The Transverse Optical Pumping of Rubidium using Linearly-polarized Light

UCARE

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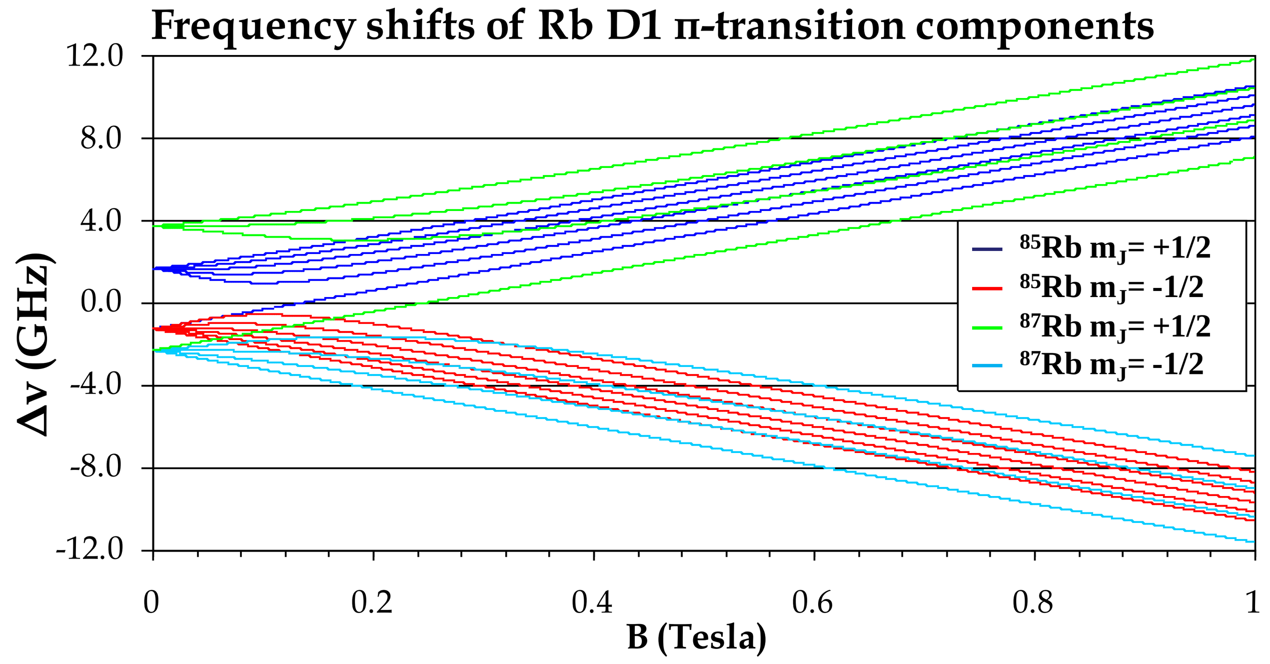
Introduction

Optically-pumped alkali vapors are studied for a wide range of reasons. As an example, many accelerators throughout the world have used optically-pumped spin exchange sources to produce beams of polarized ions. To date, similar work exploring optically-pumped alkalis as a spin exchange source for electron beams has not been as prevalent. Our group has done preliminary development work in this area and was able to construct a device that served as a proof of principle [4]. Recently, we have made efforts to improve our understanding of the optical pumping process in order to make refinements on the original design. In this regard, we investigate the potential for using a transverse optical pumping scheme with linearly-polarized light as described by Martin *et al.* [5] to increase our pumping efficiency and allow greater alkali polarizations.

