

THE IDENTIFICATION OF EXCITED SPECIES IN ARC JET FLOW

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Ronald J. Willey
Department of Chemical Engineering
Northeastern University
360 Huntington Ave.
Boston, Massachusetts 02115

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LYNDON B. JOHNSON SPACE CENTER
Houston, Texas 77058

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16. Abstract Spectrographic work done at the Atmospheric Reentry Material and Structures Facility (Arc Jet) located at the Johnson Space Center has led to the identification of several excited molecular and atomic states. The excited molecular states identified are: first positive nitrogen system ($B^3\Pi \leftarrow A^2\Sigma$), second positive nitrogen system ($C^3\Pi \leftarrow B^3\Pi_2$), first negative nitrogen system ($B^3\Sigma_u^+ \leftarrow X^2\Sigma_g^+$), the γ system for nitric oxide ($A^2\Sigma^+ \leftarrow X^2\Pi$) and the 306.4 nm system of OH ($A^2\Sigma^+ \leftarrow X^2\Pi$). Excited atoms identified were nitrogen, oxygen, hydrogen, silicon, copper, sodium, barium, potassium, and calcium. The latter five are considered contaminants. Excited molecular states of oxygen were not seen, suggesting full dissociation of oxygen molecules to oxygen atoms within the arc column and nozzle. Further, evidence exists that O^- may be present since a background continuum is seen, and because of the existence of positive species (first negative system of N_2^+). Interpretation of spectrographic plates was enhanced by the use of a Perkin Elmer PDS Microdensitometer, and by the application of a second order least squares routine which determined wavelength as a function of plate location. Results of this work will ultimately improve models used in the calculation of heat transfer rates to the Space Shuttle and the aerobraking orbital transfer vehicles.			
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Ronald J. Willey
Assistant Professor
Department of Chemical Engineering
Northeastern University
Boston, Massachusetts

ABSTRACT

Spectrographic work done at the Atmospheric Reentry Material and Structures Facility (Arc Jet) located at the Johnson Space Center has led to the identification of several excited molecular and atomic states. The excited molecular states identified are: first positive nitrogen system ($B^3\Pi \rightleftharpoons A^3\Sigma$), second positive nitrogen system ($C^3\Pi \rightleftharpoons B^3\Pi$), first negative nitrogen system ($B^3\Sigma_u^+ \rightleftharpoons X^2\Sigma_g$), the system for nitric oxide ($A^2\Sigma^+ \rightleftharpoons X^2\Pi$) and the 306.4 nm system of OH ($A^3\Sigma^+ \rightleftharpoons X^2\Pi$). Excited atoms identified were nitrogen, oxygen, hydrogen, silicon, copper, sodium, barium, potassium, and calcium. The latter five are considered contaminants. Excited molecular states of oxygen were not seen, suggesting full dissociation of oxygen molecules to oxygen atoms within the arc column and nozzle. Further, evidence exists that O^- may be present since a background continuum is seen, and because of the existence of positive species (first negative system of N_2^+). Interpretation of spectrographic plates was enhanced by the use of a Perkin Elmer PDS Microdensitometer, and by the application of a second order least squares routine which determined wavelength as a function of plate location. Results of this work will ultimately improve models used in the calculation of heat transfer rates to the Space Shuttle and the aerobraking orbital transfer vehicles.

Center Research Advisor: Dr. Carl Scott

INTRODUCTION

It has been recognized that catalytic recombination of atoms on spacecraft surfaces affects the heat flux during atmospheric reentry (Scott, 1982, and Breen et al., 1973). Current heat flux predictions account for chemical heat flux by recombination coefficients for ground state atoms to ground state molecules (Scott, 1981 a & b) and have greatly improved previous predictions. Although measured heat transfer rates on the forward fuselage agree with calculations, rearward vehicle heat transfer rates under predict observed temperatures by as much as 160 K°. To account for low rearward predictions, it has been hypothesized that energy is carried from the forward section of the vehicle by excited molecules and atoms. The excited species then shed their excitation energy at rearward portions of the vehicle as they relax.

It is the purpose of this work to determine what excited species exist in a flow environment similar to spacecraft reentry.

EXPERIMENTAL

Experiments were conducted at the NASA Lyndon B. Johnson Space Center (JSC) 10-MW arc tunnel facility. More specifically, experiments were conducted in Test Position No. 2 which consists of a 5-MW arc heater, and a 2.44 m diameter chamber. Typical chamber pressures are 60 to 100 Pa. A 3.175 cm diameter throat was used with one of two exit nozzles of 19.05 cm and 63.50 cm diameters respectively.

Spectra were measured in the shock layer of three test articles, an RCC (reinforced carbon-carbon) puck, an HRSI (high temperature reusable surface insulation) wedge, and an RCC wedge, in one of four gas mixtures. The four gas mixtures were: O_2 in N_2 (air) with a mole ratio of O_2 to N_2 equivalent to that of air; N_2 only; O_2 in argon with a mole ratio of O_2 to argon equivalent to that of O_2 to N_2 in air; and argon only. Test article and gas mixture combinations are given in Table 1. Spectra were also taken of free stream conditions, conditions in which no test article was present.

A typical run condition for the 19 cm exit nozzle consists of arc power at 1.41 MW with inlet gas flow rates at 0.0105 kg/sec for O_2 and 0.0355 kg/sec for N_2 . Under these conditions, the exit gas from the nozzle has an enthalpy of 13.3 MJ/kg and a pitot pressure of 2.54 kPa. The range of enthalpy was 11.5 to 16.1 MJ/kg for air and N_2 conditions. Further details of run conditions may be obtained from the JSC arc tunnel facility.

Spectra were measured with a McPherson Model 216.5 0.5 m combination scanning monochromatic spectrograph and polychromator. The majority of the species identification was done by evaluation of spectra recorded on spectrographic plates. Spectra were taken at five centering wavelengths of 260, 380, 500, 620, and 740 nm on Kodak Type 103-0 (260 and 380 nm wavelengths), Type 103-F (500 and 620 nm wavelengths), and Type 1-N (740 nm wavelength) spectrographic plates. Each plate spanned approximately 140 nm of wavelengths, thus there was some overlap at each setting. The spectrograph's entrance and exit slits openings were set at 10 microns. Slit height was set at 4 mm for both slits. Exposure times varied with conditions studied, however, typical times with a test article in place were 2 and 25 seconds for

all center wavelengths except 740 nm, in which 10 and 100 seconds were used. A 440 nm long wavelength band pass cut-off filter was used for wavelengths above 440 nm to prevent the low wavelength second order lines from appearing on the plates.

Wavelength calibration of the plates was done by taking spectra of spectral calibration lamps. Lamps used were mercury for 260, 380, and 500 nm centerline wavelengths, neon for 620 and 740 nm, and argon for 740 nm. A xenon lamp was overlaid the mercury 500 nm calibration to provide some additional lines in this wavelength range.

The spectrograph was also set up as a scanning monochromator and used with limited success. Using the spectrograph successfully in this mode, may save time in species determination since plate development time will be eliminated. Figure 1 is the current equipment arrangement for the scanning monochromator mode.

Species Identification Procedure

Species identification was accomplished by three approaches: comparison of plates, wavelength determination by a hand operated micrometer, and wavelength determination by a microdensitometer. The first approach, comparison of plates, worked very well.

By taking spectra at conditions of air, pure nitrogen, pure argon and oxygen/argon feed mixtures, molecular bands could be separated and identified. An example would be the comparison of spectra for the three conditions of pure nitrogen, oxygen/argon, and air. Inspection of these three together would show molecular bands due to nitrogen only, molecular bands due to oxygen only (none were detected in this work), and finally molecular bands due to nitrogen and

oxygen together (most notably NO bands). Atomic lines due to oxygen or nitrogen atoms could also be separated by the same procedure. Once a particular molecular band or atomic line had been identified, overlaying the plate with the known band or line over a plate with an unknown band or line, allowed a comparison and verification of an excited species presence or absence. Alignment of overlaid plates is checked by aligning the calibration lamp spectra on each plate.

Wavelength determination by a hand operated micrometer was done by finding X-location in inches of various atomic lines on a plate. The procedure required knowledge of at least one known line in a spectrum and a plate "equation" of the form.

$$Y = b_0 + b_1x + b_2 x^2 \quad (1)$$

where Y = wavelength in nm
 x = micrometer reading in inches
 b_0, b_1, b_2 = constants

The constants, b_0 , b_1 , and b_2 , were determined by using the calibration lamp spectrum with known atomic lines and plate locations. Further details of the procedure are presented below under the description of the microdensitometer. With a spectrum positioned properly (the known line located such that its micrometer location gave the correct wavelength in Equation (1)), other unknown atomic lines and band head locations could be measured and assigned a wavelength by Equation (1).

Wavelengths could then be compared to known wavelengths for elemental atomic lines or molecular bands given in the MIT Wavelength Table or Pearse

(Pearse, 1965). Based on a suitable match, and some insight, an assignment of an excited species to that particular wavelength was made.

Wavelength determination by microdensitometer scans were similar to that used for the hand operated micrometer. In this approach, the microdensitometer is scanned across a spectrum, recording image density on a nine-track tape. The process, all automated by a Digital PDP 11/05 microcomputer, required input of the desired pixel size (in microns), the step size, the number of pixels in one scan, and scan mode. Data are then recorded sequentially on a nine-track tape by scan (each scan represented a record of data). Each block of data are preceded by a header which identifies the plate scanned and which half. Scanning of plates was done with a 10 x 400 micron pixel at a 10 micron step in the X-direction for 5000 pixels and a 6000 micron (6 mm) step in the Y-direction for the number of spectrum on a plate. In this mode, half of a plate could be scanned at a time. A move command allowed relocation of the microdensitometer table to the second half of the plate. Further details of the microdensitometer operation are presented in Appendix A.

Raw data for the nine-track tape were read into mass storage of Univac 1182-E computer located at JSC by using FORTRAN (ASCII) subroutines of NTRAN\$ and BITS. NTRAN\$ provided the input/output operations from the foreign tape to the Univac mass storage. BITS converted the 32 bit word format of the Digital PDP microprocessor to the Sperry Rand 36 bit word format (stored in mass storage). Once sequential density readings were stored in mass storage, further processing consisted of locating maximum density versus location (atomic line location) and preparing plots of density versus wavelength. Since locations were in microns, the plate calibration equation used was:

$$Y = b_0 + b_1 x + b_2 x^2 \quad (2)$$

where $Y = \text{wavelength in nm}/100$

$$x = \frac{\text{micron location} - 50000}{5000}$$

= centimeter location from the center of the plate

The choice of centering the x-location was to minimize errors at the edges of a plate. The constants, b_0 , b_1 , b_2 , were determined by a least squares fit of the calibration lamp known wavelengths versus locations. An example of a fit is shown in Appendix B for Hg and the 260 nm centerline. Actual versus predicted wavelength differed by a maximum of only 0.015 nm. Plate constants determined by this approach are shown in Table 2.

Better accuracy was achieved with the microdensitometer than with the hand micrometer and allowed determination of unknown wavelengths to within 0.03 nm. The procedure does require a known line in the spectrum since a small offset occurs plate to plate. Known atomic lines of copper, sodium, or oxygen were present in most cases.

Plots of spectrum data could be accomplished by use of a subroutine library called DISSPLA. Examples of the plots generated are shown in Figures 2-4 and are discussed under results. Appendix C contains a listing of program names used to read and process data from the microdensitometer. Copies of these programs are located in Appendix C.

RESULTS

A series of spectral measurements made of the shock layer and free stream emission are discussed here.

A summary of measured excited atoms and molecules is presented in Table 3. Excited atomic species identified were: oxygen, nitrogen, copper, sodium, hydrogen, calcium, barium, silicon, potassium, and argon. Excited molecular species identified were: 1st positive nitrogen, 2nd positive nitrogen, 1st negative nitrogen (N_2^+), nitric oxide γ system, and OH 306.4 nm system.

Discussion

Excited atomic species such as oxygen, nitrogen, potassium, barium, calcium, copper, and silicon were mainly observed in the bright white light of the RCC puck surface. This surface perpendicularly faced the arc column, and thus it is suspected that some of this light may represent reflected light from the arc column itself. A continuum was also seen under these conditions suggesting O^- and possible O_2^- negative ions.

In the shock layer of the RCC puck with air, excited states of N_2 (N_2 1st and 2nd positive and N_2^+ 1st negative) are readily observed as well as the NO system. The mechanism for creation of these excited states of N_2 was probably ground state N_2 molecules raised to higher energy levels as they passed into the high temperature shock layer. Similarly, excited oxygen atoms are observed in the shock layer. The probably source was ground state oxygen atoms from the column excited as they cross into the shock layer. No molecular bands of O_2 were observed. This suggests that all oxygen is

dissociated in the arc column. Excited NO molecules also existed in the free stream (at a lower concentration compared to the shock layer) and were probably created in the arc column.

Excited copper atoms, particularly those associated with the 324.7540 and 327.3962 nm wavelength, were prevalent in any condition in which N_2 was present (copper was observed in the free stream, shock layer, and surface), however, no excited copper atoms were observed for conditions in which argon was a carrier. Argon probably erodes the anode slower than nitrogen.

Figure 2 shows a sample spectrum for the shock layer of air before the RCC puck surface. The atomic copper lines are pronounced along with the band structure of the 1st negative system of N_2^+ . Less pronounced (to the left of the figure) is the band structure for the 2nd positive system of N_2 .

Comparing Figure 3 to Figure 4 shows an interesting phenomenon of argon line broadening when oxygen is present. Note that the argon lines are very broad in Figure 3 (the oxygen condition) while in Figure 4 they are quite narrow (as expected). The reason for this is not clear with a possibility of electron densities being higher when oxygen is present.

Excited atomic hydrogen and OH were observed in only one instance: the shock layer of the RCC puck with pure argon. Existence of H and OH suggests some residual water in the test chamber at the time the spectra were taken. Some residual N_2 was also seen under these conditions. This spectrum centered at 260 and 380 nm gives the best example of the 2nd positive N_2 system (Plate 42 of this work). Plate's photographs, annotated with species identification, are shown in Appendix D.

The best example of NO γ system can be seen in the air free stream spectrum centered at 260 nm (Plate 45). Examples of the 1st negative N_2^+ and 1st positive N_2 systems can be seen in the spectrum of the N_2 shock layer in spectrum centered at 380 nm, 500 nm, 620 nm and 7400 nm (Plates 23, 24, and 25).

Spectrum of the HRSI wedge air shock layer showed two distinct zones between the shock layer and the surface layer. 1st negative N_2^+ and 2nd positive N_2 were seen in the surface layer clearly, but they only faintly appear in the shock layer. The spectrum showed both zones because the spectrograph slit was focused across both layers (Plate 58, which is not shown in Appendix D).

An important question arises, which currently remains unresolved: Is the surface composed of excited N_2 molecules or is the spectrum of reflected light from the arc column? The implication of surface excited N_2 molecules would support surface energy transfer mechanisms by chemical means to excited molecular states.

A summary of excited species observed when the RCC puck was inserted in air is shown in Figure 5.

CONCLUSIONS

1. Three excited states of N_2 have been identified, first positive, second positive and first negative systems.
2. Excited NO is present as the γ system.
3. Excited oxygen and nitrogen atoms are present.
4. Contaminants observed include copper, sodium, potassium, barium, and calcium.
5. No excited molecular states of O_2 were observed.
6. A second order linear regression equation is sufficient for data analysis.
7. Argon is less severe on anode erosion compared to nitrogen.

RECOMMENDATIONS

1. Continue developing monochromatic mode of scanning.
2. Improve optics so that spectra of point positions can be taken.
3. Take spectra of the afterglow from various test articles.
4. Determine if the "white" surface light seen on test articles is from the surface or a reflection from the arc column.

