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# CHANGES IN THE POPULATION OF NEON LEVELS INDUCED BY 0.61 μm, 0.63 μm AND 3.39 μm LASER ACTION

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Relative changes in the intensities of some selected spectral lines of neon in an He–Ne mixture which occur at the instant laser action is initiated have been measured. From the obtained data conclusions have been arrived at as regards the mechanism by which excitation is transferred between different energy levels of neon. Moreover, the ratio of the $3s_2$ level's decay constant and the probability of spontaneous $3s_2 \rightarrow 3p_4$ emission has been determined.

## 1. *Introduction*

The interaction of a generated standing wave with atoms of the active medium in a laser cavity leads to essential changes in the population of the various levels of the active atoms. The changes in level populations of active atoms in the gas mixture filling the laser show up at commencement of laser action as changes in the ratio of line intensities of spontaneous emission due to transitions between levels associated directly or indirectly with those which participate in laser action. The phenomenon of changes in spectral line intensities in the presence and absence of laser action may provide a great deal of information about the atomic properties of the laser medium. The intensity of a spectral line associated with spontaneous transitions between two energy states of an atom is proportional to the population of the higher atomic state. By "population of a state" we understand here the number of atoms in a given energy state in a unit volume. Denoting the population of state $k$ by $N_k$, we express the energy emitted from a unit volume into a full solid angle within unit time by means of the formula [1]

$$I = h\nu_{kl}\gamma_{kl}N_k \tag{1}$$

where $h\nu_{kl}$ is the quantum of energy emitted in the transition from level $k$ to level $l$, and $\gamma_{lk}$ is the probability of the spontaneous $k \rightarrow l$ transition. If laser action develops between

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the $k$ and $l$ states, then owing to the strong stimulation of transitions from the upper level $k$ to the lower level $l$ the population of the $k$ level becomes decreased while that of level $l$ increases. The intensities of all lines of spontaneous emission from these levels will also change correspondingly. Depending on the direction of observation the profiles of the inhomogeneously broadened spectral lines differ somewhat. When observing the spectrum along the axis of the resonance cavity of the laser, the lines have a Doppler shape (insofar as Doppler broadening predominates) with a structure of narrow absorption minima for lines from the upper level of the laser transition and a structure of peaks for lines from the lower level. This phenonemon appears because there are some modes of natural vibrations of the resonance cavity for which laser action may develop, and some for which it may not [2]. The profile of the spectral line observed perpendicularly to the laser cavity is Dopplerian.

## 2. *Method of studies*

In order to make an analysis of the change in population in the presence and absence of laser action, let us consider the simplified scheme of energy levels in Figs 1, 2, 3 and 4. Let us assume we are dealing with a continuously-operating laser and we consider the stationary states of the system. Four of the excited atomic levels are denoted by the numbers 1, 0, 2, 3. Spontaneous transitions are drawn as the wavy lines, whereas the laser transitions are represented by the bold straight lines. Moreover, we introduce the notation $\gamma_k$ as the decay constants of levels $k$, and $\gamma_{20}$, $\gamma_{21}$ and $\gamma_{01}$ as the probability of the 2 → 0, 2 → 1 and 0 → 1 spontaneous transitions. The decay constants $\gamma_k$ also take account of the radiationless processes of excitation transfer to other energy states of the atom, thereby leading to a rise in the decay of the given level. On the other hand, they do not account for stimulated processes.