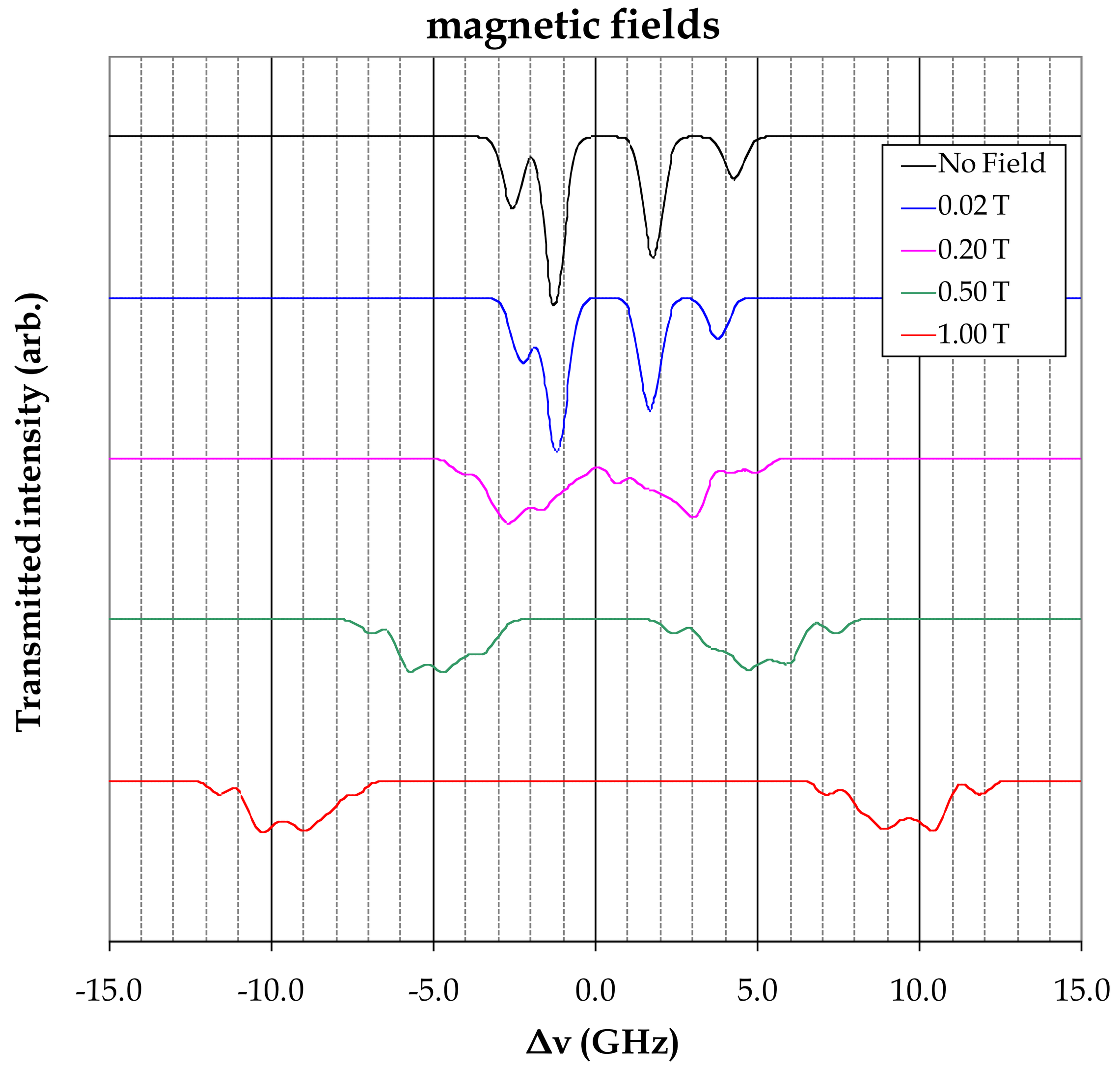
Frequency shifts of Rb D1 π-transition components

