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This tech note summarizes the December, 1988 emission spectroscopy measurements made on the 4X source discharge with and without N_2 gas added to the H + Cs discharge. This study is motivated by the desire to understand why small amounts of N_2 gas added to the source discharge results in a reduction in the H^- beam noise. The beneficial effect of N_2 gas on H^- beam noise was first discovered by Bill Ingalls and Stu Orbesen on the ATS SAS source. For the 4X source the observed effect is that when N_2 gas is added to the discharge the H^- beam noise is reduced about a factor of 2 (Figs. 1B and 1C). For comparison purposes the N_2 effect in the SAS is illustrated in Fig. 2.

We do not understand the "physics" of what the N_2 gas does to cause the H^- beam current noise reduction in the 4X source. To try to determine the difference between the N_2 off and N_2 on discharges, the whole optical spectrum, from 3500 Å to 7400 Å, was recorded and the prominent lines identified. Several selected lines were studied in detail. The principal finding of this investigation is that the CsII lines observed without N_2 gas become much stronger when N_2 gas is added to the discharge (3-4 times stronger), and many more CsII lines appear in the spectrum than were observable without N_2 gas. Only work on the 4X source is discussed in this note. For a write-up on the SAS the reader is referred to Bill Ingall's poster for the 1988 NPB review at Los Alamos in October, 1988.

The experimental arrangement is shown in Fig. 3. The region of the 4X source discharge examined is that from the emission aperture (0.26-cm-diam) to the back of the discharge chamber 2.1 cm away. The examined region includes only the center of the discharge - the cathodes are 0.72 cm away. To record the total spectrum, a strip chart recorder was used. Because the discharge is pulsed, a sample-and-hold circuit was used to feed the PMT signal 1.4 ms into the 2-ms-long arc pulse into the strip-chart recorder input. The electronic setup for the total-spectrum measurement is shown in Fig. 4. The monochrometer grating drive was driven at a speed of 2 Å/s, and for all but the first spectrum recorded the strip chart was driven at 2 cm/min. This means that the whole 3900 Å spectrum was recorded on 65 cm of strip-chart paper. For the 4X source running in Mode II (100V/~200A arc) six total scans were made - three with no N_2 added to the arc (noisy H^- beam) and three with 0.3 sccm of N_2 added to the arc. The three scans for each N_2 condition were done at low, medium, and high gain on the PMT (photomultiplier tube) output (proportional to the light output) at the monochromator exit. The approximate ratios of the gains are 1:10:200 for the three scans. These 6 scans are shown in Figs. 5-7, paired by gain with the no N_2 scan on top and the 0.3 sccm N_2 scan on the bottom of the figures.

Because of the complexity of the scan taken at the highest gain, no attempt was made to identify every line in these spectra. However, for reasons discussed later, an attempt was made to identify the lines from 6400 to 7400 Å in these high-gain runs (Fig. 7). Careful attention was paid to identifying each of the lines above background in the intermediate gain runs (Fig. 6). This proceedure was very laborous and is briefly discussed below.

For the intermediate gain scan without N_2 gas (Fig. 6a), the conversion to wavelength from position on the strip chart recording was obtained by using H_α and H_β as calibration points to get the number of Å per mm, then the distance of each line from H_α or H_β was measured with a rule and the wavelength determined from the scale conversion. Thus, H_α is at 6562.8 Å, H_β is at 4861.3 Å, and there is 282.4 mm between them, so the conversion is (6562.8 Å - 4861.3 Å)/282.4 mm = 6.025 Å/mm. Note that to get accuracy to within 0.5 Å the rule must be read to within 0.083 mm! The wavelengths for 43 lines above background in the intermediate gain spectrum without N_2 (Fig. 6a) are given in Table I. It is remarkable that most of the lines which are positively identified are within 1 Å of the tabulated wavelengths. Note that all of the 43 lines identified in the spectrum without N_2 can be attributed to hydrogen(4), cesium (29-32), or molybdenum (10-7), with most of the lines being cesium ion lines.

