RATES OF TRANSITIONS BETWEEN NEON EXCITED LEVELS INDUCED BY ELECTRON COLLISIONS

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The excitation rates per particle $\langle\sigma v\rangle$ for transitions between neon excited states induced by electron impact are measured by the modulation technique described earlier.[1] Optical allowed ($4p'[^3/_2]_2 \rightarrow$ (4 to 6)d') as well as forbidden ($5s'[^1/_2]_1^\circ \rightarrow$ (4 to 6)d') transitions are investigated. In accordance with the fact that the initial states are strongly excited, these rates considerably exceed those for transitions from the ground state. The results are interpreted and compared with the theory.

1. INTRODUCTION

WE have previously described[1] a procedure for investigating the transfer of excitation in a gas-discharge plasma with the aid of a laser; this procedure makes it possible to measure the excitation rate per particle $\langle\sigma v\rangle$ for collisions of electrons or atoms with excited atoms. It is based on the fact that when an excited gas is exposed to the strong field of a laser having the same frequency as some transition in the gas (e.g., $2 \rightarrow 1$, see Fig. 1, where the neon levels are described in accordance with the Racah system[2]) the processes of stimulated emission and absorption change the populations N_2 and N_1 of the upper and lower levels of the transitions by amounts ΔN_2 and ΔN_1. No matter what the values of N_2 and N_1, the changes ΔN_2 and ΔN_1 are always opposite (with exception of the case $N_2 = N_1$, when the populations are not changed by irradiation), with

$$\Delta N_2/\Delta N_1 = -W_1/W_2, \quad (1)$$

where W_2 and W_1 are the total rates of de-excitation of levels 2 and 1. Periodic interruption of the laser radiation (modulation) causes modulation of the populations N_2 and N_1, with amplitudes ΔN_2 and ΔN_1 and with opposite phases. The intensities of all the spontaneous lines that begin with levels 2 and 1 are modulated together with the populations. Thus, owing to the modulation of the irradiation, the levels 2 and 1 stand out from among all the other levels. The occurrence of modulation of the populations at other levels is possible only by transfer of excitation from levels 2 or 1 (in spontaneous transitions or collisions).

In [1] we started from the following simple model. It was assumed (in accordance with the experimental observations of the modulation phases) that the population modulation at the levels 3 (Fig. 1), which lie higher than 2 and 1, are due exclusively to collision between electrons and atoms excited to the level 2 (transition $2 \rightarrow 3$ with probability $S_{23} = n_e\langle\sigma_{23}v\rangle$, where n_e is the electron density and $\langle\sigma_{23}v\rangle$ is the rate of the process. The possibility of excitation of the levels 3 in collisions between the electrons and atoms in state 1 was initially excluded. In this approximation, the ratio $\Delta N_3/\Delta N_2$ of the alternating parts (i.e., the modulation amplitudes) of the

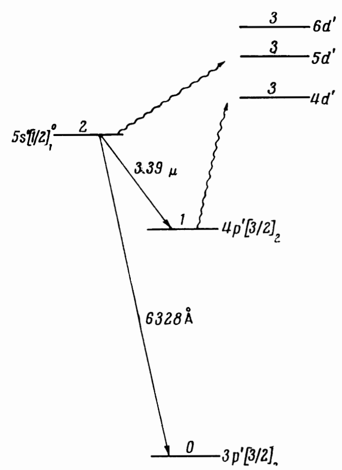

FIG. 1. Level scheme

populations at the levels 3 and 2 depends on the concentration of the electrons n_e in the following manner.[1)]

At small n_e, when the contribution of the electron collisions to the de-excitation of the levels 3 is small, the relative modulation amplitude $\Delta N_3/\Delta N_2$ is proportional to n_e, and the proportionality coefficient α is determined by the ratio of the rate $\langle\sigma_{23}v\rangle$ of the transition $2 \rightarrow 3$ to the rate W_3^R of the radiative de-excitation of the levels 3.

