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DETERMINATION OF THE HYPERFINE STRUCTURE OF THE 2p LEVELS OF ^{21}Ne USING A CW TUNABLE DYE LASER

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Résumé. — Les structures hyperfines de niveaux 2p de ^{21}Ne ont été mesurées par la méthode des croisements de niveaux. Les niveaux étudiés étaient pompés optiquement par un laser à colorant.

Abstract. — H.f.s. measurements on the 2p levels of ^{21}Ne have been performed using the level-crossing method. The investigated levels were optically pumped using a dye laser.

Experimentally, the hyperfine structures of the excited levels of ^{21}Ne are rather poorly known. At the present time, there are available only a few spectroscopic determinations [1, 2, 3] and (for the ls_5 level) one very accurate atomic beam determination by Grosof *et al.* [4]. From the available experimental values, Liberman [1] was able to determine the atomic parameters of several configurations and to predict their hyperfine structures.

In this letter, hyperfine structure measurements on the 2p series ($2p_5$ 3p configuration) by the level-crossing technique are reported. We have determined the position of the level-crossings between the hyperfine sublevels of the $2p_2$, $2p_4$, $2p_5$, $2p_6$, $2p_7$, $2p_8$ states and deduced their magnetic dipolar and electric quadrupolar hyperfine interaction constants *a* and *b*. The metastable (and excited) states were populated by a R.F. discharge (frequency 1 MHz), and alignment was induced with a linearly polarized CW dye laser tuned on one of the transitions between the ls states and the state under investigation. The transitions we used are given in Table I. Their wavelengths are all in the laser spectral range covered by Rhodamine 6G. The laser was a Coherent Radiation jet stream dye laser. The cavity length had been increased up to 1.5 m by moving the output mirror further off. Thus the number of modes in the Doppler profile was increased and the pumping signal was much less sensitive to intensity fluctuations between modes and to the frequency drift of these modes. The width of the emission spectrum of the dye laser, in which the wavelength selection is determined by the use of a Lyot filter, varied between 10 and 40 GHz, depending on the output power; thus the spectrum of the pumping light was several times broader than the hyperfine structure and Zeeman separations.

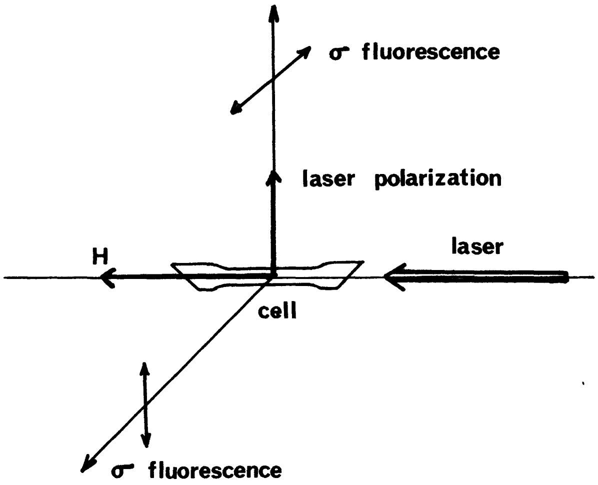

FIG. 1. — Sketch of the experimental set-up.

A sketch of the experimental set-up is shown in figure 1. The cell containing neon, or a mixture of helium and neon, was illuminated by the laser beam

TABLE I

Pumping lines used in our experiments for the 2p *levels*

$2p_2$	$2p_4$	$2p_5$	$2p_6$	$2p_7$	$2p_8$
6 030 Å ($2p_2$-$1S_4$) 6 163 Å ($2p_2$-$1S_3$)	5 944 Å ($2p_4$-$1S_5$) 6 096 Å ($2p_4$-$1S_4$)	6 266 Å ($2p_5$-$1S_3$)	6 143 Å ($2p_6$-$1S_5$)	6 383 Å ($2p_7$-$1S_4$)	6 334 Å ($2p_8$-$1S_5$)

and submitted to a d.c. magnetic field produced by Helmholtz coils. The current in the coils was stabilized and the magnetic field was calibrated from observations of the proton magnetic resonance. The field was parallel to the laser beam, and consequently perpendicular to the laser polarization (« σ » pumping). The magnetic field was swept around a given value with auxiliary coils. The fluorescence light was detected perpendicularly to the magnetic field in two directions, parallel ($I_{\parallel}^{\sigma}$) and perpendicular ($I_{\perp}^{\sigma}$) to the laser polarization. The laser was chopped at 360 Hz and a lock-in technique was used to monitor the difference $I_{\parallel}^{\sigma} - I_{\perp}^{\sigma}$. Experimental curves are shown in figures 2 and 3.

