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NATIONAL BUREAU OF STANDARDS REPORT

8007

THE ABSORPTION SPECTRUM OF THE "PINK" AFTERGLOW OF NITROGEN IN THE VACUUM ULTRAVIOLET

by

Arnold M. Bass

Technical Report

to

National Aeronautics and Space Administration

Washington, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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ABSTRACT

The absorption spectrum of the short-lived "pink" afterglow in nitrogen was photographed in the vacuum ultraviolet from 1600 to 1150 A. A large number of relatively intense absorption bands were observed. It is suggested that these may result from transitions between the ground state ($X^2\Sigma_g^+$) and several excited electronic states ($b\ ^1\Pi_g$, $b'\ ^1\Sigma_u^+$, and others) in which ground state vibrational levels of the ground electronic state are populated to very high levels (up to about $v'' = 20$). It appears that more than 10% of the nitrogen molecules are excited to vibrational levels greater than $v'' = 8$.

INTRODUCTION

In recent years a number of studies have been made of the characteristics of a short-lived afterglow in nitrogen. This glow, which is pink, was shown by Beale and Broida[1] to be conveniently observed when the products of an electrodeless discharge in pure nitrogen are rapidly pumped away from the discharge region. The glowing gas which is observed several milliseconds after the discharge has the characteristic pink color; the region on either side of the pink, corresponding to shorter or longer times after the discharge, shows the typical straw-yellow color of the Lewis-Rayleigh afterglow. As described by Beale and Broida[1], the pink color of the short-duration afterglow results from the addition of the emission from excited N_2^+ molecular ions, which are present in that region of the afterglow, to the emission from the First Positive bands of nitrogen.

While several spectroscopic investigations have been made of the "pink" afterglow[1-5], only a limited number[6,7] have involved the emission spectrum in the vacuum ultraviolet region. There have been some studies of the absorption spectra of atomic and molecular nitrogen in the Lewis-Rayleigh afterglow[8,9]. However, in the "pink" region the only absorption measurements previously reported are those of Fairchild, et al.[7] who used a resonance emission line source to observe the absorption by atomic nitrogen.

This paper describes the absorption spectrum of the "pink" afterglow as observed in the vacuum ultraviolet region from 1150 to 1600 A. In addition to the atomic absorption previously observed ($3s\ ^4P \leftarrow 2p^3\ ^4S^\circ$), there appears a very rich and intense molecular absorption which probably originates from highly excited vibrational levels of molecular nitrogen in the electronic ground state.

Experimental

The system used for producing and observing the nitrogen afterglow is shown in Figure 1. An electrodeless discharge in flowing nitrogen gas ("prepurified" nitrogen flowing through liquid oxygen-cooled traps) was established in each of two 10 mm i.d. fused silica tubes. The discharge products were rapidly pumped from the region of the discharge through a distance of 23 cm into a compartment where the absorption or emission of radiation by the afterglow species was observed. The afterglow chamber was 50 cm long and tube diameters from 13.5 mm to 108 mm were used. The tube was closed at both ends by LiF windows which permitted observations to be made in the vacuum UV region to approximately 1150 A. Additional gas inlets were provided downstream of the discharge to permit studying the effects of adding other gases to the active species.

Emission and absorption spectra were obtained by using a 2-meter vacuum spectrograph, with a 30,000 lines per inch grating

blazed near 1500 A (reciprocal dispersion 4.32 A/mm). For absorption spectra the background continuum was provided by either a Lyman condensed discharge or a microwave electrodeless discharge in argon[10] (Figure 2). The most intense argon continuum was obtained by operating the discharge at about 650 mm Hg pressure, using argon that had flowed through two charcoal traps cooled by liquid oxygen. Under these conditions good exposures were obtained on SWR plates through a 25-micron slit in 20 minutes over the wavelength range 1150 to 1600 A. The atomic lines of nitrogen, oxygen, and carbon which appear strongly in the source were used as wavelength standards for the plate calibration, and the wavelength determinations are reliable to ± 0.05 A for the intense features and to ± 0.1 A for the weak features.

