L = (n^2 + 2)/3, n is the refractive index of medium.

Another indication of the role of Q-band in resonance enhancement of TPA can be found from the TPA spectrum. We showed that the frequency of one-photon intermediate transition, which can be found from (1), as

\[ \omega_n = \omega_p + 2 \frac{\partial \omega}{\partial \Delta} \Delta \]

coincides well with the real maximum of the Q-band.

We have also calculated the \( \partial \omega / \partial \Delta \) value for ZnOEP directly from (1), by taking all other parameters from independent measurements, and obtained a 10% correspondence with our experimental value.

In our paper we will show how the present relationship facilitates a search for new porphyrins with greatly enhanced nonlinear properties.

References

**QTuB**
8:00 am – 9:45 am
Room: 202

High Resolution Spectroscopy and Fundamental Measurements
Kurt E. Gibble, Penn State Univ., USA, Presider

**QTuB1**
Invited 8:00 am
Quenched Narrow-Line Cooling in Neutral Calcium
E.A. Curtis, C.W. Oates, and L. Hollberg, National Institute for Standards and Technology, 325 Broadway, Boulder, CO 80305, USA, Email: curtis@boulder.nist.gov

The successful laser cooling of alkali elements to microkelvin temperatures has led to a host of important applications ranging from atomic interferometry to quantum degenerate gases. The alkali-earth elements show similar promise, including original applications that exploit their unique atomic structure. However, many of these applications are hindered by warm (Doppler-limited) trap temperatures of typically a few mK, which are a consequence of the alkali-earth ground-state structure. Thus, strategies for second-stage cooling of these atoms need to be developed. Here we demonstrate a cooling scheme for neutral Ca that has attained microkelvin temperatures and is applicable to other alkaline-earth elements. This large reduction in temperature should significantly improve absolute frequency measurements for our Ca-based optical frequency standard, for which the most recent result was limited (with an uncertainty of 26 Hz) primarily by the residual velocity of the laser-cooled atomic sample.1

A second-stage cooling scheme for another alkaline-earth atom, Sr, used an intercombination line and achieved temperatures at the recoil limit.2 The corresponding transition in Ca (S0 → P1, at 657 nm) is 20 times narrower, making it a good choice for our frequency standard, but unfortunately too weak to produce effective cooling for the high initial atom temperature. Nonetheless, we can take advantage of the high velocity selectivity of this narrow transition by implementing an approach first demonstrated with trapped ions, which uses quenching of the long-lived excited state via another transition in order to accelerate the cooling process.3 In our version we start with a magneto-optic trap based on the 63S → 62P transition at 423 nm. With this apparatus we can load 10^7 atoms in ~10 ms with a resultant atomic temperature of 2 mK. We then implement a second stage of cooling that uses the clock transition to drive chosen velocity classes of atoms towards zero velocity and quenches the 62P excited state with 552 nm light (see Fig. 1) to reduce the decay time. In our first demonstration we used multiple sets of counter-propagating, suitably detuned pulses of 657 nm light followed by quenching pulses (effective decay time of 50 μs), and were able to reduce the atom cloud temperature in one dimension to 0.4 μK. A recent increase in quenching laser power enabled more cooling cycles. We were also able to improve the net transfer efficiency from 15 to 25% by chirping the 657 nm pulses towards the center frequency of the transition during the cooling process. (See Fig. 2.) We note that a group at Physikalisch Technische Bundesanstalt has demonstrated quenched cooling and trapping for Ca in three dimensions (3D) using spectrally-broadened 657 nm light and quenching light at 453 nm, which differs from our use of pulsed light fields.

We are presently investigating various schemes for quenched cooling in 3D, which should give sub-recoil temperatures and higher transfer efficiencies. Such schemes should provide significant improvement in the performance of optical frequency standards as well as open the door to other applications, enabling efficient loading of dipole traps and higher phase-space densities.

References

**QTuB2**
8:30 am
Measurement of Dynamics In Strontium Magneto-Optical Trap
Xinye Xu, Matthew J. Smith, John L. Hall, Alan Gallagher, and Jun Ye, JILA, National Institute of Standards and Technology and University of Colorado Boulder, Colorado 80309-0440, xuxu@jila.colorado.edu

Recently, laser-cooled alkaline earth atoms have become prime candidates for constructing optical frequency standards and studying cold collisions. Since the even isotopes have no hyperfine structure, they provide an ideal system for testing Doppler-cooling theory (alkali atoms are subject to sub-Doppler cooling mechanisms.) We have measured the spring constant (k) and damping coefficient (α) in a Strontium MOT by observing the damped oscillation response of the trapped-atom location to a square-wave chopped pushing beam. The experiment consists of a Sr vapor cell MOT using the 451 nm 6S1/2 → 6P3/2 cycling transition to cool and trap. The MOT is a standard six-beam σ+ σ− configuration with a magnetic quadrupole field. We use an on-resonance beam to push the trapped atoms away from the trap center by 10–20% of the cloud diameter. In addition, a weak on-resonance probe beam, focused off the trap center, propagates perpendicular to the pushing beam. During the chopping cycle of the pushing beam, the step response of the trapped atoms is observed in the probe absorption signal, as shown in Fig. 1. The motion of the trapped atoms is clearly underdamped in Fig. 1b, differing from the strongly overdamped motion of a previous alkaline-metal atom MOT.1 We have also measured the dependencies of k and α on the
magnetic field gradient and the intensity and detuning of the trapping beam. Preliminary experimental values of k and α are smaller than those predicted by standard Doppler theory.\textsuperscript{5} It is worth noting that the temperature of the atom cloud is intensity dependent, also in contradiction with standard Doppler theory.\textsuperscript{7} Since during the cooling cycle trapped atoms slowly leak from the excited \( |p⟩ \) state through \( |d⟩ \) to \( |p⟩ \), and are then lost, the simple two-level Doppler theory is not complete for this system. At present, a modified semi-classical Doppler theory is being developed to account for the resulting variations in k and α.

Since the temperature can be determined by the measured spring constant and the trap size, this experiment also offers a new possibility of temperature measurement. We will further study the dynamics of the trapped atoms after second-stage Doppler cooling, using the 689 nm narrow, spin-forbidden \( ^{133}\text{Rb} \rightarrow ^{85}\text{Rb} \) intercombination line. Since the 689 nm photon recoil frequency shift is greater than the cooling transition linewidth, a full quantum mechanical cooling theory needs to be explored.

References