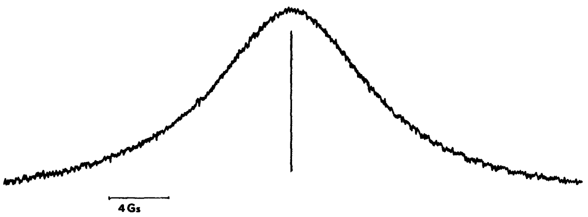

FIG. 2. — Recording of $2p_5$ C_1 crossing in 1.4 torr of neon.

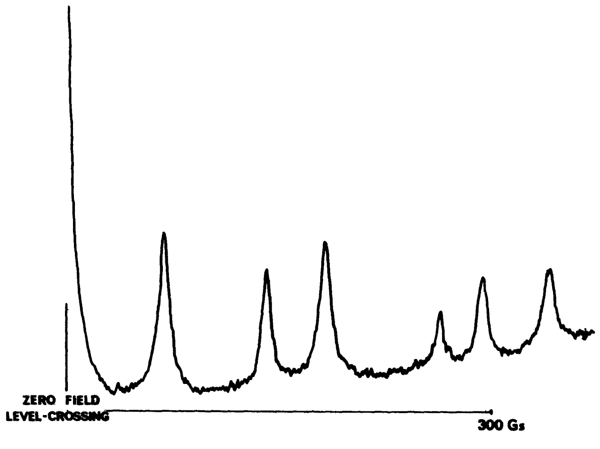

FIG. 3. — Recording of the $2p_6$ level-crossings. For accurate determination of the h.f.s., the region around each crossing was observed with a narrow magnetic field sweep.

In this geometry only $\Delta m = 2$ level-crossings can be observed and show up as lorentzian absorption curves. For the $J = 1$ levels there are two such crossings ($I = \frac{3}{2}$) (C_1 and C_2), one of which (C_2) is 21 times less intense and 7 times broader than the other. We had to store the signal during several hours in a multichannel analyser in order to observe it. For the $J = 2$ levels, there are seven $\Delta m = 2$ crossings. As the last one is much less intense than the other, we did not study it. Several phenomena can introduce an asymmetry in the curves. First, if there is a slight error in the detection directions of the fluorescence light, a dispersion curve is superimposed on the absorption curve. Second in high magnetic fields, when the metastable state ($1s_5$ or $1s_3$) was sufficiently populated, we observed a Faraday rotation of several degrees of the laser polarization after the laser beam had passed through a few centimeters of gas. One can eliminate almost entirely this effect by operating at low pressures and low discharge levels, and by reducing the length of the cell. In addition to these experimental causes, there can be more fundamental deformations of the resonance curves. The energies of the levels do not vary strictly linearly with the magnetic field near the level-crossing point. When one takes into account the curvature of the levels, one gets a slight shift of the lorentzian absorption curve and an additional dispersion curve. In our case, one can calculate that the shift is at most 5×10^{-3} of the width of the level-crossing signal (¹), and that the relative amplitude of the dispersion curve is of the order of 1 %. Another perturbation is due to the variation of wave-functions with the magnetic field. These variations also introduce a dispersion curve with relative amplitude of a few percent. In view of the above reasons, we made a computer fit of the experimental curves to a sum of absorption and dispersion shapes of adjustable heights, and with the same width and center. The fit to the dispersion curve is only significant when the signal to noise ratio is sufficiently large. In the other cases, we took into account a possible asymmetry in evaluating the accuracy of our results. The effects of the variation of the discharge level with magnetic field, and the wings of the neighbouring level-crossings have also been taken into account in the computer fit.

We have measured the position of each level-crossing under various experimental conditions (neon and helium pressures, discharge level, laser intensity). No significant shifts appear in our results. Examples of such measurements are given in Tables II and III for the $2p_5$ and $2p_8$ levels. A computer calculation allows one to find the values of a/g_J and b/g_J which minimize the mean square deviation of the calculated positions of the level-crossings from the experimental data. Tables II and III also give these a/g_J and b/g_J values and the positions of the level-crossings calculated with these values. All the calculated positions agree with the experimental results within the error bars. This is not surprising when there are only two crossings, but this fact shows that there is no important systematic error on the position of each crossing when a and b are determined from the positions of six level-crossings. Table IV gives the a/g_J, b/g_J and a and b values for all the investigated levels. To deduce the a and b values, we used g_J values from the litterature [5]. Theoretical considerations show that the fine structure decoupling corrections can be neglected for the magnetic fields we used. Let us point out that our experiments give only the relative sign of a and b. We assumed the sign of a as given either by previous

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(¹) Except for the $2p_2$ level-crossing. The corresponding correction has been taken into account in the results given in Table IV.

TABLE II

Crossings of the $2p_5$ *level* ($J = 1$). *As* C_2 *is much more difficult to observe than* C_1, *it has been studied in less various experimental conditions; the a and b values have been calculated from the mean values of the positions of* C_1 *and* C_2.