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TABLE 1

EXPERIMENT TEST ARTICLES AND GAS MIXTURES

TEST ARTICLE	SIZE	MOUNTING DETAILS	GAS MIXTURES EXAMINED
Free Stream			O_2/N_2 (Air)
RCC Puck	7.1 cm in diameter	In a 10.16 cm diameter graphite-silicon carbide holder which was in a 12.70 cm diameter copper holder	O_2/N_2 (Air) N_2 O_2 /Argon Argon
HRSI Wedge	0.4m X 0.6m	-15° angle with respect to the camber line	O_2/N_2 (Air) N_2 O_2 /Argon
RCC Wedge	0.4m X 0.6m	-15° angle with respect to the camber line	No tests as of 9/4/84

TABLE 2

CALIBRATION CONSTANTS FOR PLATE WAVELENGTH CALIBRATION EQUATIONS

Plate Equation:

$$Y = b_0 + b_1 x + b_2 x^2$$

where

Y = Wavelength in angstroms/100

$$x = \frac{\text{micron location} - 50000}{5000}$$

PLATE CENTERLINE WAVELENGTH, cm	CONSTANTS			PLATE USED	EXPOSURE #
	b_0	b_1 ($\times 10^{-4}$)	b_2 ($\times 10^{-4}$)		
260	2.589955	7.852731	-2.285499	32	1
380	3.790448	7.485376	-1.627544	42	6
500	5.001239	7.187476	-2.042028	43	1
620	6.179126	6.824881	-2.21267	15	6
740	7.392686	6.388521	-2.487615	31	1

TABLE 3
EXCITED SPECIES IDENTIFIED

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS ¹	PLATE	EXP. SEQ. NO. ON PLATE
O Oxygen	394.7330		Ar/O ₂ Sh	32	4
	394.751		Ar/O ₂ Sh	32	4
	436.8300		Ar/O ₂ Sh	30	3
	532.8561		Air Su	34	3
	645.607	5S ⁵ S ⁰ --> 3p ⁵ P	Ar/O ₂ Sh	30	5
	700.2202	3S ³ D ⁰ --> 3p ⁵ P	Ar/O ₂ Sh	31	4
	715.6380		Ar/O ₂ Sh	31	4
	777.1928	3p ⁵ P --> 3S ⁵ S ⁰	Air Sh	16	4
	777.4139	3p ⁵ P --> 3S ⁵ S ⁰	Air Sh	16	4
	777.5433	3p ⁵ P --> 3S ⁵ S ⁰	Air Sh	16	4
	N Nitrogen	491.4900		Air Su	34
493.5030			Air Su	34	3
517.008 (N II)			Air Su	34	3
518.146 (N II)			Air Su	34	3
528.1180			Air Su	34	3
530.9480			Air Su	34	3
535.6770			Air Su	34	3
537.2660			Air Su	34	3
566.6640 (N II)			Air Su	34	3
567.9560 (N II)			Air Su	34	3
742.3880			N ₂ Sh	25	3

TABLE 3
EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS ¹	PLATE	EXP. SEQ. NO. ON PLATE
	744.2560		N ₂ Sh	25	3
	746.8790		N ₂ Sh	25	3
Cu Copper	324.7540	4p ² P ⁰ -->4s ² S	Air Su	33	3
	327.3962	4p ² P ⁰ -->4s ² S	Air Su	33	3
	510.5541	4p ² P ⁰ -->4s ² S	Air Su	34	3
	515.3235	4d ² D-->4p ² P ⁰	Air Su	34	3
	521.8202	4d ² D-->4p ² P ⁰	Air Su	34	3
	529.2517		Air Su	34	3
	578.2130	4p ² P ⁰ -->4s ² D	Air Su	34	5
Na Sodium	588.9953		Air Su	34	5
	589.5923		Air Su	34	5
H Hydrogen	656.2790	H	Ar Sh	43	3
	486.1327	H	Ar Sh	43	3
	434.0465	H	Ar Sh	43	3
	410.1735	H	Ar Sh	42	5
Ca Calcium	393.3666		Air Su	33	4
	396.8468		Air Su	33	4
Ba Barium	455.4042		Air Sh	15	3
	493.4086		Air Sh	15	3

TABLE 3
EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS ¹	PLATE	EXP. SEQ. NO. ON PLATE
Si Silicon	250.6899		Air Su	33	3
	251.6123		Air Su	33	3
	252.8516		Air Su	33	3
	288.1578		Air Su	33	3
K Potassium	766.4907		Air Su	35	2
	769.8978		Air Su	35	2

Calibration lamps (atomic lines identified on photographs) and argon)

Hg	260 nm Centerline Wavelength		Ar Sh	42	1
	380	" "	Air Sh	14	6
	500	" "	Ar/O ₂ Sh	30	1
Ne	620	" "	Ar/O ₂ Sh	30	6
	740	" "	Ar/O ₂ Sh	31	2
A	380	" "	Ar Sh	42	5
	500	" "	Ar Sh	43	3
	620	" "	Ar Sh	43	5
	740	" "	Ar Sh	48	3

TABLE 3
EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm OF STRONGEST BAND HEAD	TRANSITION	CONDITIONS ¹	PLATE	EXP. SEQ. NO. ON PLATE
N ₂ 1st Positive	645.58	B ³ --> A ³	Air Sh	15	3
	750.39		Air Sh	16	4
N ₂ 2nd Positive	315.93 V	C ³ --> B ³	Ar SH	42	5
	337.13				
N ₂ ⁺ 1st Negative	358.21 V	B ² + --> X ² g ⁺	Air Sh	14	4
	391.44				
	427.81				
NO, System	247.11	A ² + --> X ²	Air F	45	3
	247.81				
	258.55				
	259.57				
OH 306.4 nm System	306.36	A ² + --> X ²	Ar Sh	42	3
	306.72				

¹Air F Air Free Stream
 Air Sh Air Shock Layer of RCC Puck
 Air Su Air Surface Layer of RCC Puck
 Ar Sh Argon Shock Layer of RCC Puck
 Ar/O₂ Argon/Oxygen Mixture
 N₂ Sh Nitrogen Shock Layer of RCC Puck

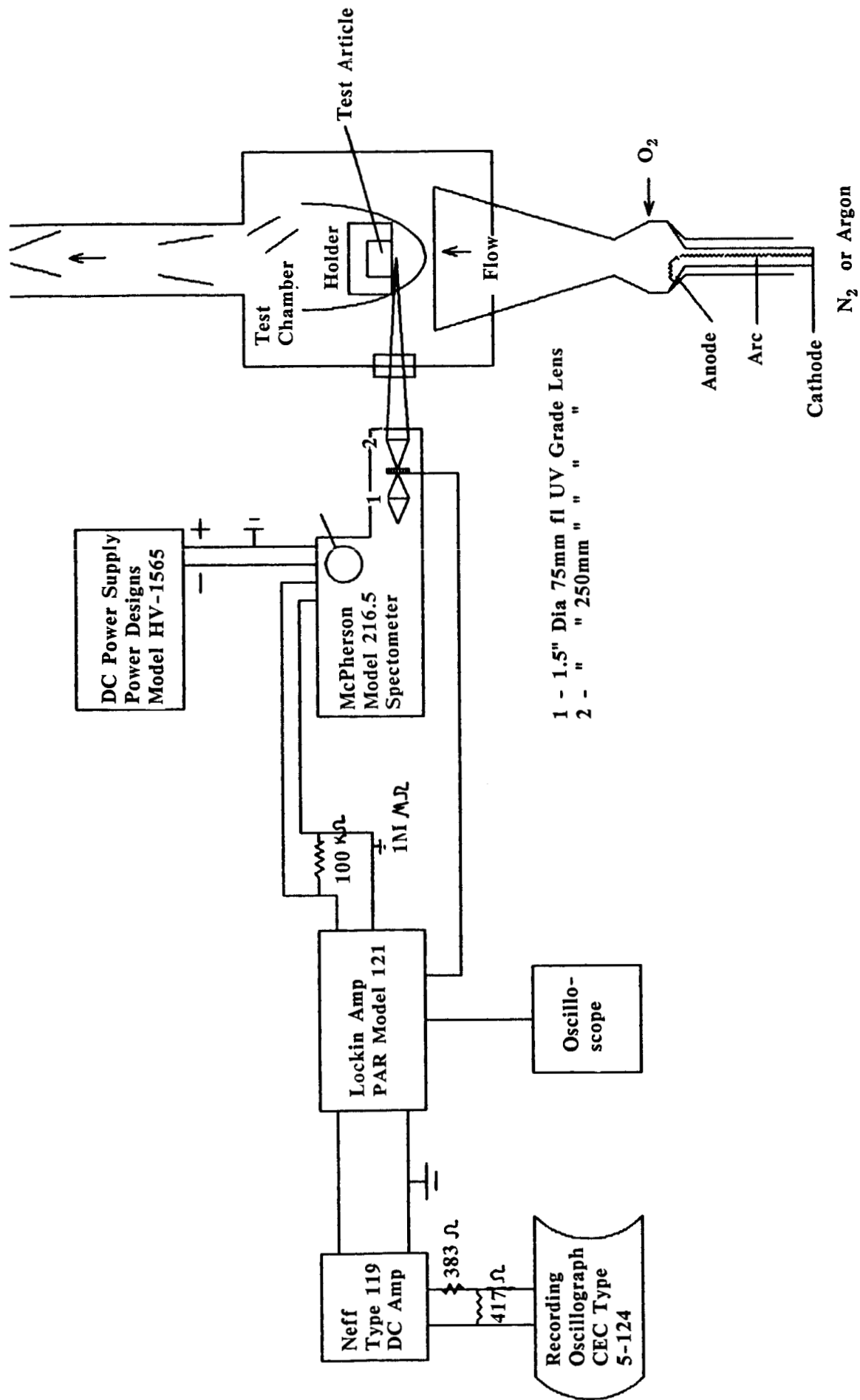


Figure 1. Arc Jet Flow Sheet and Spectrographic Equipment Diagram

AIR FLAT FACED MODEL CARBON CARBON
 PINK SHOCK LAYER
 PLATE 36 EXP #5

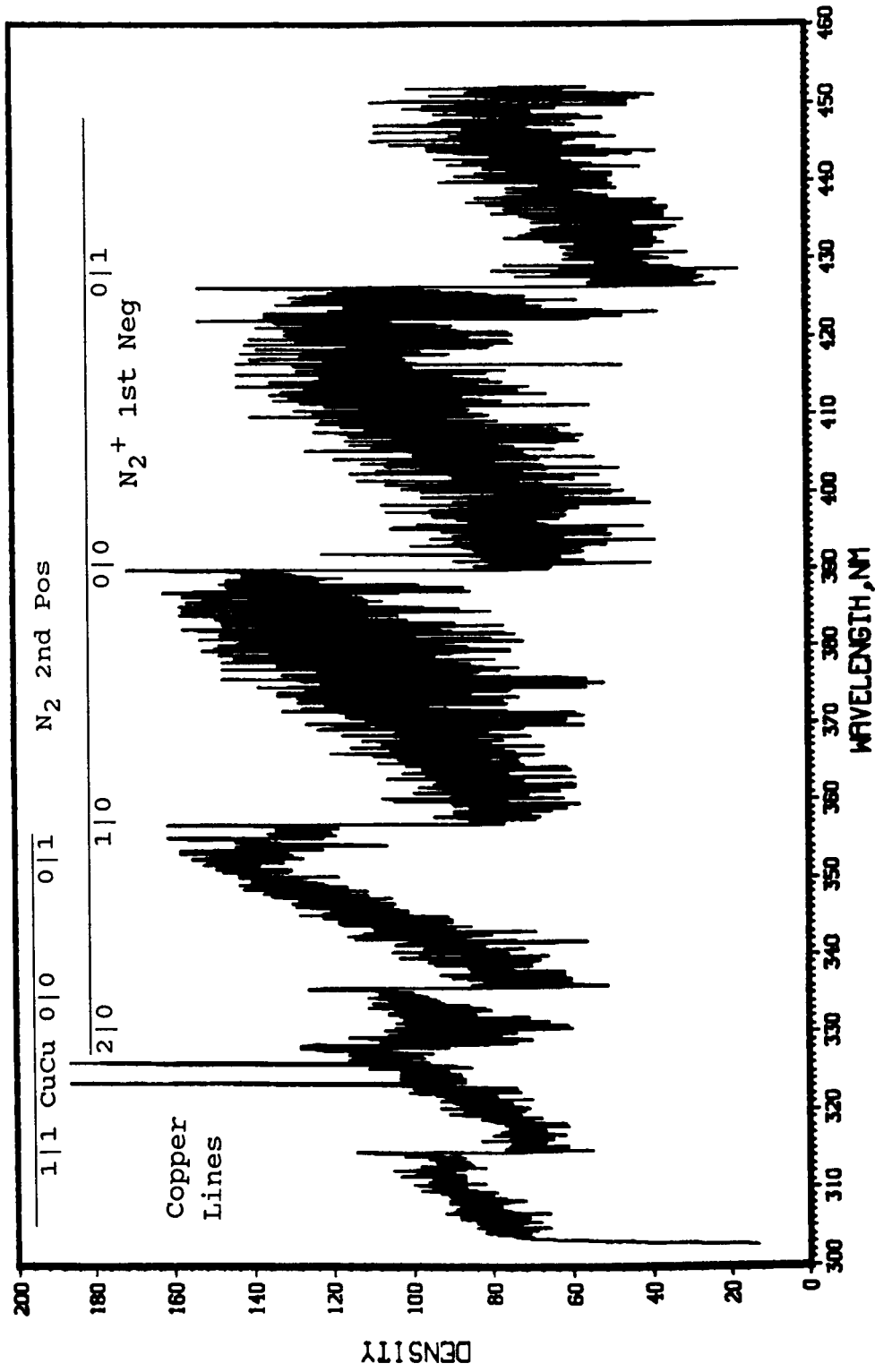


Figure 2. Spectrum of Shock Layer before RCC Puck at 380 nm Centering Wavelength - Air

ARGON/OXYGEN FLAT FACED MODEL CARBON CARBON

PLATE 30 EXP #5

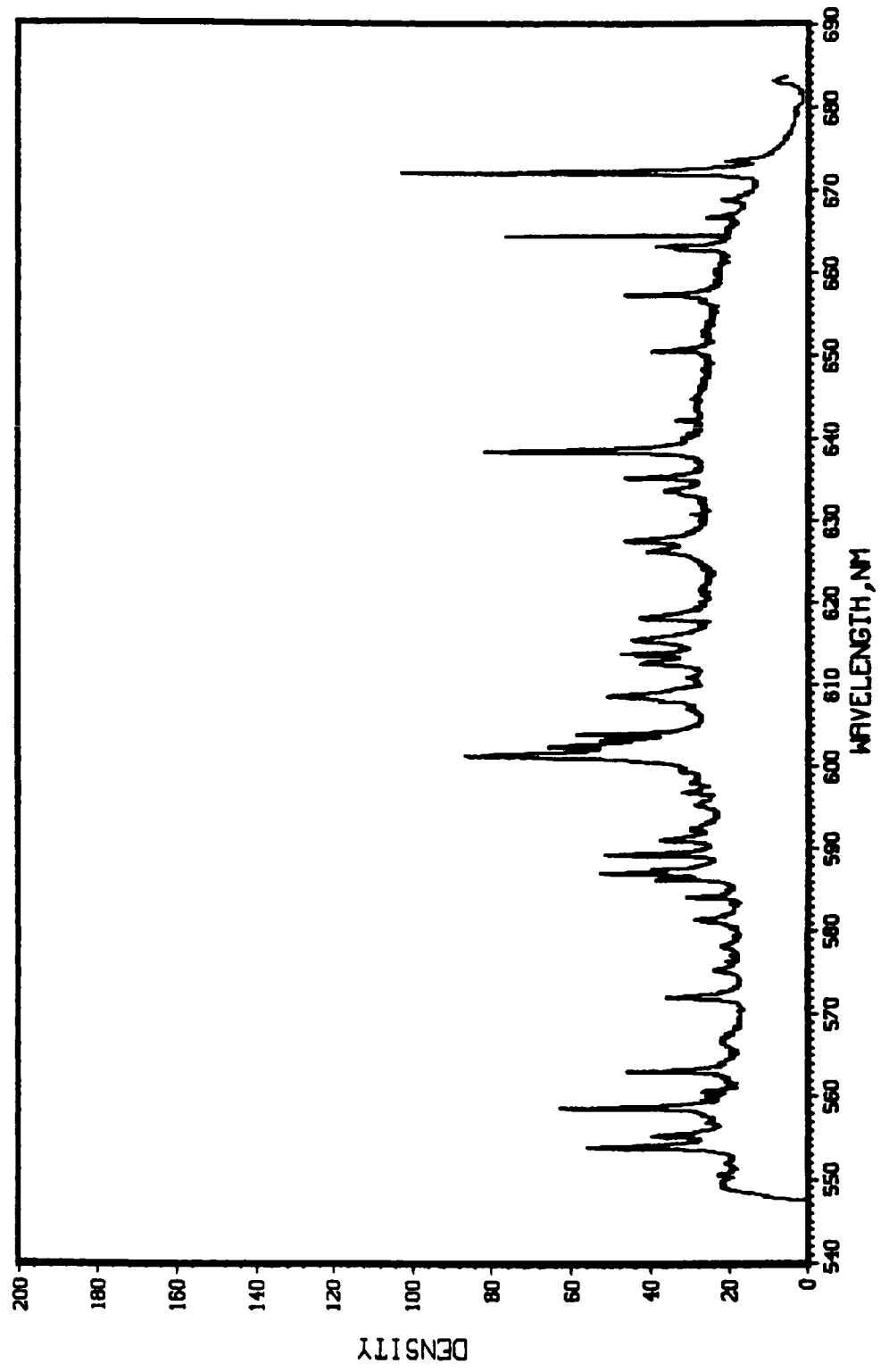


Figure 3. Spectrum of Shock Layer before RCC Puck at 620 nm Centering Wavelength - Oxygen in Argon

