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Nuclear Spin Polarized Atomic Alkali-Metal Beams by Laser Optical Pumping +)

H. Bechtel and D. Fick

Philipps-Universität, Fachbereich Physik, 3550 Marburg, W-Germany

The source for polarized heavy ions (^7Li, ^{23}Na both with nuclear spin I=3/2) at the Heidelberg MP-Tandem[1]) uses Laser optical pumping in front of a spin state selecting quadrupole magnet. The hyperfine splitting between F=2 and F=1 of the ground states of both nuclei is so large that the laser can pump only the F=2 multiplet. The remaining F=1 component which is not pumped but fed by the laser excitation is removed by the spin state selecting quadrupole magnet, on the account of a 75% loss of the original atomic beam intensity.

With modern acoustooptic or electrooptic devices following a single mode dye laser it is possible to produce light beams at two different frequencies with separations even reaching the hyperfine splitting of 1772 MHz for ^{23}Na. With such laser light both hyperfine multiplets F=2 and F=1 can be pumped simultaneously. However, the laser intensity in the side bands becomes more and more limited with increasing frequency difference. Thus, less and less intense atomic beams can be pumped by this method.

Another method utilizes a double resonance technique[2]) which uses as before optical pumping from the F=2 multiplet but simultaneously induces rf-transitions with $\Delta m_F=0$ between the F=1 and F=2 multiplet. A detailed investigation of the dynamics of the processes involved was performed using laser induced fluorescence (LIF)[3]) to measure the relative occupation numbers of the eight hyperfine levels of the F=1 and F=2 multiplets. Fig. 1 presents LIF-spectra for a optical pumped ^{23}Na atomic beam without (upper part) and with (middle part) rf-power 'on'.(The hyperfine levels $|F,m_F\rangle$ are labeled according to their energy in a magnetic field by $|2,2\rangle$="1", $|2,1\rangle$ = "2",...,$|1,1\rangle$= "8".) Without rf-power 'on' a fair amount (around 75%) of the intensity is in the levels labeled "6" to "8" which are just the members of the F=1 multiplet. Switching the rf-power in the double resonance region 'on', more than 95% of the atomic beam intensity is now pumped to the state $|2,2\rangle$ = "1". To demonstrate the efficiency of the double resonance more clearly the lowest part of Fig. 1 displays again the spectrum in the middle but now enlarged by a factor of 50.

In Fig. 2 the dependence of the occupation number of state "1" on the rf-frequency is displayed for different rf-power. For low rf-power opposite to what one might expect naively a double peak structure with a minimum (!) at the hyperfine frequency of Na appears! The double peaked curve is known in double-resonance spectroscopy as Autler-Townes or dynamic Stark effect[4]). It is a consequence of the coherent coupling of levels involved in the laser transition (D_1), leading to the generation of 2 'quasi energy levels' separated by the Rabi frequency[5]). For a power density of the laser radiation field of 280 mW/cm^2 it is about 20 MHz for the optical transitions under consideration. As the Rabi frequency induced by the rf-field is small compared to that of the laser radiation field, the occupation number of state "1" is determined by the number of rf-transitions occuring during the optical pumping. So the rf-frequency dependence in Fig. 2 monitors the effect of the laser induced coherent coupling on the hyperfine level F=2 probed by the rf-field.

With increasing rf-power the depth of the minimum is reduced and for 20 W a plateau appears whose width as well as the distance of the peaks is determined by the laser induced Rabi frequency. The magnitude of the static magnetic field in the double resonance region should not exceed 0.5 mT with a well defined direction to allow only rf-transition with $\Delta m_F=0$.

In particular because the rf-resonance frequency becomes less critical by the coherent interaction with the hyperfine levels involved and because no laser intensity is lost whatsoever by this method, it promises to be very suitable to produce full intensity atomic beams in one single Zeeman level of a hyperfine multiplet.

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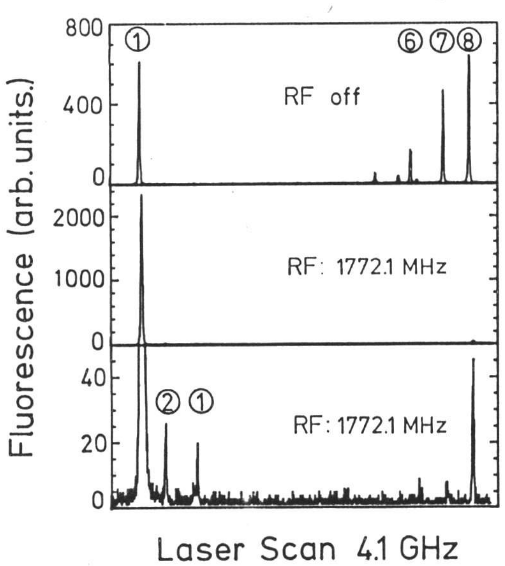

Fig. 1 Fluorescence of ^{23}Na beam in a magnetic field as a function of the laser frequency. Upper part: beam optically pumped with circular D_1 light of a laser (transition $F=2 \rightarrow F'=2, \Delta m_F=+1$), middle part: beam pumped by a laser - rf-double resonance technique, lower part: the same with enlarged scale.

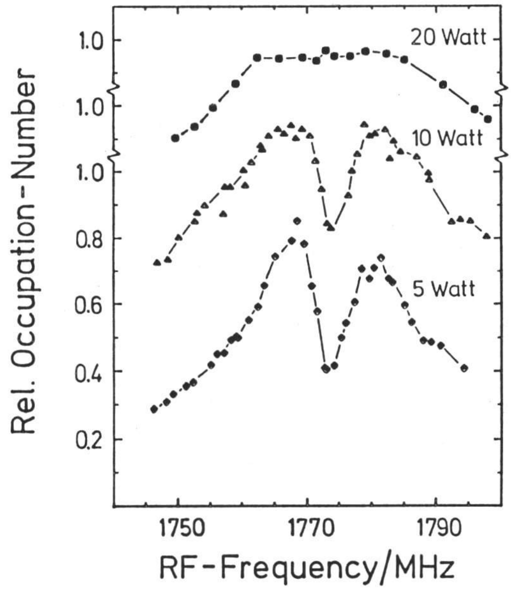

Fig. 2 Relative occupation number of level "1"=|2,2> as a function of the applied rf-frequency for various rf-powers. The intensity of the laser was 280 mW/cm^2.

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