$$\alpha = \langle\sigma_{23}v\rangle / W_3^R$$

(Fig. 2a). With increasing n_e, the role of the electrons in the de-excitation of the levels 3 increases, and the proportionality between n_e and $\Delta N_3/\Delta N_2$ is violated; further, when the rate of the impact de-excitation of the levels 3 greatly exceeds the rate of their radiative de-excitation, the relative amplitude of the modulation $\Delta N_3/\Delta N_2$ ceases to depend on n_e. The corresponding asymptotic value of $\Delta N_3/\Delta N_2$ is determined by the ratio of $\langle\sigma_{23}v\rangle$ to the total rate $\langle\sigma_3 v\rangle$ of impact de-excitation,

[1)]It is assumed throughout that the rates of excitation, which determine the constant parts of the populations N_2 and N_1 (i.e., the rates of excitation from the ground and metastable states) do not change when the gas is illuminated. Experiment confirms this assumption with good accuracy [1].

$$\beta = \langle \sigma_{23} v \rangle / \langle \sigma_3 v \rangle$$

(Fig. 2a) The obtained dependence can be readily transformed into a linear one; to this end, it is sufficient to perform a hyperbolic transformation with respect to both axes and to plot the reciprocal density $1/n_e$ and the reciprocal relative modulation amplitude $\Delta N_2/\Delta N_3$ (Fig. 2b). The slope of this line and its intercept with the ordinate axis are determined by the reciprocals of the slope at zero and the asymptote of the curve of Fig. 2a.

Thus, if the simplified model is valid, experiment should yield the linear dependence of Fig. 2b. Going over to the reciprocal relative modulation amplitude $y = \Delta I_2/\Delta I_3$ of the intensities of the spontaneous lines, with respect to which the measurements are made, we obtain formulas (12)–(14) of [1] for the parameters of the line of Fig. 2b:

$$y = ax + b, \quad x = 1/n_e, \tag{2}$$

$$a = M_{23} W_3{}^R / \langle \sigma_{23} v \rangle, \quad b = M_{23} \langle \sigma_3 v \rangle / \langle \sigma_{23} v \rangle, \tag{3}$$

where $M_{23} = A_2 H_2 \nu_2 / A_3 H_3 \nu_3$ is the apparatus coefficient (A_2, A_3, ν_2, and ν_3 are the Einstein coefficients and the frequencies for the spontaneous lines; H_2 and H_3 are the corresponding spectral sensitivities of the recording apparatus).

In [1] we obtained a formula that takes into account the possibility of excitation from the lower level 1 (Fig. 1). It is clear that in this case the dependence of y on x remains principally the same, but the parameters a and b vary in accordance with the contribution of the lower level 1, the phase of the modulation of the population of the level 3 should be determined by the phase of the population modulation of that level (1 or 2) the excitation from which gives the greater contribution to the population N_3. We have (formula (17) of [1])

$$y = \frac{ax + b}{1 - S_{13} W_2 / W_1 S_{23}}, \tag{4}$$

where S_{13} is the probability of the transition $1 \to 3$ in collisions with electrons. The dependence (4) will be linear, as before, if the ratio W_2/W_1 does not depend (or depends weakly) on n_e. If the contribution of the process $1 \to 3$ is not larger than the contribution of the process $2 \to 3$, then the phase of the modulation of N_3 will coincide, as before, with the phase of N_2, and the parameters a and b increase in equal ratios.

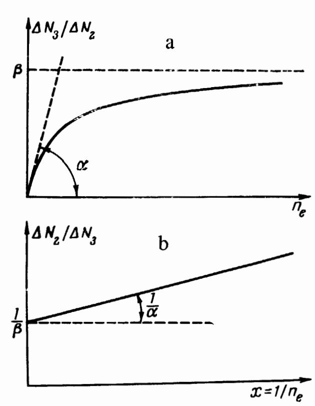

FIG. 2.

