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Self-alignment of neon $5d_2$ - level in hollow cathode discharge

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Résumé. — Un autoalignement du niveau $5d_2$ de configuration $(2p^5 5d)$ du néon a été enregistré dans une décharge de cathode creuse. Après élimination de l'effet de capture radiative sur la largeur du signal Hanle, la valeur (37 ± 7) ns a été trouvée pour la durée de vie du niveau $5d_2$.

Abstract. — A self-alignment of $5d_2$ -level of neon (configuration $2p^5 5d$) is detected in a hollow cathode discharge. After correction of the Hanle-signal width for the effect of trapping, the radiative life time of $5d_2$ -level is found to be (37 ± 7) ns.

The possibilities of the level crossing technique [1, 2] stimulate its application on levels not easily investigated by other ways. The effect of the self-alignment in the positive discharge column allows the measurement of the relaxation constants of various He, Ne, Xe, Hg, N_2 states by level crossing at zero magnetic field [3-11]. The self-alignment in hollow cathode discharge supplements this group with some metals which are more difficult for atomization [12]. The self-alignment mechanism [13] and the peculiarities of the electron energy distribution in hollow cathode discharge are factors which promise coherent excitation (alignment type) of higher energetic levels too. The purpose of the present study is to check this possibility for $5d_2$ -level of the $2p^5 5d$ neon configuration (Paschen's notation). Alignment of this level has not been reported so far.

1. Experimental part. — The magnetic field dependence of the intensity of polarized light, $\frac{\partial I}{\partial H_0}(H_0)$ of the line NeI 470.25 nm ($5d_2$ - $2p_{10}$) is investigated. Here I is the line intensity and H_0 the calibrated magnetic field applied to the hollow cathode discharge. The aluminium hollow cathode with traditional cylindrical form is cooled with running water. The cathode dimensions are as follow : diameter $2R = 20$ mm and length $L = 40$ mm. The cathode diameter is specially selected in order to create a stable regime of the discharge at low neon pressure $p_{Ne} < 0.25$ torr

which is optimal for the intensity of the investigated line. The alternative way to increase the line intensity, i.e. by increasing discharge current i_d is not preferable in our case due to the depolarizing effect of the charged particles in the discharge plasma. The Hanle-signal is recorded in the region p_{Ne} from 0.09 to 0.22 torr and i_d from 25 to 55 mA. The direction of the observation coincides with that of the magnetic field, i.e. along the cathode axis. A double lens optical system and a diaphragmed entrance slit of the monochromator separate an emitting column with a rectangular cross-section (average 0.5×2.0 mm), its longer side orientated along the chord at 4 mm distance of the cathode axis. The signal, which is close in form to the first derivative of intensity on the magnetic field is recorded by modulating the calibrated magnetic field with an alternating component.

2. Results and discussion. — 1. The recorded signal $\frac{\partial I}{\partial H_0}(H_0)$ is observed to have opposite signs in orthogonal polarization components. This proves that for the given experimental geometry, the signal results in destruction of alignment of $5d_2$ -level. Preliminary measurements of signal width $2\Delta H_{1/2}$ as a function of p_{Ne} and i_d at $i_d = 30, 50, 55$ mA and $p_{Ne} = 0.1, 0.18, 0.22$ torr respectively were made. A constant relaxation rate due to charged and uncharged particles, but a different signal/noise ratio were registered. This ratio was preferable (15 : 1) at $i_d = 50$ mA and $p_{Ne} = 0.12$ torr. Systematic registration of $2\Delta H_{1/2}(p_{Ne})$ and $2\Delta H_{1/2}(i_d)$ dependences at these values of i_d and p_{Ne} showed a linear character with constants (26.0 ± 0.2) MHz/torr and (24.0 ± 0.3) MHz/A respectively. This fact illustrates the binary character of the corresponding impacts and allows correct extrapolation of the signal width towards zero values of i_d and p_{Ne} .