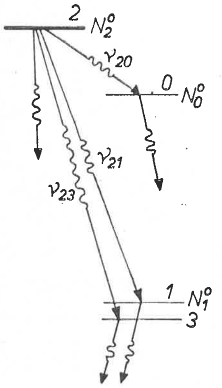

Fig. 1

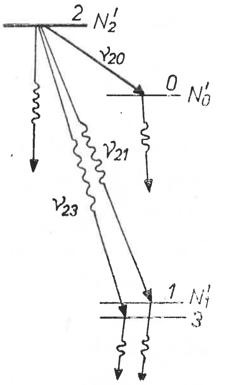

Fig. 2

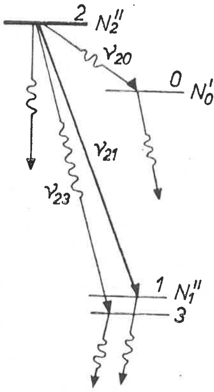

Fig. 3

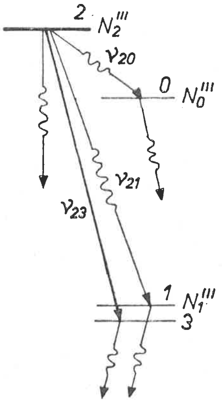

Fig. 4

It is obvious that $\gamma_k$ thus defined depends on experimental conditions, that is, the partial pressures of the gases of the active medium, temperature, ionization of the gas, and so on. Independently of the laser action power and at a fixed current supply of the laser, the influx of atoms of a given energy state per unit time and volume is described by the constants $R_k$. Finally, we denote by $R_{21}$ ($l = 0, 1, 3$) the rate of pumping from state 2 to state $l$ of the atoms induced by laser action.

Let us consider four different cases corresponding to the:

1) absence of laser action (Fig. 1),
2) presence of laser action 2 → 0 (Fig. 2),
3) presence of laser action 2 → 1 (Fig. 3), and
4) presence of laser action 2 → 3 (Fig. 4).

We denote the populations of level $k$ in the cases 1, 2, 3 and 4 by $N_k^0$, $N'_k$, $N''_k$ and $N'''_k$, respectively. For the specified eventualities we can write equations giving the balance of level populations in the stationary state [3]. In case 1) (Fig. 1) we see that

$$N_2^0 \cdot \gamma_2 = R_2 \qquad \text{(1a)}$$

$$N_0^0 \gamma_0 = R_0 + N_2^0 \gamma_{20} \qquad \text{(1b)}$$

$$N_1^0 \gamma_1 = R_1 + N_2^0 \gamma_{21} + N_0^0 \gamma_{01}. \qquad \text{(1c)}$$

In a similar way we obtain in succession the respective equations for the other cases:

$$N'_2 \gamma_2 = R_2 - R_{20} \qquad \text{(2a)}$$

$$N'_0 \gamma_0 = R_0 + R_{20} + N'_2 \gamma_{20} \qquad \text{(2b)}$$

$$N'_1 \gamma_1 = R_1 + N'_2 \gamma_{21} + N'_0 \gamma_{01} \qquad \text{(2c)}$$

$$N''_2 \gamma_2 = R_2 - R_{21} \qquad \text{(3a)}$$

$$N''_0 \gamma_0 = R_0 + N''_2 \gamma_{20} \qquad \text{(3b)}$$

$$N''_1 \gamma_1 = R_1 + R_{21} + N''_2 \gamma_{21} + N''_0 \gamma_{01} \qquad \text{(3c)}$$

$$N'''_2 \gamma_2 = R_2 - R_{23} \qquad \text{(4a)}$$

$$N'''_0 \gamma_0 = R_0 + N'''_2 \gamma_{20} \qquad \text{(4b)}$$

$$N'''_1 \gamma_1 = R_1 + N'''_2 \gamma_{21} + N'''_0 \gamma_{01}. \qquad \text{(4c)}$$

We can find the change in the population of a given level when the appropriate laser action is initiated by solving the systems of equations (1a, b, c), (2a, b, c), (3a, b, c) and (4a, b, c). When we initiate the 2 → 0 laser action the changes in level populations are described by the following equations:

$$N'_0 - N_0^0 = \frac{\gamma_2 - \gamma_{20}}{\gamma_0} (N_2^0 - N'_2) \qquad \text{(5)}$$

$$N'_1 - N_1^0 = \frac{\gamma_{21} - \delta \left( \dfrac{\gamma_2}{\gamma_{20}} - 1 \right)}{\gamma_1} (N'_2 - N_2^0) \qquad \text{(6}$$

where $\delta = \dfrac{\gamma_{20}\gamma_{01}}{\gamma_0}$. The solution in the case when 2 → 1 and 2 → 3 laser actions are initiated give the next equations:

$$N_0'' - N_0^0 = \frac{\gamma_{20}}{\gamma_0}(N_2'' - N_2^0) \tag{7}$$

$$N_1'' - N_1^0 = \frac{\gamma_2 - \gamma_{21} - \delta}{\gamma_1}(N_2^0 - N_2'') \tag{8}$$

$$N_1''' - N_1^0 = \frac{\gamma_{21} + \delta}{\gamma_1}(N_2''' - N_2^0). \tag{9}$$