Experiments [1] confirmed the validity of the described model for certain levels of neon. However, the data were insufficient to determine the contribution of the excitation from the lower level in accordance with formula (4), since a single equation of type (4) is not enough for this purpose. In the present investigation, unlike in [1] the measurements were made with the excited neon illuminated with two generation lines, $\lambda = 3.39\ \mu$ ($2 \to 1$, Fig. 1) or $\lambda = 6328$ Å ($2 \to 0$, Fig. 1). As a result, owing to variation of the lower modulation level (1 or 2) at a constant upper level (2) we were able to obtain an additional equation of type (4) and to separate the rate of the transitions $1 \to 3$. In addition, as shown by experiment, probe measurements of n_e in an analog group[1] yielded electron densities that were too high by a factor 10–15. In the present investigation n_e was measured by a resonator method at centimeter wavelengths, thus ensuring not only the reliability of the new data, but also an appreciable refinement of the results of [1].

2. THE EXPERIMENT

The schematic diagram of the experiment is shown in Fig. 3. Direct measurements in the laser tube 1 itself are inconvenient, since variation of the discharge conditions greatly alters the generation power and consequently the useful signal. Therefore, unlike in [1], we introduced into the laser resonator a short measuring tube 2. Owing to its short length, it was possible to vary the discharge conditions in this tube over a wide range without noticeably changing the generation regime and the signal loss. In our setup the generator tube 1 had an active discharge-section length of 90 cm with inside diameter 0.3 cm; the measuring tube had an active working part (quartz) 5 cm long with an inside diameter 0.35 cm. Both tubes were fed with direct current from separate rectifiers. The measurement tube had an oxide cathode; the discharge current could be varied from zero to 150 mA. Generation in the helium-neon laser is possible at any of the following two neon transitions: $\lambda = 3.39\ \mu$ ($2 \to 1$, Fig. 1) and $\lambda = 6328$ Å ($2 \to 1$, Fig. 1). To change over from the ir generation line to the visible one it is sufficient to fill part of the resonator with methane (see Fig. 3) which absorbs the $\lambda = 3.39\ \mu$ radiation. The laser radiation is modulated with a shutter 6 at a frequency 40 Hz. The spontaneous emission of the discharge, emerging through the side walls of the tube 2, is guided to the entrance slit of a DFS-12 diffraction spectrometer (4), and an FÉU-38 photomultiplier (5) is located behind the spectrometer exit slit. The output signal of the photomultiplier is fed to a selective low-frequency amplifier (7), which separates the 40-Hz component of the signal. The filtered and amplified signal is detected with a synchronous detector (8) and registered with an automatic recorder (9).

The electron density n_e in tube 2 is measured with the aid of a microwave resonator 3 (Fig. 3). These measurements will be described in detail later; we only indicate that the resonator (cylindrical) operates on the TM_{020} mode with a resonance frequency $f_0 = 4460$ MHz ($\lambda_0 \cong 6.7$ cm), and the typical values of n_e under our conditions are of the order of 10^{11} cm^{-3}. The changeover from probe measurements to resonator measure-

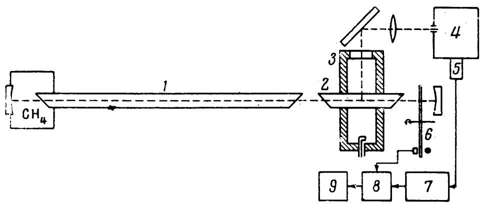

FIG. 3. Experimental setup

ments has made it possible not only to measure n_e reliably, but also to do this simultaneously with the measurements of the line-intensity modulation amplitudes. Thus, we eliminated the serious systematic errors connected with the fact that the measurements of n_e and the intensity modulation are measured at different times.

The electron temperature T_e (i.e., their average energy), is of no fundamental significance for our measurements, since the energy of all the investigated transitions does not exceed 1 eV, which is much lower than kT_e (~10 eV). Under such conditions, small changes of T_e, by several electron volts, have practically no influence on the measurement results. For the same reason, deviations from a Maxwellian electron velocity distribution, which are observed in the region of large velocities,[3] are of no significance to us. According to experimental data,[4] T_e in a helium-neon discharge satisfies the similarity laws quite well; we therefore did not measure T_e, but calculated it from the universal relation derived by Von Engel and Steenbeck.[5] The accuracy of these calculations is perfectly adequate for our purposes. To increase T_e and consequently the populations of the investigated levels, the measurement tube was filled not with pure neon, but with a He–Ne mixture in a ratio 10:1, the mixture pressure being varied in the range 1–2.7 Torr.

