Cross Sections for Depolarization of 6 $^2P_{3/2}$ Cesium Atoms Induced in Collision with Noble Gases from D_2 Optical Pumping *

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Possibilities of examing the relaxation of alkali atoms in $6^2P_{3/2}$ state by analysing the pumping process with a weak circularly polarized D_2 line are presented. Results of an experiment on Cs-He and Cs-Ne systems have also been given. Assuming the J-randomization model for relaxation of alkali atoms in $^2P_{3/2}$ state and neglecting energy transfer between 6^2P_J states, we obtained the cross sections for relaxation: Cs-He, 62.6 ± 10.0; Cs-Ne, 54.0 ± 9.0; in 10^{-16} cm^2 units.

1. Introduction

The effect of relaxation of alkali atoms in resonant excited states ^2P_J on the parameters describing the observed pumping process is sufficiently strong to provide information about the relaxation once these parameters are determined. Such analysis of pumping with a weak D_1 line was carried out by Franz et al. [1, 2].

This analysis also gave simultaneously a smart measuring method for examining the cross section for relaxation of alkali atoms in the $^2P_{1/2}$ state. This method was used in the present work to examine relaxation of alkali atoms in the $^2P_{3/2}$ state. In this case the rate equations that describe the evolution of the ground state with D_1 line are also valid. It is only necessary to modify the evolution equations so as to take into account excitation of the system with a weak D_2 line and relaxation of alkali atoms in the $^2P_{3/2}$ state. These terms describing depopulation and repopulation pumping for longitudinal electronic polarizations of alkali atoms in hyperfine levels of the ground state can be calculated when random relaxation (standard sudden model of relaxation) of atoms in the $^2P_{3/2}$ state has been assumed. In these calculations, the rate equations for relaxation in an excited state given by Elbel et al. [4] were used.

2. Measuring Method

The experimental method is based on the analysis of the pumping process with a resonant D_2 line of low intensity and circular polarization. The change of absorption of the pumping light is proportional to the variation of $\langle S_z \rangle$, i. e. longitudinal electronic polarization of alkali atoms in the $^2S_{1/2}$ state.

We can observe a change of the absorption signal after switching on the pumping light or other initial conditions corresponding to equal populations of atoms at Zeeman's sublevels of a ground state. Then according to [1, 2]:

$$I_a \sim \langle S_z(t) \rangle = \langle S_z(\infty) \rangle - D_1 e^{-Z_1 t} - D_2 e^{-Z_2 t}, \quad (1)$$

where Z_1 and Z_2 depend on the relaxation times of alkali atoms in the ground state and pumping time T_p.

D_1 and D_2 additionally depend on the relaxation of atoms in the excited state. According to [3, 4] relaxation of atoms in an excited state can be described by one universal nuclear-spin-independent parameter $\Gamma_2 = N V_r \sigma^{(2)}$ if sudden relaxation is assumed. In that case the ratio $D = D_1 Z_1 / D_2 Z_2$ is expressed as follows:

$$\frac{D_1 Z_1}{D_2 Z_2} = \frac{[\Delta - I(2I-1) + 2I(I+1)\delta]\mathcal{L}^+ + [-\Delta - (I+1)(2I+3) + 2I(I+1)\delta]\mathcal{L}^-}{[\Delta + I(2I-1) + 2I(I+1)\delta]\mathcal{L}^+ + [\Delta + (I+1)(2I+3) + 2I+1)\delta]\mathcal{L}^-},$$

$$\Delta = \sqrt{I(I+1)[4I(I+1)\delta^2 - (2I+3)(2I-1)]},$$

$$\delta = \sqrt{1 + \frac{24I(I+1)+9}{[4I(I+1)]^2} - \frac{8(2I+1)^2(1+T_h/T_{ex})^2}{[4I(I+1)]^2(1+2T_h/3T_{ex})^2}}. \quad (2)$$