ARGON ONLY FLAT FACED MODEL CARBON CARBON

PLATE 43 EXP #5

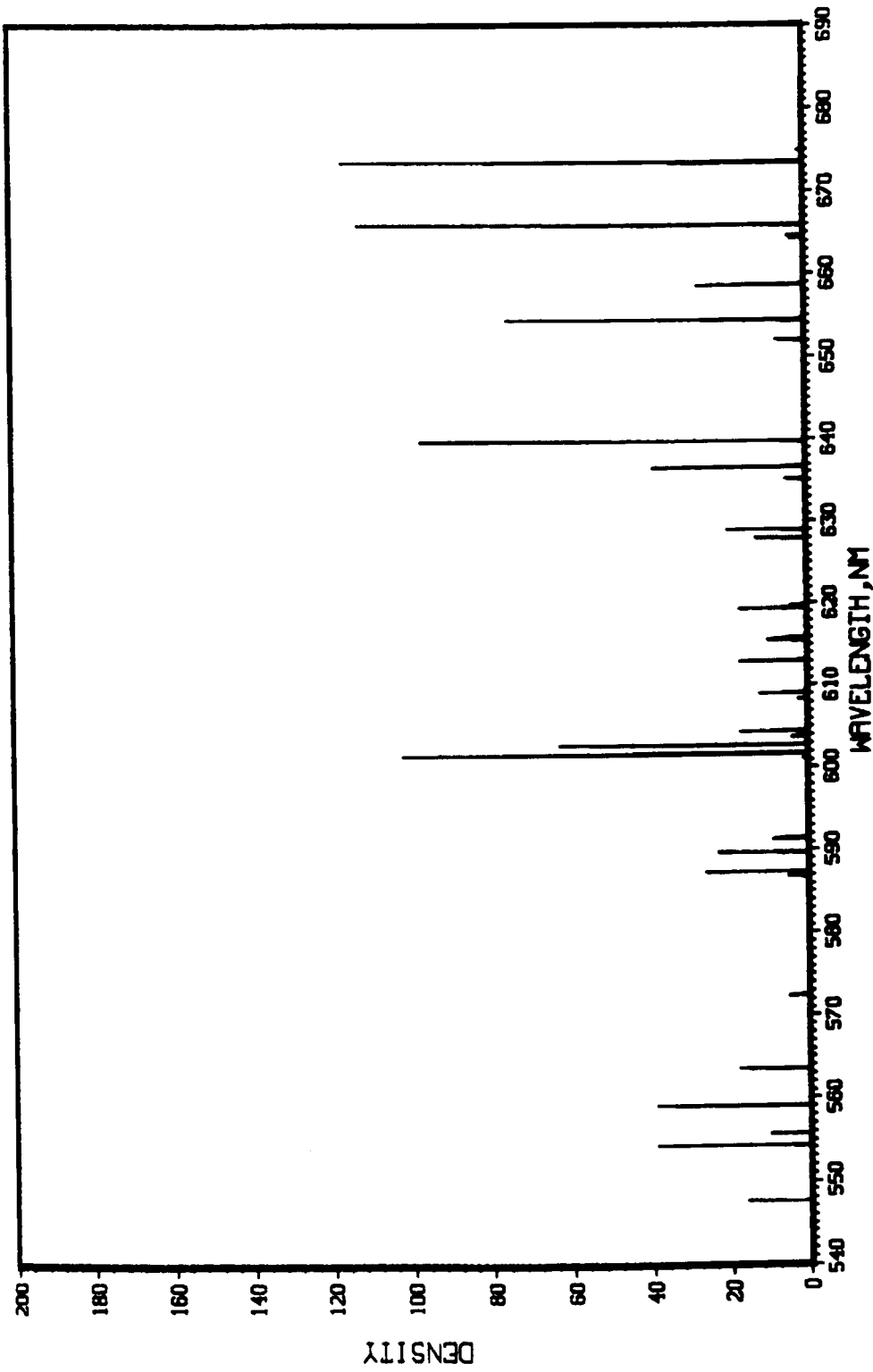


Figure 4. Spectrum of Shock Layer before RCC Puck at 620 nm Centering Wavelength - Argon Only

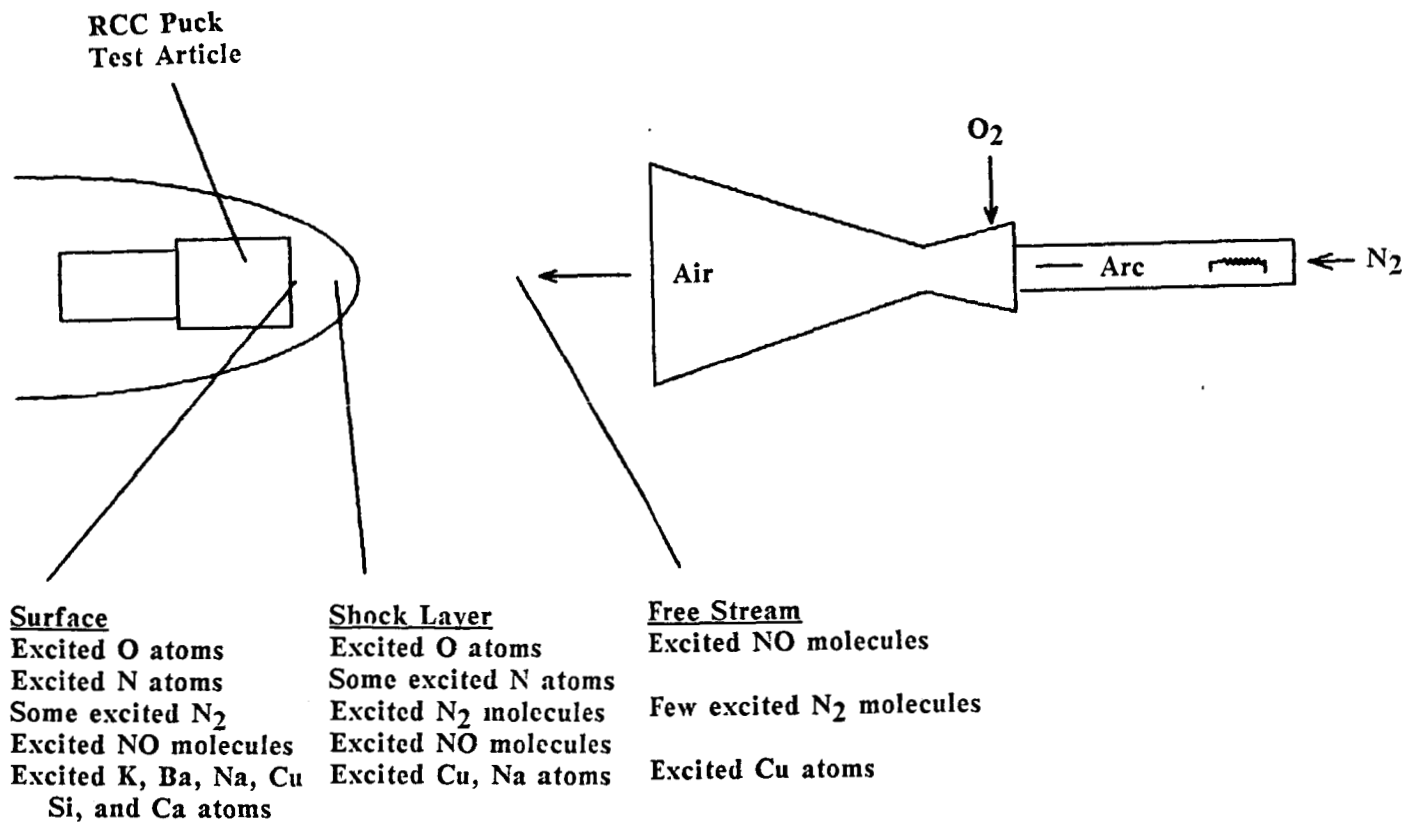


Figure 5. Excited Species Observed When the RCC Puck Test Article is in Air from the Arc Jet

APPENDIX A

MICRODENSITOMETER DETAILS

Location: USDA Forest Service
1050 Bay Area Blvd.
Houston, TX 77058

Start-Up

Follow lettered sequence of turning on equipment (Steps A-H).

Load tape in bottom tape drive.

Microprocessor Details

From a cold start load

Set half down

Enter 157744 (see p. 24 instruction manual)

Press Load Address

Enable halt up

Press Start

Type DIADS after 30 seconds

After DIADS is loaded

Type the following commands to scan a plate

<u>Command</u>	<u>Description</u>
1 TAPE-UNIT	Set lower tape drive to receive data
NEW-TAPE	Optional, use when starting with a fresh tape
PDS Parameters	Sets the PDS parameters
6000 UY	Sets Y step of 6000 microns
10 UX	Sets X step of 10 microns
6 5000 SIZE	Sets scan size of 6 lines by 5000 pixels
21 IO-UNIT	Sets automatic command mode
TAPE PDS P MOVE	Move PDS parameters to tape parameters
TAPE PARAMETERS SHOW	Shows tape parameters
Reset Set	Sets zero on densitometer at present table position
UL H Set	Sets upper left as home and horizontal scan mode
FLY-BACK	Scans in one direction only
SCAN	Begins automatic scan

Microdensitometer Adjustments

The microdensitometer has a dual optical system called upper and lower optics.

1. Mount plate(s)
2. With the photomultiplier tube off, select aperature size and pixel type for the upper and lower optical systems (both must match).
3. Focus the upper and lower optics.
4. Select a clear area and zero the density reading as shown in the instruction manual.
5. Check the density gain as shown in the instruction manual.

APPENDIX B

EXAMPLE OF LEAST SQUARES FIT OF PLATE CALIBRATION EQUATION TO KNOWN DATA
SOURCE - PLATE 32, EXPOSURE 1 (Hg CENTERED AT 260 nm)

$$Y = b_0 + b_1 x + b_2 x^2$$

where $Y = \text{Wavelength}/100$

$$x = (\text{microns}-50000)/5000$$

DATA NUMBER	MICRONS MEASURED	ACTUAL WAVELENGTH, nm (Hg ATOMIC LINES)	PREDICTED WAVELENGTH, nm	RESIDUAL nm
1	53970	265.2042	265.2162	-0.0120
2	54060	265.3681	265.3569	0.0112
3	69550	289.3595	289.3503	0.0092
4	74380	296.7278	296.7421	-0.0143
5	77930	302.1499	302.1477	0.0022
6	78060	302.3476	302.3452	0.0023
7	84810	312.5663	312.5585	0.0078
8	85210	313.1546	313.1611	-0.0065

Constants found by least squares

$$b_0 = 2.589955$$

$$b_1 = 0.07852731$$

$$b_2 = -0.0002285499$$

APPENDIX C

PROGRAMS USED TO READ AND PROCESS MICRODENSITOMETER DATA

PROGRAM	DESCRIPTION	CONTROL PROGRAM WHICH MAPS IN PROGRAM AND REQUIRED SUBROUTINES
RW.START	Assign the necessary data files needed for plotting	
RW.READIN	Reads in information one word at a time from mass storage	RW.CONTROL12
RW.STORE	Stores information one word at a time into mass storage	RW.CONTROL13
RW.REDATA1	Reads data from 9-track tape. Stores it in mass storage. ¹	RW.CONTROL2
RW.LOCATELINE3	Finds maximum intensity versus micron (pixel) location	RW.CONTROL11
RW.FINDCONST	Finds plate offset for known wavelength and micron location	RW.CONTROL7
RW.BRINGIN	Sets up spectrum data for plots	RW.CONTROL10
RW.PLOTDAT	Plots density versus wavelength of a spectrum	RW.CONTROL5
RW.MASTER	Least squares fit of known wavelength versus micron location	RW.CONTROL
RW.END	Program which frees all assigned files after a run	

¹ Requires an address location in 1000K at the plate number address, i.e., Plate 14's 60,000 pieces of data were stored at a starting location of 3,000, thus mass storage location 14 had the number 3. New plates should start at mass storage location 1,131,000.

Example of how to create a plot of microdensitometer trace of plates using elements in file RW. under ES3-N03200

```
@ADD RW.START
DATA IGNORED - IN CONTROL MODE
I:002333 ASG complete.
I:002333 USE complete.
I:002333 ASG complete.
I:002333 USE complete.
I:002333 ASG complete.
I:002333 USE complete.
>@ADD RW.CONTROL10
DATA IGNORED - IN CONTROL MODE
I:002333 FREE complete.
I:002333 ASG complete.
Collector 31R2B (841126 1925:45) 1987 Aug 11 Tue 1356:54
END MAP. ERRORS: 0 TIME: 13.838 STORAGE:
11308/6/021777/0107377
I:002333 USE complete.
WHAT PLATE NUMBER IS THIS ?
>36
WHAT EXPOSURE DO YOU WISH TO LOOK AT ?
>5
WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT?
>0
WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ?
>9999
IS THE OFFSET TERM IN MASS STORAGE ?
>N
IS THE OFFSET TERM KNOWN ?
>N
IS PACKING REQUIRED? MAX # OF POINTS PLOTTED = 2500
>Y
WHAT IS THE PACKING FACTOR ? PCKNG FCTR = # PNTS
DIVIDED BY 2500
>4
DATA IS ON UNIT 7
READY TO XQT PLOTDAT
@@XQT RW.PLOTDAT
>@ADD RW.CONTROL5
Collector 31R2B (841126 1925:45) 1987 Aug 11 Tue 1357:41
END MAP. ERRORS: 0 TIME: 1:05.201 STORAGE:
24940/30/034077/0127777
WHAT WAVE LENGTH RANGE IS THIS ?
TYPE 1 FOR 260 NM
TYPE 2 FOR 380 NM
TYPE 3 FOR 500 NM
TYPE 4 FOR 620 NM
TYPE 5 FOR 740 NM
>2
```

continued on the next page

Continued from the previous page....

WHAT IS THE OFFSET TERM ?
WHAT IS THE PIXEL STARTING POINT OF THE DATA ?
NUMBER OF PIXELS YOU WISH TO PLOT ?
WHAT IS THE PIXEL WIDTH ?
PIXEL STARTING POINT 302.56349
ENDING POINT 452.21375
WHAT IS THE X ORIGIN AND X ENDING POINT ?