For the intermediate gain scan with N_2 gas (Fig. 6b), the conversion from position to wavelength was done in an improved way. First, the position of each of the lines above background was measured with the rule. Then several lines (28 in all) from throughout the spectrum whose identification was not in doubt were chosen for a calibration curve. The least-squares fitting routine in Cricket Graph was used to obtain the calibration curve shown in Fig. 8. The curve Wavelength = 6562.7 + 6.0259 x Position was then used to calculate the wavelength for the rest of the lines in the spectrum. There are 96 total lines above background in fig. 6b. They are tabulated in Table II. The lines used for the calibration curve in Fig. 8 are indicated with a + in column 2 of Table II. It is amazing to me that of the 28 lines used in the wavelength calibration of Fig. 6b, only 3 lines are more than 1 Å from the calibration curve, and 23 of the 28 lines are within 0.62 Å of the calibration curve!

Once the wavelengths have been determined, the game to be played is to identify the lines according to the emitting species. For this I used several reference tables from the library. I estimate that the wavelength error is about ± 1Å, so this was used in giving assignments to each of the 96 lines (column 4 of Table II). One line that appears in the N_2-free discharge, the CsI line at 4555.28 Å, is given in Table II (between lines 49 and 50), but it is not numbered. Of the 96 lines , 53-70 can be attributed to CsI, CsII, or CsIII emission and 28-11 to MoI or MoII lines (the measured line wavelength is within ~1.5 Å of the tabulated Cs and Mo line wavelengths for 17 of the observed lines, so no positive identification can be made. However, we can say that there are a total of 81 Cs and Mo lines.) There are 4 (or 3) H-Balmer lines (α, β, γ, and maybe δ) and 6 (or 7) NII and NIII lines. (I can't tell if the line near 4101 Å is H_δ or NIII. We can make the statement that there are 10 total hydrogen and nitrogen lines.) Thus, 91 of the 96 lines in Fig. 6b are identified, leaving 5 lines whose identitification is questionable, most in the upper 1000 Å of the spectrum.

One of the important results of this investigation is that no positive identification of any Ti, Cr, or O line has been made, with or without N_2 gas added to the arc. This is important for 2 reasons - first it is unlikely that using Cs metal in place of the 2Ti + Cs_2CrO_4 powder will result in any change in the H^- beam current or emittance (no Ti, Cr, or O in the discharge), and second the N_2 gas addition to the discharge does not result in any measureable release of Ti, Cr, or O (at least in atomic form), so the only possible effect that the N_2 gas could have on the chromate powder is to increase (catalyze) the Cs evolution rate. This possible reason for the discharge quieting will be checked by simply turning up the Cs oven to the point that the CsI lines are as strong w/o N_2 as they are with N_2 (and quiet beam) to see if increased Cs is the only story. I doubt if that is the case, because we have never in the past been able to quiet the whole H^- beam pulse with increased Cs flow (at least up until the point that the high Cs results in extractor breakdown and extinguishing the source arc).

The conclusion that no Cr, Ti, or O lines have been observed is based on looking in the wavelength tables in the 68th edition of the CRC handbook (pp E-201 to E-327) and looking for the strongest transitions. For example, for Cr the strongest 2 lines in the visible are the CrI lines at 4254.35 and 3578.69 Å - neither of these 2 lines show up in Fig. 6b (see Table II). For that matter, the 3578.69 Å line does not show up in Figs. 7a or 7b. Thus, no Cr is present in the arc. For TiI the strongest 3 lines are at 3642.68, 3653.50, and 3998.64 Å. In Fig. 6b no line is within 7 Å of the first, 1.6 Å of the second, and 3 Å of the last. Perhaps the second by itself is a problem (within 1.6 Å of the line observed at 3651.89 Å), but taken with the absence of the first and third lines the inescapable conclusion is there is no Ti in the discharge, with or without N_2. Even in Figs. 7a and 7b the prominent TiI line at 4533.24 Å does not show up. For OI the prominent line is at 6158.18 Å with another OI line almost as high at 6156.77 Å. Neither of these lines show up in Fig. 6a or 6b, nor do they show up in Figs. 7a or 7b.

Since most of the unidentified lines in Fig. 6b are in the upper 1000 Å of the spectrum, I went to the highest gain spectra (Figs. 7a and 7b) to try to identify the lines there, figuring that there may be more clues to the line identifications in Fig. 6b in those spectra. The high-wavelength portion of Figs. 7a and 7b are given in Figs. 9a and 9b. The calibration for Fig. 9a was done in the same manner as for Fig. 6b. The resulting calibration curve is