Observations

The conditions under which the various visible afterglow phenomena were produced were in accord with those described previously[1-8]. At moderate flow rates (~ 600 cc/min, STP) the straw-yellow emission of the normal Lewis-Rayleigh afterglow was readily observed to fill the afterglow tube. As the flow rate of the nitrogen was increased, the "pink" afterglow region was observed to be displaced from the discharge region and to appear in the afterglow tube. By the appropriate choice of flow rate, pressure, and discharge conditions it was possible to have the "pink" region fill completely the entire 50 cm length of the

afterglow tube. In an afterglow tube of 22 mm i.d. the most intense "pink" glow was produced at a pressure of approximately 4.5 mm Hg and a flow rate of about 1600 cc/min (STP). The visual brightness of the "pink" afterglow depended markedly upon the amount of microwave power supplied to the discharge tubes. To produce the brightest afterglow, each of the two discharges was excited by three microwave power supplies (2450 mc/sec, 125 watts maximum input power), for a total input power of up to 750 watts.

At the flow rate mentioned above it is estimated that the "pink" emission appeared in the afterglow tube about 4×10^{-3} seconds after the discharge, and extended down stream for at least 20×10^{-3} sec. The afterglow tube was connected to a metal pumping line and so it was not possible to observe the secondary "pink" emission region described by Beale and Broida[1], and others.

The "pink" afterglow was also produced in afterglow tubes of 13.5 mm and 108 mm i.d. In the 13.5 mm tube the brightest visible emission was produced at a pressure of about 6.5 mm Hg, and a flow rate of about 1300 cc/min (STP); in the 108 mm tube the optimum pressure was about 1 mm Hg, flow rate about 2000 cc/min (STP). It appears, therefore, that the pressure at which the "pink" afterglow appears most intensely is inversely proportional to the diameter of the afterglow tube.

Table I summarizes the conditions over which the "pink" region was studied.

Table I. Conditions for appearance of "pink" afterglow in nitrogen

Afterglow tube diameter (mm)	Pressure for maximum intensity (mm Hg)	Flow rate for maximum intensity (cc/min STP)	Time from discharge to "pink" in afterglow tube (millisec.)	Time extent of "pink" emission in afterglow tube (millisec.)
13.5	6.5	1300	7	14
22	4.5	1600	4	21
108	1	2000	0.7	77

Over this range of conditions no differences were observed in the spectrum features described below, except for the strength of absorption which is proportional to the pressure.

In the region between 2000 and 1100 A the emission spectrum of the "pink" afterglow showed only the Lyman-Birge-Hopfield bands of molecular nitrogen ($a\,^1\Pi_g \rightarrow X\,^1\Sigma_g^+$), and the 1495 A ($3s\,^2P \rightarrow 2p^3\,^2D^o$) and 1745 A ($3s\,^2P \rightarrow 2p^3\,^2P^o$) groups of atomic nitrogen. The Birge-Hopfield bands [$b\,^1\Pi_u \rightarrow X\,^1\Sigma_g^+$) and $b'\,^1\Sigma_u^+ \rightarrow X\,^1\Sigma_g^+$)] of molecular nitrogen, reported by Young[6] and by Fairchild, et al.[7], were not observed in a three-hour exposure with a 25 micron slit.

The absorption spectrum of the "pink" nitrogen afterglow is quite different from that of the normal Lewis-Rayleigh afterglow. In the latter we observed the same features as those reported by Tanaka, et al.[8] and by Dressler[9] -- that is, atomic nitrogen absorption at 1200 A ($3s\,^4P \leftarrow 2p^3\,^4S^o$), and molecular nitrogen absorption ($a\,^1\Pi_g \leftarrow X\,^1\Sigma_g^+$) with one quantum of ground state

vibrational excitation observed in several of the bands (see Figure 3). These features were observed at times later than 100 milliseconds after the discharge.