In the present investigation we studied the following transitions between the excited neon levels in collisions with electrons (see Fig. 1; the levels are designated in accordance with the Racah system,[2] and the parentheses indicate the wavelengths of the lines with respect to which the measurements were made):

$$5s'[{}^1/_2]_1{}^0(\lambda = 6046\ \text{Å}) \to 4d'(\lambda = 5902\ \text{Å}),\quad 5d'(\lambda = 5145\ \text{Å}),$$
$$6d'(\lambda = 4810\ \text{Å}),\quad 5p'[{}^1/_2]_0(\lambda = 3057\ \text{Å});\quad 4p'[{}^3/_2]_2 \to 4 - 6d'.$$

To measure the relative amplitudes of the intensity modulation, the spectral sensitivity of the DFS-12 with the FÉU-38 was calibrated in the visible region (4600–6500 Å, order II) against the radiation of a standard ribbon lamp. In the ultraviolet region (order III, FÉU-39) the calibration was against the radiation of a hydrogen lamp, but since this lamp is not a standard, the calibration can be regarded as true only accurate to a factor ~2. Accordingly, the absolutization of the results for the transition $5s' \to 5p'$ is possible with the same accuracy.

The depth of modulation of the populations of the initial levels (i.e., $5s'[{}^1/_2]_1^0$ and $4p'[{}^3/_2]_2$) ranges from 5 to 20%, depending on the experimental conditions. At the final levels (4 to 6d′, 5p′), however, the modulation depth is much smaller, from 1 to 5%. Therefore exposure of the photomultiplier to the unmodulated part of the radi-

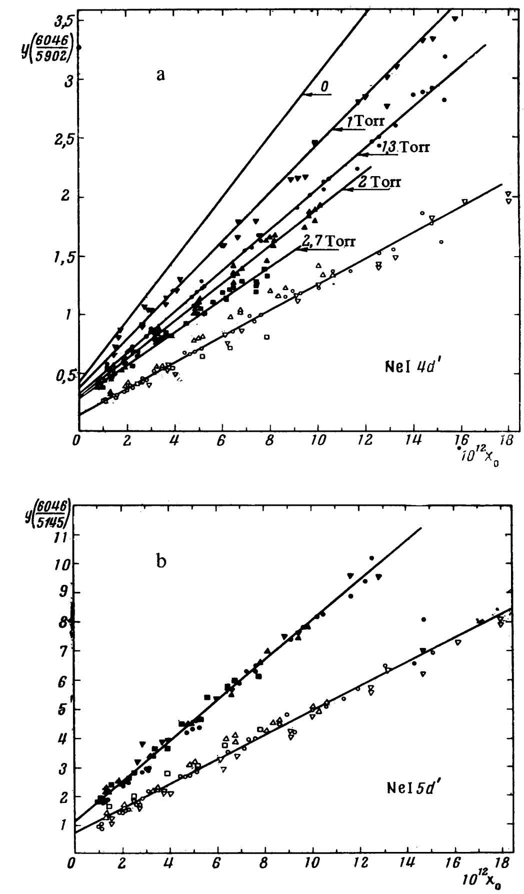

FIG. 4. Results of experiments

ation gives rise to a strong shot noise, which is comparable with the useful signal in the case of the highest investigated levels. To separate this signal, the lines were recorded slowly with a large time constant (the time to plot the line was ~ 60 sec and the time constant 3 sec). We note that here, unlike in [1], the amplitude of the population modulation at the initial level $5s'[{}^1/_2]_1^0$ (2, Fig. 1) was investigated by means of the emission of the line λ = 6046 Å and not λ = 6328 Å. This made it possible to eliminate the systematic errors connected with the scattering of the laser radiation with λ = 6328 Å in the walls of the tube.