$$\text{Wavelength} = 6562.1 + 6.0367 \text{ Position}$$

where Position is the distance in mm from H_α. The lines used in this calibration are marked with a + in column 5 of Table III. The wavelengths calculated for each of the 34 lines in Fig. 9a are given in column 3 of Table III, and the assignments, where known, are given in column 5. The same calibration curve used for Fig. 6b was used for Fig. 9b. The wavelengths for each of the 39 lines in Fig. 9b are given in column 3 of Table IV, with the assignments, where known, in column 5. Very few of the lines which appear in either Figs. 9a or 9b are identified, which is very interesting! Perhaps they are mostly uncataloged Cs lines, but maybe they belong to some atomic or molecular species that is crucial to the quieting of the H^- beam pulse with N_2 gas added. Further attempts to identify these lines will be done in connection with other LANL personnel - perhaps Bob Sander of CLS or Paul Weber of CTR will have some good ideas on what these lines are, or will know someone who does.

We now turn our attention to the amplitudes and shapes of selected H, Cs, Mo, and N lines, with and without N_2 gas added to the discharge, as recorded in oscillograms of the PMT output at the peak of these lines. Fig. 10 shows H_α, CsI(4555.28 Å), CsII(4603.76 Å), MoI (3902.96 Å), MoII (3941.49Å), and NII(3995.00 Å) with no N_2 gas and with ~0.4 sccm of N_2 added to the 4X source discharge. The first thing to note is that we see a tremendous decrease in the NII line when the N_2 gas is shut off - it drops from 18 μA to 1.9 μA in about 7-8 min, about a factor of 10! The next largest change comes in the CsII line - it drops from 20 μA to ~4.5 μA in 6-7 min, a factor of 4.5. The MoII line shows the next largest change, dropping from 2.7 μA to 0.9 μA in 6-7 min from the time the N_2 gas is shut off. The MoI shows some change early on in the pulse when the N_2 gas is turned on, but by the time the arc pulse is over the MoI line is almost identical in the N_2 off and N_2 on cases. The CsI line is an enigma - despite the tremendous difference in the CsII line, the CsI line changes hardly at all when N_2 gas is added! The CsI line does become more uniform with N_2 gas, but that's about it. Even the post-pulse burst seen in the CsI line doesn't change noticeably. I think this blows a large hole in my suggestion that the effect of the N_2 gas is to simply act as a catalyst in the Cs evolution from the 2Ti + Cs_2CrO_4 powder (if all the N_2 does is to increase the Cs concentration, then how come the CsII lines go up by a factor of ~4-5, but the CsI lines don't change!?). The H_α line decreases (!) when the N_2 gas is added - however, the H_α light becomes slightly less noisy with the N_2 than without it (17% total noise with, 27% total without N_2).

That leads to the question of the noise on the other emission lines. The H_α and CsII oscillograms shown have 1 MHz bandwidth, whereas the others all have 10 kHz bandwidth. The 10 kHz filter was used because these lines are very noisy, ± 100% noise on all of them (I haven't moved the monochromator grating to a position where there is no line to see if it is arc induced or not). Provided the noise on the CsI, MoI, MoII, and NII lines (all taken with 800 V PMT bias) doesn't turn out to be spurious, I speculate that these lines are all associated with processes going on on the cathode surface whereas the H_α and CsII lines, which are relatively quiescent, are associated with volume processes.

The use of the 10 kHz filter results in the (mistaken) impression that the turn-on transient for the MoI and MoII lines is much longer than for the others. Examining the MoI and MoII lines at 1 MHz bandwidth reveals that they reach an equilibrium value within ~50 μs of turn-on, just about as fast as the H_α, CsI, and CsII lines do. However, the NII line takes ~120 μs to reach an equilibrium value.

The interesting point to contemplate is what does the N_2 do to reduce the H^- beam noise? Whatever theory one comes up with, it has to be consistent with several other facts: 1) the average value of the H^- current does not change, only the fluctuations; 2) the discharge current and voltage are not significantly changed; and 3) the Cs atom density in the source discharge is not altered. Another fact (pointed out earlier) is that the Cs^+ concentration in the monochromator line-of-sight (ie, the CsII line strength) goes way up with the addition of N_2. The MoII concentration (or MoII line strength) goes up too. This is suggestive of one of two things - either the Cs^+ ions help quiet the H^- beam current oscillations themselves or their higher density is indicative that something else has changed, such as the plasma potential having switched from positive to negative (hence trapping the + ions rather than dumping them out), and as a result (not understood how) of the plasma potential being negative, the H^- beam fluctuations are damped out, presumably because the negative plasma potential results in damping whatever plasma instability is causing the H^- instabilities.

