Zeitschrift: Helvetica Physica Acta
Band: 59 (1986)
Heft: 4

Artikel: New infrared tunable lasers for polarizing 3He by optical pumping
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DOI: https://doi.org/10.5169/seals-115750

Helvetica Physica Acta
Vol. 59, 1986 747-751

018-0238/86/040747-05$1.50+0.20/0

NEW INFRARED TUNABLE LASERS FOR POLARIZING ^{3}He BY OPTICAL PUMPING

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ABSTRACT

Optical pumping produces significant polarization in gaseous ^{3}He at relatively high densities, by using both low temperature and laser techniques. Colour centre lasers allow 70% of polarization but are rather complicated. More easy to handle are some infrared Neodymium lasers which can be tuned to the helium wavelength. We review the achievements and the prospects of these new laser sources, in relation to the applications of optically polarized ^{3}He to nuclear physics.

INTRODUCTION

Various methods are possible to obtain nuclear polarization of ^{3}He . The brute force technique works well for solid ^{3}He ; by fast melting of solid ^{3}He polarized in a large magnetic field (5-10 Tesla) at low temperature ($\sim$ 10 mK), several groups have obtained large transient nuclear polarizations of liquid ^{3}He [1]. An alternative method of polarization is optical pumping, which does not require high fields nor very low temperature techniques operates continuously and is well suited for moderatly dense gases. Since its discovery in 1963 [2], this technique has been used for many applications, ranging from ^{3}He polarized targets [3] [4] to beams of polarized He^+ ions [5] and polarized electrons [6]. (A review of this field can be found in [7] and [8]).

Optical pumping is a transfer of angular momentum from the photons of a pump beam to the atoms. In the case of ^{3}He , the 2^3S_1 metastable level of helium is pumped at the wavelength $\lambda = 1.08\ \mu$ ($2^3S - 2^3P$ transition). Metastability exchange collisions strongly couple the nuclear polarization of the metastable and ground states [2] [9]. This method applies well to ^{3}He number densities ranging from 3×10^{15} to 3×10^{17} atoms/cm^3 at 300K . Two orders of magnitude can be gained by polarization transfer techniques between room and liquid helium temperature [8] ; numbers for densities, volumes and polarization are discussed in [10].

The present text does not intend to give details about a method described in the previous references. It only contains informations about the various pump sources which can be used for helium optical pumping, for which some recent progress has been

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registered, and which might open new possibilities for the use of polarized ^3He in nuclear physics.

NEODYMIUM LASERS TUNABLE AT 1.08 μm

With conventional helium discharge lamps, optical pumping provides typically 20% nuclear polarization of ^3He gas [2] [11]. Much larger polarizations were achieved with colour centre lasers developed after 1980 [12] : 70% nuclear polarization was registered with a $NaF/F_2^{+\star}$ laser, pumped by a tandem of Kr^+ laser followed by a dye laser [13]. However, this laser set-up has several disadvantages (low temperature operation of crystals, fading of the output, tedious adjustments, high cost). These reasons motivate the search for better laser sources.

Neodymium doped crystals, such as YAG, provide lasers operating on many lines in the near infrared, which do not have the same drawbacks as colour centre lasers ; furthermore, they can eventually be excited by lamps (easy to handle and not expensive) and deliver very large continuous output powers (100 W for YAG). Unfortunately such lasers usually cannot be tuned over a large range (only about 5 Å on each line of a YAG laser [14]). However the Nd^{3+} ions can be included in various other host crystals, resulting in laser wavelengths slightly shifted by the crystalline field and possibly spread over larger bandwidths. Two such new IR lasers have been tried so far, because they might be tunable to 1.08 μm ; preliminary results are discussed here.

1. YAP LASERS

YAP crystals are Nd doped Yttrium-Aluminium-Perovskite ($Y\ A\ell\ O_3$). Long rods of good laser quality are commercially available from Heraeus and can be excited in Kr arc lamp pumped cavities with thresholds and efficiencies comparable to YAG lasers [14]. Recently some studies were made of the tuning of this laser across several of its main lines, by inserting a Lyot filter and an etalon inside the cavity , as reported in [16]. The main transition at 1.0795 μm could be inhibited and a weaker transition peaking at 1.0845 μm could be tuned over 23 Å. The helium wavelength at 1.0834 μm could actually be reached on the side of such a line and a very small fraction of the laser power could be extracted from the cavity, leading to ^3He nuclear polarization of the order of 10%. These results are very preliminary. Considerable improvement can be expected if the cavity is optimized for this particular wavelength. Also there is hope that different YAP crystals (for instance with a different Nd concentration) might exhibit slightly shifted emission peaks, so that the helium wavelength could be more easily reached. Cooling the crystal might also help shifting down the YAP wavelength [14]. Unfortunately this also narrows the expected tuning range.

