TUNABLE LASERS AT 1080 nm FOR HELIUM OPTICAL PUMPING : NEW USES FOR AN OLD TECHNIQUE

L. Schearer

► To cite this version:

L. Schearer. TUNABLE LASERS AT 1080 nm FOR HELIUM OPTICAL PUMPING : NEW USES FOR AN OLD TECHNIQUE. Journal de Physique IV Proceedings, 1991, 01 (C7), pp.C7-429-C7-433. 10.1051/jp4:19917115 . jpa-00250764

HAL Id: jpa-00250764

<https://hal.science/jpa-00250764>

Submitted on 1 Jan 1991

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

TUNABLE LASERS AT 1080 nm FOR HELIUM OPTICAL PUMPING: NEW USES FOR AN OLD TECHNIQUE

L.D. SCHEARER

Physics Department, University of Missouri-Rolla, Rolla, MO 65401, USA

Abstract - A number of tunable, IR lasers have been developed recently which can be used to optically pump the metastable atoms of helium. This laser optical pumping, producing spin-polarized helium atoms, has led to an extraordinary number of important applications including magnetometry, nuclear targets, and polarized electron beams. We describe the current status of these lasers and some of the applications.

1. - Introduction.

The recent development of new tunable lasers in the infrared region of the spectrum which lase on the helium resonance lines near 1083 nm, has greatly expanded the range of applications of which requires spin-polarized ensembles of ^3He and ^4He . The extraordinary range of applications which are currently being investigated is summarized in Table I.

Magnetometers	[1]	Magnetic field measurements to $1:10^9$ Geologic exploration precision mapping of the earth's magnetic field. Space probe to measure planetary fields from 10^{-5} to 10 gauss.
^3He Maser Gryoscope	[2]	Underwater navigation.
Quantum properties of Fermi fluids	[3]	Spin waves, conductivity of polarized ^3He , equation of state.
Polarized ^3He targets	[4]	Nuclear scattering : measurement of neutron form factors, neutron spin filter.
Polarized electron beams	[5]	High energy accelerators, nuclear scattering.
Spectroscopy of $\text{He}(2^3\text{S}_1)$	[6]	Precision Lamb shift measurements. Laser cooling/trapping.

Table I

As might be expected, the wide range of applications requires that the optical pumping lasers have varied characteristics. It was thus necessary to develop several lasers using different pump mechanisms, different host materials, and different cavity configurations.

Table II summarizes a number of Nd-doped materials which have been successfully developed for the helium optical pumping process. The Nd : LMA (La Al₁₁ O₁₉) material offers the widest variety of useful properties and is presently the laser of choice.

Host Material	Pump Source	Bandwidth (mode structure)	Power	Ref.
YAlO ₃	Arc-lamp	3GHz (multimode)	1 W	7
YAlO ₃	Diode array	1GHz (multimode)	10 mW	8
Li NbO ₃	Kr ⁺ laser	450 mHz (3 modes)	120 mW	9
La Al ₁₁ O ₁₉	Diode array	< 10 MHz (single mode)	20 mW	10
La Al ₁₁ O ₁₉	Ar ⁺ , Kr ⁺ laser	450 Mhz (3 modes)	500 mW	11
La Al ₁₁ O ₁₉	Arc-lamp	2 GHz (multimode)	3 W	12
S _i O ₂ (fiber)	Single-element diode	(multimode) < 2GHz (single-mode)	100 μW 20 μW	13

Table II

2. - Optical Pumping in He

The absorption of appropriately polarized resonance radiation by He metastable atoms contained in a discharge cell results in an orientation of the metastable spin system, an electronic or nuclear orientation depending the choice of ⁴He or ³He atoms. Prior to the development of the lasers of Table II, polarizations produced by conventional discharge sources rarely exceeded 10-20 %. This limited the number of proposed applications, especially in nuclear physics.

It was clear that a laser which could be tuned to a single absorption component would produce much greater polarizations. Indeed, this was demonstrated by M.Leduc and co-workers in 1982 with their development of a tunable color center laser. Its application to ³He optical pumping yielded nuclear polarizations of over 60 %. These results provided much impetus for the development of other tunable lasers, and by 1987 most of the lasers in Table II had been investigated.

3. - The LNA Laser

As the present time, the Nd-doped La Al₁₁ O₁₉ laser offers the greatest variety of characteristics of interest for Helium optical pumping and the many applications of Table I.

In its most useful configuration an LNA crystal ($L = 1$ cm) is end-pumped by a 5 watt argon ion laser at 514.5 nm. A Lyot filter for course tuning and a thin, coated etalon for fine tuning and narrow-banding are placed inside the cavity. About 10 % of the pump power appears as tunable emission at the helium transitions. Depending upon the cavity length, the output consists of 1 or more longitudinal modes. A single mode has a bandwidth of less than 10 MHz. For optical pumping application it is generally desirable that a large fraction of the Doppler profile of the helium absorption line be illuminated. A cavity length on the order of 1 m yields 3-4 modes separated by 150 MHz, thus spanning the 2 GHz Doppler width.

A more recent development has been the arc-lamp pumped LNA laser. A conventional Nd : YAG laser cavity, available commercially, is modified slightly by the addition of tuning elements and replacement of the YAG rod with a similar crystal of LNA. The uncoated etalon(s) yields more than 5 watts of multimode emission in a bandwidth nearly matching the Doppler profile. With this laser, nuclear polarizations of 90 % or more are achievable with similar results reported for the electronic polarization of ^4He metastable atoms.

