TRANSITION PROBABILITIES AND RADIATIVE DECAY CONSTANTS OF THE EXCITED LEVELS OF Ne

By L. Wosiński

Institute of Physics, Polish Academy of Sciences, Warsaw*

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Transition probabilities for eight optical transitions between the $3p$ and $3d$ neon levels have been measured by the "plasma transparency method". The transition probabilities are placed on an absolute scale by use of the recently reported values for the $4p \rightarrow 3s$ transitions. The measurements of induced changes in populations allowed the determination of the ratios of the radiative decay constants for the $4p$ and $3d$ levels. The experimental results are compared with the theoretically calculated transition probabilities of Murphy and Lilly.

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1. Introduction

Using the methods developed by Hänsch and Toschek [1] and Parks and Javan [2] many authors obtained the relative transition probabilities for the $5s \rightarrow 3p$ [3–8], $4p \rightarrow 3s$ [9–12], $4s \rightarrow 3p$ [5], and $3p \rightarrow 3s$ [7, 12] transitions in Ne. In the previous paper [11] we reported the observation of ten laser transitions between the $4p$ and $3d$ levels in neon. Here we utilize eight of them to determine such parameters as the lifetimes and transition probabilities. $3d \rightarrow 3p$ transition probabilities have been measured in side light emission from a discharge probe cell placed inside a Ne laser cavity. The gas pressure and the discharge current of the cell were adjusted so as to obtain a transparent plasma at the respective atomic transition. Such plasma is characterized by an absence of both resonance absorption and stimulated emission and so the ratio of population of upper and lower laser levels is equal to the ratio of their statistical weights

$$\frac{N_1}{N_2} = \frac{g_1}{g_2}, \tag{1}$$

where N_1, N_2 are populations of the upper-1 and lower-2 laser levels, and g_1, g_2 are their statistical weights. Hence, the ratio of transition probabilities can be easily found from

* Address: Instytut Fizyki PAN, Lotników 32/46, 02-668 Warszawa, Poland.

the equation

$$\frac{I_1}{I_2} = \frac{A_1 N_1 h\nu_1}{A_2 N_2 h\nu_2} = \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}, \tag{2}$$

where I_i is an emission intensity of spectra originating from energy level "i", A_i is an absolute transition probability, $h\nu_i$ is photon energy, and λ_i is wavelength of the transition originating from the level "i". By analyzing intensity changes in spontaneous emission originating from a gas discharge cell it was also possible to determine the ratios of radiative decay constants for $4p$ and $3d$ levels. The most essential part of the experiment was to construct the Ne laser, whose oscillations could be tuned individually at single wavelengths of $4p \rightarrow 3d$ transitions.

2. Experiments

The experimental arrangement shown in Fig. 1 is nearly the same as that in Ref. [11]. The laser tube was 3 m long and 8 mm in internal diameter and was filled with neon at variable pressure in order to adjust the best parameters of laser oscillations. The discharge probe cell, connected to the high-vacuum and handling system, was placed inside the laser cavity formed by two aluminized mirrors. The laser was tunable at the infrared lines be-

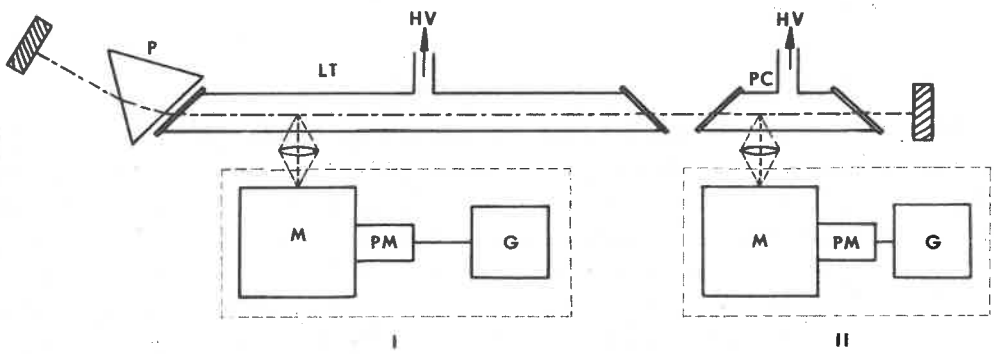

Fig. 1. Experimental set-up. LT — laser tube, PC — probe cell, HV — high vacuum system, P — prism, M — grating monochromator, PM — photomultiplier, G — galvanometer. I — detection system 1; II — detection system 2

longing to the $4p \rightarrow 3d$ array. The prism and Brewster windows were made of NaCl. The detection system I served to adjust and control the laser action. The spontaneous emission from the side of the probe cell, for the respective neon levels, was detected by system II.