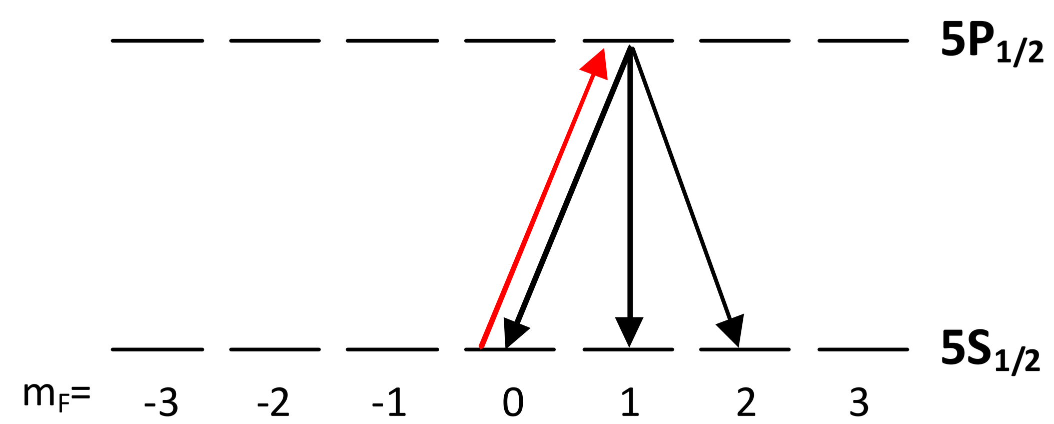


High Field Conditions

Under a large enough magnetic field, the Zeeman splitting that occurs in the electronic transitions can be great enough to separate states that, under weaker fields, are degenerate. The plot above shows the Zeeman splitting, as a function of magnetic field, for each component of the Rb D1 transition. The internal structure of each ground state hyperfine transition becomes apparent, and then reorganizes according to angular momentum. The result of this can be seen in the simulated absorption spectra below. At higher fields, the $m_I = \pm 1/2$, $\Delta m_I = 0$ transitions are distinct.

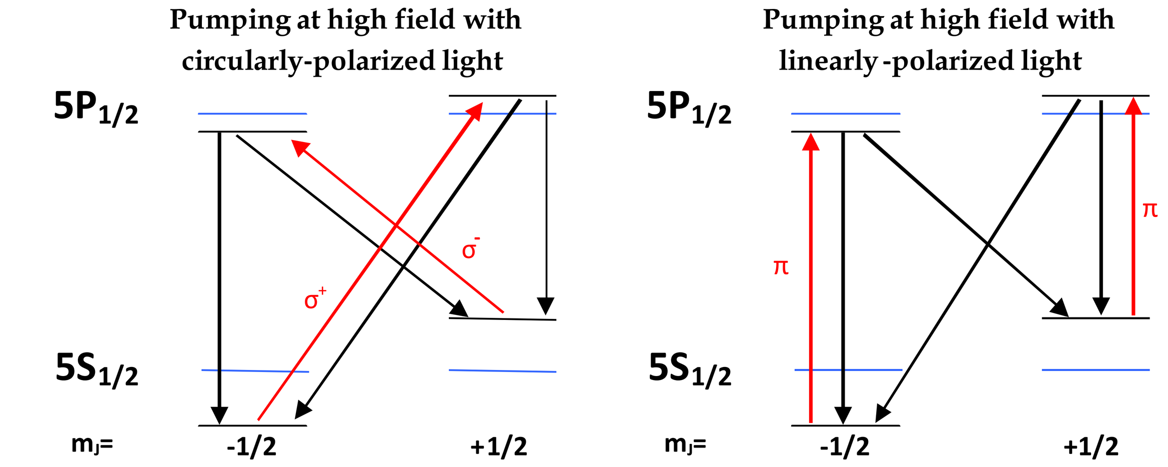
Rubidium absorption spectra at varying magnetic fields





Typical Optical Pumping for an F=3 state using D1 light (with ^{85}Rb, I=5/2). The red arrow represents the absorption of a circularly-polarized photon and the black arrows represent the available decay channels. In this situation, atoms that are pumped to the m_F=3 state become dark and are said to be completely polarized.