In the "pink" region a very rich band spectrum was observed (Figure 3). The atomic absorption lines remain clearly visible. The band absorption is much stronger than the Lyman-Birge-Hopfield bands observed in the straw-yellow afterglow or in undischarged nitrogen. The most intense "pink" absorption bands are more than 10 times stronger than the L-B-H bands. However, visual examination of the plates gave the impression that the intensity of the L-B-H bands in the "pink" region may be less, by as much as 50%, than in the same quantity of nitrogen but with the discharges turned off. The absorption bands in the "pink" region generally are degraded to longer wavelengths, and many of them show considerable rotational line structure. Tables II - IV give partial lists of the prominent band heads of the a-X, b-X, and b'-X transitions observed in the region 1600 to 1175 A. Several other long sequences of the ground state vibration frequencies, involving some of the most intense absorption bands, were recognized, but the upper electronic states involved have not yet been identified (Table V). The band system did not seem to extend to longer wavelengths than 1600 A; at the short wavelength end the spectrum appears to continue with greater intensity and complexity.

The absorption spectrum of the "pink" region was the same over the entire range of times included, as described above, about 0.7 to 75 msec. With more rapid pumping the "pink" region could be substantially removed from the line-of-sight and the yellow afterglow, which precedes the "pink" in time, could be observed. In this portion of the afterglow the same bands are observed as in the "pink" region, but with slightly lower intensity.

Discussion

The "pink" region absorption bands have not yet been completely analyzed. However, preliminary comparison of these observations with those reported by Ogawa, Tanaka, and Jursa[11] on the absorption spectrum of active nitrogen in the argon continuum region suggests that many of the same bands are involved. Ogawa, et al. observed in the discharge through pure nitrogen, abosorption bands arising from highly excited ground state vibrational levels of nitrogen molecules. In particular they identified the allowed transitions j-X, b-X, ℓ-X, m-X, and b'-X with ground state vibrational quanta (v") up to 10. Using their identifications as a guide we have extended some of these series to higher ground state vibrational levels - to approximately level v" = 20 in the b'-X and b-X transitions. Some of these suggested identifications are included in Tables II-IV; it must be emphasized that these are tentative assignments only, and that a detailed analysis will be reported later. The

calculated values listed in Tables III and IV are based upon the vibrational spacings in the electronic states involved as specified in the references mentioned in the tables. The entries in Table III in parentheses are those for which the difference between the calculated and observed values is much larger than the experimental uncertainty.

Several possibilities for explaining the mechanism by which the "pink" afterglow arises have been proposed. The various explanations require long-lived metastable species which carry sufficient energy to produce the observed effects. None of the suggested energy carriers (N atoms in the ^6S level[12]; N_4 molecules[14]; vibrationally excited N_2 molecules in the $X^1\Sigma_g^+$ state and N_2 molecules in the $A^3\Sigma_u^+$ state[15]) have been directly observed previously, and so it has not been possible to state definitely which is the correct mechanism. The observations of the effect of the afterglow tube diameter on the pressure for maximum "pink" glow intensity and on the duration of the "pink" afterglow (Table I) indicate the importance of the effect of the walls upon the lifetime of the emissions. The trend of these measurements indicates that the previously reported decay times of the N_2^+-bands, considered by Innes and Oldenberg[16] to be inconsistent among each other, are actually in accord in relation to the volumes of the vessels in which the observations were made.

A very rough estimate of the populations of the vibrationally excited ground state levels leading to the $b(^1\Pi_u)$ and $b'(^1\Sigma_u^+)$ states was made by comparing the intensities with those of the L-B-H bands

and by using as the relative transition probabilities the values[17]: $2\times10^{-3}(a\ ^1\Pi_g - X^1\Sigma_g^+)$ and 1 ($b\ ^1\Pi_u - X^1\Sigma_g^+$; $b'\ ^1\Sigma_u^+ - X^1\Sigma_g^+$). In this approximation the populations of the high vibrational levels of the ground state are about 1 to 2% of the population of the lowest levels. This estimate agrees well with that made by Ogawa, et al.[11] for the N_2 discharge. This would indicate that a substantial number of the nitrogen molecules, perhaps more than 10%, is excited to vibrational levels greater than v" = 8, in agreement with the previously mentioned decrease in the strength of the L-B-H absorption of up to 50%.