>300
>460

RW.START

ES3-N03200*RW(1).START(11)

```
1 .  
2 .  
3 . RW.START  
4 .  
5 . THIS IS A CONTROL PROGRAM TO ASSIGN DATA FILES  
6 . FOR USE IN ANY PROGRAMS RELATED TO READING  
7 . MICRODENSITOMETER DATA FROM MASS STORAGE  
8 .  
9 .  
10 . TO EXECUTE TYPE @ADD RW.START  
11 .  
12 @ASG,A DATA1.  
13 @USE 2.,DATA1.  
14 @ASG,T DATAIN.  
15 @USE 4.,DATAIN.  
16 @ASG,T DATAOUT.  
17 @USE 3.,DATAOUT.
```

RW.CONTROL12

ES3-N03200*RW(1).CONTROL12(2)

```
1 .
2 .
3 . RW.CONTROL12
4 .
5 .
6 @PACK,P RW.
7 @MAP,N RW.READIN
8 IN RW.READIN
9 LIB JSC*FTN.
10 END
11 @XQT RW.READIN
```

RW.READIN

ES3-N03200*RW(1) READIN(11)

```
1 DIMENSION A(100)
2 REAL X(100)
3 C
4 C
5 C RW.READIN
6 C
7 C
8 C THIS PROGRAM WILL READ IN DATA LOCATED IN MASS STORAGE 1 WORD AT A TIME
9 C THIS PROGRAM IS USEFUL FOR CHECKING STORAGE OF A NUMBER IN MASS STORAGE
10 C
11 C
12 CHARACTER WORD(48)*1,QU*1
13 INTEGER NA(100)
14 CALL NTRAN$(2,10,22)
15 WRITE(6,*)'AT WHAT POINT DO YOU WISH TO READ FROM ?'
16 READ(5,6)NB
17 6 FORMAT()
18 CALL NTRAN$(2,6,NB)
19 WRITE(6,*)'HOW MANY WORDS DO YOU WISH TO CHECK ?'
20 READ(5,6)NW
21 NW1=4*NW
22 WRITE(6,*)'IS THIS AN INTEGER,CHARACTER,REAL,OR OCTAL ?'
23 READ(5,7)QU
24 7 FORMAT(A1)
25 IF(QU.EQ.'I')CALL NTRAN$(2,2,NW,NA(1),JSTAT,22)
26 IF(QU.EQ.'C')CALL NTRAN$(2,2,NW,WORD(1),JSTAT,22)
27 IF(QU.EQ.'R')CALL NTRAN$(2,2,NW,X(1),JSTAT,22)
28 IF(QU.EQ.'O')CALL NTRAN$(2,2,NW,A(1),JSTAT,22)
29 IF(QU.EQ.'I')WRITE(6,8)(NA(I),I=1,NW)
30 8 FORMAT(1X,I8)
31 IF(QU.EQ.'C')WRITE(6,9)(WORD(I),I=1,NW1)
32 9 FORMAT(1X,48A1)
33 IF(QU.EQ.'R')WRITE(6,10)(X(I),I=1,NW)
34 10 FORMAT(1X,E14.7)
35 IF(QU.EQ.'O')WRITE(6,11)(A(I),I=1,NW)
36 11 FORMAT(1X,O12)
37 WRITE(6,*)'PRINT PROGRAM IS FINISHED'
38 STOP
39 END
```

RW.CONTROL13

ES3-N03200*RW(1).CONTROL13(5)

```
1 @PACK,P RW.  
2 .  
3 .  
4 . RW.CONTROL13  
5 .  
6 . THIS IS A CONTROL PROGRAM WHICH MAPS IN REQUIRED  
7 . INFORMATION TO RUN RW.STORE.  
8 .  
9 .  
10 @MAP,N RW.STORE  
11 IN RW.STORE  
12 LIB JSC*FTN.  
13 END  
14 @XQT RW.STORE
```

RW.STORE

ES3-N03200*RW(1).STORE(10)

```
1 INTEGER NC  
2 C  
3 C  
4 C RW.STORE  
5 C  
6 C  
7 C THIS PROGRAM IS USEFUL FOR PLACEMENT OF PLATE  
8 C CALIBRATION CONSTANTS, PLATE LOCATION, AND PLATE  
9 C OFFSETS INTO MASS STORAGE  
10 C  
11 C AN EXAMPLE IS TO STORE THE NUMBER 3 AT MASS STORAGE  
12 C LOCATION NUMBER 14. THIS NUMBER REPRESENTS THE LOCATION  
13 C IN MASS STORAGE TIMES 1000 WHERE THE 60000 PIECES OF INFORMATION  
14 C FOR PLATE 14 IS LOCATED.  
15 C  
16 CC  
17 WRITE(6,*)'HOW MANY NUMBERS ARE YOU STORING ? '  
18 READ(5,21)IA  
19 DO 30 I=1,IA  
20 WRITE(6,*)'WHAT LOCATION DO YOU WISH TO STORE AT ? '  
21 READ(5,21)NB  
22 WRITE(6,*)'WHAT NUMBER DO YOU WISH TO STORE ? '  
23 READ(5,21)NC  
24 CALL NTRAN$(2,10,22)  
25 CALL NTRAN$(2,6,NB)  
26 CALL NTRAN$(2,1,1,NC,JSTAT,22)  
27 CALL NTRAN$(2,10,22)  
28 30 CONTINUE  
29 21 FORMAT()  
30 WRITE(6,*)'PROGRAM IS FINISHED'  
31 STOP  
32 END
```

RW.CONTROL2

ES3-N03200*RW(1).CONTROL2(47)

```
1 .
2 .
3 . RW.CONTROL2
4 .
5 .
6 . THIS PROGRAM IS USED TO MAP IN AND RUN
7 . RW.REDATA1
8 .
9 .
10 @MAP,N ,RW.REDATA1
11 IN RW.REDATA1
12 LIB JSC*FTN.
13 END
14 @USE 1.,TAPE1.
15 @USE 2.,DATA1.
16 @XQT RW.REDATA1
```

RW.REDATA1

ES3-N03200*RW(1).REDATA1(5)

```
1 CHARACTER*1 CHRBUF(66),CHRID(64),QU(1),CHRID2(64)
2 C
3 C
4 C RW.REDATA1
5 C
6 C
7 C THIS PROGRAM READS A 9 TRACK TAPE WITH MICRO-
8 C DENSITOMETER DATA STORES IT INTO MASS SOTRAGE
9 C
10 C
11 C
12 C SCNNUM = SCAN NUMBER
13 C CHRID = 64 CHARACTER IDENTIFIER
14 C SCNVEL = SCAN VELOCITY
15 C XORG = X-ORIGIN
16 C YORG = Y-ORIGIN
17 C SSPACX = SCAN SPACING X (MICRONS)
18 C SSPACY = SCAN SPACING Y (MICRONS)
19 C NUMPXL = NUMBER OF PIXELS IN A LINE
20 C
21 INTEGER IBUF1(32),IBUF2(1250,7),BINVAL(5000,7)
22 EQUIVALENCE (CHRBUF(1),IBUF1(1))
23 INTEGER SCNVEL,XORG,YORG,SSPACX,SSPACY,NUMPXL,NUMLIN
24 INTEGER IOUNIT,XOFSET,YOFSET,NRATIO,DRATIO,BITPIX,APSIZE
25 C
26 C TRY TO OPEN A DEFINED FILE
27 C
28 DO 50 NC1=2,46
29 C
30 C
31 C SET UP THE HEADER INTO LOGICAL FORM
32 C
33 C
34 C READ IN THE DATA
35 C
36 WRITE(6,27)
37 27 FORMAT(1X,'CHECK POINT ZERO HEADING INTO CALL NTRAN')
38 CALL NTRAN$(1,2,32,IBUF1,JSTAT,22)
39 WRITE(6,24)JSTAT
40 24 FORMAT(1X,'CHECK POINT ONE ',I6)
41 12 FORMAT(I32)
42 C
43 C CONVERSIONS
```

```

44 C
45 SCNNUM=BITS(IBUF1(1),1,16)
46 SCNVEL=SBITS(IBUF1(17),16,16)
47 XORG=IBUF1(18)
48 YORG=IBUF1(19)
49 SSPACX=SBITS(IBUF1(20),1,16)
50 SSPACY=SBITS(IBUF1(20),16,16)
51 NUMPXL=BITS(IBUF1(21),1,16)
52 NUMLIN=BITS(IBUF1(21),16,16)
53 APSIZE=BITS(IBUF1(22),1,16)
54 IOUNIT=BITS(IBUF1(22),1,16)
55 BITPIX=BITS(IBUF1(29),16,16)
56 DO 20 I=1,64
57   CHRID(I)=CHRBUF(I+2)
58 20 CONTINUE
59 C
60 C RE-ARRANGE LETTERS
61 C
62   DO 60 I=2,64,2
63   K=I-1
64   CHRID2(K)=CHRID(I)
65   CHRID2(I)=CHRID(K)
66 60 CONTINUE
67   WRITE(6,14)(CHRID2(I),I=1,64)
68   WRITE(6,*)'IS THIS THE CORRECT PLATE ? ANSWER YES BY TYPING O'
69   READ(5,21)IQU
70   IF(IQU.NE.0)GO TO 50
71 C
72 C READ IN DATA FOR LA NUMBER OF SCANS
73 C
74   WRITE(6,16)
75 16 FORMAT(1X,'HOW MANY LINES ARE ON THIS PLATE?')
76   READ(5,21)LA
77   DO 15 L=1,LA
78   CALL NTRAN$(1,2,1250,IBUF2(1,L),JSTAT,22)
79 15 CONTINUE
80 13 FORMAT(I32)
81 C
82 C
83 C
84   XOFSET=((BITS(IBUF1(23),16,16)*256)+(BITS(IBUF1(24),1,16)))
85   YOFSET=((BITS(IBUF1(24),16,16)*256)+(BITS(IBUF1(25),1,16)))
86   NRATIO=((BITS(IBUF1(25),16,16)*256)+(BITS(IBUF1(26),1,16)))
87   DRATIO=((BITS(IBUF1(26),16,16)*256)+(BITS(IBUF1(27),1,16)))
88 C
89 C TRANSLATE RAW DATA
90 C
91   DO 30 L=1,LA
92   DO 11 I=1,1250
93   IA=((L-1)*1250+I)
94   DO 10 J=1,4
95   K=(I-1)*4+J
96   BINVAL(K,L)=BITS(IBUF2(I,L),((J-1)*9+1),9)
97 10 CONTINUE
98 11 CONTINUE
99 30 CONTINUE
100 C
101 C PRINT OUT DATA TO A DATA FILE
102 C
103 C
104 C WRITE HEADER
105 C TO FIRST DATA FILE
106 C
107   WRITE(6,17)
108 17 FORMAT(1X,'IS THIS AN A, B, C, OR D QUADRANT')
109   READ(5,18)QU
110 18 FORMAT(A1)
111   WRITE(6,19)
112 19 FORMAT(1X,'NUMBER OF LINES IN THIS QUADRANT')
113   READ(5,21)LB
114 21 FORMAT()
115 C

```

```

116     WRITE(2,14)(CHRID2(I),I=1,64)
117  14  FORMAT(1X,64A1)
118     WRITE(2,22)QU
119  22  FORMAT(1X,'QUADRANT ',A1)
120     DO 25 L=1,LB
121     DO 35 I=1,5000
122     WRITE(2,23)I,BINVAL(I,L)
123  23  FORMAT(1X,I6,2X,I6)
124  35  CONTINUE
125  25  CONTINUE
126     ENDFILE 2
127  C
128  C
129  C WRITE DATA OUT
130  C TO SECOND DATA FILE
131  C
132     WRITE(6,17)
133     READ(5,18)QU
134     WRITE(6,19)
135     READ(5,21)LC
136     WRITE(2,14)(CHRID2(I),I=1,64)
137     WRITE(2,22)QU
138     LD=LC+LB
139     DO 45 L=(LB+1),LD
140     DO 40 I=1,5000
141     WRITE(2,23)I,BINVAL(I,L)
142  40  CONTINUE
143  45  CONTINUE
144  @MOVE TAPE1.,1
145     ENDFILE 2
146  50  CONTINUE
147     STOP
148     END

```

RW.CONTROL11

ES3-N03200*RW(1).CONTROL11(4)

```
1 . R
2 .
3 .
4 . RW.CONTROL11
5 .
6 .
7 . THIS PROGRAMS MAPS AND CONTROLS RW.LOCATELINES3
8 .
9 .
10 @MAP,N ,RW.LOCATELINES3
11 IN RW.LOCATELINES3
12 LIB JSC*FTN.
13 END
14 @USE 2.,DATA1.
15 @XQT RW.LOCATELINES3
```

RW.LOCATELINES3

ES3-N03200*RW(1).LOCATELINES3(11)

```
1 INTEGER INTENS(10000),INTEN2(10000)
2 CHARACTER QR(3),QS(3),Y(1)
3 C
4 C
5 C RW.LOCATELINES3
6 C
7 C
8 C THIS PROGRAM WILL LOCATE MAXIMUM
9 C INTENSITY VERSUS MICRON PIXEL LOCATION
10 C
11 C AN EXAMPLE WOULD BE TO @ADD RW.CONTROL11
12 C ANSWER THE QUESTIONS AS THEY APPEAR
13 C
14 C OUTPUT IS ON FILE 3.
15 C
16 NEXP=6
17 CALL NTRAN$(2,10,22)
18 WRITE(6,*)'WHAT PLATE NUMBER IS THIS ? '
19 Y(1)='Y'
20 READ(5,21)LOC
21 IF(LOC.EQ.16.OR.LOC.EQ.25.OR.LOC.EQ.31.OR.LOC.EQ.34.OR.LOC.
22 1 EQ.35.OR.LOC.EQ.38)NEXP=4
23 IF (LOC.EQ.44)NEXP=3
24 21 FORMAT()
25 CALL NTRAN$(2,6,LOC)
26 CALL NTRAN$(2,2,1,NB,JSTAT,22)
27 CALL NTRAN$(2,10,22)
28 NB=NB*1000
29 WRITE(6,*)'WHAT EXPOSURE DO YOU WISH TO LOOK AT ? '
30 READ(5,21)NELOC
31 LINE=NEXP-NELOC
32 NB=NB+LINE*10000
33 WRITE(6,*)'WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT ? '
34 READ(5,21)LPIX1
35 NB=NB+LPIX1
36 WRITE(6,*)'WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ? '
37 READ(5,21)LPIX2
38 NPIX=LPIX2-LPIX1+1
39 CALL NTRAN$(2,6,NB)
40 CALL NTRAN$(2,2,NPIX,INTENS(LPIX1),JSTAT,22)
41 CALL NTRAN$(2,10,22)
42 WRITE(6,*)'IS THE OFFSET TERM IN MASS STORAGE ? '
43 READ(5,12)QS(1)
44 IF(QS(1).NE.Y(1))GO TO 30
```

```

45     NB=LOC*12+LINE
46     CALL NTRAN$(2,6,NB)
47     CALL NTRAN$(2,2,1,NAO,JSTAT,22)
48     CALL NTRAN$(2,10,22)
49     AO1=NAO
50     NB=LOC*12+LINE+6
51     CALL NTRAN$(2,6,NB)
52     CALL NTRAN$(2,2,1,NAO,JSTAT,22)
53     AO2=NAO
54     GO TO 40
55 30 CONTINUE
56     WRITE(6,*)'IS THE OFFSET TERM KNOWN ?'
57     READ(5,12)QS(1)
58     IF(QS(1).NE.Y(1))GO TO 35
59     WRITE(6,*)'WHAT IS THE SIDE A OFFSET TERM ?'
60     READ(5,21)NAO
61     AO1=NAO
62     AO2=0.0
63     NB=LOC*12+LINE
64     CALL NTRAN$(2,6,NB)
65     CALL NTRAN$(2,1,1,NAO,JSTAT,22)
66     CALL NTRAN$(2,10,22)
67 11 FORMAT(1X,I6,2X,I6)
68 33 CONTINUE
69     WRITE(6,*)'WHAT IS THE SIDE B OFFSET TERM ?'
70     READ(5,21)NAO
71     AO2=NAO
72     NB=LOC*12+LINE+6
73     CALL NTRAN$(2,6,NB)
74     CALL NTRAN$(2,1,1,NAO,JSTAT,22)
75     CALL NTRAN$(2,10,22)
76     GO TO 40
77 35 AO1=0.0
78     AO2=0.0
79 40 WRITE(6,*)' IS PACKING REQUIRED ? '
80     READ(5,12)QR(1)
81     IF(QR(1).NE.Y(1))GO TO 60
82     WRITE(6,*)'WHAT IS THE PACKING FACTOR ?'
83     READ(5,21)NPACK
84     KA=LPIX1/NPACK+1
85     KK=NPIX/NPACK+KA
86     DO 55 K=KA,KK
87     DO 53 I=1,NPACK
88     L=(K*NPACK-NPACK)+I
89     INTEN2(K)=INTENS(L)+INTEN2(K)
90 53 CONTINUE
91     INTEN2(K)=INTEN2(K)/NPACK
92 55 CONTINUE
93     NPIX=NPIX/NPACK
94     CALL LOCATE(INTEN2,AO1,AO2,LOC,NELOC,LPIX1,
95     1LPIX2,NPACK)
96     GO TO 70
97 60 NPACK=1
98     CALL LOCATE(INTENS,AO1,AO2,LOC,NELOC,LPIX1,
99     1LPIX2,NPACK)
100 12 FORMAT(A1)
101 70 CONTINUE
102 STOP
103 END
104 SUBROUTINE LOCATE(INTENS,AO1,AO2,IP,IR,IP1,IP3,IP4)
105 INTEGER INTENS(10000),N,I,IA
106 REAL INCHES
107 REAL A(5),B1(5),B2(5)
108 CALL NTRAN$(2,10,22)
109 NB=100
110 CALL NTRAN$(2,6,NB)
111 CALL NTRAN$(2,2,5,A(1),JSTAT,22)
112 CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
113 CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
114 IP4=IP4*10
115 WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
116 WRITE(6,*)'TYPE 1 FOR 260 NM '

