Mode-Crossing Signals of High Order on the $4d^9 5s^2 2D_{5/2}$ State of Cd II Isotopes

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Received July 10, 1978

In the linearly polarized radiation field of a 442 nm He–Cd laser containing a natural isotope mixture, saturation-induced mode-crossing signals of the $4d^9 5s^2 2D_{5/2}$ state of Cd II are observed due to the even as well as the odd isotopes. The signal width of about $10^{-4}$ T yields high resolution. Thus the signal splitting respective to the magnetic quantum number can be resolved. The $g_J$- and $g_F$-factors of the $2D_{5/2}$ state are determined as follows:

$$g_J = 1.1980 \pm 0.0036, \quad g_F(2) = 1.397 \pm 0.008, \quad g_F(3) = 1.002 \pm 0.009.$$ 

1. Introduction

The zero-field power dip of the 441.6 nm He–Cd laser has already been measured by Dienes et al. [1] and Taszner et al. [2] on $^{113}$Cd and isotopes of natural abundance, respectively. The pressure dependence of the alignment relaxation rate was investigated to determine the radiative lifetime of the upper laser state and the disalignment cross-section. Dienes et al. attempted to observe mode crossings of higher order too, which would allow to determine the $g_J$-factor. They failed, however, due to the considerable noise of the laser. Our main interest in performing mode-crossing experiments on Cadmium was established on the one hand by the existence of Cd isotopes of odd mass number. Thus mode crossings of hyperfine levels will be expected. On the other hand the width of the crossing signals of the $2D_{5/2}$ state is very small because of its long lifetime.

2. Fundamental Remarks

The mode-crossing technique makes use of the simultaneous nonlinear interaction of two unidirectionally travelling waves with two atomic or molecular transitions optically coupled to a common level.

In Figure 1 the levels $a_i$ and $b_j$ are tunable Zeeman or Stark components and the monochromatic radiation field consists of two oscillating laser modes of well-known frequency separation. Resonances occur whenever the splitting $\omega_{a_i a_i} - \omega_{b_i b_j}$ of one level equals the frequency difference of the two laser modes:

$$\omega_{a_i a_i} - \omega_{b_i b_j} = \omega_{\mu} - \omega_{\nu} = \omega_{\mu \nu}. \quad (1)$$

This resonance condition only depends on the separation $\omega_{\mu \nu}$ between the two laser modes $\mu$, $\nu$, being insensitive to their absolute values $\omega_{\mu}$, $\omega_{\nu}$. Thus mode-crossing experiments do not require frequency stabilisation.

$$\omega_{\nu} = \frac{\pi c_0}{L} = v \Delta$$

being the fundamental modes of the laser cavity, the resonance condition reduces to

$$\omega_{a_i a_i} - \omega_{b_i b_j} = (\mu - \nu) \Delta = n \Delta \quad (2)$$

($v, \mu, n$ integers, $c_0$ velocity of light, $L$ optical cavity length, $\Delta$ axial mode spacing). $n$ refers to the order of the resonance. The laser intensity shows Lorentzian-like dips:
Fig. 1. Scheme of mode crossing. $\omega_a, \omega_b$ laser frequencies; $\omega_{a(b)}, \omega_{b(a)}$ transition frequencies, $\omega_{a(b)}, (\omega_{b(a)})$ splitting of the upper (lower) laser level.

Fig. 2. Simplified experimental arrangement.

$$I = A - \sum_{ii} B_{ii}^a \left( \omega_{uv} - \omega_{a(ia)} \right)^2 + \gamma_a^2$$

$$- \sum_{jj} B_{jj}^b \left( \omega_{uv} - \omega_{b(jb)} \right)^2 + \gamma_b^2$$

$$- \sum_{ii} B_{ii}^{ab} \left( \omega_{uv} - \omega_{a(iab)} \right)^2 + 4 \gamma_{ab}^2$$

(A constant; $\gamma_a, \gamma_b$ are the polarization relaxation rates of the crossing upper or lower levels, respectively; $\gamma_{ab}$ relaxation rate of the optical coherence ($\gamma_{ab} = (\gamma_a + \gamma_b)/2$ at vanishing gas pressure), $B_{ii}^a, B_{jj}^b, B_{ii}^{ab}$ constants depending on the dipol matrix elements as well as on the relaxation constants). The contribution of the third term vanishes at zero pressure.

Thus mode-crossing experiments yield high resolution in spectroscopic measurements, such as the determination of Landé-values [3], of fine and hyperfine structures [4], and of line width parameters as well as of pressure broadening mechanisms [5].

The resonances are caused by changing the population of the common level as well as the polarization of the split level under the influence of the saturating radiation field. Following Lamb's theory of a gaseous laser [6-8] the theory of mode crossing has been developed by Schlossberg et al. [9], Hermann et al. [10, 11], and Feld et al. [12]. First mode-crossing experiments were carried out on Xenon [4] and Neon [13].

3. Experimental Arrangement and Measurements

In this experiment the laser medium itself has been investigated applying an axial magnetic field. Figure 2 shows the experimental arrangement. The output power of the laser as a function of the magnetic field...