With such a large population of vibrationally excited ground state molecules it may be of interest again to consider these species as the possible energy carriers required for the production of the "pink" afterglow. The observation of transitions which are tentatively identified with ground state vibrational energy of up to 42,000 cm^{-1}(~ 5ev) must be considered in attempting to establish the details of the mechanisms. These vibrationally excited molecules with considerable energy in states from which radiative transitions are forbidden may be of particular value in accounting for the observation of the repetitive appearance of the "pink" region.(1) Another problem to be considered is the manner in which the excess vibrational energy is dissipated. The observations of the volume effect on the "pink" glow (Table I) and the fact that walls of the afterglow tube become quite warm to the touch would indicate that much of this energy is lost by collisions with the walls of the tube.

The observation of the same bands in absorption through the "pink" afterglow as in the discharge[11] is in accord with the observation on the emission spectra[1-7] that the "pink" afterglow resembles the discharge region rather than the Lewis-Rayleigh afterglow region.

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Table II. Lyman-Birge-Hopfield Bands ($a^1\Pi_g - X^1\Sigma_g^+$) Observed in the Nitrogen "Pink" Afterglow.

v', v"	L-B-H λ_{BH}(A)*	"Pink" Afterglow Absorption Bands λ_{BH}(A)	ν(cm^{-1})	Intensity**
10,0	1185.2	1184.95	84391.9	45
9,0	1205.3	1204.96	82990.2	100 (blend)
8,0	1226.6	1226.58	81527.6	60 (blend)
7,0	1249.3	1249.06	80060.5	20
6,0	1273.1	1272.90	78560.5	30
5,0	1298.4	1297.94	77045.3	20
4,0	1325.2	-	-	-
5,1	1339.3	1339.39	74661.0	35
3,0	1353.6	1353.62	73875.8	30
4,1	1367.3	1366.99	73153.5	55
5,2	1382.0	1382.62	72326.6	40
2,0	1383.8	1383.75	72267.6	20
6,3	1396.0	1396.03	71631.8	50 (blend)
1,0	1415.9	1415.88	70627.2	30
5,3	1426.6	1426.96	70079.2	10
3,2	1444.3	1444.27	69238.9	35
0,0	1450.1	-	-	-
1,1	1464.1	1464.53	68281.2	20
0,1	1500.7	-	-	-

*R. T. Birge and J. J. Hopfield, Astrophys. J. 68, 257 (1928)
Y. Tanaka, J. Opt. Soc. Amer. 45, 663 (1955).

**Visual intensity estimates on scale of 0 to 100.

Table III. Birge-Hopfield Bands ($b\ ^1\Pi_u - X\ ^1\Sigma_g^+$) observed in the Nitrogen "Pink" Afterglow.

v', v"	"Pink" Afterglow λ^*_{BH}(A)	$\nu(cm^{-1})$ (calc)	"Pink" Afterglow Absorption Bands λ_{BH}(A)	$\nu(cm^{-1})$	Intensity
2,8		(85050)	(1174.76	85123.6)	20
1,8		84336	1185.87	84326.2	55
0,8	1195.7		1195.79	83626.8	75
2,9		82951	1204.96	82990.2	100 (blend)
3,10		(81566)	(1225.58	81593.8)	60 (blend)
0,9	1226.4		1226.58	81527.6	
2,10		80880	1236.25	80889.7	100 (blend)
4,11		80110	1248.41	80102.1	20
3,11		79525	1257.82	79502.4	15
0,10	1258.4		1258.61	79452.6	20
2,11		78839	1268.69	78821.6	60
5,12		78658	1271.47	78649.0	30
1,11		78124	1280.22	78111.8	20
4,12		78098	1280.85	78072.9	20
3,12		77513	1290.35	77498.6	20
0,11	1291.7		1291.76	77414.1	30
2,12		76827	1301.85	76813.7	15
5,13		(76675)	(1304.90	76634.5)	25
1,12		76112	1314.02	76102.3	30
4,13		76115			
3,13		75530	1324.19	75517.7	40
0,12	1326.2		1326.22	75402.4	60