In addition, from Eqs (1a), (2a), (3a) and (4a) we get

$$\frac{N_2^0 - N_2'}{N_2^0} = \frac{R_{20}}{R_2}, \quad \frac{N_2^0 - N_2''}{N_2^0} = \frac{R_{21}}{R_2}, \quad \frac{N_2^0 - N_2'''}{N_2^0} = \frac{R_{23}}{R_2}.$$

As there is the relation $\dfrac{N_2^0 - N_2}{N_2^0} = \dfrac{I_2^0 - I_2}{I_2^0}$ (where $I_2$ is the intensity of the spectral line due to the transition beginning at level 2), the quantities $R_{20}/R_2$, $R_{21}/R_2$ and $R_{23}/R_2$ can be determined experimentally. The quantity $R_{2l}$ ($l = 0, 1, 3$) is the number of photon, emitted from unit volume per unit time in the process of the stimulated 2 → $l$ emissions and multiplying this quantity by the "active volume of the laser" should yield the number of photons which are lost by the laser cavity. The relations (5) to (9) may be used for determining the ratio of atomic level populations if the relevant decay constants and spontaneous transition probabilities are known. In subsequent considerations it will be convenient to present the relations mentioned above in somewhat different forms:

$$\alpha_0 = \frac{\dfrac{N_0'}{N_0^0} - 1}{1 - \dfrac{N_2'}{N_2^0}} = \frac{\gamma_2 - \gamma_{20}}{\gamma_0}\,\frac{N_2^0}{N_0^0} \tag{10}$$

$$\beta_0 = \frac{\dfrac{N_1'}{N_1^0} - 1}{\dfrac{N_2'}{N_2^0} - 1} = \frac{\gamma_{21} - \delta\left(\dfrac{\gamma_2}{\gamma_{20}} - 1\right)}{\gamma_1}\,\frac{N_2^0}{N_1^0} \tag{11}$$

$$\alpha_1 = \frac{\dfrac{N_0''}{N_0^0} - 1}{\dfrac{N_2''}{N_2^0} - 1} = \frac{\gamma_{20}}{\gamma_0}\,\frac{N_2^0}{N_0^0} \tag{12}$$

$$\beta_1 = \frac{\dfrac{N_1''}{N_1^0} - 1}{1 - \dfrac{N_2''}{N_2^0}} = \frac{\gamma_2 - \gamma_{21} - \delta}{\gamma_1} \frac{N_2^0}{N_1^0} \tag{13}$$

$$\beta_3 = \frac{\dfrac{N_1'''}{N_1^0} - 1}{\dfrac{N_2'''}{N_2^0} - 1} = \frac{\gamma_{21} + \delta}{\gamma_1} \cdot \frac{N_2^0}{N_1^0}\,. \tag{14}$$

The coefficients $\alpha$ and $\beta$ can be determined experimentally by measuring the changes in intensity of the relevant spectral lines at the instant laser action is initiated, as the relative changes in level populations are equal to the relative changes in intensity of the spectral

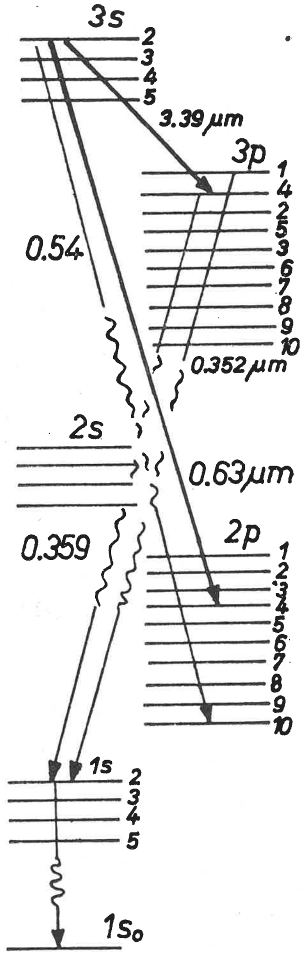

Fig. 5. Scheme of neon levels considered in this study

lines originating at these levels. The coefficients $\alpha_0$ and $\beta_0$ concern the case when the $2 \rightarrow 0$ laser action is initiated, $\alpha_1$ and $\beta_1$ corresponds to the $2 \rightarrow 1$ transition, and $\beta_3$ to the $2 \rightarrow 3$ transition. In turn, the relative changes in intensity of spectral lines can be expressed (assuming the detector is linear) by the relative changes of detector current.