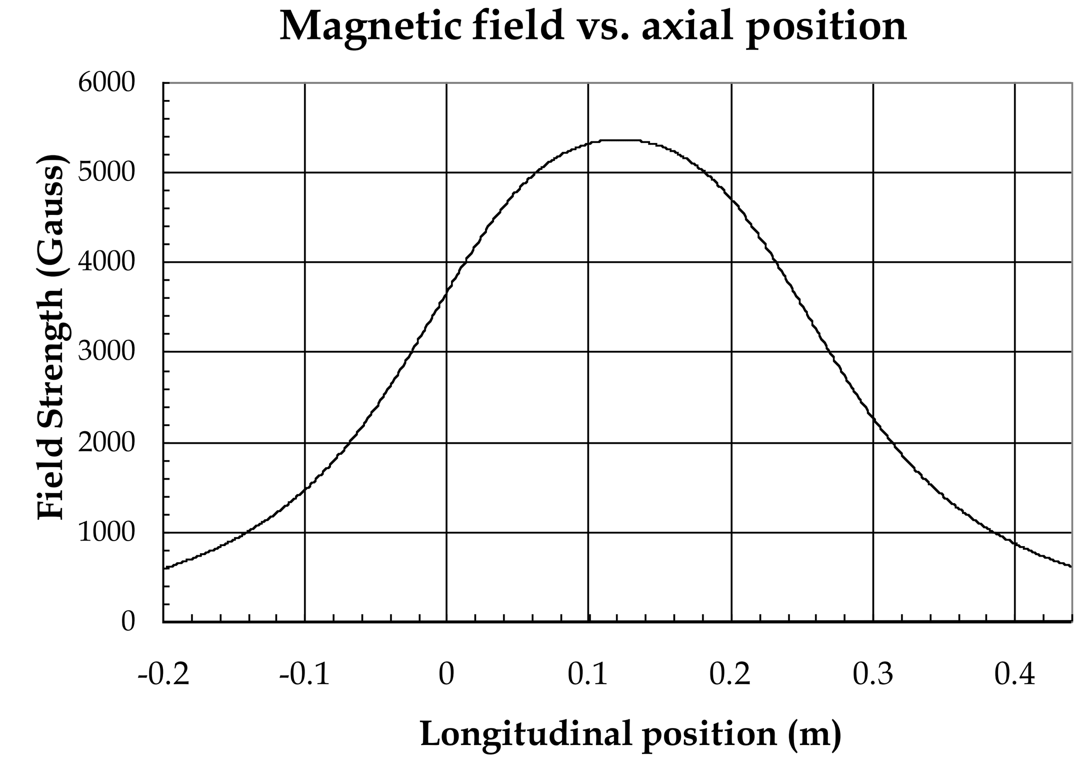
High B-field Optical Pumping. At high magnetic fields F ceases to become a good quantum number and the pumping process simplifies. Now m_J states are pumped, and they can be accessed by either linearly or circularly-polarized light since the π transitions are no longer degenerate.

