Saturated absorption spectroscopy is an effective and reliable technique that is used frequently in atomic and optical physics in order to precisely measure the hyperfine energy structure of atoms, such as the alkali metals that are used in laser-cooling experiments. We present an experimental design to measure the $A_{22}$ transition of potassium-39 ($\lambda=766.7$ nm) in a vapor cell with a diameter of 2.502 mm and a length of 150 mm. The MOT was used to achieve a temperature of $\langle v^2 \rangle = 0.11 \pm 0.008$ mm$^2$ s$^{-2}$ (6 MHz (~10 ppb) accuracy). Counter-propagating laser beams are used to excite an atomic vapor cell of $9$K to obtain sub-Doppler resolution peaks of the excited atoms. The design consists of several optical elements including the introduction of an anamorphic prism pair to optimize the beam shape and a set of telecentric lenses for magnification and collimation of the beams.

**MOTIVATION**

In order to efficiently trap and cool neutral potassium-39 atoms to the micro-Kelvin temperatures required as a precursor to creating Bose-Einstein condensates, a low intensity cooling design was required. The initial temperature of the atoms is approximately 50°C (323 K). A magneto-optical trap (MOT) is necessary for the initial cooling step. In order for the MOT to be effective, the optical frequency of our commercial diode laser (Moglias 767AR150) must be accurate and stable at 766.700921 nm ± 0.000004 nm. The use of an interferometric wavemeter provides a coarse wavelength measurement that is matched within the Doppler-broadened atomic linewidth resolution of 0.8 MHz. Saturated absorption spectroscopy of the 9K D$_2$-line further improves the resolution of the frequency measurement to allow stabilization of the laser to within the natural linewidth of the atomic resonance ($\gamma = 0.6$ MHz). With this resolution, the laser diode will be sufficiently stable to laser cool atoms in the MOT.

**MAGNETO-OPTICAL TRAP**

The magneto-optical trap utilizes a combination of laser beams and spatially-varying magnetic fields. Six laser beams (two counter-propagating and three along each axis) pass through a sample of atoms. The atoms absorb light from resonant photons from the laser beams and then emit a photon in a random direction.Each absorption and emission changes the orientation and momentum of the atom by $h/\lambda$. We can pick the polarization of each laser so that the light is resonant with the lasers opposing their motion. This allows the atoms to be cooled to the Doppler cooling limit which is proportional to the magnetic field. For K-39 atoms, we expect the MOT to reach a limit of approximately 300 $\mu$K$^2$. A quadrupole magnetic field is formed by the addition of a pair of coils arranged in an antiparallel configuration. The magnetic field shifts the resonance frequency of the atoms by the Zeeman effect. This pushes the atoms towards the center of the field, effectively trapping them in a 3-D space.

**COOLING BEAMS**

We characterized the shape of the laser beam using the knife-edge method. The total power of the beam was measured by a power meter as a razor blade, attached to a calibrated translation stage, was moved through the beam path. The power with respect to the position is given by the formula:

$$P(x) = P_0 \left( 1 - \frac{x}{w} \right)^2,$$

where $P_0$ is the initial power, $w$ is the position of the beam center, and $w$ is the 1/10 beam radius. We performed a chi-square fitting on the collected data in Excel. Our data shows that the elliptical beam shape has a horizontal diameter of 1.108 mm ± 0.008 mm and a vertical beam diameter of 2.502 mm ± 0.014 mm. (See graphs right).

**ABSTRACT**

Saturated absorption spectroscopy is an effective and reliable technique that is used frequently in atomic and optical physics in order to precisely measure the hyperfine energy structure of atoms, such as the alkali metals that are used in laser-cooling experiments. We present an experimental design to measure the $A_{22}$ transition of potassium-39 ($\lambda=766.7$ nm) in a vapor cell with a diameter of 2.502 mm and a length of 150 mm. The MOT was used to achieve a temperature of $\langle v^2 \rangle = 0.11 \pm 0.008$ mm$^2$ s$^{-2}$ (6 MHz (~10 ppb) accuracy). Counter-propagating laser beams are used to excite an atomic vapor cell of $9$K to obtain sub-Doppler resolution peaks of the excited atoms. The design consists of several optical elements including the introduction of an anamorphic prism pair to optimize the beam shape and a set of telecentric lenses for magnification and collimation of the beams.

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**Optical Design**

The optical design of the saturated absorption spectroscopy utilizes a series of mirrors, beam splitters, and lenses. A beam sampler transmits most of the power of the initial laser beam along the beam’s initial path for use in the laser cooling apparatus. A small fraction (~4%) of the total power is used for the spectroscopy measurements. A 4x telecentric lens (lens=50 mm, focal length=50 mm) increases the resolution of the transmitted intensity of the probe beam can be seen.

**CONCLUSIONS AND FUTURE WORK**

We are currently waiting for the parts of the interferometric wavemeter to be machined. Once we have those components, the wavemeter will be assembled and we will be able to measure the wavelength of the commercial diode laser within the Doppler-broadened atomic linewidth. With this parameter, we will be able to efficiently use the saturated absorption spectroscopy set-up to find the laser to a frequency within the Doppler width of the D$_2$-line of the K-39 atoms. When these parts are completed, the next step in our lab will be to design and build the components for the magneto-optical trap, including the vacuum system in which the atoms will eventually be cooled. A long-term goal is to model the interfaces of different materials with ultracold atoms in two-dimensions and eventually, in three-dimensional lasers.

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**REFERENCES**