The estimated error in the relative measurements was $\pm 2.5\%$ and the gas pressure was measured with an accuracy as good as 0.2 torr.

3. *Results and comments*

a. Transition probabilities

In the experiment, the intensity of the spontaneous emission from pairs of the levels, were measured with and without the respective laser line [14–16] (the levels and wavelengths of these lines are presented in columns 1, 2 and 3 in Table II). The changes in intensity (the difference between the intensity, when the laser action is switched on and off) measured as a function of neon pressure are related to the changes in the populations by

$$\frac{\Delta I_1}{\Delta I_2} = \frac{\Delta N_1}{\Delta N_2} \frac{A_1 \nu_1}{A_2 \nu_2}, \tag{3}$$

where ΔI_1, ΔI_2 are changes in the intensities of lines from the upper and lower laser levels; ΔN_1, ΔN_2 are induced changes in the population of the levels. The measurements allowed the plotting of the curve of the pressure dependence of population inversion for each laser transition (Fig. 2). The pressures, in which the inversion of populations between the respec-

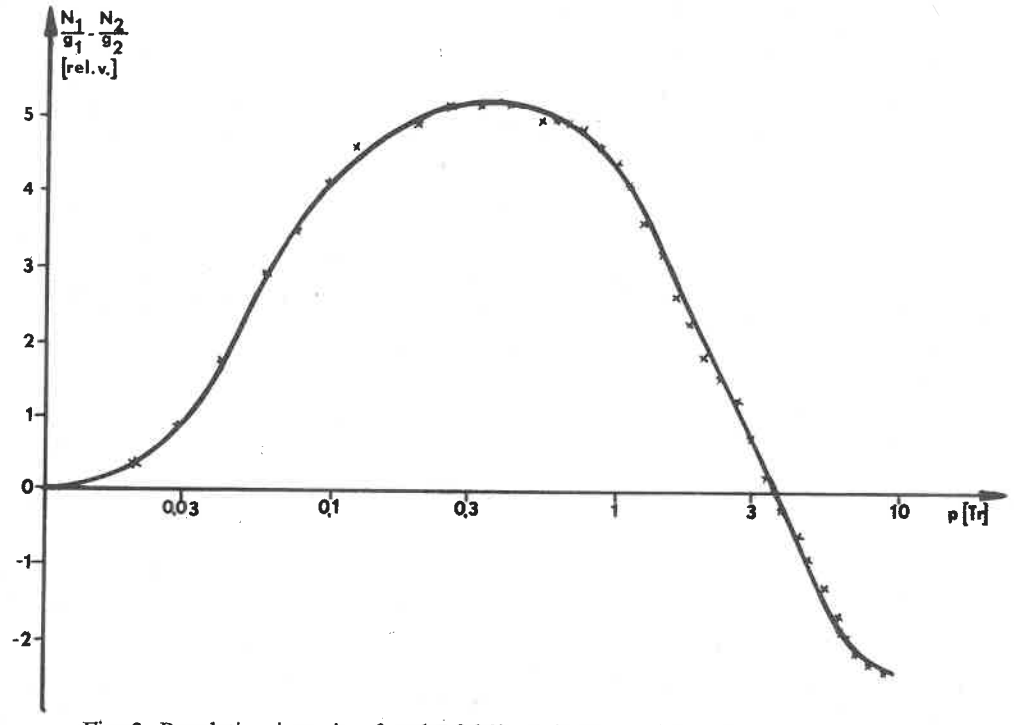

Fig. 2. Population inversion for the 8.060 μm laser transition versus neon pressure

tive $3d$ and $4p$ levels are equal to zero ($N_1/g_1 = N_2/g_2$), were established and the ratios of transition probabilities were obtained. From the data presented in [10], the probabilities for the $3d \rightarrow 3p$ transitions of Ne were calculated. Measured and calculated values are given in Table I. For comparison the last two columns give the theoretical transition probabilities computed by Murphy [17] and Lilly [18].

