

Laser spectroscopic analysis of N₂ pulsed discharges at low temperatures

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Received 2 June 1980.

0003-6935/80/213590-03\$00.50/0.

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Molecular nitrogen laser action in axial pulsed discharges in the IR spectral region between 0.8 and 1.2 μm corresponding to several bands of the first positive system was observed in 1963 by Mathias and Parker,¹ and in the 0-0 (337.1-nm) band of the UV second positive system was reported by Heard² in the same year.

After that, extensive spectroscopic studies of the laser emission, including rotational analysis and intensity distribution of lines, were made by several research groups³⁻¹³ using either axial or transverse discharge excitation modes at low or room temperature.

In this work we report a new IR laser band at 1.43 μm (1-3) and the classification of new IR and UV laser lines as rotational quantum numbers. Also, the intensity distribution of laser lines follows the theoretical prediction formerly made.¹¹

The complete experimental arrangement has been described in detail elsewhere.¹¹ However, some differences can be pointed out. Laser tubes, 11-mm i. d., 130 cm long ending in Brewster angle windows, were coupled to a bypass helicoid pipe that circled around it. This pipe had a 2.30-m equivalent length. In addition, the entire laser tube was submerged in a liquid air bath, and nitrogen pressure ranged from 0.2 to 1.2 Torr.

The excitation was accomplished by discharging a 5-nF capacitor bank charged up to 35 kV. One of the laser tubes was provided with a coaxial electrode to diminish the circuit inductance. Typical voltage pulses of 20-kV amplitude in the first hemicycle and 0.7- μsec halfwidth were applied across the laser tube, generating current peak pulses of 1-kA and 0.6- μsec halfwidth. Voltage and current pulses were measured using a high voltage probe and a Rogowsky coil, respectively. Under

these conditions the measured laser peak power was of 500 W/cm². In the appropriate optical regions Kodak photographic plates were used; I-Z plates were hypersensitized in the recommended fashion.

Tables I and II summarize the laser spectroscopic results obtained in the observation of the first positive and second positive systems, respectively. To our knowledge, the 1-3

Table I. Laser Lines of the First Positive System (0-0 band)

λ_{air} (Å)	σ_{vac} (cm ⁻¹)	Intensity	Assignment	Previous observations (Ref.)
10537.58	9489.84	4	<i>OP</i> ₁₂₋₉	7
10535.78	9491.46	4	<i>OP</i> ₁₂₋₈	
10533.74	9493.30	5	<i>OP</i> ₁₂₋₇	7
10531.52	9495.31	1	<i>OP</i> ₁₂₋₆	
10529.06	9497.52	5	<i>OP</i> ₁₂₋₅	7
10526.46	9499.87	2	<i>OP</i> ₁₂₋₄	
10523.68	9402.37	5	<i>OP</i> ₁₂₋₃	
10512.42	9512.56	1	<i>P</i> ₁₋₃	
10511.82	9513.10	2	<i>PQ</i> _{12-1, P₁₋₄}	
10511.57	9513.32	3	<i>PQ</i> ₁₂₋₂	
10511.23	9513.64	5	<i>PQ</i> _{12-3, P₁₋₅}	7
10510.66	9514.15	4	<i>PQ</i> ₁₂₋₄	
10509.95	9514.79	4	<i>PQ</i> ₁₂₋₅	7
10509.28	9515.39	4	<i>P</i> ₁₋₇	
10509.05	9515.60	3	<i>PQ</i> ₁₂₋₆	
10508.75	9515.87	4	<i>Q</i> ₁₋₁	
10507.98	9516.57	4	<i>PQ</i> _{12-7, P₁₋₈}	
10506.47	9517.94	4	<i>P</i> ₁₋₉	
10505.24	9519.05	4	<i>Q</i> ₁₋₂	
10501.51	9522.44	5	<i>Q</i> ₁₋₃	7
10497.60	9525.98	5	<i>Q</i> ₁₋₄	7
10493.48	9529.72	5	<i>Q</i> ₁₋₅	7
10489.17	9533.64	4	<i>Q</i> ₁₋₆	7
10484.62	9537.77	0	<i>Q</i> ₁₋₇	7
10482.51	9539.70	5	<i>PQ</i> _{23-7, R₁₋₃}	7
10481.55	9540.57	0	<i>PQ</i> ₂₃₋₆	
10480.14	9541.85	1	<i>PQ</i> ₂₃₋₅	
10479.84	9542.13	3	<i>Q</i> ₁₋₈	7
10478.35	9543.49	4	<i>PQ</i> ₂₃₋₄	
10476.34	9545.31	0	<i>PQ</i> ₂₃₋₃	