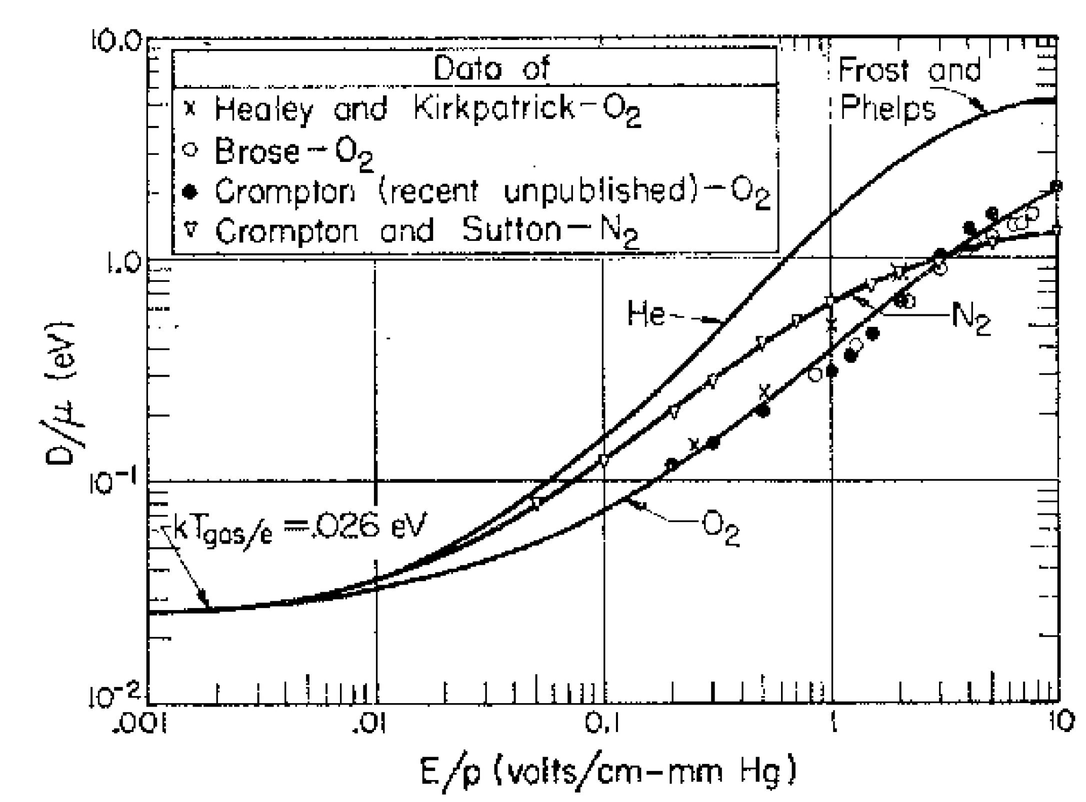


Optical Pumping

Optical pumping is a process in which light, in our case provided by a Titanium:Sapphire laser, is used to control the quantum states of an atomic or molecular target. The process is commonly used to induce a population imbalance in the ground state of alkali atoms. By carefully selecting the parameters of the pumping light, one can excite particular electronic transitions, forcing atoms into a single ground state, rather than several degenerate states. Traditionally, the optical pumping of alkali vapors is done with circularly-polarized light so that with each absorption of a photon, one unit of angular momentum is deposited. In a strong magnetic field though, several factors can combine to make it more efficient to pump with linearly-polarized light (something that is not possible in a weak field.)