The nd′ configurations have each four levels, of which three are very close together (our apparatus does not resolve them), and the fourth is located $\lesssim$ 10 cm^{-1} from the first three. The emission of the separately located fourth levels amounts to only 10–15% of the emission of the closely-lying groups of three, so that our results can be regarded as valid for the nd′ configurations as a whole (accurate to the emission of the fourth levels).

3. RESULTS AND THEIR DISCUSSION

Figures 4a–d show the results of measurements for the levels 4 to 6d′ and $5p'[{}^1/_2]_0$. The points show the dependence of the quantities $y = \Delta I_2/\Delta I_3$ on $x = 1/n_{e0}$ (n_{e0}—electron density on the discharge axis, where the

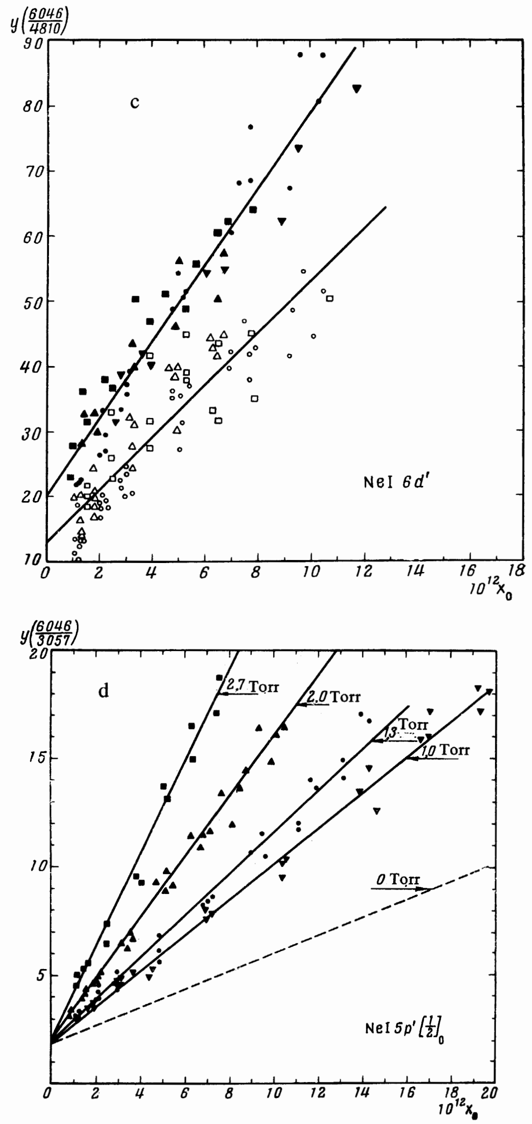

FIG. 4. (cont'd)

observation is carried out). For all the levels (with the exception of $5p'[{}^1\!/_2]_0$, Fig. 4d), the measurements were made with the gas illuminated with both generation lines: λ = 6328 Å (light circles) and λ = 3.39 μ (filled circles). The least-squares method was used to fit the linear functions (2) to the experimental points and to determine the corresponding parameters a and b (3), which are listed in Table I for the levels 4 to 6d′. For the level $5p'[{}^1\!/_2]_0$ (Fig. 4d), the absolute calibration of the ordinate scale is not reliable, but in an arbitrary scale the results are just as accurate as in Figs. 4a–c.

Attention is called here to two effects: first, the dependence of the parameters of the straight lines in Figs. 4a–c on the modulating transition (no measurements could be made for the level $5p'[{}^1\!/_2]_0$ with illumination by the 6328 Å line, owing to the insufficient sensitivity); second, a strong dependence of the slope of the lines on the mixture pressure is observed for the levels 4d′ and $5p'[{}^1\!/_2]_0$ when 3.39 μ illumination is used.