Table III. Continued

v', v"	λ^{*}_{BH}(A)	"Pink" Afterglow Absorption Bands			
		$\nu(cm^{-1})$ (calc)	λ_{BH}(A)	$\nu(cm^{-1})$	Intensity
2,13		74844	1335.82	74860.1	10
1,13		74129	1349.18	74119.3	55 (blend)
0,13	1362.0		1362.02	73420.4	50
2,14		(72890)	(1371.28	72924.7)	30
1,14		72175	1385.39	72181.9	80 (blend)
0,14	1399.3		1399.22	71468.3	50 (blend)
2,15		70966	1408.92	70976.5	50
1,15		70251	1423.63	70242.9	80
0,15	1438.0		1438.01	69540.5	35
2,16		69072	1447.99	69061.4	95
1,16		68357	1462.80	68361.9	65
0,16		(67655)	(1478.74	67625.0)	40
2,17		67207	1488.19	67195.6	60
1,17		66492	1504.10	66484.9	45
0,17		65790	1520.14	65783.3	20
2,18		65362	1530.00	65359.4	65
1,18		64657	1546.76	64651.3	40
0,18		(63955)	(1562.02	64003.8)	50

*R. T. Birge and J. J. Hopfield, Astrophys. J. 68, 257 (1928).
(calc): calculated, $\nu_{o,o}$ = 101469 cm^{-1}.

Table IV. Birge-Hopfield Bands ($b'\ ^1\Sigma^+ - X\ ^1\Sigma_g^+$) Observed in the Nitrogen "Pink" Afterglow.

v', v"	λ^*_{BH}(A)	"Pink" Afterglow Absorption Bands λ_{BH}(A)	$\nu(cm^{-1})$	Intensity
0,9	1194.1	1194.06	83747.9	40
2,10	1202.7	1202.81	83139.0	30
1,10	1213.4	1213.30	82419.6	40
3,11	1222.1	1222.04	81830.0	35
0,10	1224.4	1224.32	81677.7	40
2,11	1232.9	1233.10	81096.6	15
1,11	1244.2	1244.12	80378.3	20
3,12	1253.0	1252.87	79816.9	20
0,11	1255.8	1255.68	79637.8	26
5,13	1261.9(c)	1261.14	79293.6	20
4,13	1273.2(c)	1272.90	78560.5	30
1,12	1276.1	1276.06	78366.3	20
3,13	1284.8	1284.75	77836.3	25
0,12	1288.3	1288.26	77624.0	20
2,13	1296.9(c)	1296.72	77117.5	25
1,13	1309.2	1309.16	76384.7	25
0,13	1322.2	1322.04	75640.4	25
0,14	1357.2	1357.07	73688.4	50
0,15	1393.6	1393.47	71763.3	30
0,16	1431.4	1431.23	69869.9	45

Table IV. Continued

"Pink" Afterglow Absorption Bands

v', v"	λ^{*}_{BH}(A)	λ_{BH}(A)	$\nu(cm^{-1})$	Intensity
0,17	1470.7	1470.33	68011.8	50
1,18	1494.7	1495.22	66879.6	30
0,18	1511.4	1511.25	66170.6	35
1,19	1536.1	1535.96	65105.8	50
0,19	1533.8	1553.64	64364.8	40
1,20	1579.2	1578.98	63331.9	75 (blend)
0,20	1597.9	1597.68	62590.6	20
1,21	1623.9	1623.68	61588.7	20

*W. W. Watson and P. G. Koontz, Phys. Rev. 46, 32 (1934)
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(c) : calculated, $\nu_{0,0}$ = 103672.1 cm^{-1}

Table V. Strong Unidentified Absorption Band Heads in the "Pink" Nitrogen Afterglow.