Magnetic field vs. axial position

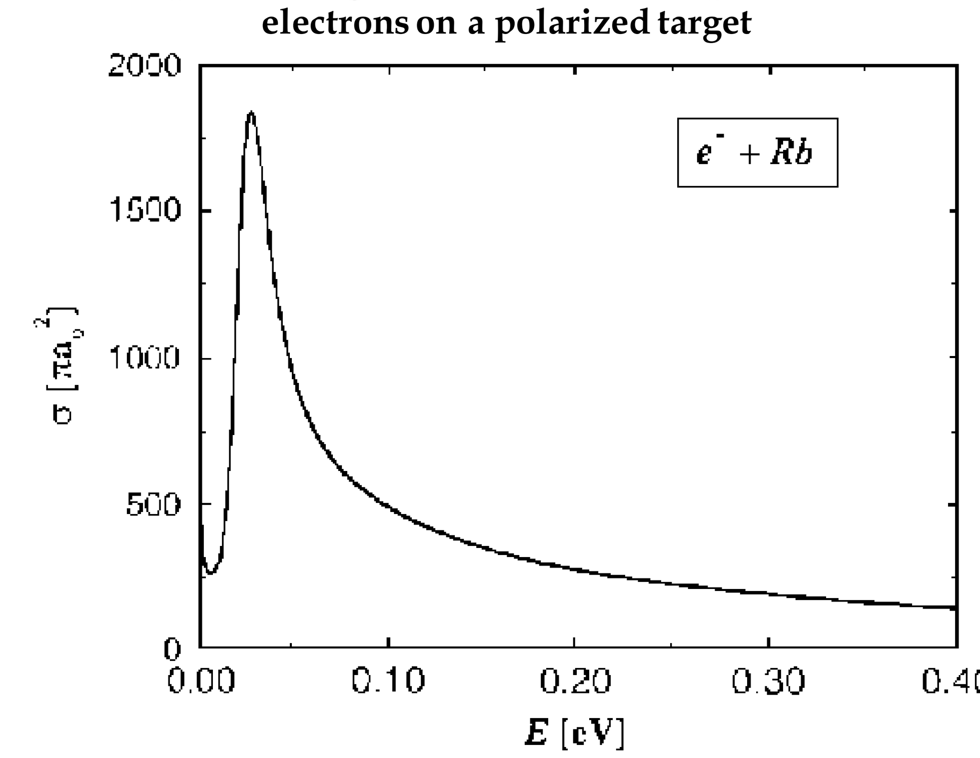




Challenges

There are several factors to consider to design an efficient spin exchange source. As shown by the plot at left, a magnetic field of at least 5000 Gauss must be maintained to be able to resolve and thus pump certain m_J transitions. Above is a plot of magnetic field versus position from the outside end of a large coil (see apparatus diagram at top right), considering realistic current and wire gauge. Another consideration one has to make concerns spin exchange process by which the free electrons acquire angular momentum. The two plots at right show the important factors affecting this process. The first is the characteristic energy of a free electron driven though various gases by a static electric field [11]. The second is a plot of the spin exchange cross section for unpolarized electrons colliding with a polarized rubidium target [12].

Spin exchange cross section for unpolarized electrons on a polarized target



Acknowledgements

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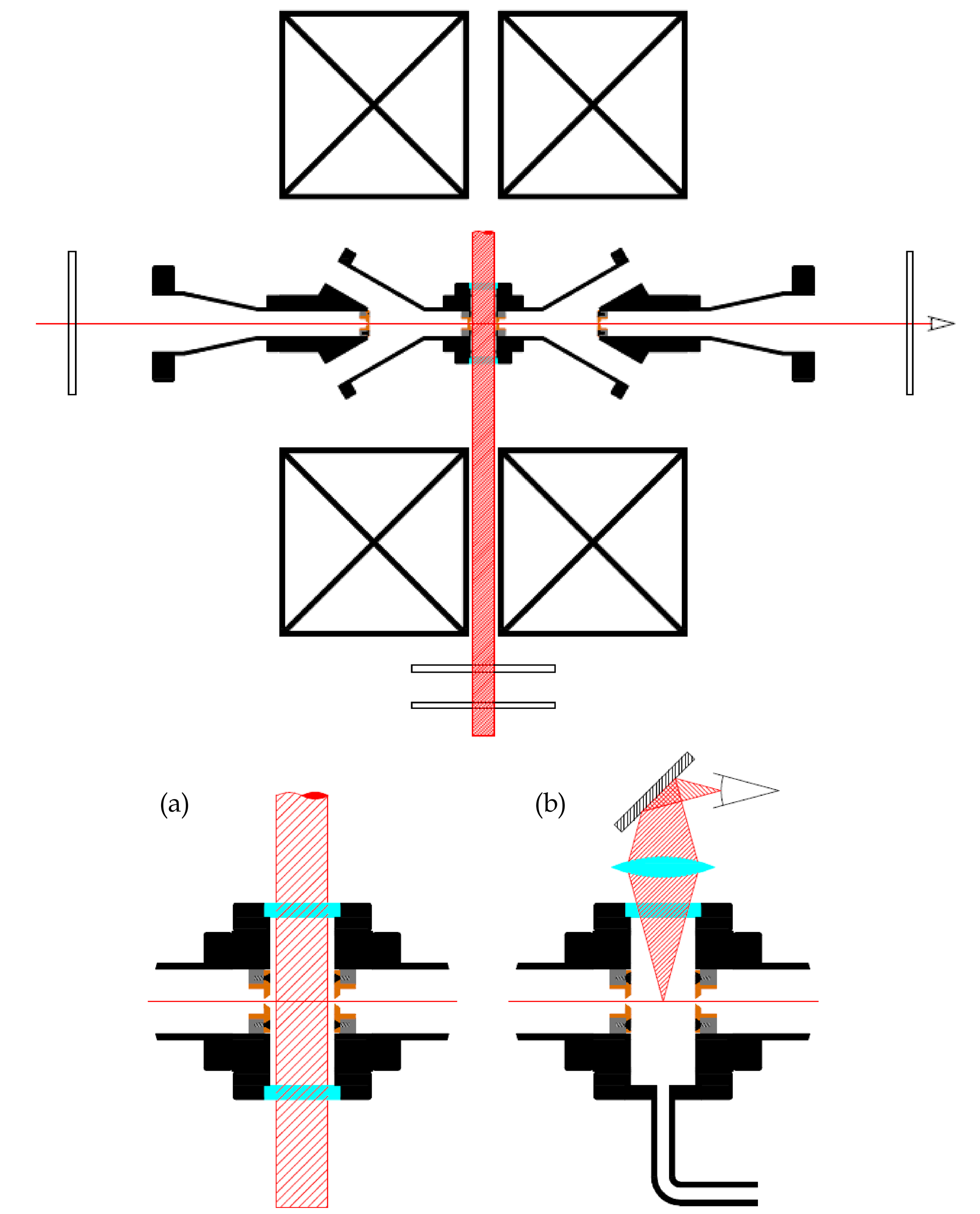
A Possible Apparatus. The top figure is a schematic of a possible vacuum system showing the red pump beam incident perpendicular to the axis of the electron path (thin red line). Differential pumping apertures are shown along with vacuum ports to minimize gas pressure outside the pumping cell. Below this are detailed top (a) and side (b) views of the pumping cell. The side view shows a port for the introduction of Rb vapor and optics for measuring resonance fluorescence (a method of monitoring Rb polarization.)