Further evidence that the Cs^+ concentration (CsII line strength) either causes the noise reduction or indicates something else which causes it is shown in the series of H^- beam current and CsII line oscillograms shown in Fig. 1. In Fig. 1A the Cs level is very low, as evidenced by the low H^- current (~40 mA) and the high H^- beam noise. The CsII line at 4603.76 Å is also very weak for this source condition. When the Cs oven temperature was raised, the oscillograms in Fig. 1B result (1 3/4 hours after Fig. 1A). Note that the H^- current is up, the H^- beam noise is down, and the CsII line intensity is up. In fact, the H^- noise is not all that bad at the end of the extraction pulse, but the H^- noise increases as the front of the pulse is approached. If the extraction pulse would have been as wide as the arc pulse, then the first half of the H^- pulse would show large noise, at least as large as in Fig. 1A (the reader will have to take my word for it right now). Note something interesting about the CsII line - it is much lower at the front of the arc pulse than at the end - low CsII means large H^- noise, high CsII means low H^- noise! No such correlation was seen in CsI. The oscillograms in Figs. 1A and 1B are for no N_2. When N_2 gas is added, the H^- pulse gets very quiet, and the CsII peak increases by a factor of 9 (400 μs into the pulse) to 3 (at the end of the pulse). So it is tempting to conclude that as a result of adding the N_2 gas 1) either the resulting higher Cs^+ ion concentration quiets the H^- beam (through some as yet unexplained mechanism) or 2) the N_2 itself, or the resulting larger Cs^+ concentration, lowers the plasma potential to some negative value, resulting in the Cs^+ ions being trapped in the discharge volume. The argument would then go that the negative plasma potential results in quenching the instability that is responsible for the H^- beam noise.

Table I.
Summary of Spectral Lines observed in the 4X Source on 6 December 1988
Without N_2 Gas Added to the Discharge, 600 V PMT Bias, Fig. 6a

Line No.	Observed Wavelength (Å)	Tabulated Wavelength (Å)	Line Designation	Wavelength Difference (Å)
1	6583.6	6586.51	CsI	-2.91
2	— 6562.79	—	H_α	Calib. Point
3	5925.6	5925.65	CsII	-0.05
4	5831.6	5831.16	CsII	+0.46
5	5563.8	5563.02	CsII	+0.78
6	5349.6	5349.16	CsII	+0.44
7	5249.9	5249.37	CsII	+0.53
8	5227.3	5227.00	CsII	+0.30
9	5209.6	5209.62	CsII	-0.02
10	5043.0	5043.80	CsII	-0.80
11	4972.8	4972.59	CsII	+0.21
12	4952.9	4952.84	CsII	+0.06
13	4869.7	4870.02	CsII	-0.32
14	— 4861.33	—	H_β	Calib. point
15	4829.1	4830.16	CsII	-1.06
16	4763.1	4763.62	CsII	-0.52
17	4615.5	4616.13	CsII	-0.63
18	4603.4	4603.76	CsII	-0.36
19	4556.1	4555.28	CsI	+0.82
20	4540.2	4538.94	CsII	+1.26
21	4527.5	4526.73	CsII	+0.77
22	4363.6	4363.28	CsII	+0.32
23	4340.7	4340.47	H_γ	+0.23
24	4288.0	4288.35	CsII	-0.35
25	4276.9	4277.10	CsII	-0.20
26	4263.9	4264.68	CsII	-0.76
27	4251.0	4249.50	MoI	+1.50
28	4232.3	4232.58	MoI	-0.28
		and/or 4232.18	CsII	+0.12
29	4101.2	4101.74	H_δ	-0.54
30	4038.6	4039.84	CsII	-1.24
31	3975.0	3974.24	CsII	+0.76
32	3959.9	3959.49	CsII	+0.41
33	3941.0	3941.49	MoII	-0.49
34	3926.5	3925.83	MoII	+0.67
		and/or 3925.58	CsII	+0.92
35	3903.3	3902.96	MoI	+0.34
36	3864.7	3864.37	CsII	+0.33
		and/or 3864.11	MoI	+0.59
37	3799.1	3798.26	MoI	+0.84
38	3703.6	3702.03	MoI	+1.57
39	3693.6	3694.94	MoI	-1.34
40	3689.4	3687.64	CsII	+1.76
41	3653.3	3655.73	CsII	-2.43
		and/or 3651.07	CsIII	+2.23
42	3637.6	3635.43	MoI	+2.17
43	3598.4	3598.97	CsII	-0.57
		and/or 3597.45	CsIII	+0.95