T_h is the hyperfine relaxation time and T_{ex} the exchange relaxation time of atoms in the ground state. $\mathcal{L}^+$ and $\mathcal{L}^-$ are independent of the time terms of depopulation and repopulation pumping in the evolu-

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tion equations for electronic polarization of atoms occupying hyperfine levels $f_{\pm} = I \pm 1/2$ pumped with a weak circulary polarized D_2 line:

$$\langle \dot{S}_z \rangle_- = \mathcal{L}^- - \frac{2}{3\,T_p} \langle S_z \rangle_- + \langle \dot{S}_z \rangle_- |_g$$
$$\langle \dot{S}_z \rangle_+ = \mathcal{L}^+ - \frac{2}{3\,T_p} \langle S_z \rangle_+ + \langle \dot{S}_z \rangle_+ |_g \,. \qquad (3)$$

$\langle \dot{S}_z \rangle_{\pm} |_g$ describes relaxation of atoms in the ground state. T_p is the pumping time.

$\mathcal{L}^-$ and $\mathcal{L}^+$ depend only on parameters describing relaxation in the excited state and on the pumping time.

Under the assumption of "weak pumping" [1, 2] we can calculate these terms explicity for the standard model of relaxation in excited $^2P_{3/2}$ state [4].

For nuclear spin $I = 7/2$ we obtain

$$\mathcal{L}^- = -\frac{7}{128}\,\frac{1}{3T_p}\left[1 + \frac{(66\,x - 25)}{3\,(3\,x + 20)\,(x+1)}\right]$$
$$\mathcal{L}^+ = -\frac{15}{128}\,\frac{1}{3T_p}\left[1 - \frac{(390\,x + 661)}{15\,(3\,x + 20)\,(x+1)}\right], \qquad (4)$$

where $x = \Gamma_2 \tau_2$.

τ_2 denotes the mean lifetime of atoms in the excited $^2P_{3/2}$ state. The measurement of D is equivalent to determining Γ_2 under the conditions that we know T_h/T_{ex} for fixed experimental conditions. Independently of the possibility of using the cross sections determined repeatedly for hyperfine and exchange relaxation (σ_h and σ_{ex}) it is possible to determine them in this experiment from measurement of Z_1 and Z_2 or $Z_2 - Z_1 = 1/T_h + 2/3\,T_{ex}$ [1, 2].

In Fig. 1 the dependence D on $\Gamma_2 \tau_2$ for various ratios T_h/T_{ex} is shown. For comparison the dependence for pumping with a circulary polarized D_1 line is shown.

In the other case the value of D gives us information about $\Gamma_1 \tau_1$, i. e. about the parameter describing processes of relaxation in the $^2P_{1/2}$ state. From comparison of these dependences we can see that under conditions of pumping with D_2 line we observe much greater changes of the ratio D depending on $\Gamma_2 \tau_2$. This gives us clear evidence in favour of using this method for examining relaxation of atoms in the $^2P_{3/2}$ state. We have additional possibilities of an easy measurement of the value D in

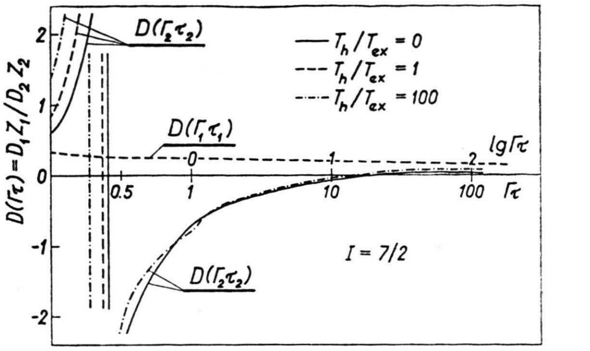

Fig. 1. Dependence $D = Z_1 D_1 / Z_2 D_2$ on $\Gamma_2 \tau_2$ for various T_h/T_{ex} values.

the range in which $D(\Gamma_2 \tau_2)$ changes from -1 to 0. In this range the signal of pumping has its minimum and

$$\frac{D_1 Z_1}{D_2 Z_2} = -\exp\{-(Z_2 - Z_1)\,t_{min}\}\,, \qquad (5)$$

where t_{min} is the time after which the pumping signal reaches minimum.

