# Optical Pumping

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**Abstract**

We will show that doppler broadening due to thermal fluctuations can be alleviated in order to show spectral features that would otherwise be hidden. In this case, we will show measurement of the hyperfine states of Rubidium (whose linewidth requires higher resolution than the doppler broadening allows) in order to demonstrate this technique.

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# 1 Introduction

We show that it is possible to spectally resolve features of the Hyperfine structure of Rubidium that would otherwise be impossible outside some sort of atomic trap using a technique called doppler-free spectroscopy. We also show that it is possible to make use of the interference pattern of a Michelson Interferometer to make calibrations and create a conversion from time into frequency for the purposes of measurement on a time-resolved oscilloscope. This means that we can use an oscilloscope with (potentially) much better-resolved time dynamics to mimic the purpose of a spectrum analyzer.

In particular, we discuss the methods used for finding the information required, including the methods used to find the Hyperfine transitions, measure the linewidth of the resonances, and the linewidth of the doppler-broadened peak.

# 2 Theory

Rubidium is often used as an atom for optical experiments because it has a hydrogen-like spectrum in its ground state, which allows for the splitting and simplification of the system hamiltonian. If we ignore the relativistic effects and assume that the nucleus is much heavier than the outer electrons, we can write the Hamiltonian of the system as the sum of different parts. We have

$$H_{kin} = \frac{p^2}{2m}$$
$$H_{em} = \frac{-Z_{eff}e^2}{4\pi\epsilon_0 r}$$
$$H_{so} = \frac{1}{m_e ec^2}\frac{1}{r}\frac{\partial V}{\partial r}\vec{L}$$
$$H_{hyp,1} = \alpha\vec{J}\cdot\vec{I}$$
$$H_{hyp,2} = \frac{\beta}{2I(2I-1)j(2j-1)}\left(3(\vec{I}\cdot\vec{J})^2 + \frac{3}{2}(\vec{I}\cdot\vec{J}) - I(I+1)j(j+1)\right)$$

The first three are fairly basic - they stem from the electron's motion and interactions between the electron's magnetic moment and the magnetic moment of its motion around the nucleus. They are the standard additions to the Hydrogen atom hamiltonian with the exception of the relativistic correction term.

The second two are more complex. $H_{hyp,1}$ is the hyperfine interaction that occurs between the electon's total angular momentum $\vec{J} = \vec{L} + \vec{S}$ and the atom's intrinsic nuclear spin $\vec{I}$. The constant $\alpha$ is called the magnetic hyperfine structure constant. This interaction is also present in other atoms, but we see it very prominently in atoms like Rb due to the fact that the outer valence electrons typically have very high $\ell$ (hereafter the quantum number associated with $\vec{L}$) states, which directly increases j (quantum number associated with $\vec{J}$), it is a magnetic dipole interaction. Along that same vein, we have $H_{hyp,2}$. It is the interaction between the electric quadrupole moment of the nucleus and the electron. The dipole moment of the interaction is given in $H_{em}$.