In this work, the processes occurring during the electric discharge in an He–Ne laser tube were studied by utilizing the changes which are brought about by laser action. At the outset, we chose for the studies the 3.39 μm ($3s_2 \rightarrow 3p_4$), 0.63 μm ($3s_2 \rightarrow 2p_4$) and 0.61 μm ($3s_2 \rightarrow 2p_6$) laser transitions. The scheme of neon energy levels necessary in subsequent considerations is given in Fig. 5. The energy states 2, 0, 1 and 3 of the simplified scheme correspond respectively to the $3s_2$, $3p_4$, $2p_4$ and $2p_6$ states of the neon atom. Therefore, the formulae (5), (6), (10) and (11) describe the case when the 3.39 μm laser action is initiated, (7), (8), (12) and (13) when the 0.63 μm laser action is concerned, and (14) when the 0.61 μm action is considered. The possibility of achieving separated laser actions in mention allow the ratios $\gamma_2 : \gamma_{20}$, $\gamma_2 : \gamma_{21}$ and $\gamma_2 : \delta$ to be determined by appropriate manipulations with the results obtained in the four analyzed cases. A noteworthy virtue of this method is the avoidance of the use of the detector's spectral sensitivity curve when determining the ratio of atomic transition probabilities. The relative population of the $3s_2$ level was found by measuring the change in intensity of the 0.54 μm line corresponding to the $3s_2 \rightarrow 2p_{10}$ transition.

In a similar way, measurements of the relative populations of the other levels employed the transitions:
$3p_1 \rightarrow 1s_2$ (0.352 μm), $3p_4 \rightarrow 1s_2$ (0.359 μm), $3p_5 \rightarrow 1s_2$ (0.36 μm), $2p_4 \rightarrow 1s_5$ (0.59 μm), and $2p_2 \rightarrow 1s_4$ (0.60 μm).

## 3. *Experimental conditions*

The experimental set-up consisted of an He–Ne laser with a prism permitting selection of stimulated transitions, and an arrangement for measuring the intensity of the investigated lines of spontaneous emission (Fig. 6). At first, experiments were carried out with a laser tube without the prism. Measurements made under these conditions showed that the changes in spectral line intensities were diverse, depending on the way in which laser action at 0.63 μm was interrupted (whether a plate of fused silica glass was placed into the resonance cavity).

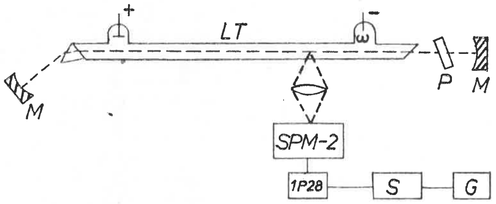

Fig. 6. Experimental set-up. *M* — mirrors, *LT* — laser tube, *L* — converging lens, *P* — fused quartz plane-parallel platelet, *SPM*-2 — grating monochromator, *IP*-28 — photomultiplier, *S* — high-voltage supply, *G* — galvanometer

An analysis of the changes in intensity of various lines due to transitions from the $3s_2$ and $3p_4$ states led to the conclusion that even when the laser is adjusted at 0.63 μm oscillations there appears at the same time, indeed, with considerable intensity, the 3.39 μm laser transition. It proved, therefore, that to get unique results use must be made of a laser with a dispersive medium inside the resonance cavity, which allows infallible separation of only one predetermined laser transition. Hence, in the final version a 1300 mm long laser tube was employed, terminated at one end by a quartz Brewster window and at the other by a 68° quartz prism [4]. The laser tube was supplied with d.c. current from a current-stabilized high-voltage power supply unit. With the use of mirrors of reflectivity of 99.9% for the 0.63 μm line, other laser actions were also obtained in the laser described here; these corresponded to the transitions: $3s_2 \rightarrow 2p_6$ (0.61 μm), $3s_2 \rightarrow 2p_2$ (0.64 μm) and $3s_2 \rightarrow 2p_5$ (0.629 μm). These transitions were first observed in laser action by White and Rigden in 1963 [5].