The pressure effect is most probably connected with

Table I

Levels	Modulating line	P, Torr	Number of points	$10^{-12}\,a$	b	a_{20}/a_{21}	b_{20}/b_{21}	S_3/W_3R
4d′	6328 (2→0)	1–2.7	80	0.112±0.002	0.14±0.02	0.47±0.05	0.44±0.09	0.38
	3,39 (2→1)	2.7	42	0.138±0.003	0.31±0.02			
		2.0	46	0.164±0.002	0.28±0.02			
		1.3	40	0.177±0.002	0.32±0.02			
		1.0	38	0.210±0.004	0.38±0.04			
		0 (extrapolation)	166	0.24±0.02	0.32±0.02			
5d′	6328 (2→0)	1–2.7	81	0.418±0.006	0.76±0.05	0.60±0.02	0.67±0.07	0.54
	3,39 (2→1)	1–2.7	68	0.693±0.008	1.13±0.05			
6d′	6328 (2→0)	1–2.7	76	4.07±0.21	12.8±1.0	0.68±0.06	0.64±0.09	0.94
	3,39 (2→1)	1–2.7	58	5.96±0.22	20.1±1.2			

the transition 5p′→ 4d′ (ΔE = −0.10 eV), which occurs in atom–atom collisions. However, a detailed investigation of the atom–atom collisions is not part of our program, and therefore to obtain data free of pressure effects we extrapolate the slope of the lines to zero pressure by least-squares. Such an extrapolation is possible for the 4d′ levels with accuracy better than 5%; the corresponding results are shown in Table I. For the $5p'[{}^1\!/_2]_0$ level, the extrapolation is less accurate, but this is immaterial, since a sufficiently accurate absolutization of the corresponding result is impossible here.

Now, eliminating the pressure effect, we turn to the changes of the parameters of the straight lines for the levels nd′ (3, Fig. 1) on going from illumination with the λ = 6328 Å to illumination with the λ = 3.39 μ line. Such a transition means replacement of the level 0 by the level 1, which is closer to 3 (Fig. 1), i.e., an increase of the rate of excitation from the lower modulating level. As expected (see formula (4)), the parameters a and b increase in this case. The constancy of the phase of N_3 (which in our conditions always coincides with the phase of N_2) indicates that the contribution of the process 1 → 3 to N_3, while significant, is still smaller than the contribution of the process 2 → 3. The correctness of the interpretation of the dependence of a and b on the modulating line is confirmed by the fact that, as follows from Table I, both parameters for each of the nd′ configurations change in equal ratios (accurate to the measurement errors).

From formula (4) it is easy to find that the ratios of the parameters of the straight lines as functions of the modulating line are given by the expression

$$k = \frac{a_{20}}{a_{21}} = \frac{b_{20}}{b_{21}} = \frac{1 - S_{13}W_2/W_1S_{23}}{1 - S_{03}W_2/W_0S_{23}}. \tag{5}$$

From the experimental values of k in Table I we can find the ratio of the rates of the processes 1 → 3 and 2 → 3. To this end, we assume that the contribution of the process 0 → 3 to N_3 is negligibly small compared with the contribution of the process $2 \rightarrow 3$; then the denominator in (5) is close to unity, and we get

$$k = 1 - \frac{S_{13}}{W_1}\frac{W_2}{S_{23}}. \qquad (6)$$

For the ratio of the rates of the processes we obtain, after transforming,

$$\langle \sigma_{13} v \rangle = \langle \sigma_{23} v \rangle \frac{W_1}{W_2}(1-k). \qquad (7)$$

Neglect of the second term in the denominator (5) underestimates the final result for $\langle \sigma_{13} v \rangle$ in (7) by at most 50%, and in fact results in a much smaller error. This can be readily demonstrated with the aid of arithmetic manipulations, starting from the fact that the experimental values of k are positive and do not exceed 0.7. The smallness of the contribution of the process $0 \rightarrow 3$ compared with the contribution of the process $2 \rightarrow 3$ is confirmed also by theoretical data (see below).