Intensity	λ_{vac}	ν_{vac}
60	1372.88	72839.5
90	1385.39	72181.9
50	1396.03	71631.8
50	1399.22	71468.3
50	1408.92	70976.5
50	1410.49	70897.5
85	1423.63	70242.9
50	1432.24	69820.6
100	1447.99	69061.4
60	1454.60	68747.4
65	1462.80	68361.9
50	1470.33	68011.8
65	1473.34	67873.1
60	1488.19	67195.6
40	1502.49	66556.3
50	1504.10	66484.9
75	1514.09	66046.2
45	1525.24	65563.6
65	1530.00	65359.4
50	1535.96	65105.8
30	1537.74	65030.5
40	1538.50	64998.4
25	1543.61	64783.1
40	1546.76	64651.3
75	1567.02	63815.3

FIGURE CAPTIONS

Figure 1. Schematic drawing of the afterglow tube used for observing the absorption and emission spectra of nitrogen afterglows.

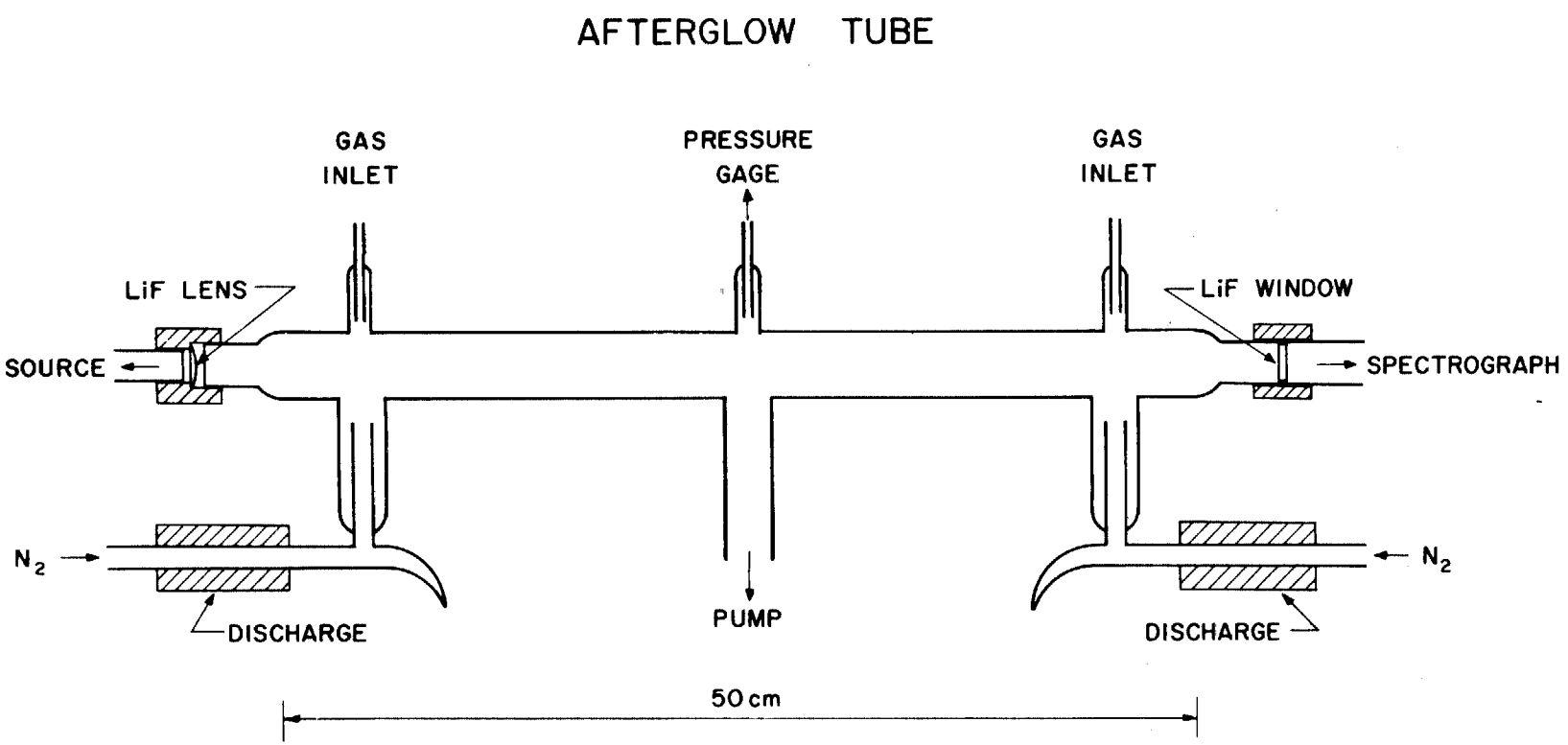
Figure 2. Microwave-powered argon discharge lamp used as a background continuum source for absorption spectra in the region 1150 to 1600 A.

