

Chapter 2

Experimental Apparatus

An overview on the experimental apparatus is shown in Fig. 2.1. A frequency-tripled Nd:YAG laser pumps a tunable dye laser whose beam is spatially filtered to produce a nearly Gaussian spatial profile with a flat phase front at the entrance of a Sr vapor cell. The exit plane of the cell is imaged onto CCD No. 1. Emission angles from the cell are imaged as a height variation on the input slit of a 1.5 m monochromator. The exit plane of the monochromator is imaged onto CCD No. 2. Most of the work presented in the next two chapters has been published. (B. Paul et al. [40])

2.1 The Dye Laser

The 355 nm light from a tripled Nd:YAG pulsed laser is used to pump a Littman[34, 35, 36] tunable dye laser, using Coumarin 460 laser dye, and producing a pulse length of 5.9 ns at 10 Hz with a bandwidth < 300 MHz. The dye laser normally operates with a single, longitudinal mode with the laser-cavity length fine-tuned with a piezoelectric transducer (PZT) behind the back mirror. As the laser is scanned through a range of frequencies, it occasionally goes double-mode. However, since the laser mode spacing of 8 GHz is much smaller than the detunings that are used in the experiment, this has a negligible effect on the results.

To obtain a beam with a nearly Gaussian spatial profile, we perform two stages of spatial filtering. The first stage consists of a $250 \mu\text{m}$ aperture, a_1 , fixed to the inside edge of the grating in the dye laser cavity (see Fig. 2.1). This aperture changes the far-field output of the dye laser from a long thin beam to a round beam. This round beam passes through an iris i_1 , which is attached to lens f_1 , to block scattered light due to irregularities in the diffraction grating in the laser. Lens f_1 focuses the beam through a second aperture a_2 ($100 \mu\text{m}$), which produces Airy rings in the far field. These rings are clipped at the radius of the first Airy minimum by an iris i_2 on a 50 cm lens, f_2 , spaced 75 cm beyond aperture a_2 . The 50 cm lens focuses the beam to a spot with a diameter of $25 \mu\text{m}$ and lenses f_3 and f_4 , of focal length 9 cm and 20 cm, respectively, focus this spot on the entrance of the cell. By changing the location of f_3 and f_4 , we can vary the diameter of the beam focus at the entrance of the cell from $25 \mu\text{m}$ to $100 \mu\text{m}$. A microscope objective and a CCD camera are used to check the properties of the final focus; throughout a region on both sides of the focus the intensity distribution and diameter follow ideal Gaussian optics, implying a flat phase front at the focus.

After the spatial filtering, the output of the laser can reach $7.5 \mu\text{J}$. An amplifier just after the second aperture can increase the beam energy to $70 \mu\text{J}$. However, along with the increase in energy comes an increase in amplified spontaneous emission (ASE). Since ASE can both partially obscure CE and affect new frequency generation, most of our work has been performed under experimental conditions for which the amplifier is not needed.

2.2 The Cell

The stainless-steel Sr-vapor cell consists of a 5 cm, cylindrical hot region that contains the Sr, separated from cold Brewster windows by 8 cm of argon buffer gas. The hot region is bounded by a hot entrance aperture (diameter 2.1 mm and depth 4.5 mm) and a hot exit aperture (diameter 3.5 mm and

