.3**

We demonstrate a Magneto-Optical Trap (MOT) configuration which employs optical forces due to light scattering between two electronically excited states of Cesium. A multi-photon cooling mechanism allows for the replacement of standard MOT beams in up to 4 of the usual 6 directions with MOT beams connecting excited to further excited states. The multi-photon mechanism creates cooling and trapping on both red and blue sides of the two-photon resonance. The new configuration also exhibits many of the same experimentally appealing features found in a standard MOT including: efficient capture from a vapor cell, densities approaching 10^{11} atoms per cubic cm and sub-Doppler temperatures. Operating this multi-photon MOT in a far single photon detuned regime, we observe sub-Doppler temperatures on the blue side of two photon resonance indicating a fundamentally different two color polarization gradient cooling effect. Possible applications of this MOT are improved single-atom detection by efficiently collecting fluorescence along the path of the excited MOT beams, using optical filters to separate the fluorescence from the trapping light, and the ability to trap new species with inconvenient laser wavelengths by relaxing power requirements on the MOT beams. **PRL 103, 173003**