```

```

117 WRITE(6,*)'TYPE 2 FOR 380 NM '
118 WRITE(6,*)'TYPE 3 FOR 500 NM '
119 WRITE(6,*)'TYPE 4 FOR 620 NM '
120 WRITE(6,*)'TYPE 5 FOR 740 NM '
121 READ(5,6)IAV
122 WRITE(3,9)IP,IR
123 9 FORMAT(1X,'PLATE',2X,I3,1X,'EXPOSURE #',1X,I2,1X,'SIDE',1X,A1)
124 WRITE(6,*)'WHAT IS THE MINIMUM INTENSITY YOU WISH TO PRINT OUT ?'
125 READ(5,6)ID1
126 6 FORMAT()
127 AO=AO1
128 DO 20 I=IP1,IP3,1
129 IF(I.EQ.5001)GO TO 60
130 28 IF(INTENS(I).LE.ID1)GO TO 20
131 IF(INTENS(I).GE.INTENS(I-1))GO TO 30
132 GO TO 20
133 30 IF(INTENS(I).GE.INTENS(I+1))GO TO 35
134 GO TO 25
135 35 IF(INTENS(I).GT.INTENS(I+1))GO TO 37
136 NCOUNT=NCOUNT+1
137 GO TO 20
138 37 IF(INTENS(I).GT.INTENS(I-1))GO TO 40
139 K=I-(NCOUNT)/2
140 INCHES=K/2540.
141 N=N+1
142 IA=K*IP4
143 XA=(IA+AO-50000.)/5000.
144 WAVE=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
145 WAVE=WAVE*100.
146 BI=IA/10000.
147 WRITE(3,12)IA,BI,INCHES,INTENS(K),WAVE
148 GO TO 25
149 40 INCHES=I/2540.
150 N=N+1
151 IA=I*IP4
152 XA=(IA+AO-50000.)/5000.
153 WAVE=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
154 WAVE=WAVE*100.
155 BI=IA/10000.
156 WRITE(3,12)IA,BI,INCHES,INTENS(I),WAVE
157 12 FORMAT(1X,'THERE IS A LINE AT',1X,I6,1X,'MICRONS',1X
158 1 ,F4.2,1X,'CM',1X
159 1 ,F6.4,1X,'INCHES',2X,'OF INTENSITY OF',1X,I6
160 1 ,1X,'WAVELENGTH',1X,F9.4,1X,'NM')
161 25 NCOUNT=0
162 20 CONTINUE
163 50 CONTINUE
164 WRITE(6,13)N
165 13 FORMAT(1X,'THE NUMBER OF LINES = ',I3)
166 WRITE(6,*)'END OF PROGRAM DATA IS ON FILE 3.'
167 GO TO 70
168 60 AO=AO2
169 GO TO 28
170 70 CONTINUE
171 RETURN
172 END

```

RW.CONTROL7

ES3-N03200*RW(1).CONTROL7(3)

```
1 .
2 .
3 .
4 . RW.CONTROL7
5 .
6 .
7 . CONTROL PROGRAM TO MAP AND RUN RW.FINDCONST
8 .
9 .
10 @MAP,N,RW.FINDCONST
11 IN RW.FINDCONST
12 LIB JSC*FTN.
13 END
14 @XQT RW.FINDCONST
```

RW.FINDCONST

ES3-N03200*RW(1).FINDCONST(14)

```
1 REAL A(5),B1(5),B2(5)
2 C
3 C
4 C RW.FINDCONST
5 C
6 C
7 C THIS SIMPLE PROGRAM ASSISTS IN FINDING
8 C PLATE OFFSETS. AN EXAMPLE WOULD BE TO
9 C EXAMINE PLATE 23 EXPOSURE 6 (TOP LINE)
10 C USING LOCATELINES AND COMPARE WITH KNOWN
11 C WAVELENGTHS SHOWN ON PLATE 14 EXPOSURE
12 C 6 (HG CALIBRATION) . THE OFFSET IS
13 C RETURN AN CAN BE STORED INTO MASS
14 C STORAGE BY RW.LOCATELINES3 OR RW.BRINGIN
15 C
16 C
17 CALL NTRAN$(2,10,22)
18 NB=100
19 CALL NTRAN$(2,6,NB)
20 CALL NTRAN$(2,2,5,A(1),JSTAT,22)
21 CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
22 CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
23 WRITE(6,*)'HOW MANY LOCATIONS ARE YOU GOING TO CHECK ?'
24 READ(5,6)NUM
25 WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
26 WRITE(6,*)'TYPE 1 FOR 260 NM '
27 WRITE(6,*)'TYPE 2 FOR 380 NM '
28 WRITE(6,*)'TYPE 3 FOR 500 NM '
29 WRITE(6,*)'TYPE 4 FOR 620 NM '
30 WRITE(6,*)'TYPE 5 FOR 740 NM '
31 READ(5,6)I
32 DO 10 N=1,NUM,1
33 WRITE(6,*)'WHAT IS THE KNOWN WAVELENGTH ?'
34 6 FORMAT()
35 READ(5,6)Y
36 Y=Y/100.
37 X=(-B1(I)+SQRT(B1(I)**2-4*B2(I)*(A(I)-Y)))/(2*B2(I))
38 X=X*5000.+50000.
39 WRITE(6,*)' KNOWN X PLATE IS ',X
40 WRITE(6,*)' WHAT IS THE MICRON LOCATION ON THE PLATE ?'
41 READ(5,6)Y1
42 UY=X-Y1
43 WRITE(6,*)'OFFSET TERM ',UY
44 10 CONTINUE
```

```
45  WRITE(6,*)'END OF PROGRAM'  
46  STOP  
47  END
```

RW.CONTROL10

ES3-N03200*RW(1).CONTROL10(11)

```
1 .
2 .
3 . RW.CONTROL10
4 .
5 .
6 . CONTROL PROGRAM TO RUN
7 . RW.BRINGIN A PROGRAM TO SET
8 . UP THE PLOT HEADER
9 .
10 @FREE TPF$.
11 @ASG,T TPF$.F//300
12 @MAP,N,RW.BRINGIN
13 IN RW.BRINGIN
14 LIB JSC*FTN.
15 END
16 @USE 2.,DATA1.
17 @XQT RW.BRINGIN
```

RW.BRINGIN

ES3-N03200*RW(1).BRINGIN(34)

```
1 INTEGER INTENS(10000),INTEN2(10000)
2 CHARACTER QR(3),QS(3),Y(1)
3 CHARACTER PLATE(1)*6,LINE1(6)*1,DOLL(1)*1,TOPLIN(1)*48
4 CHARACTER SELINE(1)*36,WORD4(1)*4,LINE2(1)*7
5 DATA PLATE/'PLATE '/,LINE2/' EXP # '/,DOLL/'$'/
6 DATA LINE1/'1','2','3','4','5','6'/
7 C
8 C
9 C RW.BRINGIN
10 C
11 C
12 C THIS PROGRAM SETS UP HEADERS AND
13 C DETAILS REQUIRED TO RUN RW.PLOTDAT
14 C
15 C AN EXAMPLE WOULD BE TO PLOT
16 C PLATE 43 EXPOSURE 5
17 C
18 C
19 C
20 WRITE(6,*)'WHAT PLATE NUMBER IS THIS ? '
21 Y(1)='Y'
22 READ(5,21)LOC
23 CALL NTRAN$(2,10,22)
24 NB=601
25 INDEX=(LOC-14)*22
26 NB=NB+INDEX
27 CALL NTRAN$(2,6,NB)
28 CALL NTRAN$(2,2,12,TOPLIN(1),JSTAT,22)
29 WRITE(7,14)TOPLIN(1)
30 14 FORMAT(A48)
31 16 FORMAT(A36)
32 17 FORMAT(A6,A4,A6,A1,A1)
33 CALL NTRAN$(2,2,9,SELINE(1),JSTAT,22)
34 WRITE(7,16)SELINE(1)
35 CALL NTRAN$(2,2,1,WORD4(1),JSTAT,22)
36 CALL NTRAN$(2,10,22)
37 21 FORMAT()
38 CALL NTRAN$(2,6,LOC)
39 CALL NTRAN$(2,2,1,NB,JSTAT,22)
40 CALL NTRAN$(2,10,22)
41 NB=NB*1000
```

```

42 WRITE(6,*)'WHAT EXPOSURE DO YOU WISH TO LOOK AT ?'
43 READ(5,21)NELOC
44 NEXP=6
45 IF(LOC.EQ.16.OR.LOC.EQ.25.OR.LOC.EQ.31.OR.LOC.EQ.34
46 1 .OR. LOC.EQ.35.OR.LOC.EQ.38)NEXP=4
47 IF(LOC.EQ.44)NEXP=3
48 LINE=NEXP-NELOC
49 WRITE(7,17)PLATE(1),WORD4(1),LINE2(1),LINE1(NELOC),DOLL(1)
50 NB=NB+LINE*10000
51 WRITE(6,*)'WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT? '
52 READ(5,21)LPIX1
53 NB=NB+LPIX1
54 WRITE(6,*)'WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ?'
55 READ(5,21)LPIX2
56 NPIX=LPIX2-LPIX1+1
57 CALL NTRAN$(2,6,NB)
58 CALL NTRAN$(2,2,NPIX,INTENS(LPIX1),JSTAT,22)
59 CALL NTRAN$(2,10,22)
60 WRITE(6,*)'IS THE OFFSET TERM IN MASS STORAGE ?'
61 READ(5,12)QS(1)
62 IF(QS(1).NE.Y(1))GO TO 30
63 NB=LOC*12+LINE
64 CALL NTRAN$(2,6,NB)
65 CALL NTRAN$(2,2,1,NAO,JSTAT,22)
66 CALL NTRAN$(2,10,22)
67 AO1=NAO
68 NB=LOC*12+LINE+6
69 CALL NTRAN$(2,6,NB)
70 CALL NTRAN$(2,2,1,NAO,JSTAT,22)
71 AO2=NAO
72 GO TO 40
73 30 CONTINUE
74 WRITE(6,*)'IS THE OFFSET TERM KNOWN ?'
75 READ(5,12)QS(1)
76 IF(QS(1).NE.Y(1))GO TO 35
77 WRITE(6,*)'WHAT IS THE SIDE A OFFSET TERM ?'
78 READ(5,21)NAO
79 AO1=NAO
80 AO2=0.0
81 NB=LOC*12+LINE
82 CALL NTRAN$(2,6,NB)
83 CALL NTRAN$(2,1,1,NAO,JSTAT,22)
84 CALL NTRAN$(2,10,22)
85 11 FORMAT(1X,I6,2X,I6)
86 33 CONTINUE
87 WRITE(6,*)'WHAT IS THE SIDE B OFFSET TERM ?'
88 READ(5,21)NAO
89 AO2=NAO
90 NB=LOC*12+LINE+6
91 CALL NTRAN$(2,6,NB)
92 CALL NTRAN$(2,1,1,NAO,JSTAT,22)
93 CALL NTRAN$(2,10,22)
94 GO TO 40
95 35 AO1=0.0
96 AO2=0.0
97 40 WRITE(6,*)' IS PACKING REQUIRED? MAX # OF POINTS PLOTTED =
98 1 2500'
99 READ(5,12)QR(1)
100 IF(QR(1).NE.Y(1))GO TO 60
101 WRITE(6,*)'WHAT IS THE PACKING FACTOR ? PCKNG FCTR = # PNTS
102 1 DIVIDED BY 2500'
103 READ(5,21)NPACK
104 KA=LPIX1/NPACK+1
105 KK=NPIX/NPACK+KA
106 DO 55 K=KA,KK
107 DO 53 I=1,NPACK
108 L=(K*NPACK-NPACK)+I
109 INTEN2(K)=INTENS(L)+INTEN2(K)
110 53 CONTINUE
111 INTEN2(K)=INTEN2(K)/NPACK
112 55 CONTINUE
113 NPIX=NPIX/NPACK

```

```
114     WRITE(7,21)AO1,AO2
115     WRITE(7,21)LPIX1
116     WRITE(7,21)NPIX
117     WRITE(7,21)NPACK
118     WRITE(7,11)(I,INTEN2(I),I=KA,KK)
119     GO TO 70
120 60 CONTINUE
121     WRITE(7,21)AO1,AO2
122     WRITE(7,21)LPIX1
123     WRITE(7,21)NPIX
124     NPACK=1
125     WRITE(7,21)NPACK
126     WRITE(7,11)(I,INTENS(I),I=LPIX1,LPIX2)
127 70 CONTINUE
128     WRITE(6,*)'DATA IS ON UNIT 7'
129     WRITE(6,*)'READY TO XQT PLOTDAT'
130     WRITE(6,*)'@@XQT RW.PLOTDAT'
131 12 FORMAT(A1)
132     STOP
133     END
```

RW.CONTROL5

```
ES3-N03200*RW(1).CONTROL5(21)
  1 @MAP,N,RW.PLOTDAT
  2 IN RW.PLOTDAT
  3 LIB DISSPLA*AGEM.
  4 LIB JSC*FTN.
  5 END
  6 @XQT RW.PLOTDAT
```

RW.PLOTDAT

```
ES3-N03200*RW(1).PLOTDAT(52)
  1  COMPILER (PROGRAM=BIG),(BANKED=ALL)
  2  INTEGER INTENS(5000)
  3  C
  4  C
  5  C RW.PLOTDATA
  6  C
  7  C
  8  C WITH RW.BRINGIN, THIS PROGRAM WILL PLOT MICRODENSITOMETER
  9  C DATA ON A TEKTRONIX 4014-1 TERMINAL
 10  C
 11  C
 12  CHARACTER WORD1*47,WORD2*31,WORD3*17,QU*1
 13  REAL XARAY(2500),YARAY(2500)
 14  REAL A(5),B1(5),B2(5)
 15  CALL REDC(A,B1,B2)
 16  WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
 17  WRITE(6,*)'TYPE 1 FOR 260 NM '
 18  WRITE(6,*)'TYPE 2 FOR 380 NM '
 19  WRITE(6,*)'TYPE 3 FOR 500 NM '
 20  WRITE(6,*)'TYPE 4 FOR 620 NM '
 21  WRITE(6,*)'TYPE 5 FOR 740 NM '
 22  READ(5,6)IAV
 23  6 FORMAT()
 24  REWIND 1
 25  REWIND 7
 26  READ(7,14)WORD1
 27  14 FORMAT(A47)
 28  READ(7,16)WORD2
 29  16 FORMAT(A31)
 30  READ(7,17)WORD3
 31  17 FORMAT(A17)
 32  WRITE(6,*)'WHAT IS THE OFFSET TERM ?'
 33  READ(7,6)AO1,AO2
 34  WRITE(6,*)'WHAT IS THE PIXEL STARTING POINT OF THE DATA ?'
 35  READ(7,6)IP1
 36  WRITE(6,*)'NUMBER OF PIXELS YOU WISH TO PLOT ?'
 37  READ(7,12)IP5
 38  WRITE(6,*)'WHAT IS THE PIXEL WIDTH ?'
 39  READ(7,12)IP4
 40  IP4=IP4*10
 41  READ(7,11)(INTENS(I),I=1,IP5)
 42  YORIG=0
 43  YMAX=200
 44  YSTEP=20
 45  XSTEP=10.
 46  IB=IP1+IP5-1
 47  IC=IB-IP1
 48  AO=AO1
 49  DO 10 I=IP1,IB
 50  IBA=I*IP4/10
```

```

51 IF(IBA.GE.5001)AO=AO2
52 K=I-IP1+1
53 IA=(I-IP1)*IP4+IP1*10
54 XA=(IA+AO-50000.)/5000.
55 XARAY(K)=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
56 XARAY(K)=XARAY(K)*100.
57 YARAY(K)=INTENS(K)
58 10 CONTINUE
59 WRITE(6,*)'PIXEL STARTING POINT ',XARAY(1)
60 K=IB-IP1+1
61 WRITE(6,*)'ENDING POINT ',XARAY(K)
62 WRITE(6,*)'WHAT IS THE X ORIGIN AND X ENDING POINT ?'
63 READ(5,12)XORIG,XMAX
64 12 FORMAT()
65 11 FORMAT(1X,6X,2X,I6)
66 CALL TEKEGM(480,1,0)
67 CALL SETDEV(10,10)
68 CALL PAGE(11.0,8,5)
69 CALL HWROT('AUTO')
70 CALL HWSCAL('SCREEN')
71 CALL NOBRDR
72 CALL YTICKS(5)
73 CALL YAXANG(0.)
74 CALL AREA2D(9.35,6.00)
75 CALL FRAME
76 CALL XNAME('WAVELENGTH,NM',14)
77 CALL YNAME('DENSITY',7)
78 CALL HEADIN(WORD1,47,1.,3)
79 CALL HEADIN(WORD2,31,1.,3)
80 CALL HEADIN(WORD3,17,1.,3)
81 CALL INTAXS
82 CALL XTICKS(10)
83 CALL GRAF(XORIG,XSTEP,XMAX,YORIG,YSTEP,YMAX)
84 CALL CURVE(XARAY,YARAY,IC,0)
85 CALL ENDPL(0)
86 CALL DONEPL
87 STOP
88 END
89 SUBROUTINE REDC(A,B1,B2)
90 REAL A(5),B1(5),B2(5)
91 CALL NTRAN$(2,10,22)
92 NB=100
93 CALL NTRAN$(2,6,NB)
94 CALL NTRAN$(2,2,5,A(1),JSTAT,22)
95 CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
96 CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
97 RETURN
98 END