This corresponds to a change of $\Gamma_2 \tau_2$ from 0.86 to $16 - 20$ (depending on T_h/T_{ex}, and for $I = 7/2$).

The left-side limit corresponds to the minimum for $t = 0$, the right-side one to $t = \infty$. We can notice that $D(\Gamma_2 \tau_2)$ is practically independ of temperature for $\Gamma_2 \tau_2 > 0.86$ (Fig. 1), and that the value of $(Z_2 - Z_1) \cdot t_{min}$ will remain constant for constant pressure of buffer gas. These additional possibilities (in a limited range of variation of $\Gamma_2 \tau_2$) allow us to determine the cross sections more precisely. Designation of t_{min} is more precise than determination of $D(\Gamma_2 \tau_2)$ from D_1, D_2, Z_1 and Z_2 values recieved from the analysis by the least squares method of the run of the observed pumping process (1).

3. Experiment

An experiment was carried out for the atomic systems Cs-He and Cs-Ne. The set-up of the measuring apparatus is shown in Figure 2. The resonant cell, situated in the field $H_0 = 0.12$ gaus, was pumped with a wide D_2 line with σ^+ polarization. $1/T_p$ was lower than $20\,s^{-1}$. Initial conditions were realized by acting on the system with a strong, long-lasting pulse of radio-frequency field produced by the gate system (GATE). The frequency corresponded to the resonances frequency of Zeeman's alkali atoms in the $^2S_{1/2}$ state.

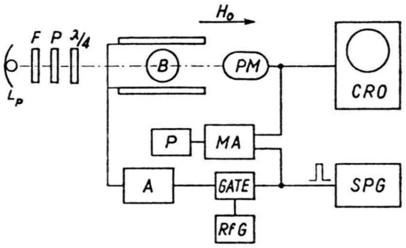

Fig. 2. Set-up of the experimental apparatus: L_p — pumping lamp, F — interference filter, P — polaroid, $\lambda/4$ — quarter wave plate, RfG — radio-frequency generator, SPG — square pulses generator, CRO — oscilloscope, PM — photomultiplier, A — amplifier, MA — multichannel analyser as signal averager, P — printer.

After ending the "mixing" pulse, detection of the absorption change in the pumping process was made by a photomultiplier PM. The pumping signal could be observed on an oscilloscope if the changes of the signals were large enough. Next, the runs were averaged in a multichanel analyser MA. In order to do this, the pumping signal was sampled with clock pulses of the analyser. The number of runs in the averaged signal was from 500 to 2000. The averaged run of the pumping process was introduced to a printer P.

Typical signals are shown in Figure 3.

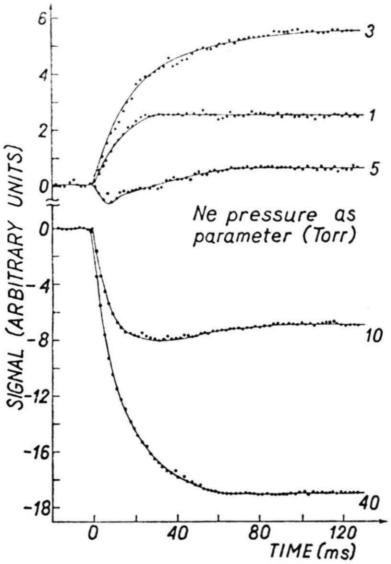

Fig. 3. Averaged runs of the pumping process obtained for various pressures of Ne at temperature 305 K. The contents of the channels is marked every 2 ms. The signal is proportional to $\langle S_z(t) \rangle$.