Conclusions

This poster summarizes the basic principles behind transverse optical pumping of alkali vapors using linearly-polarized light. Special attention is giving to the experimental requirements for pumping rubidium. The advantages of using this type of scheme makes it an enticing option for optical pumping sources where high pressure buffer gases are not maintainable. Considering the simplicity of the apparatus and the potential benefits of using this scheme for spin-filter-type electron sources, it is certainly worthwhile to explore the pumping characteristics experimentally. Depending on the results of these preliminary studies, it may be worthwhile to try transverse pumping in our group's polarized electron source.

References

[1] T. Chupp, S. Swanson: Adv. At. Mol. Opt. Phys. **45**, 51 (2001).
[2] J. Prestage, R. Tjoelker, L. Maleki, Phys. Rev. Lett. **74**, 3511 (1995).
[3] P. W. Schmor, 1995, *Proc. of the 1995 Particle Accelerator Conference*. **Vol**. **2**. 853.
[4] H. Batelaan, A.S. Green, B.A. Hitt, and T.J. Gay, Phys. Rev. Lett. **82**, 4216 (1999).
[5] C. Martin, T. Walker, L. W. Anderson, D. R. Swenson, Nucl. Inst. and Meth. **335** 233 (1993).
[6] W. Happer, Rev. Mod. Phys. **44**, 169 (1972).
[7] A. Corney, *Atomic and Laser Spectroscopy*, (Clarendon Press, Oxford, 1977).
[8] D. Steck, *Rubidium 87 D Line Data*, Los Alamos National Laboratory, (2001, revised 2003).
[9] M. Rosenberry, J. Reyes, D. Tupa, T. Gay, Phys Rev A, **75**, 023401 (2007).
[10] J. P. Reyes, *Systematic Studies of Rubidium Optical Pumping at Low Buffer Gas Pressures*, Master's Thesis, University of Nebraska (2005).
[11] L. M. Chanin, A. V. Phelps, and M. A. Biondi, Phys. Rev.**128**, 219 (1962).
[12] C. Bahrim, U. Thumm, I. Fabrikant, Phys. Rev. A, **63**, 042710 (2001).
[13] I. I. Fabrikant, Phys. Lett. **58A**, 21 (1976).