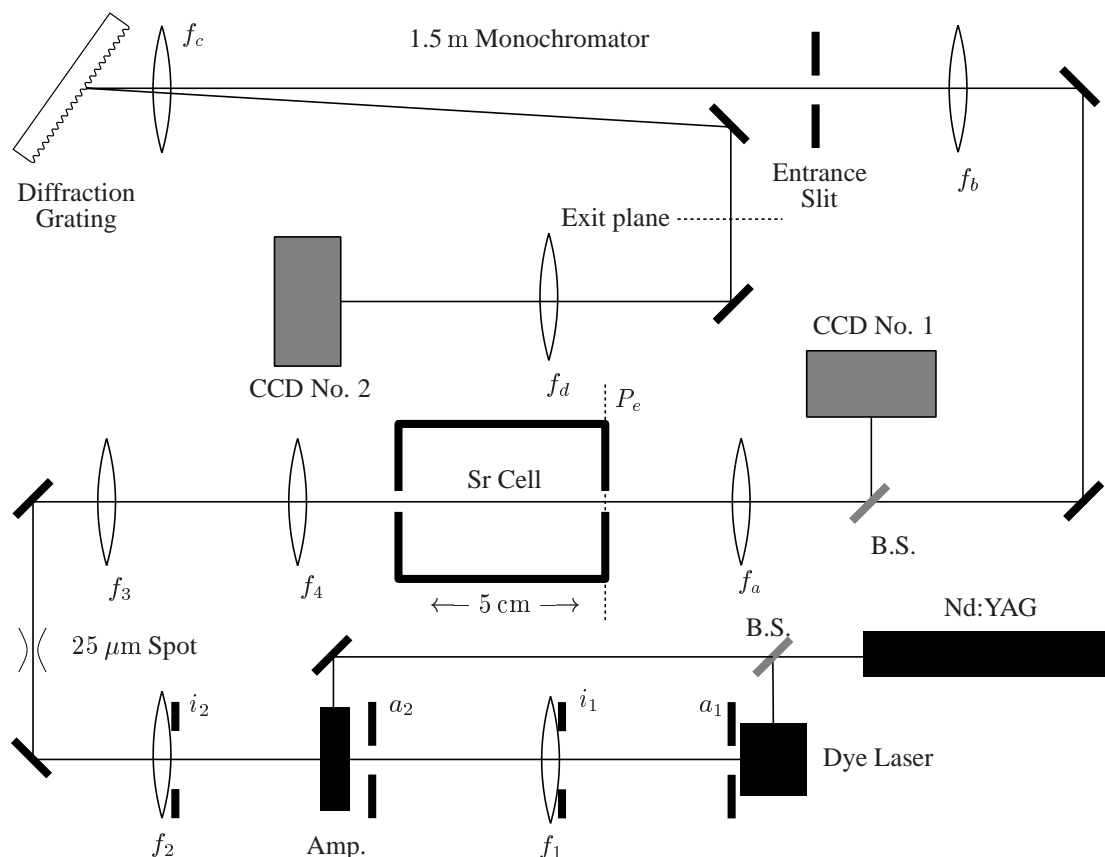


Figure 2.1: **The experimental arrangement:** A pulsed Nd:YAG laser pumps a single mode Littman dye laser and an amplifier. A $250\ \mu\text{m}$ aperture a_1 attached to the dye cell side of the diffraction grating in the dye laser produces a round spot on lens f_1 . Iris i_1 on lens f_1 blocks the scattered light from the dye laser. Some spatial filtering is done by placing aperture a_2 at the focus spot after lens f_1 . Iris i_2 clips the Airy rings at lens f_2 . Lens f_2 produces a $25\ \mu\text{m}$ FWHM focus spot that is imaged onto the entrance plane on the Sr cell by lenses f_3 and f_4 . After the Sr Cell, lens f_a images the exit plane, P_e onto CCD No. 1. Lens f_a also maps angles exiting the cell into height in a plane one focal length past the lens. This plane is imaged onto the slit of a $1.5\ \text{m}$ Monochromator by lens f_b . The entrance slit is imaged into the exit plane of the monochromator by lens f_c . The exit plane of the monochromator contains angle and frequency information that is imaged onto CCD No. 2 by lens f_d .

depth 7.5 mm). The length and diameter of each aperture have been chosen to minimize the loss of Sr without introducing a significant region of varying Sr number density that might distort the laser beam.

Because the Sr $5s^2\ ^1S_0 - 5s5p\ ^1P_1$ transition is a $J=0$ to $J=1$ transition, it may be used as an approximation to an ideal “two-level” system. However, a possible ground-state population-loss mechanism is the decay of the $5s5p\ ^1P_1$ state into the metastable $4s4d\ ^1D$ state by spontaneous emission. Since the fraction of atoms lost through this channel during the laser pulse is negligible (2×10^{-4}), and the transition is not stimulated at the $\sim 10^{14}\text{ cm}^{-3}$ Sr densities of this experiment, the accumulation of atoms in the metastable state over multiple laser pulses is negligible.

2.3 Imaging Optics

To investigate the spatial profile of the exiting beam, lens f_a in Fig. 2.1 images the exit plane, P_e , onto a CCD camera (CCD No. 1). The resolution at the cell exit plane is 15-20 μm . (A high-resolution, in-depth study of the filaments has previously been reported [15].) Lens f_a also maps angles exiting the cell (θ) into height in a plane one focal length (20 cm) past the lens. Lens f_b images this plane onto the entrance slit ($w = 120\ \mu\text{m}$) of a $f_c = 1.5\text{ m}$ monochromator to yield a measured resolution of 35 GHz. Thus, the exit plane of the monochromator yields angle (θ) parallel to the slit and frequency (ν) perpendicular to the slit. The exit plane of the monochromator is re-imaged onto a CCD camera (CCD No. 2). The raw camera images will be referred to as $E(\nu, \theta)[w/(2\pi f\theta)]$; the images corrected for the fact that the monochromator only images a thin slice of the azimuthally symmetric cone will be referred to as $E(\nu, \theta)$. To avoid severe saturation of the camera as the laser frequency is scanned, a stepper motor moves a thin brass strip in the exit plane of the monochromator that blocks the laser frequency. This blocks about a 200 GHz frequency range. At large laser energies, we also put a circular laser-beam block at the first lens after the cell, blocking $\theta \leq 5\text{ mRad}$. To separate the entrance and exit beam, the monochromator utilizes a single lens in front of the grating and small off-axis angles, thereby producing only small aberrations.