The radiation of spontaneous emission was analyzed with a Carl Zeiss SPM-2 grating monochromator. Radiation propagating perpendicularly to the tube axis was observed. An encased 1P-28 photomultiplier was positioned beyond the exit slit. Photomultiplier current was measured by means of a galvanometer of maximum sensitivity $3 \times 10^{-9}$ A/division. The measured photomultiplier current did not exceed twenty microamperes, what ensured photomultiplier operation in the rectilinear part of its characteristic. The width of the monochromator slits was 0.02 mm. The width of the instrumental function for this slit width estimated by means of the laser beam to be about $1.5 \times 10^{-4}$ μm.

## *4. Results of measurements*

Initially, studies dealt with the change in population of the $3s_2$, $3p_4$ and $2p_4$ states of neon. However, closer observations showed that it is necessary to examine practically all of the $3s$, $2p$ and $3p$ states.

The population of the $3s_2$ level was altered by making use of the 0.63 μm, 3.39 μm and 0.61 μm laser actions. The results of these measurements are gathered in Table I. Columns 1 and 2 give the symbols of the various terms in Paschen and Racah notations. Wave numbers of the terms, in $\text{cm}^{-1}$, are presented in column 3 [6]. Columns 4, 5 and 6 contain the wavelengths and the symbols of the lower states of the spectral lines which had been utilized in measurements of relative changes in atomic level populations [7]. The other columns hold the results for the relative changes in population of the various levels. In each of the columns 7, 8 and 9 the percentage changes in population of the $2p$ and $3p$ levels were obtained at a fixed, through maximum for the given laser action, change in population of the $3s_2$ level. The values in columns 7, 8 and 9 are for the respective 0.63 μm, 3.39 μm and 0.61 μm laser actions.

The changes in intensity of the various lines are expressed in per cent relative to the value of line intensity in the absence of laser action; the minus sign means the intensity of the given line becomes decreased after laser action is commenced, whereas the plus sign means an increase.

The intensity of laser action was attenuated until breakdown occurred by spoiling

TABLE I

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Paschen notation | Racah notation | Wave number cm$^{-1}$ | $\lambda$ μm | Paschen notation | Racah notation | $\Delta N_k : N_k^0$ % 0.63 μm | $\Delta N_k : N_k^0$ % 3.39 μm | $\Delta N_k : N_k^0$ % 0.61 μm |
| $3s_2$ | $5s'[1/2]_1$ | 166658 | 0.5434 | $2p_{10}$ | $3p\ [1/2]_1$ | −35 | −47 | −3 |
| $2p_2$ | $3p'[1/2]_1$ | 151040 | 0.6030 | $1s_4$ | $3s\ [3/2]_1$ | −8 | +2 | |
| $2p_4$ | $3p'[3/2]_2$ | 150860 | 0.5945 | $1s_5$ | $3s\ [3/2]_2$ | +42 | −2 | −1.5 |
| $2p_6$ | $3p\ [3/2]_2$ | 150318 | 0.6304 | $1s_4$ | $3s\ [3/2]_1$ | −3 | +2 | |
| $3p_1$ | $4p'[1/2]_0$ | 164288 | 0.3520 | $1s_2$ | $3s'[1/2]_1$ | | −17 | |
| $3p_4$* | $4p'[3/2]_2$ | 163711 | 0.3594 | $1s_2$ | $3s'[1/2]_1$ | −28 | +100 | |
| $3p_2$ | $4p'[1/2]_1$ | 163710 | 0.3461 | $1s_3$ | $3s'[1/2]_0$ | −28 | +94 | |
| $3p_5$ | $4p'[3/2]_1$ | 163659 | 0.3467 | $1s_3$ | $3s'[1/2]_0$ | −26 | +65 | |
| $3p_3$ | $4p\ [1/2]_0$ | 163403 | 0.3454 | $1s_4$ | $3s\ [3/2]_1$ | −14 | +10 | |
| $3p_6$ | $4p\ [3/2]_2$ | 163040 | 0.3488 | $1s_5$ | $3s\ [3/2]_2$ | | +6 | |
| $3p_7$ | $4p\ [3/2]_1$ | 163015 | 0.3450 | $1s_5$ | $3s\ [3/2]_2$ | | +7 | |
| $3p_9$ | $4p\ [5/2]_3$ | 162833 | 0.3473 | $1s_5$ | $3s\ [3/2]_2$ | | +8 | |

*$(3p_4+3p_2)$*

the $Q$-factor of the cavity. For the 0.63 μm laser action the $Q$-control was accomplished by rotating the quartz plane-parallel platelet placed in the laser cavity. In the case of the 3.39 μm action this method was ineffective because of the high amplification of this transition, and $Q$-spoiling had to be achieved by twisting one of the mirrors. By altering the $Q$-factor it was possible to change the population of the $3s_2$ level in a controlled manner and at the same time to measure the populations of the other levels in which we were interested.