Table II. Laser and Superradiant Lines of the Second Positive System (0-0 band)

Operation modes	λ_{air} (Å)	σ_{vac} (cm ⁻¹)	Intensity	Assignment	Previous observations (Ref.)
s	3365.502	29704.73	0	QP'_{32-2}	
s	3365.568	29704.15	0	R_{1-6}	13
s	3366.298	29697.71	0	R_{2-5}	
s	3366.704	29694.12	0	R_{1-4}	13
s	3366.924	29692.18	1	R_{2-4}	
s	3367.208	29689.68	0	R_{1-3}	
s	3367.228	29689.50	0	R_{1-3}	13
s	3367.480	29689.28	s	R_{2-3}	
s	3367.491	29687.18	0	R_{2-3}	
s	3367.683	29685.49	1	R_{1-2}	
s	3368.017	29682.55	0	R_{2-2}, R_{2-2}	
s	3368.135	29681.51	0	R_{1-1}	
s	3368.528	29687.05	1	Q_{2-6}	
s	3368.606	29677.36	0	Q_{3-6}	
s	3368.915	29674.64	0	Q_{3-5}	
l	3369.124	29672.80	0	Q_{2-3}	
s-l	3369.173	29672.36	1-0	Q_{3-4}	
s	3369.248	29671.71	0	Q_{2-1}, Q_{2-1}	
s	3369.379	29670.55	1	Q_{3-3}	
l	3369.501	29669.47	0	P_{2-18}	
s-l	3369.543	29669.18	3-0	Q_{3-2}	11
s-l	3369.547	29669.07	2-0	P'_{1-2}	11
l	3369.685	29667.86	0	P_{1-18}	
s-l	3369.827	29666.61	1-3	P_{1-3}	11
s-l	3369.833	29666.55	2-0	P_{1-3}	11
s-l	3369.986	29665.21	2-3	P'_{1-17}	
s	3370.026	29664.85	1	P_{2-2}	
s	3370.028	29664.83	1	P_{2-2}	
s-l	3370.076	29664.42	3-0	P_{1-4}	11
s	3370.082	29664.36	1	P_{1-4}	11
s-l	3370.289	29662.54	2-0	P'_{1-5}	11
s-l	3370.296	29662.47	3-3	P_{1-5}	11,7
s-l	3370.308	29662.37	3-1	R_{2-7}	13
l	3370.435	29661.25	2	P'_{2-15}	
s-l	3370.448	29661.14	3-4	P_{2-15}	3,9
s-l	3370.472	29660.93	3-4	P_{1-6}	11
l	3370.480	29660.86	2	P_{1-6}	11
l	3370.492	29660.75	3	P_{3-2}	
l	3370.521	29660.50	1	P_{1-14}	
s-l	3370.553	29660.21	4-4	P_{1-14}	11
l	3370.568	29660.09	2	P_{2-4}	11
s-l	3370.608	29659.73	4-4	P_{1-7}	11
s-l	3370.618	29659.64	4-4	P_{1-7}	7,11
s-l	3370.652	29659.34	0-1	P_{2-14}	
l	3370.668	29659.21	2	P_{2-14}	3
s-l	3370.676	29659.13	1-3	P_{1-13}	
s-l	3370.683	29659.07	0-3	P_{1-13}	11
s-l	3370.713	29658.81	3-3	P_{1-8}	7,11
s-l	3370.726	29658.69	3-4	P_{1-8}	11
s	3370.749	29658.49	3	P'_{1-12}	7,11
s-l	3370.756	29658.43	5-5	P_{2-5}	11
l	3370.764	29658.36	2	P_{2-5}	
s-l	3370.769	29658.32	3-5	P_{1-12}	
s-l	3370.781	29658.21	3-4	P_{1-9}	11
s-l	3370.795	29658.08	4-3	P_{1-9}	7,11
l	3370.802	29658.02	3	P'_{1-11}	
s-l	3370.813	29657.93	3-3	P'_{1-10}	7,11
l	3370.819	29657.87	1	P_{1-11}	7,11
s-l	3370.827	29657.80	2-1	P_{1-10}	11
s-l	3370.841	29657.68	2-2	P_{2-13}	
l	3370.853	29657.57	3	P_{2-13}	
s-l	3370.919	29656.98	5-5	P_{2-6}	7,11
s	3370.977	29656.48	2	P_{2-12}	
s-l	3370.986	29656.40	4-5	P_{2-12}, P_{3-4}	7,11,13
s	3370.995	29656.32	4	P_{3-4}	13
s-l	3371.037	29655.94	4-5	P_{2-7}	7,11
l	3371.042	29655.91	4	P_{2-7}	13