Table II. Summary of Spectral Lines observed in the 4X Source on 6 December 1988
With N2 Gas Added to the Discharge, 600 V PMT bias, Fig. 6b

No.	Observed Wavelength (Å)	Tabulated Wavelength (Å)	Line Designation	Wavelength Difference (Å)	Seen in N_2-free arc?	Height in N_2 arc	Height in arc w/o N_2	% change
1	7323.77	-	?		No	0.20	-	∞
2	7271.35	7270.70	CsI	+0.65	No	0.28	-	∞
3	7196.02	-	?		No	0.32	-	∞
4	6980.90+	6979.67	CsII	+1.23	No	0.12	-	∞
5	6955.89+	6955.50	CsII	+0.39	No	0.10	-	∞
6	6805.85	-	?		No	0.26	-	∞
7	6736.25	6733.98	MoI	+2.27 NC?	No	0.21	-	∞
8	6647.36+	6646.57	CsII	+0.79	No	0.18	-	∞
9	6585.30	6586.51	CsI	-1.21	Yes	0.13	0.25	-192
10	6562.70+	6562.79	Hα	-0.09	Yes	>9.8	>9.8	-125
11	6536.79+	6536.44	CsII	+0.35	No	0.21	-	∞
12	6128.53+	6128.62	CsII	-0.09	No	0.24	-	∞
13	5925.76+	5925.65	CsII	+0.11	Yes	1.70	0.76	+224
14	5830.55+	5831.16	CsII	-0.61	Yes	0.67	0.47	+143
15	5679.00+	5679.56	NII	-0.56	No	0.34	-	∞
16	5666.05+	5666.63	NII	-0.58	No	0.21	-	∞
17	5561.80+	5563.02	CsII	-1.22	Yes	2.30	0.42	+548
18	5531.67	5533.05	MoI	-1.38	Yes	0.21	0.16	+131
19	5505.76	5507.17	(CsII or CsIII)	-1.41	No	0.20	-	∞
	and/or	5506.49	MoI	-0.73				
20	5419.59	5419.69	CsII	-0.10	Yes	0.26	0.13	+200
21	5402.11	5402.79	(CsII or CsIII)	-0.68	Yes	0.18	0.10	+180
22	5371.38+	5370.98	CsII	+0.40	Yes	1.44	0.13	+1104
23	5349.08	5349.13	(CsII or CsIII)	-0.05	Yes	0.55	0.25	+220
24	5306.30	5306.61	CsII	-0.31	No	0.24	-	∞
	and/or	5306.26	MoI	+0.04				
25	5274.06	5274.04	CsII	+0.02	Yes	0.43	0.13	+331
26	5248.75+	5249.37	CsII	-0.62	Yes	2.11	0.48	+440
27	5226.76+	5227.00	CsII	-0.24	Yes	4.93	1.00	+493
28	5209.28	5209.58	CsII	-0.30	Yes	0.43	0.23	+187
29	5096.00	5096.60	CsII	-0.60	Yes	0.30	0.23	+130
	and/or	5096.65	MoI	-0.65				
30	5059.84	5059.88	MoI	-0.04	No	0.31	-	∞
	and/or	5059.87	CsII	-0.03				
31	5052.61	5052.70	CsII	-0.09	Yes	0.19	0.15	+127
32	5043.27+	5043.80	CsII	-0.53	Yes	1.98	0.53	+374
33	5005.61	5005.15	NII	+0.46	No	0.66	-	∞
34	4972.47+	4972.59	CsII	-0.12	Yes	1.04	0.27	+385
35	4952.28+	4952.84	CsII	-0.56	Yes	3.08	1.12	+275
36	4879.67	4879.95	CsII	-0.28	Yes	0.48	0.17	+282
37	4870.03+	4870.02	CsII	+0.01	Yes	2.02	0.61	+331
38	4860.99+	4861.33	Hβ	-0.34	Yes	9.56	>9.99	-162
39	4829.65	4830.51	MoI	-0.86	Yes	1.50	0.67	+224
	and/or	4830.16	CsII	-0.51				
40	4794.70	4796.52	MoI	-1.82 NC?	No	0.30	-	∞
41	4785.36	4786.36	CsII	-1.00	No	0.27	-	∞
42	4763.37+	4763.62	CsII	-0.25	Yes	1.16	0.43	+270
43	4661.23	4662.76	MoI	-1.53 NC?	No	0.28	-	∞