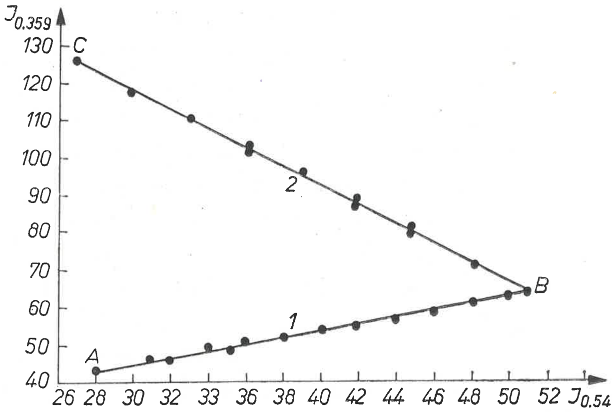

Fig. 7. Dependence of 0.359 μm line intensity on 0.5434 μm line intensity. Curve *1* — experimentally obtained points in the presence of 0.63 μm laser action. Curve *2* — experimentally obtained points in the presence of 3.39 μm laser action. Point *B* — intensity of lines under study in the absence of laser action

The validity of the derived formulae (2) and (4) was checked in this way. It follows from Eq. (1) that the relationships between the relevant populations of levels 2, 0 and 1 are identical with those, up to a constant factor, between the intensities of the corresponding spectral lines. The latter, or actually, the photomultiplier currents, are given on the coordinate axes of the relevant graphs (Figs 7, 8 and 9). Curve *2* of Fig. 7 was acquired by changing the intensity of the 0.54 μm line *via* decreasing the power of the 3.39 μm laser action and at the same measuring the intensity of the 0.359 μm spectral line. The experimental points are arranged along a straight line. Point *B* marks the relative values of intensity of the lines under consideration when there is no laser action. Curve *2* corresponds to the case described by formula (5) which had been derived with the assumption that there is 2 → 0 laser generation. In our specific case this concerns the $3s_2 \rightarrow 3p_4$ transition.

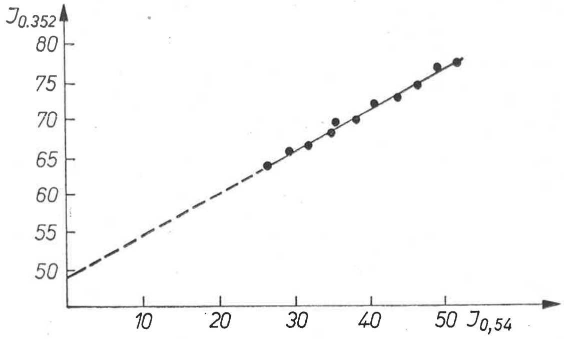

Fig. 8. Intensity of 0.352 μm line *versus* intensity of 0.54 μm line. Experimental points were obtained by utilizing the 3.39 μm laser action

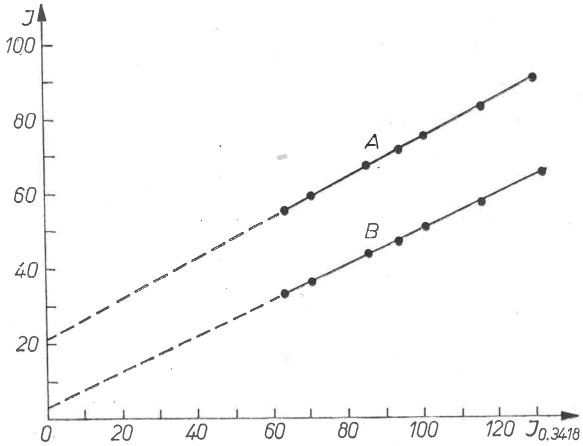

Fig. 9. Straight line *A* — intensity of 0.3467 μm ($3p_5 \rightarrow 1s_3$) line *versus* intensity of 0.3418 μm ($3p_4+3p_2 \rightarrow 1s_4$) line. Straight line *B* — intensity of 0.3461 μm ($3p_2 \rightarrow 1s_3$) line *versus* intensity of 0.3418 μm line. In both cases changes in the $3p_4$ level population were effected by the use of 3.39 μm ($3s_2 \rightarrow 3p_4$) laser action