```

RW.CONTROL

ES3-N03200*RW(1).CONTROL(25)

```
1 .
2 .
3 . RW.CONTROL
4 .
5 .
6 . RW.CONTROL IS A CONTROL PROGRAM TO
7 . DETERMINE 2ND ORDER LINEAR LEAST SQUARES
8 .
9 .
10 @ASG,T DATAIN.
11 @ED RW.PLATE326B,DATAIN.
12 EXIT
13 @USE 4.,DATAIN.
14 @MAP,N RW.MASTER
15 IN RW.MASTER
16 LIB J*AIMSL
17 LIB JSC*FTN.
18 END
19 @XQT RW.MASTER
```

RW.MASTER

ES3-N03200*RW(1).MASTER(45)

```
1 INTEGER IX,NBR(6),IER
2 C
3 C
4 C RW.MASTER
5 C
6 C
7 C PROGRAM TO FIND PLATE CONSTANTS FOR
8 C A 2ND ORDER LINEAR LEAST SQUARES
9 C FIT
10 C
11 C AN EXAMPLE PLATE 32 IS SHOWN IN
12 C APPENDIX B
13 C
14 C REQUIRES FORMATTED DATA ON IN FILE
15 C 4 RW.LOCATELINE LOCATES THE MICRONS
16 C WHERE THE LINES ARE LOCATED ON THE
17 C PLATE.
18 C
19 C
20 C FORMAT FILE
21 C
22 C FIRST NUMBER - NUMBER OF CALIBRATION POINTS
23 C
24 C COLUMN OF TWO NUMBERS X IN MICRONS AND 5 SIGN FIGURES + .
25 C AND SPACE FOLLOWED BY WAVELENGTH IN F8.4 FORMAT
26 C
27 C
28 CHARACTER QU*1
29 C
30 C IX NUMBER OF DATA POINTS
31 C NBR 6 DIMENSION VECTOR 1=NUMBER OF VARIABLES
32 C 2=NUMBER OF OBSERVATION PER VARIABLES
33 C 3= NUMBER OF OBSERVATIONS IN THE SUBMATRIX X=
34 C MAKE THIS EQUAL TO NBR(2)
35 C 4=1 (DEALING WITH ONLY ONE SUBMATRIX) NBR(5)=1
36 C IF NBR(5)=0 MEANS YOU SUPPLY THE MEANS
37 C NBR(6)=1 ELSE NBR(6)=0 RETURNS VARIANCE-COVAR MATRIX
38 C IER ERROR PARAMETER
```

```

39 C
40 REAL X(25,3),TEMP(3),XM(3),VCV(6),ANOVA(14),B(3,7)
41 REAL VARB(3)
42 C
43 C X MATRIX OF VARIABLES SET UP AS X,X**2,Y WHERE X
44 C IS MEASUREMENT IN INCHES OR MICRONS AND Y IS THE KNOWN
45 C WAVE LENGTH
46 C
47 C TEMP ARRAY WHICH CONTAINS MEANS WHEN SPECIFIED
48 C XM ARRAY WITH MEANS OF DATA
49 C VCV ARRAY WITH SUMS OF SQUARES CROSS-PRODUCTS
50 C ANOVA OUTPUT VECTOR OF RLMUL
51 C B OUTPUT VECTOR OF RLMUL B(I,1) CONTAINS THE PARAMETER
52 C ESTIMATES
53 C VARB
54 C
55 C
56 C CALL THE READ IN PROGRAM REQUIRES FORMATTED DATA
57 C
58 CALL RED(X,NBR)
59 C
60 13 FORMAT(I2)
61 CC IX NUMBER OF DATA POINTS EQUALS NUMBER OF ROWS
62 C
63 IX=25
64 C
65 C CALL TO IMSL ROUTINE TO MAKE UP SUMS OF SQUARES MATRIX
66 C
67 CALL BECOVM(X,IX,NBR,TEMP,XM,VCV,IER)
68 12 FORMAT(1X,6E14.7)
69 N=NBR(2)
70 M=2
71 IB=3
72 ALFA=0.05
73 C
74 C IMSL SUBROUTINE TO FIND PARAMETERS B(I)
75 C
76 CALL RLMUL(VCV,XM,N,M,ALFA,ANOVA,B,IB,VARB,IER)
77 C
78 C WRITE REGRESSION COEFFICIENTS
79 C
80 WRITE(6,14)B(3,1),B(1,1),B(2,1)
81 14 FORMAT(' INTERCEPT ',E14.7,' X COEFF ',E14.7,' Y COEFF ',E14.7)
82 C
83 C CALL PROGRAM TO CALCULATE UNKNOWN WAVELENGTHS
84 C
85 CALL UNKNOW(B)
86 C
87 C RESIDUAL CALCULATION
88 C
89 WRITE(6,16)
90 16 FORMAT(' DO YOU WISH TO CALCULATE RESIDUALS TYPE 0 IF YES')
91 READ(5,17)NRES
92 17 FORMAT(I1)
93 IF(NRES.NE.0)GO TO 20
94 C
95 C RE-READ X AND Y DATA
96 C
97 CALL RED(X,NBR)
98 WRITE(6,19)
99 DO 20 I=1,NBR(2)
100 YH=B(3,1)+B(1,1)*X(I,1)+B(2,1)*X(I,2)
101 YH=YH*100.
102 X(I,3)=X(I,3)*100.
103 RES=X(I,3)-YH
104 WRITE(6,18)I,X(I,3),YH,RES
105 18 FORMAT(1X,I2,2X,'RESIDUAL',1X,3F9.4)
106 19 FORMAT(15X,'ACTUAL',4X,'PREDICTED',1X,'RESIDUAL')
107 20 CONTINUE
108 WRITE(6,*)'DO YOU WISH TO STORE THESE CONSTANTS IN MASS STORAGE ?'
109 READ(5,22)QU
110 22 FORMAT(A1)

```

```

111     IF(QU.EQ.'Y')CALL STOR(B(3,1),B(1,1),B(2,1))
112     STOP
113     END
114     C
115     C
116     C SUBROUTINE FOR READING IN DATA FORMATTED
117     C
118     C
119     SUBROUTINE RED(X,NBR)
120     DIMENSION X(25,3),NBR(6)
121     REWIND 4
122     NBR(1)=3
123     READ(4,10)NBR(2)
124     NBR(3)=NBR(2)
125     NBR(4)=1
126     NBR(5)=1
127     NBR(6)=1
128     DO 100 I=1,NBR(2)
129     READ(4,11)X(I,1),X(I,3)
130     X(I,1)=(X(I,1)-50000.)/5000.
131     X(I,3)=X(I,3)/100.
132     X(I,2)=X(I,1)*X(I,1)
133     100 CONTINUE
134     10 FORMAT(I2)
135     11 FORMAT(F6.0,1X,F8.4)
136     RETURN
137     END
138     C
139     C
140     C
141     C SUBROUTINE FOR CALCULATING THE UNKNOWN Y
142     C
143     C
144     SUBROUTINE UNKNOW(B)
145     DIMENSION B(3,7)
146     WRITE(6,8)
147     8 FORMAT(' NUMBER OF UNKNOWN S')
148     READ(5,11)N
149     DO 100 I=1,N
150     WRITE(6,10)
151     10 FORMAT(' MICRONS MEASURED')
152     READ(5,11)X
153     11 FORMAT()
154     X=(X-50000.)/5000.
155     Y=B(1,1)*X+B(2,1)*X*X+B(3,1)
156     Y=Y*1000.
157     WRITE(6,12)Y
158     12 FORMAT(' WAVELENGTH IS ',F10.4 ,1X,' NM')
159     100 CONTINUE
160     WRITE(6,13)
161     13 FORMAT(' END OF INPUT')
162     RETURN
163     END
164     C
165     C SUBROUTINE TO STORE CONSTANTS IN MASS STORAGE
166     C
167     SUBROUTINE STOR(A,B1,B2)
168     WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
169     WRITE(6,*)'TYPE 1 FOR 260 NM '
170     WRITE(6,*)'TYPE 2 FOR 380 NM'
171     WRITE(6,*)'TYPE 3 FOR 500 NM'
172     WRITE(6,*)'TYPE 4 FOR 620 NM'
173     WRITE(6,*)'TYPE 5 FOR 740 NM'
174     READ(5,6)I
175     NB=I+99
176     CALL NTRAN$(2,10,22)
177     CALL NTRAN$(2,6,NB)
178     CALL NTRAN$(2,1,1,A,JSTAT,22)
179     CALL NTRAN$(2,6,4)
180     CALL NTRAN$(2,1,1,B1,JSTAT,22)
181     CALL NTRAN$(2,6,4)
182     CALL NTRAN$(2,1,1,B2,JSTAT,22)

```



```
183 6 FORMAT()
184 RETURN
185 END
```

```
RW.END
```

```
ES3-N03200*RW(1).END(2)
```

```
1 .
2 .
3 .
4 . RW.END
5 .
6 .
7 . THIS CONTROL PROGRAM FREES ALL DATA FILES USED
8 . IN PLOTTING AND WORKING WITH MICRODENSITOMETER
9 . PLATE DATA
10 .
11 .
12 @FREE DATA1.
13 @PACK,P RW.
14 @FREE DATAIN.
15 @FREE DATAOUT.
```

APPENDIX D
PHOTOGRAPHS OF SPECTRAL PLATES ANNOTATED WITH SPECIES IDENTIFICATION

Spectra of Pure Nitrogen

Shock Layer

Arc Jet Conditions:

Date	25 June 1984
Run Numbers	AC 881 to 883
Current	1,000 amps
Voltage	1,515 volts
Power	1.515 MW
Gas Flow Rate	0.0454 kg/sec nitrogen

Plate 23
Exposure 5
25 secs

Plate 23
Exposure 3
25 secs

Plate 23
N₂-Shock Layer
Wavelength Range
240-450 nm
25 June 1984

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N₂⁺(1-)
427.81
(0,1)
(1,2)
(2,3)

- Cu 327.4962
- Cu 324.7540

N₂(+2)
315.92
(1,0)

N₂(2+)
297.68
(2,0)

N₂⁺(1-)
391.44
(0,0)

N₂⁺(1-)
358.21
(1,0)
(2,1)
(2,5)

N₂(2+)
337.13
(0,0)

N₂⁺(1-)
(2,0)

N₂(2+)
315.92
(1,0)

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Range
310-450 nm

Range
240-330 nm

Plate 24
Exposure 5
25 secs

Plate 24
N₂-Shock Layer
Wavelength Range
430-690 nm
25 June 1984

N₂(1+)
vⁱ - v^u = 3

N₂(1+)
vⁱ - v^u = 4

430-690 nm

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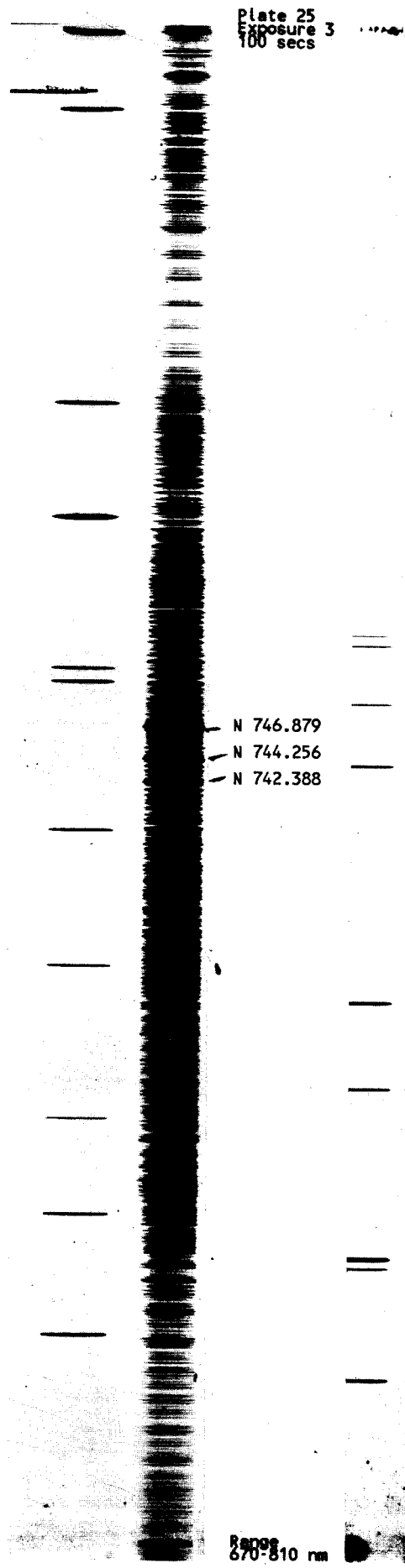


Plate 25
Exposure 3
100 secs

Plate 25
N₂-Shock Layer
Wavelength Range
670-810 nm
25 June 1984

N 746.879
N 744.256
N 742.388

Range
670-810 nm

Spectra of Pure Nitrogen

Free Stream

Arc Jet Conditions:

Date	25 June 1984
Run Number	AC 880
Current	1,000 amps
Voltage	1,515 volts
Power	1,515 MW
Gas Flow Rate	0.0454 kg/sec nitrogen

Plate 26
Exposure 5
250 secs

Plate 26
N₂ Free Stream
Wavelength Range
240-450 nm
25 June 1984

N₂⁺(1-)
427.81
(0,1)
(1,2)
(2,3)

N₂⁺(1-)
391.44
(0,0)

N₂⁺(1-)
358.21
(1,0)

N₂⁺(1-)
(2,0)

310-450 nm

ORIGINAL IMAGE IS
OF POOR QUALITY

Spectra of Pure Argon

Shock

Arc Jet Conditions:

Date	5 July 1984
Run numbers	AC 893 to 894
Current	1,000 amps
Voltage	590 volts
Power	0.59 MW
Gas Flow Rate	0.0727 kg/sec argon

ORIGINAL FILED IN
OF POOR QUALITY

84-39725

Plate 42
Exposure 5
25 secs

Ar 448.8183
Ar 447.9310

Ar 443.3830
Ar 442.3894

Ar 436.3784
Ar 434.5167
Ar 433.0485
Ar 433.5357
Ar 433.3560
Ar 430.0100

Ar 427.2168
Ar 426.6282
Ar 425.9361
Ar 425.1185

Ar 420.0675
Ar 419.8317
Ar 419.1028
Ar 418.1883
Ar 416.4178
Ar 415.8590

H 410.1735

Ar 405.4525
Ar 404.5022
Ar 404.7418
N₂(2+)
(1,4)

