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HYPERFINE STRUCTURE CONSTANTS IN THE $10^2D_{3/2}$ AND $11^2D_{3/2}$ STATES OF ^{85}Rb

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The magnetic-dipole interaction constants A and the electric-quadrupole interaction constants B of two $n^2D_{3/2}$ states of ^{85}Rb were measured by the quantum beat method. The results are — for $n = 10$: $|A| = 0.393(8)$ MHz, $|B| = 0.141(13)$ MHz, for $n = 11$: $|A| = 0.283(6)$ MHz, $|B| = 0.100(11)$ MHz, and positive ratio B/A for both states.

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1. Introduction

Quantum beats were first reported as a modulation of the fluorescence from Zeeman substates [1, 2] and were next employed in investigation of fine and hyperfine structures. In alkali metal atoms several hfs constants have been obtained by the quantum beat method. In particular, the combination of this method with two-photon excitation allowed the study of hfs structure of the D states excited directly from the ground state [3, 4]. In this way, measurements of hyperfine structure in the n^2D_J states of ^{87}Rb were extended up to $n = 12$ for $J = 3/2$ and up to $n = 13$ for $J = 5/2$. Both the magnetic-dipole interaction constant A and the electric-quadrupole interaction constant B were determined ([5, 6] and references therein). In the present paper we report the results for A and B constants in the 10 and $11^2D_{3/2}$ states for another rubidium isotope, ^{85}Rb.

2. Experimental

The atomic states involved in the experiment and the excitation and detection transitions are sketched in Fig. 1. The arrows pointing upwards symbolise two-photon excitation. The fluorescence decaying towards the $5^2P_{1/2,3/2}$ states was detected. The wavelengths of all transitions involved are also marked.

The scheme of experimental setup is drawn in Fig. 2. The cell containing ^{85}Rb was placed in an air heated oven and was maintained at the temperature of 59°C which corresponded to rubidium vapour density of about 2×10^{17} atoms/m^3. The Earth magnetic field was compensated to less than 20 mG by three pairs of the orthogonal Helmholtz coils. The nitrogen laser pumped dye laser which delivered pulses of linearly polarised light of about 4 ns duration. The intracavity etalon narrowed the laser linewidth to about 3 GHz.

The fluorescence was observed at right angle to the laser beam through an interference filter (and an edge filter). The interference filters selected for each n transmitted both fine structure fluorescence components $n^2D_{3/2} - 5^2P_{1/2}$ and $n^2D_{3/2} - 5^2P_{3/2}$. In the case of $n = 10$ the transmittance of the interference filter was nearly equal for both components, while for $n = 11$ the first component was transmitted preferentially.

The detection system was a modified version of the one described in more details in Ref. [3]. The technique of photon counting in delayed coincidence was applied to register the time dependence of fluorescence. The detection chain consisted of a cooled photomultiplier XP 2020 (Philips) and ORTEC system modules which included a pile-up inspector unit. A computer served as a multichannel analyser, this was an IBM AT clone with interface card connected to an external analog-to-digital converter. The channel width corresponded to 32 ns.

The modulated fluorescence components polarised either parallel or perpendicular to the E vector of the exciting laser light were detected (these components

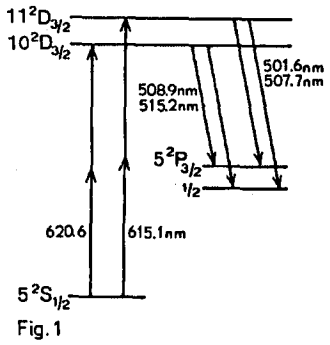

Fig. 1

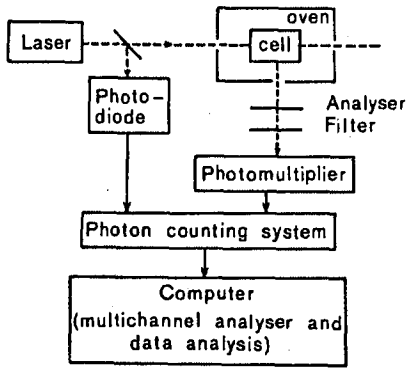

Fig. 2

Fig. 1. The energy levels (not to scale) and transitions studied.
Fig. 2. Schematic diagram of the apparatus.

are denoted in the text as $I_{\parallel}$ and $I_{\perp}$). Additionally, the signal with suppressed modulations, obtained with the analyser axis set at the "magic angle", was measured. The fine-structure splittings in the 10^2D_J and 11^2D_J states are *ca.* 15 and 11 GHz, respectively [7]. With the laser linewidth of about 3 GHz the $n^2D_{3/2}$ state was excited selectively. The hyperfine interval in the $5^2S_{1/2}$ ground state of ^{85}Rb is about 3 GHz, therefore in principle the excitation took place from both hfs sublevels of the ground state.