Figure 3. (a) Emission spectrum of the "pink" nitrogen afterglow; nitrogen pressure 6.7 mm Hg; exposure time 3 hours; slit width 25 μ; SWR plate.

(b) Absorption spectrum of the yellow (Lewis-Rayleigh) nitrogen afterglow: nitrogen pressure 62 mm Hg; exposure time 15 min.; slit width 25 μ; SWR plate.

(c) Absorption spectrum of nitrogen: same conditions as (b), but no electric discharge.

(d) Absorption spectrum of the "pink" nitrogen afterglow: nitrogen pressure 6.5 mm Hg; exposure time 1 hour; slit width 12 μ; Q-1 plate.


AFTERGLOW TUBE
GAS INLET
PRESSURE GAGE
GAS INLET
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SOURCE
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N_2
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DISCHARGE
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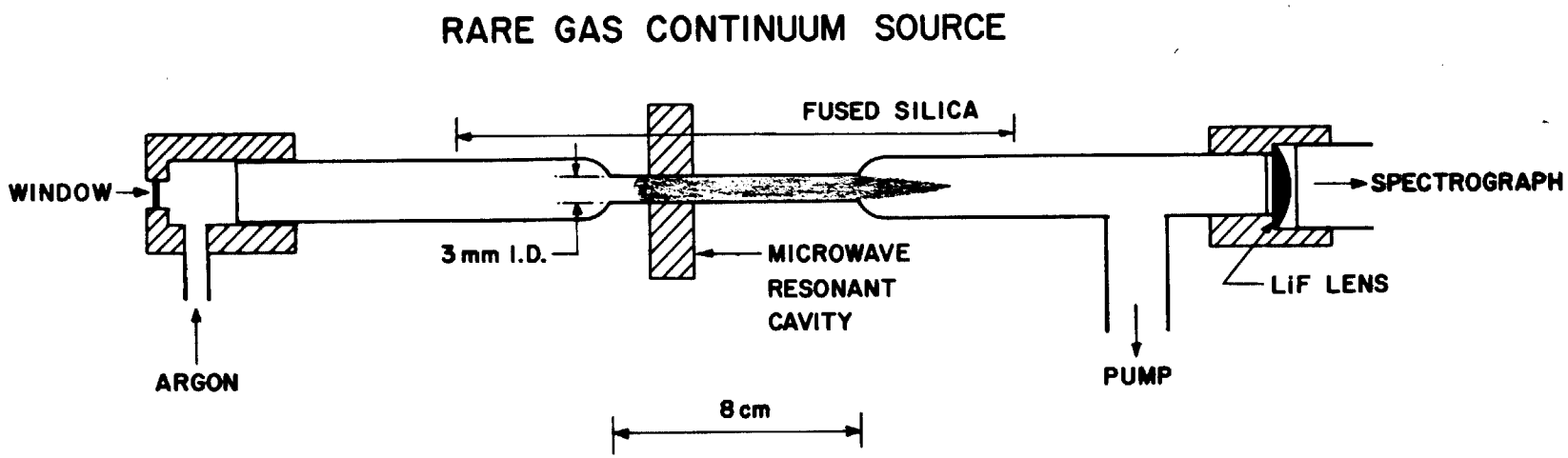
DISCHARGE
50 cm