4. - Applications in Nuclear Physics

The wide range of applications shown in Table I cannot be adequately addressed here ; thus, we limit our discussion to some recent developments of interest in Nuclear Physics. Two major innovations have been the development of dense, polarized ^3He targets and highly polarized e-beams.

The interest in a polarized ^3He target arises because the polarization resides almost entirely in the orientation of the neutron. Thus, spin-dependent scattering in the quasi-elastic region will be dominated by the neutron. Among the proposed experiments are those to determine the form factors of the neutron.

Optical pumping of ^3He is generally optimal at cell pressures of 1 Torr. However, the nuclear relaxation time is extraordinarily long, several days under ideal conditions ; thus, several techniques for target compression have been explored successfully. Cryogenic compression perfected by M. Leduc and her colleagues at the ENS in Paris, is used by the Caltech-MIT group to obtain a target with an effective thickness of 10^{19} nuclei/cm² and a polarization of 20-30 %.

The Mainz group employs a mechanical compression of the ^3He gas with a Toepler pump, obtaining a target thickness of about 5×10^{20} nuclei/cm² at a polarization of over 60 %. Improvements to this target by using a piston pump in a second stage of compression is expected to increase the density an order of magnitude while maintaining the polarization.

Both groups are currently using the tunable, arc-lamp pumped LNA laser described above to optically pump the He atoms.

The new frontier in spin-dependent, high energy collisions has also stimulated interest in polarized electron beam sources. A group at Rice University has demonstrated a novel source which involves the removal of one of the oriented electrons from the polarized ^4He metastable atom by a Penning collision with an impurity species. This chemi-organization process efficiently removes the electron from the helium metastable atoms which are contained in a flowing afterglow. The polarized electrons are extracted from the afterglow. Typical beam currents are $1\text{ }\mu\text{A}$ at polarizations of 80 %.

Modifications to the Rice source are being carried out by the group at the IPN-Orsay. The changes they incorporate are an increased flow velocity-designed to increase the extracted current, a new laser system using an arc-lamp pumped LNA laser and an improved optical pumping scheme - designed to increase the beam polarization to 90 % or more. In a very brief but concentrated effort they now obtain polarizations up to 78 % and beam currents of more than $4\text{ }\mu\text{A}$. Substantial improvements in the near future are expected with this configuration.

5. - Conclusions

The tunable, Nd-doped lasers summarized in table II have been developed in response to the extraordinary range of applications proposed for spin-polarized ensembles of ^4He and ^3He . As the interaction between the laser systems and the optical pumping process are explored further, we have every expectation that new applications will emerge.

It is not possible to include every contribution to the work summarized here and every contributor, but there is one constant that must be acknowledged : the group at the Laboratoire de Spectroscopie Hertzienne in Paris and especially the work of Dr. Michèle Leduc.

References

- /1/ J.J. Aubert, C. Wyon, A. Cassimi, V. Hardy, and J. Hamel, *Opt. Commun.* **69** (1989) 299.
R.E. Slocum, L.D. Scheerer, P. Tin, and R. Marquedant, *J. Appl. Phys.* **64** (1988) 6615.
- /2/ M. Richards, K. Machin, and P. Francks, in "Spin Polarized Quantum Systems", ed S. Stringari (world Scientific, Singapore, 1989), pp. 52-55.
- /3/ C. Lhullier and F. Laloe, *J. Phys. (Paris)* **40** (1979) 239.
- /4/ R.G. Milner, R.D. McKeown, and C.E. Woodward, *Nucl. Instrum. Methods* **A274** (1989) 56.
E.W. Otten, in "Spin-Polarized Quantum Systems", ed. S. Stringari (World Scientific, Singapore, 1989) pp 331-346.

/5/ G. Rutherford, M. Ratliff, G. Lynn, F.C. Tang, F.B. Dunning, and G.K. Walters, Rev. Sci. Instrum. 61 (1990) 1460.

S. Essabaa, J. Arianer, I. Brissaud, H. Humblot, L. Schearer, and M. Leduc, paper this conference.

/6/ A. Aspect, E. Arimondo, R. Kaiser, H. Vansteekiste, and C. Cohen-Tannoudji, Phys. Rev. Lett. 61 (1988) 826.

P. Zhao, J.R. Lawall, A.W. Kam, M.D. Lindsay, F.M. Pipkin, and W. Lichten, Phys. rev. Lett. 63 (1989) 1593.

/7/ C.L. Bohler, L.D. Schearer, M. Leduc, P.J. Nacher, J. Zachorowski, R. Milner, R.D. McKeown, and C.E. Woodward, J. Appl. Phys. 63 (1988) 2497.

/8/ L.D. Schearer and P. Tin, Opt. Commun. 71 (1989) 170.

/9/ L.D. Schearer, M. Leduc, and J. Zachorowski, IEEE J. Quantum Electr. 23 (1987) 1996.

/10/ L. D. Schearer, S. Essabaa, and M. Leduc, paper E39 this conference.

J. Hamel, A. Cassimi, H. Abu-Safia, M. Leduc and L.D. Schearer, Opt. Commun 63 (1987) 114.

/11/ J.M. Daniels, L.D. Schearer, M. Leduc, and P.J. Nacher, J. Opt. Soc. Am. 4 (1987) 1133.

/12/ C.G. Aminoff, C. Larat, M. Leduc, and F. Laloe, Rev. Phys. Appl. 24 (1989) 824.

/13/ L.D. Schearer, P. Tin, and E. Stephens, paper L4 this conference.