2. The Hanle-signal broadening due to the modulating magnetic field has been eliminated using the data from reference [14] and after the aforementioned extrapolation, the width $2\Delta H_{1/2}$ value of (3.70 ± 0.60) Oe with the corresponding coherence time $\tau_2 = (38.90 \pm 7.00)$ ns is obtained ($\tau = 56.87 \times 10^{-9}(g_j \cdot \Delta H_{1/2})^{-1}$, $g_j = 0.791$ from reference [15]-Landé factor). The transition structure from the investigated level, however, permits τ_2 to be increased compared to the radiative time τ_R . The level $5d_2$ is connected not only with the configurations $2p^5 4f$, $2p^5 5p$, $2p^5 4p$, $2p^5 3p$ but with the ground state $1S_0$, too. The possible narrowing of our signal due to the radiation trapping by the last (resonant) channel results in an effective coherence time τ_2 connected with the radiative time τ_R in the following way [16] :

$$\tau_R = \tau_2(1 - \alpha_2)$$

where

$$\alpha_2 = \frac{0.7 \times A_{k0}}{\sum_i A_{ki}} \left\{ \begin{matrix} 1 & 1 & 2 \\ J_1 & J_1 & J_0 \end{matrix} \right\}^{-2} \left\{ \begin{matrix} 1 & 1 & 0 \\ J_1 & J_1 & J_0 \end{matrix} \right\}^{-2},$$

A_{k0} is the probability of the resonant transition from the investigated level, $\sum_i A_{ki}$ the sum of probabilities of all transitions from the same level; J_1 and J_0 the angular moments of upper and lower level of the investigated transition, respectively.

To determine τ_R , the A_{k0} and $\sum_i A_{ki}$ values are needed. The transition probability $5d_2-1S_0$ is calculated in Coulomb approximation using Bates and Damgaard method [17]. The selection rules allow only three transitions between the configurations $2p^5 5d$ and $2p^6$, namely $5s_1'-1S_0$, $5d_2-1S_0$, $5d_5-1S_0$. Only the first two have been detected so far, at wavelengths 58.720 nm and 58.922 nm, and are of equal intensities.

Assuming the energy $E = 169\,518.977 \text{ cm}^{-1}$ as a weighted mean energy of the configuration $2p^5 5d$ and applying the procedures given in reference [17] (the numerical values are taken from

reference [15]), $S = 0.63 \times 10^{-3}$ atomic units for the NeI 58.992 nm line strength is found. The connection between S and A_{k0} is given by

$$A_{k0} = \frac{\gamma}{g_k} S \nu_{k0}^3,$$

where ν_{k0} (s^{-1}) is the frequency transition, $g_k = 2J + 1$, $\gamma = 64 \pi^4 / 3 hc^3$. As a result for the resonant transition $A_{k0} = 2.07 \times 10^6 \text{ s}^{-1}$.

As refer to $\sum_i A_{ki}$ we shall use the value calculated in Coulomb approximation

$$\sum_i A_{ki} = 29.94 \times 10^6 \text{ s}^{-1} \quad [18].$$

It was found that $\alpha_2 = 4.84 \times 10^{-2}$, i.e. the narrowing of Hanle-signal due to the emission trapping along the resonant channel $5d_2^{-1}S_0$ is insignificant. The found out radiative life time $\tau_R = (37 \pm 7) \text{ ns}$ differs from the above given τ_2 less than the inaccuracy ($\Delta\tau = \pm 7 \text{ ns}$), which is a result of the dispersion of the experimental data.

Our result can be compared with the only known up to now result $\tau_R = 33.4 \text{ ns}$ calculated theoretically in Coulomb approximation [18]. This comparison implies two remarks : the possibility of systematic errors due to cascade transitions from higher levels should be noted, although it was not noticed in the detected signals ; the accuracy in calculating α_2 cannot be estimated due to absence of analogous information about the used data and, in particular, about $\sum_i A_{ki}$.

3. Conclusion. — In our opinion, the result obtained illustrates the possibility for measuring by self-alignment technique relaxation constants of the high energetic levels in a hollow cathode discharge.

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