Figure 1


RARE GAS CONTINUUM SOURCE
FUSED SILICA
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3 mm I.D.
MICROWAVE
RESONANT
CAVITY
LiF LENS
ARGON
PUMP
8 cm

Figure 2

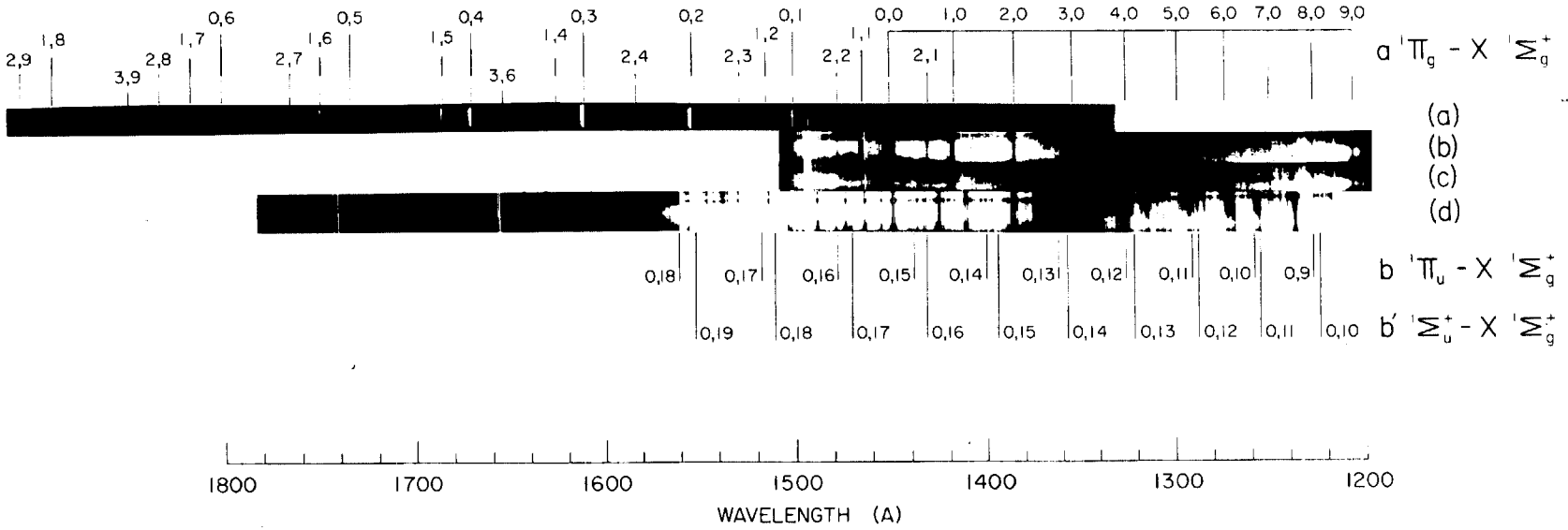
a ¹Πg - X ¹Σg+
(a)
(b)
(c)
(d)
b ¹Πu - X ¹Σg+
b' ¹Σu+ - X ¹Σg+
WAVELENGTH (A)
1800
1700
1600
1500
1400
1300
1200

Figure 3

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage. Absolute Electrical Measurements.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

Joint Institute for Laboratory Astrophysics - NBS Group (Univ. of Colo.).

USCOMM-NBS-DC