The points of curve *1* (Fig. 7) were obtained in a similar manner, except that the means of decreasing the intensity of the 0.54μm spectral line was by altering the power of the

0.62 μm laser action. In this case an increase in the intensity of the 0.63 μm laser transition is a competitive channel with respect to the 3.39 μm spontaneous emission, which affects the population of the $3p_4$ state, thereby affecting the intensity of the 0.359 μm spectral line. The latter event is described by formula (7).

The plot in Fig. 8 presents the dependence of the 0.352 μm line's intensity on that of the 0.54 μm line, whereas Fig. 9 gives the changes in intensity of the 0.3461 μm and 0.3467 μm spectral lines against the intensity of the 0.3418 μm line.

## 5. *Discussion of results*

From the data presented in Table I, and also from the plots of Fig. 7, it is possible to calculate the ratio of populations of the $3s_2$ and $3p_4$ levels in the absence or presence of laser action. For this, however, the decay constants $\gamma$ must be known.

It follows immediately from curve *2* of Fig. 7 that the stimulated $3s_2 \to 3p_4$ transition gave a boost to the population of the $3p_4$ level at the expense of the population of the upper $3s_2$ level. On the other hand, when the $3s_2$ level is emptied in a process not enhancing the population of the $3p_4$ level through stimulated transitions, a drop in the $3p_4$ level population is observed, then only being filled up as a result of the $3s_2 \to 3p_4$ spontaneous emission.

Formulae (13) and (15) show that

$$\frac{\alpha_0}{\alpha_1} = \frac{\gamma_2}{\gamma_{20}} - 1,$$

where $\alpha_0$ and $\alpha_1$ are the absolute values of the slopes of the straight lines *2* and *1*, respectively (Fig. 7). The ratio $\gamma_2 : \gamma_{20}$ calculated according to the data of Fig. 7 is equal to $4.1 \pm 0.2$. The data of Table I also let the other coefficients to be calculated:

$$\beta_0 = \tfrac{2}{47}, \quad \beta_1 = \tfrac{6}{5}, \quad \beta_3 = \tfrac{1}{2}.$$

Dividing $\beta_0$ and $\beta_1$ of formulae (11) and (13) by $\beta_3$, Eq. (14), yields

$$\frac{\beta_0}{\beta_3} = \frac{\gamma_{21} - \delta\left(\frac{\gamma_2}{\gamma_{20}} - 1\right)}{\gamma_{21} + \delta} = \frac{4}{47} \text{ and } \frac{\beta_1}{\beta_3} = \frac{\gamma_2}{\gamma_{21} + \delta} = \frac{12}{5}.$$

Solution of these equations give

$$\delta = 0.3\gamma_{21} \text{ and } \frac{\gamma_2}{\gamma_{21}} = 4.4.$$

In their paper, Faust and Mc Farlane give the absolute values of the intensities of the 3.39 μm and 0.63 μm spectral lines [8]. It is easily found that the values of the constants $\gamma_{20}$ and $\gamma_{21}$ make the ratio 2 : 3 (in our case 4.4 : 4.1). Our result of 4.4 is higher than that quoted in Ref. [8], but we did not take account of the existence of the non-isotropic distribution of intensity changes of spectral lines originating from the $2p_4$ state observed in the plane perpendicular to the laser axis [9]. This phenomenon appears in the case of linearly polarized laser light, and concerns the lines of the lower laser level (the 3.39 μm laser action is not polarized linearly because of the very large amplification of the $3s_2 \rightarrow 3p_4$ transition). A 42% change in intensity of the 0.5945 μm line in the 0.63 μm laser action has been observed in the direction of the polarization vector of the laser ray. A turn of the laser tube by $\pi/2$ about its axis brought about a drop in the intensity change of this line to 28% at the same value of population change for the $3s_2$ level.

In addition, the results obtained for the 0.61 μm laser action carry considerable error (up to 20% of the values obtained) due to the low acquired intensity of the laser action itself.