In this approximation we can assume that the data obtained upon irradiation of the lines $\lambda = 6328$ Å ($2 \rightarrow 0$) are free of effects of excitation from the level 0. Then, combining the parameters a and b from (3), we get

$$S_3/W_3^R = bn_e/a, \qquad (8)$$

$$\langle \sigma_{23} v \rangle = \frac{A_2}{a_{20}}\frac{W_3^R}{A_3}\frac{H_2\nu_2}{H_3\nu_3}. \qquad (9)$$

Formula (8) makes it possible to calculate directly from the experimental data the ratio of the total velocities of the shock and radiative de-excitations of the levels 3. It is most important that this does not require any transition probabilities or similar data, and furthermore the result (8) does not depend on the excitation from the lower level (1 or 0). The corresponding figures for the density $n_e = 3 \times 10^{11}$ cm^{-3}, which is typical under our conditions, are given in the last column of Table I. They show that with increasing principal quantum number n the role of the shock de-excitation of the levels nd′ increases and for the configuration 6d′ the shock and radiative de-excitations are equal. These results are perfectly valid, since the total rate of radiative de-excitation decreases with increasing n.

Using formula (9), we can find the $2 \rightarrow 3$ rates, and then with the aid of (7) also the $1 \rightarrow 3$ excitation rate. To this end, however, it is necessary to have additional data on the Einstein coefficients for the lines used for the measurements, and also to know the total rates of radiative de-excitation of the levels. It is clear from (7)–(9) that the absolute value is required only for the coefficients A_2. All the remaining characteristics of the levels and transitions enter in the formulas in the form of relative quantities: such are the "branching ratios" W_3^R/A_3, which characterize the role of one concrete transition in the total rate of radiative de-excitation of the levels, and such is the ratio W_1/W_2 of the total de-excitation rates.

As a result of a reprocessing of our measurements,[6] the Einstein coefficient A_2 for the neon line $\lambda = 6046$ Å ($5s'[{}^1\!/_2]_1^0 \rightarrow 3p[{}^3\!/_2]_1$) was found to be 0.44×10^6 sec^{-1}. The relative quantities can be obtained quite reliably by theoretical calculations. The "branching ratios" W_3^R/A_3 for the levels 4d′ and 5d′ were obtained with the aid of a combination of calculations by the method of [7] and experimental measurements, and are equal respectively to ≈ 7 and 12 (accurate to ~ 30%).[1] For the levels 6d′ and $5p'[{}^1\!/_2]_0$ we obtained for W_3^R/A_3 by calculation the respective values 20 and 4. The smallest amount of additional data is required to determine the rate of the forbidden transitions $2 \rightarrow 3$ (s′ → d′). When finding the rates of the allowed transitions $1 \rightarrow 3$ (p′ → d′) it is necessary to use, in accordance with (7), also the ratio W_1/W_2. Unfortunately, this ratio was not measured experimentally directly, but it would be possible to use separate measurements of W_2[8] and W_1.[9,10] However, the measurements in [9,10] yield for W_1 an exceptionally large value, $\sim 0.7 \times 10^9$ sec^{-1}. These measurements were made at a relatively high pressure, and the measurement method was such that the obtained value is apparently not free of the contribution of elastic collisions. Under such conditions, the determination of the ratio W_1/W_2 from the data of [8–10] could lead to errors, and we deemed it more reliable to use the calculated value $W_1/W_2 \approx 1.0$.

The excitation rates $\langle \sigma v \rangle_{exp}$ obtained from the experimental data are summarized in Table II together with the transition parameters (ΔE—excitation energy). As already mentioned in Sec. 1, the rates of the two forbidden transitions ($5s'[{}^1\!/_2]_1^0 \rightarrow$ 4d′, 5d′) were measured earlier;[1] in the present investigation these results were greatly improved by eliminating serious system atic errors connected with the unreliable measurement of n_e and with the scattering of the laser radiation with $\lambda = 6328$ Å. The reliability of the rates of the forbidden transitions 5s′ → nd′ listed in Table II is estimated at approximately ± 50%. On the other hand, an additional contribution is made to the error in the rates of the allowed transitions 4p′ → nd′ both by the neglect of the process $0 \rightarrow 3$ and by the uncertainty of the ratio W_1/W_2. The rate of the transition 5s′ → 5p′ can be regarded as reliable within a factor ~ 2.