4. Results of the Measurements

Measurements of the D ratio in the range of He and Ne pressures from 1 to 60 torr were carried out. Averaged in an analyser, the pumping signals were numerically analysed in order to determine the parameters describing this process. In the pressure ranges 4 – 15 torr He and 4 – 40 torr Ne the D ratio was also determined from location of the t_{min} value. Examination of the dependence of the pumping signal on the pumping light intensity allowed us to estimate the pumping time for which conditions of weak pumping were still fulfilled. It seems that for $1/T_p < 25\ s^{-1}$ these conditions are fulfilled.

To determine Γ_2 we put in formula (2) $\sigma_{ex} = 2.2 \times 10^{-14}\ cm^2$, $\sigma_h\,(Cs\text{-}He) = 3.9 \times 10^{-23}\ cm^2$, $\sigma_h\,(Cs\text{-}Ne) = 6.9 \times 10^{-23}\ cm^2$ and $\tau_2 = 3.3 \times 10^{-8}\ s$.

Experimental results are shown in Figures 3 – 5.

Comparison of the obtained values of the cross section with other measurements are shown in Table 1.

5. Summary

The method used in this work seems to be very useful in examining relaxation of alkali atoms in $^2P_{3/2}$ state. It is supported by theoretical assumption about strong dependence of the determined value D

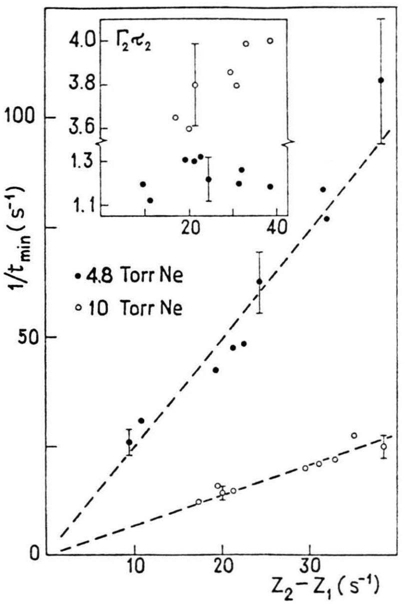

Fig. 4. Dependence of $1/t_{min}$ on $Z_2 - Z_1$ at 300–315 K. Measured values of $\Gamma_2\tau_2$ are also given.

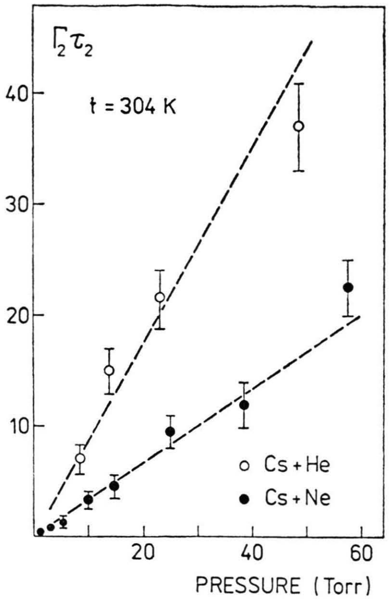

Fig. 5. Dependence of $\Gamma_2\tau_2$ on pressure of He and Ne buffer gas.

Table 1. The nuclear-spin-independent cross sections for disorientation of $6^2P_{3/2}$ Cs atoms induced in Cs-He and Cs-Ne collisions.

Cross section $\times 10^{-16}$ cm^2	Source
	Cs-He
62.6 ± 10.0	this work (290—310 K, 10—60 Tr)
93.0	F–H–L–F (1967) [5]
58.0	G–K (1976) [6] (Q_{circ})
	Cs-Ne
54.0 ± 9.0	this work (290—315 K, 10—60 Tr)
84.1	F–H–L–F (1967) [5]
73.9	G–K (1976) [6] (Q_{circ})

on parameters describing relaxation of atoms in excited state. Preliminary results also agree with the results of other works.

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