As had already been mentioned, $\delta$ expresses the probability of excitation transfer from state 2 to 1, in our specific case from $3s_2$ to $2p_4$, *via* an intermediate state $3p_4$. As direct radiative transitions between the $3p$ and $2p$ states do not take place, successive transfers of excitations from the $3p_4$ state to the $2p_4$ state can occur by cascade $3p \rightarrow 2s \rightarrow 2p$ transitions. Such possibilities had been considered in the paper by Weaver and Freiberg [10]. As there also is a strong tendency for excitations to become transferred among the $3p_4$, $3p_2$ and $3p_5$ levels by way of collisions, the first spontaneous transition may proceed from any of these states to the $2s_2$ state and then by spontaneous emission to the $2p_4$ state.

The unexpected small decrease in the $2p_4$ level population incurred during termination of 3.39 μm laser action (column 8 of Table I) despite the considerable decrease in the population of the $3s_2$ level, is caused by competitive cascade transitions from the $3p_4$ level *via* $2s$ levels to the $2p_4$ level.

Compating the data of Table I, columns 8 and 9, it may be concluded that at a 100% increase in the $3p_4$ level population due to cascade transitions there is about a 20% increase in the $2p_4$ level population.

The mutual relationships between the populations of the $3p_4$, $3p_5$ and $3p_2$ levels have been investigated. The results are illustrated by the plots in Fig. 9. The vertical axis of the coordinate system carries the intensities of the 0.3467 μm ($3p_5 \rightarrow 1s_3$) and 0.3461 μm ($3p_2 \rightarrow 1s_3$) spectral lines whereas the horizontal axis the intensity of the 0.3418 μm ($3p_2+3p_4 \rightarrow 1s_4$) line. The $3p_2$ and $3p_4$ levels are 1 $\mathrm{cm}^{-1}$ away from each other, and this is why the spectral lines originating at them were not separated by the measuring set-up. Notwithstanding, the behaviour of the population of the $3p_2$ level could be tracked independently of the $3p_4$ level by taking advantage of the $3p_2 \rightarrow 1s_3$ transition, which has no $3p_4 \rightarrow 1s_3$ counterpart because of the prohibition of $\Delta J = 2$ for electric dipole transitions. It is seen in Table I that the changes in the populations of the $3p_2$ level and the aggregate change of the $3p_4+3p_2$ levels are almost identical, that is, the populations of the $3p_4$ and $3p_2$ levels are completely equalized.

An interesting problem is that of the effect of the competitive $3s_2 \rightarrow 3p \rightarrow 2s_2 \rightarrow 2p_4$ channel in decreasing the difference in populations of the $3s_2$ and $2p_4$ levels. The main source of population losses of the $3s_2$ state is, apart from the $3s_2 \rightarrow 2p_4$ spontaneous transition, the $3s_2 \rightarrow 3p_4$ transition. Extrapolation of the straight line 1 in Fig.7 to zero population value of the $3s_2$ level shows that the transition in mention is responsible for 70% of the $3p_4$ level's population. In turn, this population is transferred in a 1 : 5 ratio to the $2p_4$ level. In the case when a resonance cavity without laser transition selection is used, account should be taken of the losses in population difference stemming from the $3s_2 \rightarrow 3p_4$ stimulated transition which almost always appears. Research has shown that 3.39 μm laser action developing parallelly with 0.63 μm action causes changes in level populations; namely, $3s_2$ by $-15\%$ and $3p_4$ by $+30\%$.

Figure 8 gives the dependence of the intensity of the 0.352 μm line (from the $3p_1$ level) on the intensity of the 0.54 μm line (from the $3s_2$ level). Changes in the intensity of the 0.352 μm spectral line are proportional to the changes in the intensity of the 0.54 μm spectral line. If the line is extrapolated to zero $3s_2$ level population, it is seen that about 30% of the $3p_1$ level population comes from the spontaneous $3s_2 \rightarrow 3p_1$ transition. In an electric discharge in pure neon there exist conditions for $3p_1 \rightarrow 2s_2$ laser action, which become disrupted when helium is added [11].

Hence, it may be expected that when helium is admixed the $3p_1$ level's population actually does become increased at the expense of the $3s_2$ state population, but at the same time the population of the $2s_2$ state increases due to collisions of unexcited neon atoms with helium atoms in the $^3s_1$ state. The latter process may abolish the conditions stimulating $3p_1 \rightarrow 2s_2$ laser action.

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