TABLE I

Wave length of laser line [μm]	Optimal* pressure [Torr]	Ratio of transition probabilities	$3d \rightarrow 3p$ transition probabilities in $10^6\ s^{-1}$		
			this experiment	Murphy [17]	Lilly [18]
5.403	0.2	$\frac{A_{3520}}{A_{7051}} = 2.6$	$A_{7051} = 3.59$	3.583	3.0
7.478	0.4	$\frac{A_{3447}}{A_{8300}} = 0.08$	$A_{8300} = 26.5$	14.286	14.27
7.614	0.3	$\frac{A_{3501}}{A_{8418}} = 0.05$	$A_{8418} = 23.2$	14.683	15.53
7.649	0.3	$\frac{A_{3515}}{A_{9495}} = 0.009$	$A_{8495} = 76.7$	35.152	37.95
7.699	0.4	$\frac{A_{3418}}{A_{7943}} = 0.17$	$A_{7943} = 5.41$	7.675	4.12
7.763	0.4	$\frac{A_{3461}}{A_{7059}} = 0.075$	$A_{7059} = 9.33$	11.115	9.35
8.007	0.6	$\frac{A_{3466}}{A_{8136}} = 0.087$	$A_{8136} = 14.4$	23.762	12.45
8.060	0.4	$\frac{A_{3472}}{A_{8378}} = 0.018$	$A_{8378} = 95.6$	49.288	49.23

* The pressure, in which the maximal inversion of the population was obtained.

b. Relative decay constants

The changes in the populations of $4p$ and $3d$ levels, when the laser action is switched on and off, also allowed the obtaining of the ratios of radiative decay constants for the above mentioned levels. Analyzing the rate equations for the steady-state population of the upper and lower laser levels, one obtains

$$\frac{\Delta N_2}{\Delta N_1} = \frac{\gamma_1 + \theta_1 - A_{12}}{\gamma_2 + \theta_2}, \tag{4}$$

where γ_1 and γ_2 are the radiative decay constants of the respective levels, and θ_1, θ_2 are their collision relaxation decay constants for processes involving nonradiative transitions from these levels to the other energy states of the atom, whereas A_{12} is the transition probability for spontaneous emission line between the levels 1 and 2. The ratio $\Delta N_2/\Delta N_1$ can be easily found from Eq. (3) using the data from Table I. In the limit of low pressure, where $\gamma_k \gg \theta_k$, Eq. (3) gives:

$$\frac{\Delta N_2}{\Delta N_1} = \frac{\gamma_1 - A_{12}}{\gamma_2}. \tag{5}$$

The ratio of the changes in populations induced by the laser line 8.060 μm (for example), as a function of neon pressure is presented in Fig. 3. From the dependence it is seen, that the value $\Delta N_2/\Delta N_1$ tends to a constant value for neon pressure below 0.25 Tr. For the other laser lines examined in this experiment, the pressure region, in which the collision relaxation processes are negligible, is nearly the same.

The values $\frac{\gamma_1 - A_{12}}{\gamma_2}$ obtained in the experiment for $4p$ and $3d$ levels are given in Table II. The last column of this table gives the analogous values calculated from the