Ar 394.8979
Ar 394.7504

Ar 389.9860
Ar 389.4880

Ar 383.4679
N₂(2+)
(0,2)

Ar 369.0896
Ar 367.8926
Ar 367.0830
Ar 367.0830
Ar 367.0830
Ar 364.7090
Ar 364.3981
Ar 363.2892
Ar 360.0342
Ar 359.9670

N₂(2+)
337.13
(0,0)

(1,1)

N₂(2+)
315.82
(1,0)

Range
310-450 nm

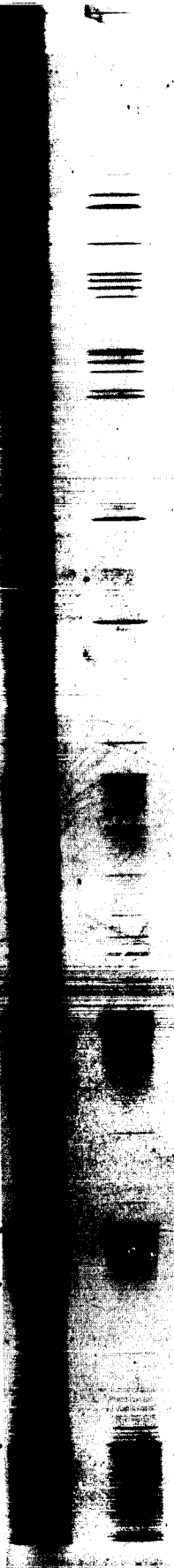


Plate 42
Exposure 3
25 secs

N₂(2+)
(1,0)

(2,1)

-OH 306.72
-OH 306.36

N₂(2+)
(2,0)

-OH 281.60
-OH 281.13

N₂(2+)
337.13
(0,0)

(1,1)

N₂(2+)
315.82
(1,0)

Range
240-330 nm

Plate 42
Exposure 1
2 secs

Plate 42
Ar (+N₂ Contam.)
Wavelength Range
240-450 nm
5 July 1984

Hg 313.1546
Hg 312.5663

Hg 302.5617
Hg 302.3476
Hg 302.1499

Hg 296.7278

Hg 282.0000
Hg 281.0510
Hg 280.3472

Hg 275.2840

Hg 265.3681
Hg 265.2042

Hg 253.6519

Hg 248.2721

Range
240-330 nm

Plate 43
Exposure 5
25 secs

Plate 43
Exposure 3
25 secs

Ar 675.2832
Ar 667.7282
H_γ 656.2725
Ar 641.6315
Ar 604.3230
Ar 603.2124
Ar 565.0703
Ar 560.6732
Ar 557.2548
Ar 555.8702

Ar 560.5632
Ar 557.2548
Ar 555.8702
Ar 549.5872
Ar 545.1650
Ar 525.2786
Ar 522.1354
Ar 518.7746
Ar 516.2284
Ar 506.0080
Ar 488.7978
Ar 487.6240
H_β 486.1327
Ar 483.6691
Ar 470.2316
Ar 462.8441
Ar 451.0740
Ar 436.3784
Ar 434.5167
H_γ 434.0465
Ar 433.3560
Ar 430.0100

Range
550-690 nm

Range
430-570 nm

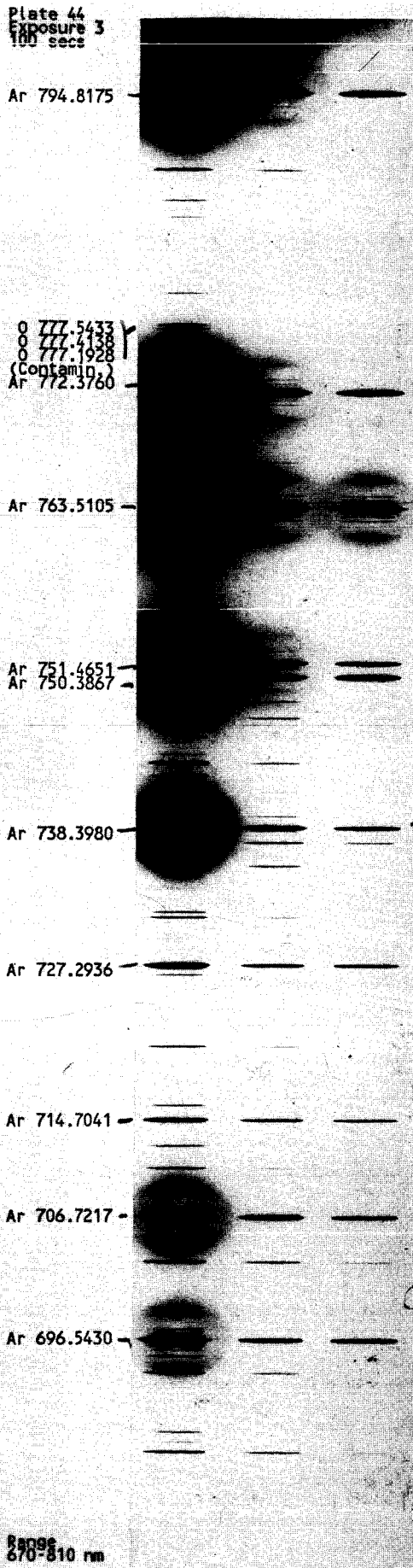
Plate 43
Argon-Shock Layer
Wavelength Range
430-690 nm
5 July 1984

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Plate 44
Argon-Shock Layer
Wavelength Range
670-810 nm
5 July 1984



SB4-39734

Spectra of Argon-Oxygen Mixture

Shock Layer

Arc Jet Conditions:

Date	28 June 1984
Run Number	AC 886
Current	1,000 amps
Voltage	535 volts
Power	0.535 MW
Gas Flow Rate	0.03732 kg/sec argon 0.00814 kg/sec oxygen

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National Aeronautics and
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Plate 32
Exposure 4
2 secs

— O 436.8300
— Ar 434.5167
— Ar 433.5337
— Ar 433.3560

— Ar 430.0100
— Ar 427.2168
— Ar 426.2530
— Ar 425.9357

— Ar 420.0675
— Ar 418.8317
— Ar 418.1028
— Ar 418.1883
— Ar 416.4179

— Ar 405.4525
— Ar 404.4218

— O 394.751
— O 394.7504
— O 394.7330

— Ar 383.4679

— Ar 369.0896
— Ar 367.0648
— Ar 364.9832

— Ar 356.7657
— Ar 356.4920
— Ar 355.7306

Range
310-450 nm

Plate 32
Exposure 1
2 secs

Plate 32
O₂-Ar Shock Layer
Wavelength Range
240-450 nm
28 June 1984

— Hg 313.1566
— Hg 312.5663

— Hg 302.5617
— Hg 302.7478

— Hg 296.7278

— Hg 289.3595

— Hg 282.0000
— Hg 281.0510
— Hg 280.3472

— Hg 275.2840

— Hg 265.3681
— Hg 265.2042

— Hg 253.6519

— Hg 248.2721

Range
240-330 nm

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584-39727

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Space Administration

Plate 30
Exposure 6
2 secs

Plate 30
Exposure 5
25 secs

Plate 30
Exposure 3
25 secs

Plate 30
Exposure 1
3 secs

Ne 671.7043

Ne 667.8276

Ne 665.2093

Ne 659.8953

Ne 653.2882

Ne 650.6528

Ne 640.2246

Ne 638.2991

Ne 633.4428

Ne 630.4789

Ne 626.6495

Ne 621.7281

Ne 616.3594

Ne 614.3062

Ne 612.8451

Ne 609.6163

Ne 607.4338

Ne 602.9997

Ne 597.5534

Ne 594.4834

Ne 588.1895

Ne 585.2488

Ne 582.0153

Ne 576.6448

Range
350-690 nm

Ar 675.2832

Ar 645.607
Ar 645.655
Ar 645.369

Range
350-690 nm

Ar 565.0703

Ar 560.6732

Ar 557.2548

Ar 555.8847

Ar 549.5872

Ar 545.7370

Ar 545.1650

Ar 542.1346

O 532.8561

Ar 525.2786

Ar 522.1270

Ar 518.7746

Ar 516.2284

Ar 515.1395

Ar 470.2316

Ar 462.8441

Ar 459.6097

Ar 452.2323

Ar 451.0733

O 436.8300

Ar 434.2167

Ar 433.3271

Ar 432.3700

Ar 430.0100

Range
430-570 nm

Plate 30
O₂-Ar Shock Layer
Wavelength Range
430-690 nm
28 June 1984

Hg 546.0740

Hg 435.8350

Range
430-570 nm

Plate 31
Exposure 4
100 secs
Ar 800.8156

Plate 31
Exposure 2
10 secs

Plate 31
O₂-Ar Shock Layer
Wavelength Range
670-810 nm
28 June 1984

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O 777.5433
O 777.4138
O 777.1928

Ar 772.3760

Ar 763.5105

Ar 751.4651
Ar 750.3867

Ar 738.3980

Ar 727.2936

Ar 714.7041

Ar 706.7217

Ar 696.5430

Ne 754.4046
Ne 753.5775

Ne 748.8872

Ne 743.8899

Ne 724.5167

Ne 717.3939

Ne 705.9109

Ne 703.2413
Ne 702.4054

Ne 692.4468

Range
670-810 nm

Range
670-810 nm

Spectra of Air (N_2 & O_2)

Surface

Arc Jet Conditions:

Date	28 June 1984
Run Number	AC 887
Current	1,000 amps
Voltage	1,430 volts
Power	1.43 MW
Gas Flow Rate	0.0355 kg/sec nitrogen 0.0105 kg/sec oxygen

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Plate 33
exposure 4
2 secs

$N_2^+(1-)$
427.81

(0,1)-
423.65
(1,2)-

N 415.146-

Ca 396.8468 -

Ca 393.3666
 $N_2^+(1-)$
391.44
(0,0)-
(1,1)-

$N_2^+(1-)$
358.21
357.10
356.30
355.80
354.80
353.80
(4,5)-

$N_2(2+)$
337.13
(0,0)-

$N_2^+(1-)$
(2,0)

Cu 327.3962 -

Cu 324.7540 -

Range
310-450 nm

Plate 33
exposure 3
25 secs

- Cu 327.3962

- Cu 324.7540

$N_2(2+)$
315.92
(1,0)

$N_2(2+)$
297.68
(2,0)

O 288.8791
Si 288.1578
NO
586.05
587.08
284.78
(0,5)

NO
572.28
571.38
(0,4)

NO
522.57
522.85
(0,3)

NO
277.81
277.91
(0,2)

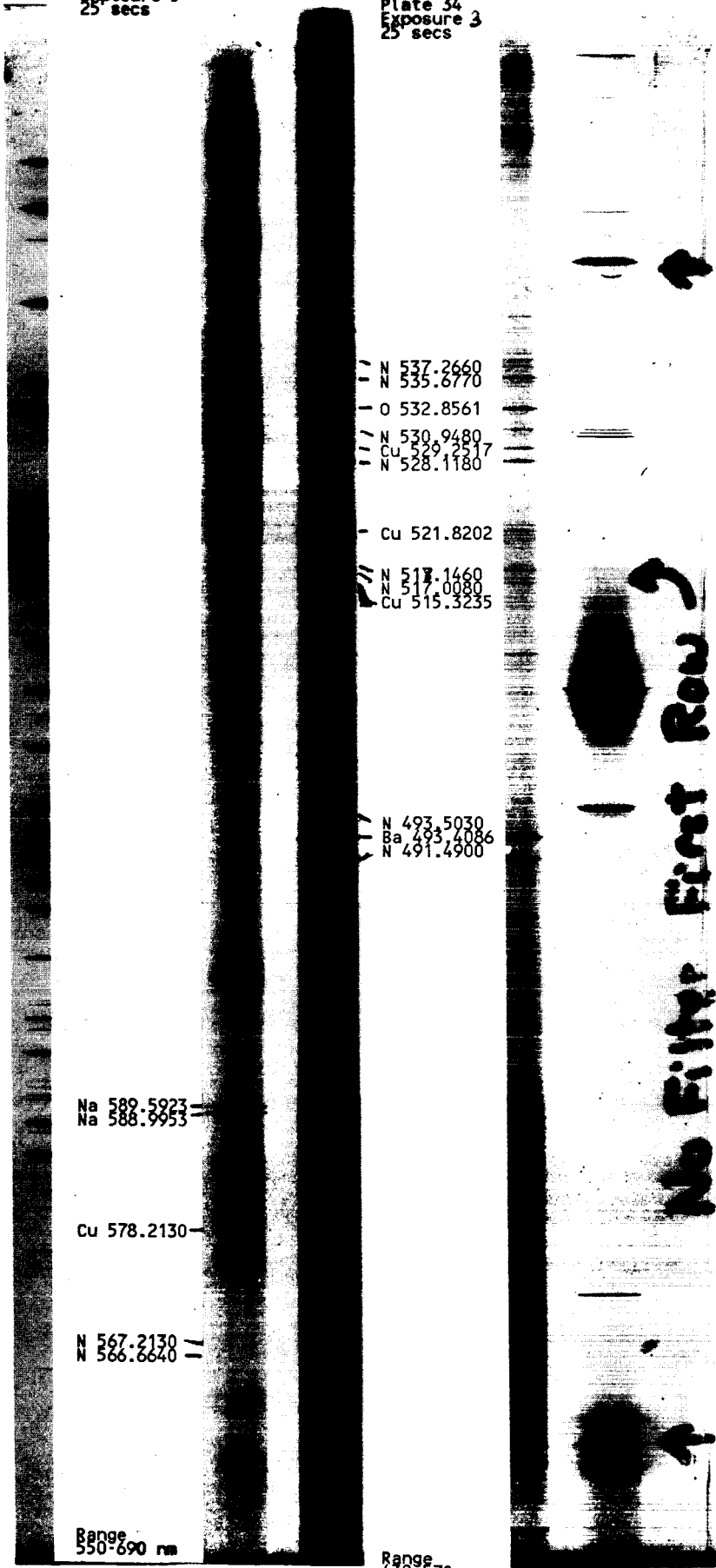
Plate 33
Air-Surface
Wavelength Range
240-450 nm
28 June 1984

Range
240-330 nm

Plate 34
Exposure 5
25 secs

Plate 34
Exposure 3
25 secs

Plate 34
Air-Surface
Wavelength Range
430-690 nm
28 June 1984



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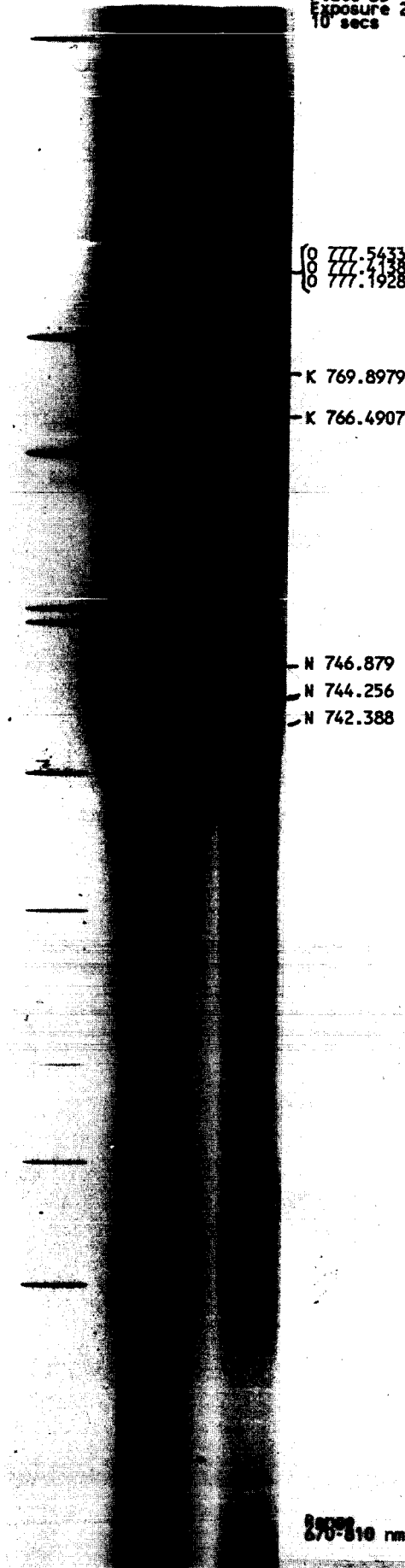