3. Results and discussion

Examples of $I_{\parallel}$ signals for the investigated states are shown in Fig. 3. The dots represent the channel contents and the solid lines were obtained by computer fitting of the theoretical time-resolved fluorescence signals to the experimental points. The fluorescence signal following coherent pulsed excitation consists of two

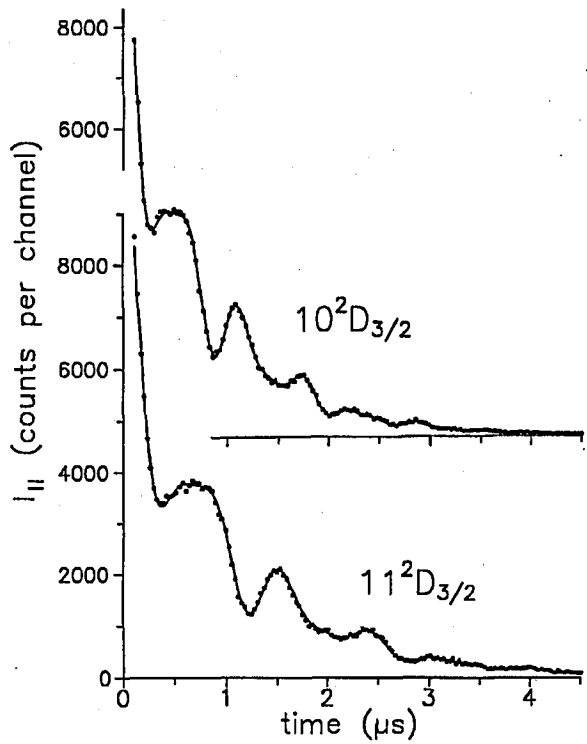

Fig. 3. Experimental quantum beat signals (dots) and typical curves obtained in a least squares fitting procedure (solid lines).

parts which are both decaying exponentially with the rate Γ ($\Gamma = 1/\tau$, where τ is the lifetime of the state). One of these parts exhibits additional time dependence

which is a sum of the oscillating components. The number of these components and their frequencies depend on the hyperfine structure of the excited state.

The nuclear spin of ^{85}Rb is 5/2 and thus the $n^2D_{3/2}$ state is split into four hyperfine sublevels with $F = 4, 3, 2, 1$. Therefore, there are five modulation frequencies which are related to the magnetic-dipole interaction constant A and the electric-quadrupole interaction constant B in the following way: $\omega_{43} = 4A+4B/5$, $\omega_{32} = 3A-9B/20, \omega_{21} = 2A-4B/5, \omega_{42} = 7A+7B/20$ and $\omega_{31} = 5A-5B/4$. The relative amplitudes of the oscillating components depend on the type of excitation. For the linearly π-polarised two-quantum transitions between the ground state $^2S_{1/2}$ and the excited $^2D_{3/2}$ state of ^{85}Rb they can be found in [4]. In the experiment reported in [4] the fluorescence towards the $5^2P_{1/2}$ state was observed, however the relative amplitudes of the beats remain the same when both $n^2D_{3/2}-5^2P_{1/2}$ and $n^2D_{3/2}-5^2P_{3/2}$ components are observed. These values of amplitudes correspond to excitation with a line which is broad in relation to the hyperfine splitting of the ground state. In the present experiment the hfs of the ground state and the laser linewidth were nearly equal, so that non-uniform excitation of the ground state sublevels was possible. For this reason the relative amplitudes of the quantum beats following absorption from each of the two sublevels of the ground state were calculated separately and in the fitting procedure a weighting factor was introduced to allow for possible narrow-line excitation. The weighting factor was either treated as a free parameter or set equal to one which assumed broad-line excitation. Several variants of the fitting procedure were explored. The decay constant Γ was either treated as a free parameter or taken from the data obtained with the analyser set at the magic angle. The fitted formula was modified in order to account for possible effects of collisional processes [8]. As mentioned above, allowance for preferential excitation from one of the hyperfine sublevels of the ground state was also made. Both $I_{\parallel}$ and $I_{\perp}$ experimental signals were analysed in this way.

The results for the magnetic-dipole interaction constant A and electric-quadrupole interaction constant B are as follows:

$$|A(10^2D_{3/2})| = 0.393(8)\ \text{MHz}, \quad |B(10^2D_{3/2})| = 0.141(13)\ \text{MHz},$$

$$|A(11^2D_{3/2})| = 0.283(6)\ \text{MHz}, \quad |B(11^2D_{3/2})| = 0.100(11)\ \text{MHz}.$$

The errors account for the spread in values derived from different fitting approaches as well as for the uncertainty in the origin of the time scale and in time scale calibration. The quantum beat method provides absolute values of the A and B constants and their relative sign. In the investigated $n^2D_{3/2}$ states of ^{85}Rb the B/A ratio was found to be positive.

The obtained values of hyperfine structure constants can be compared with the constants for the other rubidium isotope, ^{87}Rb. We believe that the hyperfine anomalies are below the accuracy of the experiment and hence, for each n, the following relation should hold for the A constants:

$$A(^{87}\text{Rb})/A(^{85}\text{Rb}) = g_I(^{87}\text{Rb})/g_I(^{85}\text{Rb}),$$

where g_I is nuclear Lande factor. If A values are taken from [5] and from the present work, their ratios are 3.35(11) and 3.37(11) for $n = 10$ and 11, respectively, which

could be compared with the value 3.39 calculated with g_I values taken from [9]. The ratio of electric-quadrupole interaction constants should be

$$B(^{87}\mathrm{Rb})/B(^{85}\mathrm{Rb}) = Q(^{87}\mathrm{Rb})/Q(^{85}\mathrm{Rb}).$$

The ratios of B constants from [5] and from the present work are 0.50(12) and 0.49(11) for $n = 10$ and 11, respectively. They are both expected to be 0.48, which is the ratio of quadrupole moments Q for the two isotopes [10]. It can be seen that when experimental errors are taken into account, the ratios of both the A constants and the B constants are in very good agreement with the expected values.

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