The Laser System for The Muonic Hydrogen Lamb Shift Measurement

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We report on the proposed laser system for the muonic hydrogen 2S-2P experiment at PSI [1]. This experiment is aiming at measuring the 2S-2P energy splitting dominated by vacuum polarization (the Lamb shift) to an accuracy of 30ppm, which corresponds to 10% of the natural linewidth. The proton charge radius can be deduced with a 10^{-3} relative accuracy, 20 times more precise than presently known.

The n=2 level diagram is shown in fig.1. The theoretical predicted energy splitting of the $2S_{1/2}(F=1) \rightarrow 2P_{3/2}(F=2)$ transition is 206meV (λ=6μm). The required laser system should provide a laser field with a linewidth of 0.1cm^{-1}, and illuminate a relatively large volume, i.e., $180 \times 15 \times 5$ mm^3, which is the muon stop volume in the hydrogen gas.

Since the beam source of PSI is quasi-cw, therefore the μp atoms are produced at random time with an average rate of $\sim$ 100/sec. The laser pulse must be triggered by the signal of an incident muon, and build up the laser field in the interaction region with a delay of less than a few hundreds ns, well below the lifetime of the muon (2 μsec). An excimer laser, which can be triggered by an external signal (the incident muon) with a delay of $\sim$ 300ns, is chosen to be the laser power generator at the first stage, followed by several stages of frequency conversion to reach the required 6 μm wavelength.

The laser system is shown in fig.2. The XeCl excimer laser is capable of providing a pulse of $>$ 600mJ with a pulse width of 28 ns and a repetition rate of 10 Hz (this will be increased to 50 Hz using a new discharge tube later). It is used to pump the dye laser, which is based on the Coumarin 307 dye, and delivers a 120mJ pulse at 500nm. It subsequently pumps the pulsed Ti:Sapphire laser. For a better frequency tuning and a narrow linewidth, a cw Ti:Sapphire laser, pumped by a frequency doubled Nd:Yag laser, is used as a seed of the pulsed Ti:Sapphire laser.

In the pulsed Ti:Sapphire laser, the oscillator-amplifier configuration is expected to generate a 12mJ pulse at 708nm. The transverse mode structure of the output will be constrained to TEM_{00}, which is important for the following multi-pass Raman shifter.

We are planning to utilize a multi-pass H_2 Raman shifter to convert the wavelength from the visible to 6μm. The third Stokes radiation, at 6μm, can be generated with a quantum efficiency as high as 36% [2]. The Raman shifter is 2m long and filled with 10 bar H_2 gas.

The final 6μm laser beam is directed into a multi-pass interaction cavity, which consists of two highly reflecting mirrors. One of the mirrors has adiabatic bent edges on both sides to achieve a lower round-trip loss. For a mirror reflectivity of 99.9%, there are more than 300 reflections in the horizontal direction providing an energy flux of $\sim$ 10mJ/cm^2 to excite the 2S-2P transition. The rate of the laser induced 2S-2P transition detected using the subsequent 2P-1S x-rays is $\sim$ 10/hr.

The recent results from the prototype of the dye and Ti:Sapphire lasers will be presented in the conference poster session.

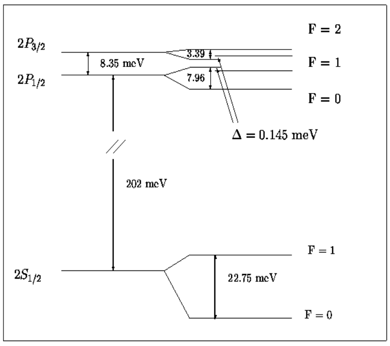

Figure 1: The energy structure of the n=2 level in μp. The shift Δ is due to the level mixing effect.

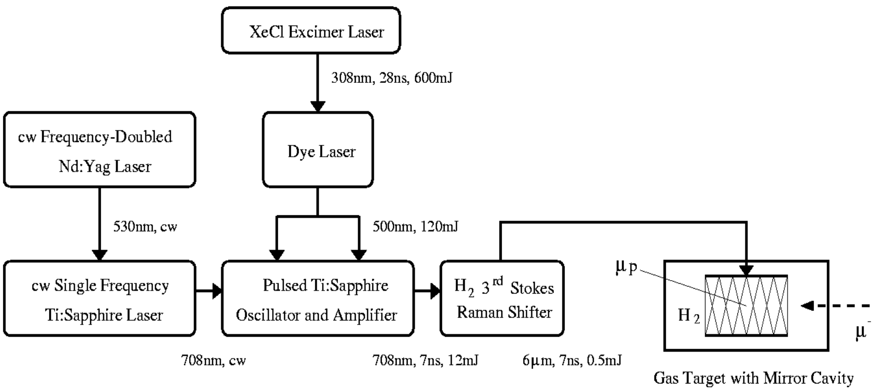

Figure 2: The 6 μm pulsed laser system for the μp 2S-2P transition.

[1] F. Kottmann *et al.*, *PSI Proposal* R-98-03.1 (1998).
[2] P. Rabinowitz *et al.*, *IEEE J. Quant. Electr.* **22** 797 (1986).