Plate 35
Exposure 2
10" secs

Plate 35
Air-Surface
Wavelength Range
670-810 nm
28 June 1984

0 777.5433
0 777.4138
0 777.1928

- K 769.8979

- K 766.4907

- N 746.879

- N 744.256

- N 742.388

670-810 nm

Spectra of Air

Shock Layer

Arc Jet Conditions:

	Plates	Plates
	14 to 16	36 to 38
Date	19 June 1984	28 June 1984
Run Numbers	AC 874 to 875	AC 887
Current	1,000 amps	1,000 amps
Voltage	1,420 volts	1,430 volts
Power	1.42 MW	1.42 MW
Gas Flow Rate	0.0355 kg/sec nitrogen 0.0105 kg/sec oxygen	0.0355 kg/sec nitrogen 0.0105 kg/sec oxygen

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Plate 14
Exposure 4
2 secs

Hg 435.8350
Hg 434.8110
Hg 433.9235

Hg 407.7811

Hg 404.6561

Hg 366.3276
Hg 365.4833
Hg 365.0128

Hg 334.1478

Hg 312.1568

Range
310-450 nm

Plate 14
Exposure 3
2 secs

$N_2^+(1-)$

424.81
(0,1)-

(1,2)-

(2,3)-

$N_2^+(1-)$

391.44
(0,0)-

(1,1)-

(2,2)-

$N_2^+(1-)$

358.21
(1,0)-

(2,1)-

(3,2)-

(4,3)-

$N_2(2+)$

337.13
(0,0)-

Cu 327.8962

Cu 324.7540

$N_2(2+)$

317.82
(1,0)-

Range
310-450 nm

Plate 14
Exposure 3
2 secs

Cu 327.8962

Cu 324.7540

$N_2(2+)$

(1,0)

(2,1)

(3,2)

$N_2(2+)$

(2,0)

297.68

$NO^+(0,4)$

272.28

271.38

$NO^+(0,3)$

259.57

257.85

$NO^+(0,2)$

247.81

247.11

Range
240-330 nm

Plate 14
Air-Shock Layer
Wavelength Range
240-450 nm
19 June 1984

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584-39735



Plate 15
Exposure 3
25secs

Plate 15
Air-Shock Layer
Wavelength Range
430-690 nm
19 June 1984

Cu 521.8202

Cu 515.3235

Cu 510.5541

Ba 493.4086

Ba 455.4042

430-690 nm

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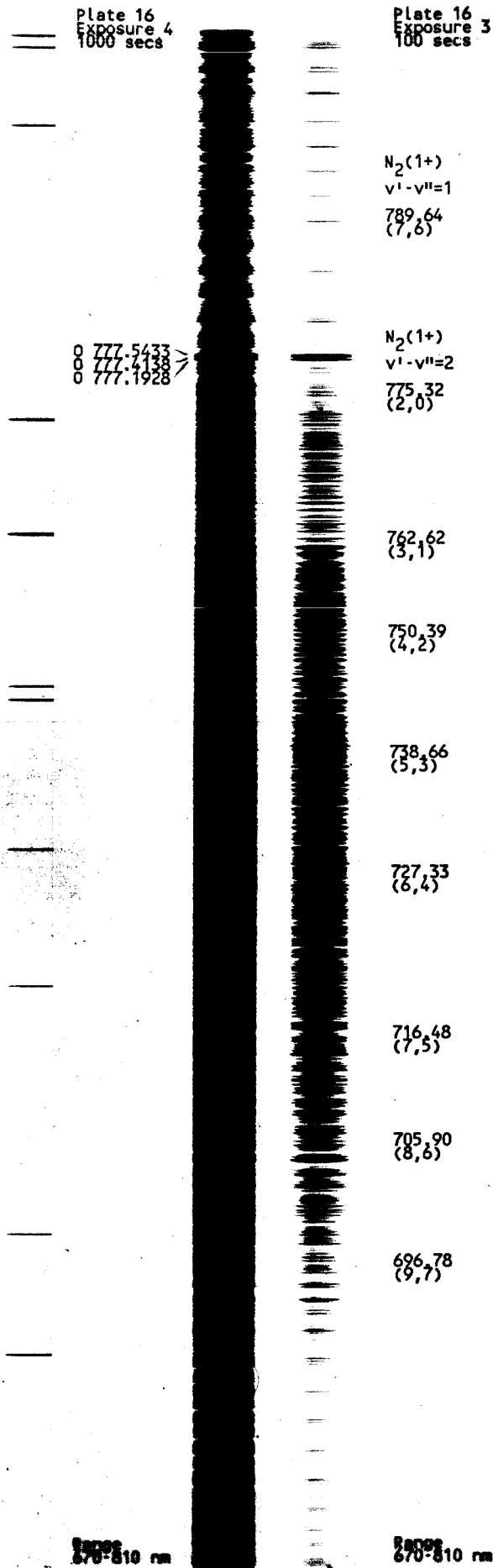


Plate 16
Air-Shock Layer
Wavelength Range
670-810 nm
19 June 1984

0 777.5433
0 777.7138
0 777.1928

N₂(1+)
v' - v'' = 1
789.64
(7,6)

N₂(1+)
v' - v'' = 2
775.32
(2,0)

762.62
(3,1)

750.39
(4,2)

738.66
(5,3)

727.33
(6,4)

716.48
(7,5)

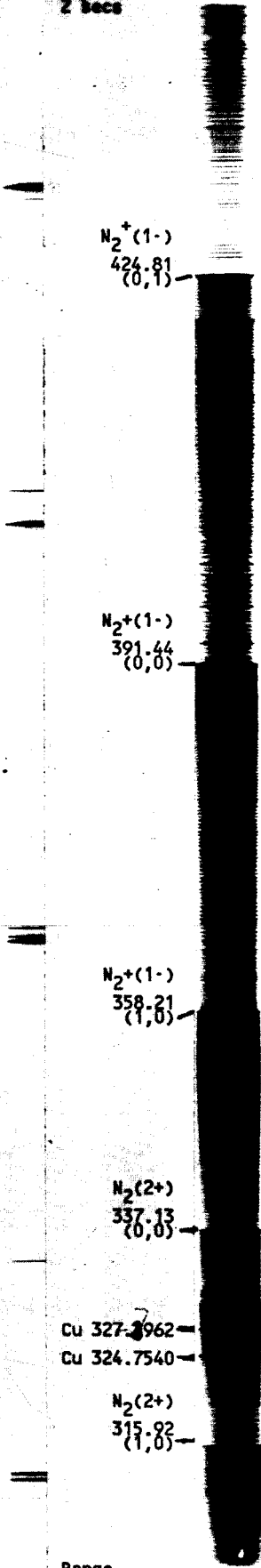
705.90
(8,6)

696.78
(9,7)

670-810 nm

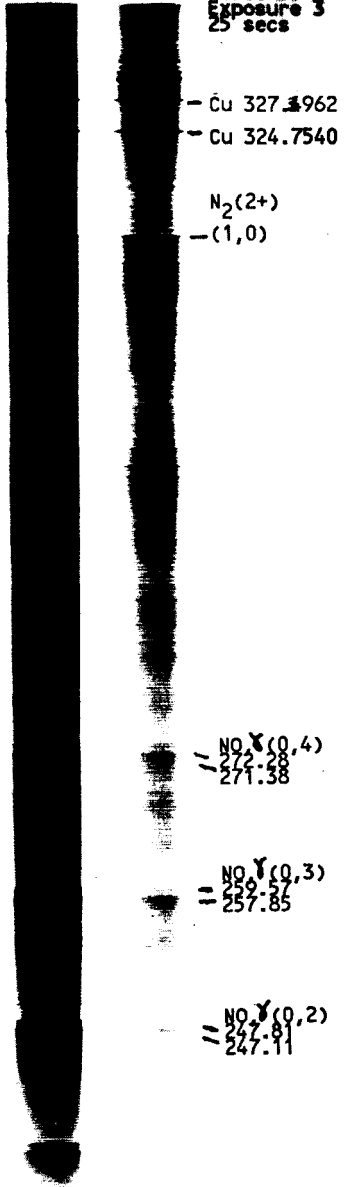
670-810 nm

Plate 36
Exposure 4
2 secs



Range
310-450 nm

Plate 36
Exposure 3
25 secs



Range
240-330 nm

Plate 36
Air-Shock Layer
Wavelength Range
240-450 nm
28 June 1984

Plate 37
Exposure 5
25 secs

Plate 37
Exposure 3
25 secs

Plate 37
Air-Shock Layer
Wavelength Range
430-690 nm
28 June 1984

$N_2(1+)$
 $v^1-v^0=3$

- Cu 521.1820
- Cu 515.3235
- Cu 510.5541

- Ba 493.4086

Na 589.5923
Na 588.9953

$N_2(1+)$
 $v^1-v^0=4$

Cu 578.2132

$N_2^+(1-)$
470.92
(0,2)

465.18
(1,3)

40000
(2,4)

455.41
(3,5)

Range
550-690 nm

Range
430-570 nm



Plate 38
Exposure 3
100 secs

Plate 38
Air-Shock Layer
Wavelength Range
670-810 nm
28 June 1984

0 777.5433
0 777.4138
0 777.1928



Range
670-810 nm

Spectra of Air

Free Stream

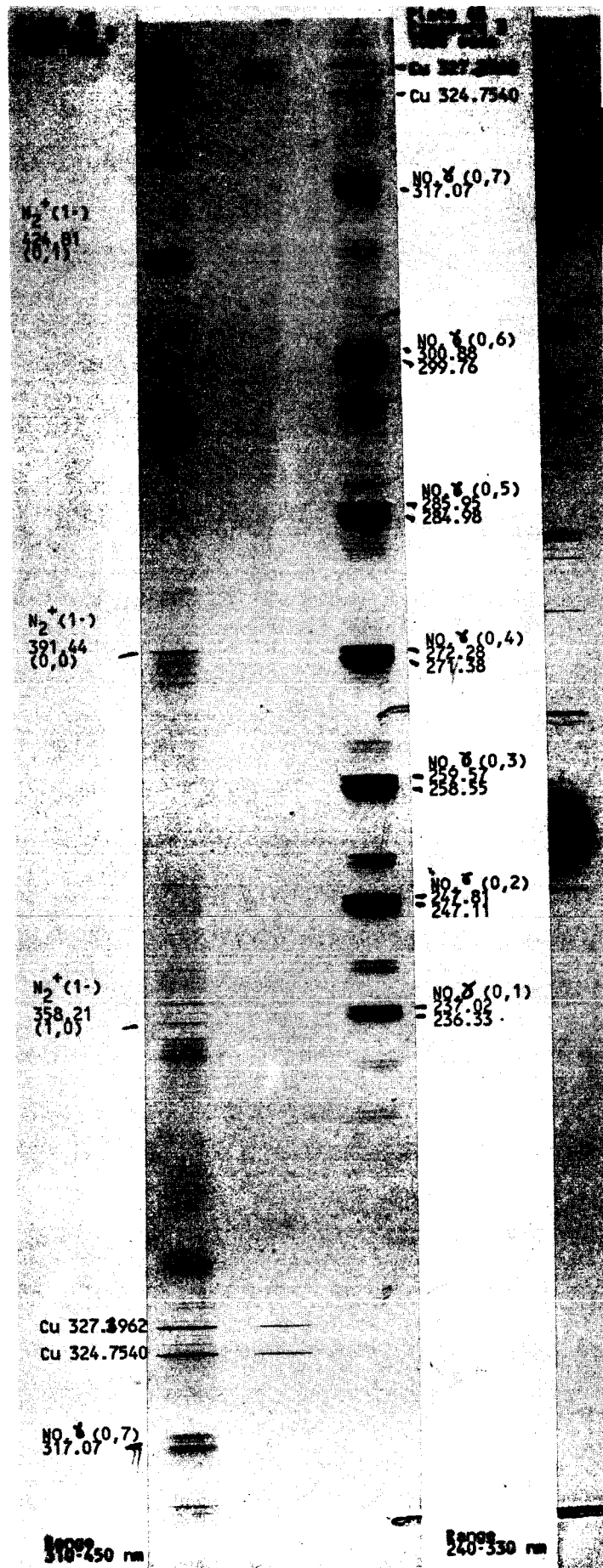
Arc Jet Conditions:

Date	5 July 1984
Run Number	AC 895
Current	1,000 amps
Voltage	1,475 volts
Power	1,475 MW
Gas Flow Rate	0.0553 kg/sec nitrogen
	0.0175 kg/sec oxygen



504-39732

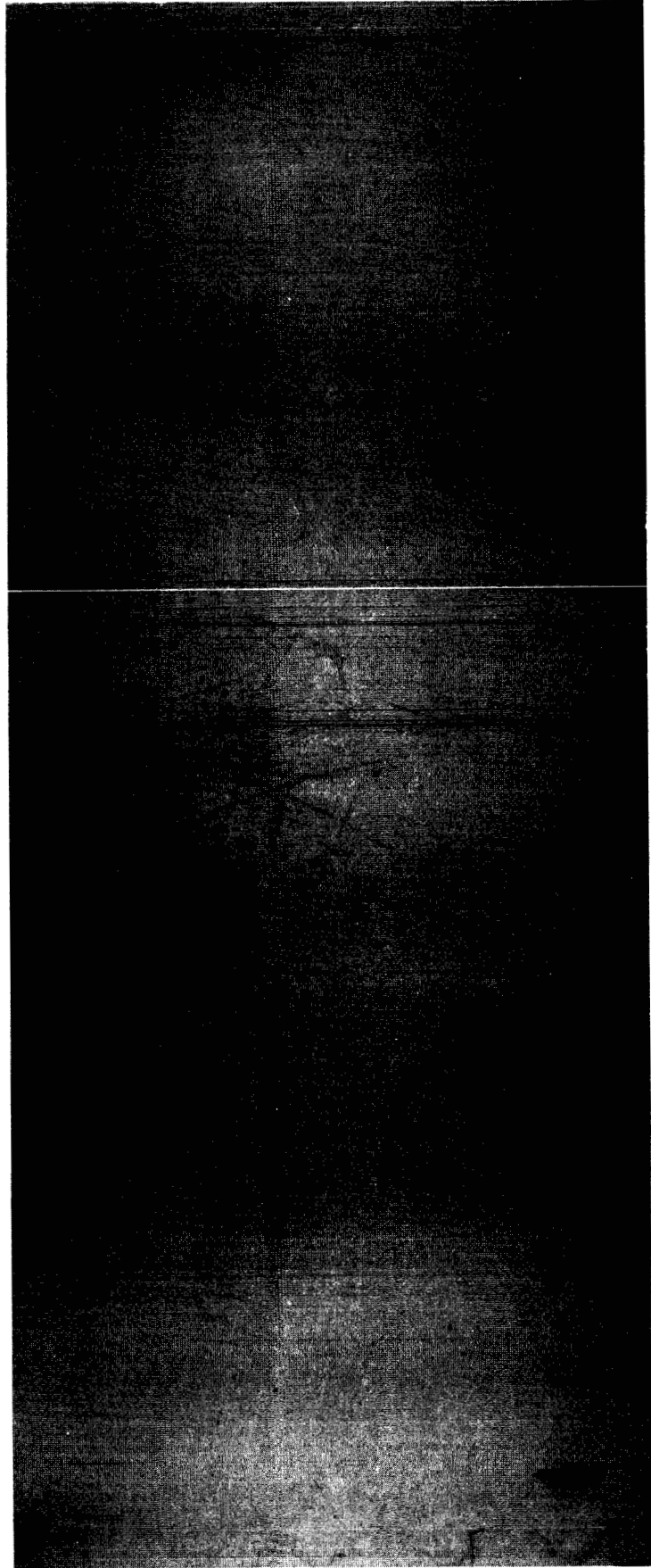
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Plate 46
Air-Free Stream
Wavelength Range
430-690 nm
5 July 1984

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Plate 48
Exposure 1
100-eps
Ar 794.8175-

Plate 48
Air-Free Stream
Wavelength Range
670-810 nm
5 July 1984

Ar 772.3760-

Ar 763.5105-

Ar 751.4651-
Ar 750.3867-

Ar 738.3980-

Ar 727.2936-

Ar 714.7041-

Ar 706.7217-

Ar 696.5430-

Range
670-810 nm