No.	Observed Wavelength (Å)	Tabulated Wavelength (Å)	Line Designation	Wavelength Difference (Å)	Seen in N_2-free arc?	Height in N_2 arc	Height in arc w/o N_2	% change
44	4648.87	4651.1	(CsII or CsIII)	-2.23 NCI	No	0.84	-	∞
	and/or	4646.51	CsII	+2.36 NCI				
45	4629.89	4630.54	NII	-0.65	No	0.72	-	∞
46	4615.73	4616.17	CsII (c)	-0.43	Yes	0.30	0.17	+176
47	4603.68+	4603.76	CsII	-0.08	Yes	6.84	3.47	+197
48	4594.94	4597.67	CsII	-2.73 NCI	No	0.24	-	∞
	and/or	4595.16	MoI	-0.27				
	and/or	4593.17	CsI	+1.77 NC?				
49	4589.82	4593.17	CsI	-3.35 NCI	No	0.18	-	∞
	-	4555.28	CsI (Seen w/o N_2, not with)			<0.08	0.17	>-213
50	4538.90	4538.94	CsII	-0.04	Yes	0.62	0.27	+230
51	4526.55+	4526.73	CsII	-0.18	Yes	1.52	0.36	+422
52	4502.45	4501.53	CsII	+0.92	Yes	1.17	0.31	+377
53	4418.08	4417.34	CsI	+0.74	No	0.36	-	∞
54	4415.67	-	?	-	No	0.75	-	∞
55	4405.73	4405.25	CsII	+0.48	No	0.79	-	∞
56	4364.15	4363.30	CsII	+0.85	Yes	1.85	0.47	+394
57	4349.39	4350.34	MoI	-0.95	No	0.34	-	∞
	and/or	4348.62	CsII	+0.77				
58	4340.65+	4340.47	H_γ	+0.18	Yes	0.78	1.15	-147
59	4289.73+	4288.35	CsII	+1.38	Yes	0.85	0.23	+370
60	4278.28	4277.24	MoI	+1.04	Yes	2.48	0.84	+295
	and/or	4277.10	CsII	+1.18				
61	4265.63	4264.68	CsII	+1.05	Yes	2.22	0.85	+261
62	-	4249.50	MoI	Not determined	Yes	0.10	0.23	-230
63	4235.50	4234.41	CsII	+1.09	No	0.21	-	∞
64	4233.09	4232.58	MoI	+0.51	Yes	0.39	0.21	+186
	and/or	4232.18	CsII	+0.91				
65	4120.10	4121.21	CsII	-1.11	No	0.28	-	∞
	and/or	4120.10	MoI	+0.00				
	and/or	4119.29	CsII	+0.81				
66	4102.93	4103.37	NIII	-0.44	Yes	0.09	0.16	-178
	and/or	4101.74	H_δ	+1.19	Yes	0.09	0.16	-178
67	4098.11	4097.31	NIII	+0.80	No	0.17	-	∞
68	4076.11	-	?	-	No	0.33	-	∞
69	4073.37	4073.36	CsII	+0.01	No	0.25	-	∞
70	4070.39	4069.88	MoI	+0.51	No	0.25	-	∞
	and/or	4068.77	CsII	+1.62 NC?				
71	4040.26	4039.84	CsII	+0.42	Yes	0.98	0.42	+233
72	4006.82	4006.77	CsIII	+0.05	No	0.69	-	∞
	and/or	4006.54	CsIII	+0.28				
73	3995.67+	3995.00	NII	+0.67	No	0.50	-	∞
74	3974.28	3974.24	CsII	+0.04	Yes	0.17	0.18	-106
75	3966.14	3965.20	CsII	+0.94	No	0.33	-	∞
76	3961.62	3959.50	CsII	+2.12 NC?	No	0.28	-	∞
77	3960.42	3959.49	CsII	+0.93	Yes	0.18	0.26	-144
78	-	3941.49	MoII	Not determined	Yes	0.10	0.16	-160
79	3925.77	3925.83	MoII	-0.06	Yes	0.35	0.22	+159
	and/or	3925.60	CsIII	+0.17				
80	3903.17+	3902.96	MoI	+0.21	Yes	0.37	0.22	+168
81	3897.44+	3896.98	CsII	+0.46	Yes	0.64	0.12	+545