2. LNA LASERS

Lanthanum neodymium hexaaluminate $La_{1-x}\ Nd_x\ Mg\ A\ell_{11}\ O_{19}$

(called LNA) is another Nd doped crystalline host which shows CW laser action [17] and retains some advantages of YAG without showing some of its disadvantages such as low solubility of Nd^{3+} in the YAG lattice and limited tuning capability. In [18] are reported the lasing characteristics of LNA and its rather broad tuning bands when pumped by either the green output of an Ar^+ laser or the infrared output of a Kr^+ laser. The LNA crystal was a cylinder, 10 mm in length, with its C crystalline axis parallel to the rod axis. It was grown by J.J. Aubert at LETI in Grenoble. With no frequency selective elements in the cavity, the laser oscillates at 1.054 μm, with an efficiency as high as 25% when pumped with the 752 nm line of a Kr^+ laser. With a one plate Lyot filter in the cavity the main line at 1.054 μm can be suppressed and the laser can be easily tuned to the helium wavelength [18].

First results for ^3He nuclear orientation have been obtained with such an LNA laser, pumped with a Kr^+ laser delivering 1.5 Watt at 752 nm. About 70 mW of tunable power at 1.083 μm allowed up to 50% nuclear polarization in a ^3He cell of 0.3 torr at room temperature. Results similar to those obtained with colour centre lasers are expected with more powerful pump gas lasers. The present LNA lasers as such are already a substantial improvement over colour centre lasers, as they operate at room temperature without fading. They are also attractive because they might be excited by arc lamps, as for YAG and YAP lasers. An attempt at pumping a 3 cm LNA rod by lamps gave encouraging but too preliminary results [18]. Longer crystals with the proper crystalline axis (rod // c axis) and good optical quality are required, which is a non trivial crystal growth problem.

3. OHTER LASERS

YAP and LNA are not the only candidates as Nd lasers operating at 1.083 μm. Other hosts exhibit a Nd fluorescence at the right wavelength. Some of them have already shown pulsed laser emission and should be tried in continuous operation, provided good enough crystals can be found. One can think of β-aluminate [19], $Ca\ WO_4$ [20] $Li\ Nb\ O_3$ [21], Y Aℓ G [22], Nd doped fibers [23] and probably many others.

Let us finally mention other possibilities than Nd solid lasers : there is a constant development of new dyes as well as of diode lasers (quaternary systems) that might sooner or later lead to a stable laser at 1.083 μm, although this has not yet been reported and the expected power is rather low.

CONCLUSION

Optical pumping allows polarizing ^3He gas to 70% at densities of 10^{16} - 10^{17} atoms/cm^3, volumes a few 100 cm^3 at room temperature. At 4.2 K densities of 10^{18} - 10^{19} atoms/cm^3 and volumes of a few 10 cm^3 can be polarized to nearly the same amount. The absolute number of nuclear spins that one is able to polarize is

directly related to the intensity of the pumping source, continuously competing against the relaxation processes (see the discussion given in [10]). Present lasers delivering powers of the order of a fraction of 1 W impose the present limitations. Clearly more efficient lasers such as YAP lasers, slightly shifted in wavelength, or LNA lasers when pumped by lamps, would allow the volume of oriented ^{3}He to be scaled up. It is also expected that much larger laser powers would lead to significantly higher polarizations : it has been calculated that 10 W would lead to 90% and 100 W to 98% [9].

For applications to polarized targets one can also think of compressing the polarized ^{3}He gas according to the method described in [24]. This has the advantage that the polarized target can be at room temperature ; the densities and volumes are, however, similar to those obtainable cryogenically.

Let us at last mention the possibility of polarizing a drop of liquid ^{3}He by this method [25], as discussed in [10]. An experiment in that sense is in progress at the ENS. This would lead to a denser ^{3}He target but to a smaller volume than for the gas studied above.

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See also secretary's report, session (D), B. van den Brandt.

Helvetica Physica Acta
Vol. 59, 1986 752

018-0238/86/040752-01$1.50+0.20/0

Secretary's report, Session (D), B. van den Brandt:

New infrared tunable lasers for polarizing ^{3}He by optical pumping, M. Leduc:

W. Haeberli : Could a higher polarization of the electrons be obtained at a higher density if one use GaAs insted of ^{3}He?
Answer : In ^{3}He one obtains the same density and a higher polarization.

W. Haeberli : At what rate can ^{3}He be optically pumped?
Answer : With a LASER of 1 Watt, 10^{+16} to 10^{+17} atoms/sec can be polarized.

Microwave induced optical nuclear polarization, W. Th. Wenckebach:

J. Arvieux : Is there less H-atoms in your material than in a normal NH^3 target?
Answer : Yes, but it is better suited for frozen spin mode since it needs less cooling.

T. Niinikoski : If you still need a ^{3}He cryostat, what is the advantage over a normal target?
Answer : The only advantage is the long relaxation time.

S. Mango : Is the relaxation time dependent of H?
Answer : We have not looked at it very well, but its dependence goes probably with H^2.

T. Niinikoski : Does this method work in glassy biological materials?
Answer : We have not yet looked at organic materials.

E. Schilling : How many triplet states do you need?
Answer : About 10^{+6}.