continued

Table II continued

Operation modes	λ_{air} (Å)	σ_{vac} (cm ⁻¹)	Intensity	Assignment	Previous observations (Ref.)
s-l	3371.068	29655.68	3-5	P_{2-11}	11
s-l	3371.080	29655.58	3-5	P_{2-11}	11
l	3371.110	29655.31	3	P_{2-8}	13
s-l	3371.116	29655.26	3-4	P_{2-8}	7,11
s-l	3371.119	29655.24	2-3	P_{3-12}, P_{3-12}	11
l	3371.127	29655.16	3	P_{2-10}	
l	3371.138	29655.07	4	P_{2-10}	7,11
s	3371.141	29655.04	4	P_{2-9}	7,11
l	3371.147	29654.99	3	P_{2-9}	
s-l	3371.266	29653.94	3-3	P_{3-11}	7,11
s-l	3371.272	29653.89	3-4	P_{3-11}	
s-l	3371.306	29653.59	5-5	P_{2-6}	7,11
s	3371.364	29653.08	4	P_{3-10}	7,11
s	3371.372	29653.01	2	P_{3-10}	
s-l	3371.391	29652.84	5-5	P_{3-7}	7,11
s	3371.398	29652.79	4	P_{3-7}	
s-l	3371.421	29652.58	4-5	P_{3-9}	7,11
s-l	3371.427	29652.53	4-5	P_{3-8}	7,11

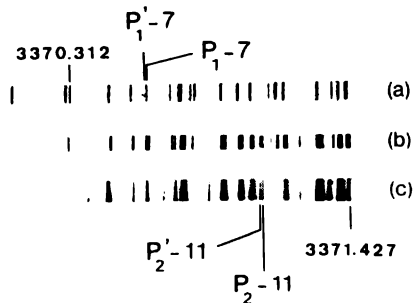


Fig. 1. Positive reproduction of the 0-0 UV stimulated band spectrograms at low temperature: (a) laser emission from a 3-mm i.d. tube¹¹; (b) superradiant emission from an 11-mm i.d. tube; and (c) laser emission from the same tube as (b).

(1.43- μm) IR laser band is reported for the first time, and the rotational analysis made for the 0-0 (1.05- μm), 1-2 (1.19- μm), and 0-1 (1.24- μm) bands in the first positive system and for the 0-0 (337.1-nm) band in the second positive system extends previous surveys.

Rotational structure was observed at liquid air temperature. To investigate the main differences from the room temperature operation of the molecular nitrogen laser, spectra at both temperatures were recorded. The previous results, reported on the behavior of the 2-1 IR laser band at room and liquid air temperatures¹¹ by using simple tubes, were confirmed in this case by using bypassed tubes. However, high intensity observation of IR laser bands was limited to low temperature operation. At room temperature only the 2-1 (0.86- μm) and 1-0 (0.89- μm) IR laser bands were observed. This fact is in accordance with the transition probability description of the Deslandres parabola and with the increase gain in diatomic molecules at low temperature.

In general, UV laser bands belonging to the second positive system were observed in axial discharges when tubes of small bore, typically 2-3-mm internal diam, were used. Figure 1

shows the comparison between the (positive reproduction of the) spectrogram of the 0-0 (337.1-nm) band previously photographed¹¹ with a 3-mm tube and the 11-mm tube in the present experiments. In both cases, laser tubes were submerged in a liquid air bath, and stimulated radiation was observed as well as superradiant emission.

Table II shows an extensive description of the UV laser spectral observation in both modes of operation, that is, laser (l) and superradiant (s). Some lines were observed in both modes (s-l). In this case two figures indicate the observed intensity in each mode, respectively.

It is useful to point out that, at the beginning of Table II, all the new superradiant lines observed belong to $^Q P'_{32}$, R'_1 , R'_2 , Q_2 , Q_3 , and Q_3 branches. The R_1 branch was also observed in superradiant emission as reported by Petit *et al.*¹³ in transverse excitation.

Λ -doublets were observed in almost all the components of the P branches of the Π -triplet. In some cases, only one component of the Λ -doublet is reported due to random overlapping of other lines or ghost screening of the other ones.

The authors wish to express their thanks to the Secretaría de Estado de Ciencia y Tecnología, Argentina, and the Organization of American Sites for partial financial support.

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