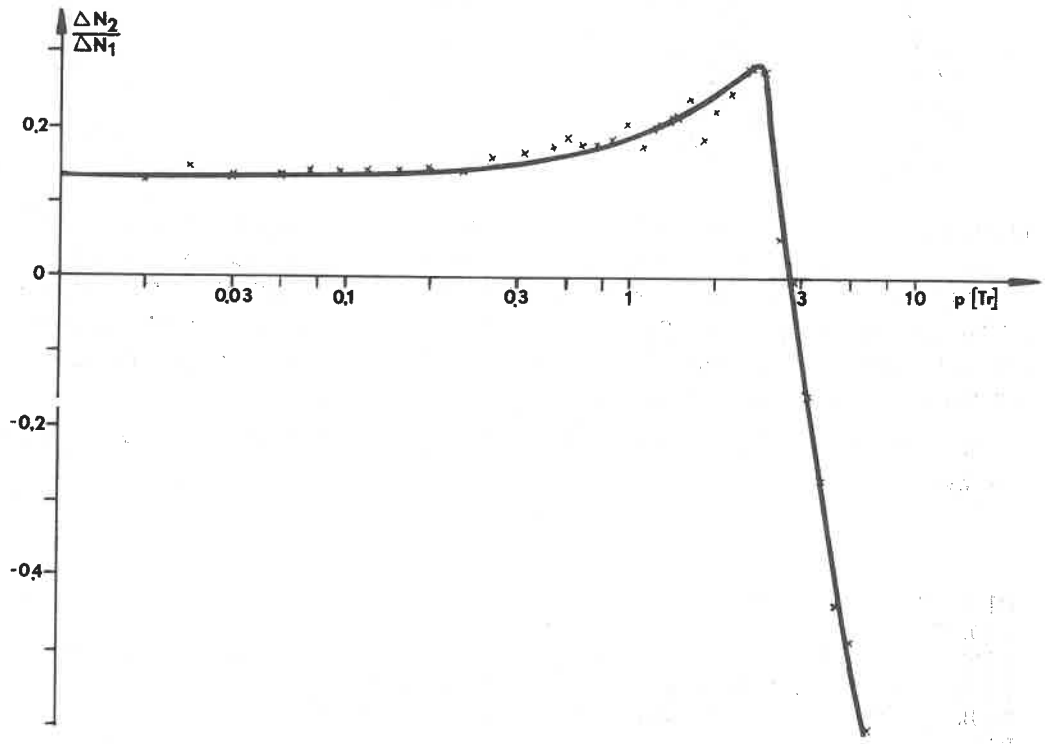

Fig. 3. The ratio of the population changes of the upper and lower laser levels for the 8.060 μm laser line of Ne[$4p[5/2]_3 \rightarrow 3d[7/2]_4$) versus neon pressure

transition probabilities presented in [17] and [19]. We estimate, that the obtained quantities are equal to the ratio of decay constants γ_1/γ_2 with the error no greater than 20% (the error is caused by neglecting A_{12}/γ_2 in Eq.(5)).

4. Conclusions

In this investigation we applied the plasma transparency method to measure the relative transition probabilities for the lines beginning from the upper and lower laser levels. The eight transition probabilities between $3p$ and $3d$ levels were obtained and com-

TABLE II

Upper level of laser line	Lower level of laser line	Wave length of laser line [μm]	$\frac{\gamma_1 - A_{12}}{\gamma_2}$	
			this experiment	calculated from [17] and [19]
$4p'[1/2]_0$	$3d'[3/2]_1$	5.403	0.405	0.350
$4p\,[3/2]_2$	$3d\,[5/2]_3$	7.478	0.240	0.205
$4p\,[3/2]_1$	$3d\,[5/2]_2$	7.614	0.150	0.187
$4p\,[5/2]_2$	$3d\,[7/2]_3$	7.649	0.125	0.157
$4p'[3/2]_2$	$3d'[5/2]_3$	7.699	0.193	0.163
$4p'[1/2]_1$	$3d'[3/2]_2$	7.763	0.055	0.166
$4p'[3/2]_1$	$3d'[5/2]_2$	8.007	0.150	0.150
$4p\,[5/2]_3$	$3d\,[7/2]_4$	8.060	0.135	0.152

pared with other results. In most cases good agreement with the theory was achieved. Because of the fact, that this is the first information about the measurements of these quantities, we did not have any experimental data to compare with them. The difficulty of the measurements lies in the fact that both, stimulated emission and detection are in the infrared spectrum. In addition, eight ratios of radiative decay constants were determined. All the results except one are similar to the theoretical data.

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