Neon pressure (torr)	Helium pressure (torr)	Discharge (arbitrary units)	Laser intensity (mW)	C_1 (GS)
0.003	3	14	80	627.42
0.01	1	16	50	627.33
0.03	3	14	50	627.47
0.03	3	20	50	627.33
0.03	0.6	15	50	627.29
0.1	1.9	15	50	627.29
0.1	1.9	15	420	627.27
1.4	0	12	80	627.39

Neon pressure	Helium pressure	Discharge	Laser intensity	C_2
0.1	1.9	14	70	906
0.1	1.9	16	70	915
0.3	1.7	16	70	899
0.03	3	15	70	904

C_1 (GS)	C_2 (GS)	a/g_J (MHz)	b/g_J (MHz)
exp. 627.34 ± 0.20	906 ± 14	− 439.61 ± 0.40	+ 42.10 ± 1.20
calc. 627.34	906		

TABLE III

Crossings of the $2p_8$ *level* ($J = 2$)

Ne pres. (torr)	He pres. (torr)	discharge (arbitrary units)	laser int. (mW)		C_1 (Gs)	C_2	C_3	C_4	C_5	C_6	error bar (Gs) on C_i	a/g_J (MHz)	b/g_J (MHz)
1.5	0	14	25	exp.	93.52	185.13	237.27	344.84	385.43	448.53	± 0.20	− 196.31	− 79.25
				calc.	93.62	184.99	237.30	344.61	385.62	448.49		± 0.15	± 0.30
1.5	0	14	4	exp.	93.43	185.05	237.29	344.50	385.65	448.20	± 0.40	− 196.27	− 79.33
				calc.	93.58	184.93	237.23	344.55	385.55	448.43		± 0.25	± 0.70
0.17	0	15	25	exp.	93.59	185.12	237.47		385.55	448.12	± 0.40	− 196.27	− 78.91
				calc.	93.71	185.05	237.37		385.50	448.30		± 0.25	± 0.70
0.1	1.9	21	30	exp.	93.37	185.11	237.26	344.50	385.65	448.25	± 0.50	− 196.29	− 79.36
				calc.	93.57	184.91	237.21	344.56	385.58	448.46		± 0.30	± 0.80
0.1	1.9	13	25	exp.	93.58	185.15	237.43		385.87	448.11	± 0.50	− 196.35	− 79.09
				calc.	93.70	185.07	237.40		385.64	448.48		± 0.30	± 0.80

TABLE·IV

Hyperfine structures

Level							Theoretical values [1]	
Paschen	j-K coupling	a/g_J (MHz)	b/g_J (MHz)	g_J ref. [5, 6]	a (MHz)	b (MHz)	a	b
$2p_2$	$3p'\,[\frac{1}{2}]\,1$	− 56.20 ± 0.40	see note	1.340 ± 0.003	+ 75.3 ± 0.8		84.9	0.45
$2p_4$	$3p'\,[\frac{3}{2}]\,2$	− 238.42 ± 0.35	+ 37.80 ± 0.40	1.298 ± 0.002	− 309.5 ± 1.1	+ 49.1 ± 0.6	− 301.8	48
$2p_5$	$3p'\,[\frac{3}{2}]\,1$	− 439.61 ± 0.40	+ 42.10 ± 1.20	0.994 ± 0.004	− 437.0 ± 2.2	+ 41.8 ± 1.4	− 433.2	43.2
$2p_6$	$3p\,[\frac{3}{2}]\,2$	− 150.69 ± 0.30	− 55.86 ± 0.50	1.232 ± 0.002	− 185.7 ± 0.8	− 68.8 ± 0.7	− 183.3	− 69.3
$2p_7$	$3p\,[\frac{3}{2}]\,1$	− 622.22 ± 0.60	− 83.8 ± 4.3	0.678 ± 0.001	− 421.9 ± 1.0	− 56.8 ± 3.0	− 412.5	− 54.6
$2p_8$	$3p\,[\frac{5}{2}]\,2$	− 196.29 ± 0.30	− 79.19 ± 0.60	1.137 ± 0.002	− 223.2 ± 0.7	− 90.0 ± 0.9	− 214.2	− 90.3

Note. — We were not able to observe the second level crossing (C_2). But calculation shows that if b is small, the position of C_1 depends significantly only on a. Reciprocally, if b is small, a is given by the position of C_1. Here we assumed (in agreement with the theoretical prediction) that $b < a/20$.

measurements, or by theoretical calculation [1, 2, 3]. Table IV also recalls the theoretical predictions of reference [1]; the agreement with our results is good. The g_J values we used are less accurate than our own results. Measurements of g_J using the double resonance method are now in progress.

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