The experimental values of $\langle \sigma v \rangle$ in Table II exceed by several orders of magnitude the typical values of $\langle \sigma v \rangle$ for transitions from the ground state ($\sim 10^{-8}$ cm^3/sec). This can be readily ascribed to the fact that in our case the initial states are strongly excited (n is equal to 4 and 5), and the mere geometrical cross section of the excited atom exceeds by hundreds of times the geometrical cross section of the atom in the ground state.

The obtained data are of interest from the point of view of verifying the applicability of the theoretical calculations. The most suitable for large scale calculations of the rates of transitions between excited states

Table II

Transition	ΔE, ev	$\beta = \Delta E/kT_e$ for $kT_e \approx 10$ ev	$10^8 \langle \sigma v \rangle$ exp, cm^3/sec	$10^8 \langle \sigma v \rangle$ theor cm^3/sec: 1st Born approximation	2nd Born approximation
$5s'[{}^1\!/_2]_1^0 \rightarrow 4d'$	0.14	0.014	2200	500	—
$\rightarrow 5d'$	0.45	0.045	370	41	260 (5p′) *
$\rightarrow 6d'$	0.62	0.062	39	13	56 (5p′)
					44 (6p′)
$4p'[{}^3\!/_2]_2 \rightarrow 4d'$	0.51	0.051	1230	1730	—
$\rightarrow 5d'$	0.82	0.082	14	178	—
$\rightarrow 6d'$	0.98	0.098	14	54	—
$5s'[{}^1\!/_2]_1^0 \rightarrow 5p'[{}^1\!/_2]_0$	0.24	0.024	~ 300	320	—

*) The parentheses in the last column indicate the virtual intermediate level.

is the Born method, being quite universal.[11] However, owing to the lack of direct experimental data, there is no assurance that the Born approximation is applicable to such transitions. The available data on the broadening of the spectral lines in a plasma (see, e.g., [12]) are only indirect and cannot be regarded as a proof of the applicability of the Born method.

In this connection, we calculated the rates of transitions in the generalized Born approximation,[11,13] using an M-20 computer. The results of the calculations are given in the last two columns of Table II. The transition rates calculated in the first Born approximation agree well with the experiment in the case of the allowed transitions $p' \to d'$ and $s' \to p'$. On the other hand, in the case of the forbidden transitions $s' \to d'$ calculation in first approximation gives strongly undervalued results. Much better agreement is obtained for these transitions using a second-approximation calculation with allowance for only one virtual intermediate level (as indicated in the parentheses in Table II). Comparison of the data apparently offers evidence in favor of the applicability of the Born approximation to calculation of transitions between excited states. Only in the $4p' \to 6d'$ transition is a noticeable disparity of the results observed. It is not excluded that this is connected with the interference of the transitions via the virtual intermediate levels, the number of which is quite large between $4p'$ and $6d'$.

The fact that theory gives reasonable results for the transition rates between the excited levels of neon make it possible to prove the validity of neglecting the process $0 \to 3$ in formula (5). Indeed, as shown by calculations, the rates of the transitions $0 \to 3$ ($3p' \to nd'$) are on the average smaller by one and a half or two orders of magnitude than the rates of the corresponding transitions $2 \to 3$ ($5s' \to nd'$). Since the condition for neglecting is

$$S_{03} / S_{23} \ll W_0 / W_2,$$

and the ratio W_0/W_2 is close to unity in accordance with the calculated and experimental data[8,14], the inequality $S_{03}/S_{23} \ll 1$ can be regarded as satisfied. Thus, the additional error in $\langle \sigma v \rangle$ for the allowed transitions $4p' \to nd'$ is connected only with the uncertainty in the ratio W_1/W_2.

We note in conclusion that the described experiments yield values of $\langle \sigma v \rangle$ which include all the possible transitions between the levels under consideration, including stepwise transitions. Experiment has shown, however, that noticeable depths of modulation of the populations take place essentially at the levels investigated here. It can therefore be assumed that the contribution of the stepwise processes is small compared with the direct processes, and the values of $\langle \sigma v \rangle$ correspond in practice to direct processes.

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