No.	Observed Wavelength (Å)	Tabulated Wavelength (Å)	Line Designation	Wavelength Difference (Å)	Seen in N_2-free arc?	Height in N_2 arc	Height in arc w/o N_2	% change
82	3864.30	3864.31	(CsII or CsIII)	-0.01	Yes	0.41	0.18	+228
	and/or	3864.11	MoI	+0.19				
83	3804.95	3805.12	CsII	-0.17	Yes	0.22	0.12	+183
84	3798.92	3798.26	MoI	+0.66	Yes	0.52	0.23	+226
	and/or	3797.91	(CsII or CsIII)	+1.01				
85	3787.17	3785.42	CsII	+1.75	Yes	0.22	0.12	+183
86	3749.81	3751.40	CsII	-1.59	No	0.34	-	∞
87	3728.12	3729.98	(CsII or CsIII)	-1.86 NC?	No	0.21	-	∞
	and/or	3727.69	MoI	+0.43				
88	3703.11	3702.03	MoI	+1.08	Yes	0.52	0.21	+248
89	3694.07	3694.94	MoI	-0.87	Yes	0.56	0.33	+170
90	3688.95	3690.59	MoI	-1.64	Yes	0.42	0.39	+108
	and/or	3687.64	CsII	+1.41				
91	3662.43	3661.39	CsIII	+1.04	No	0.62	-	∞
92	3651.89	3651.07	CsIII	+0.82	Yes	0.28	0.25	+112
93	3635.32	3635.5	MoI	-0.11	Yes	0.58	0.66	43-114
	and/or	3635.14	MoII	+0.18				
94	3598.56	3597.45	CsIII	+1.11	Yes	0.92	0.19	+484
95	3525.35+	3524.98	MoI	+0.37	No(Yes)*	1.65*	1.17*	+141*
96	3503.65	3505.32	MoI	-1.67	No	0.20	-	∞
	and/or	3504.85	(CsII or CsIII)	-1.20				
	and/or	3504.41	MoI	-0.76				

+ This line used in wavelength calibration (non-linear least-squares fit).
* From wavelength scan with PMT bias voltage = 800V (about 20X gain with 600V).

NC = not confirmed.

TABLE III. Summary of spectral lines in fig. 9a, 6400 -7400 Å without N_2 and 800 V PMT bias.

Line No	Position wrt H_α, Å	Observed λ, Å	Tabulated λ, Å	Line Designation	Wavelength Difference, Å
1	136.55	7386.41			
2	135.05	7377.35			
3	126.20	7323.93			
4	123.10	7305.22			
5	122.70	7302.80			
6	117.35	7270.51	7270.70	Cs+	-0.19
7	107.90	7213.46			
8	104.80	7194.75			
9	100.90	7171.20			
10	80.50	7048.05	7149.50	CsII	-1.45
11	73.15	7003.68			
12	65.25	6955.99	6955.50	CsII+	0.49
13	54.75	6892.61	6892.42	Cs+	0.19
14	54.60	6891.70			
15	51.05	6870.27	6870.45	CsI+	-0.18
16	40.30	6805.38			
17	36.75	6783.95			
18	32.70	6759.50			
19	32.55	6758.59	6758.60	NI ?	-0.01
20	29.99	6743.14			
21	28.75	6735.66			
22	23.60	6704.57			
23	21.50	6691.89			
24	15.75	6657.18			
25	14.50	6649.63	6646.57	CsII	3.07
26	13.05	6640.88			
27	10.65	6626.39	6628.65	CsI	-2.26
28	9.86	6621.62			
29	5.00	6592.28			
30	3.70	6584.44	6586.51	CsI	-2.07
31	0.00	6562.10	6562.79	H_α+	-0.69
32	-2.80	6545.20			
33	-4.30	6536.14	6536.44	CsII+	-0.30
34	-10.90	6496.30	6495.53	CsII+	0.77

+This line used in wavelength calibration (nonlinear least-squares fit)

TABLE IV. Summary of spectral lines in Fig. 9b, 6400 -7400 Å with N_2 added to arc and 800 V PMT bias.

Line No	Position wrt H_α, Å	Observed λ, Å	Tabulated λ, Å	Line Designation	Wavelength Difference, Å
1	136.70	7386.44			
2	135.35	7378.31			
3	126.30	7323.77			
4	123.50	7306.90			
5	119.75	7284.30			
6	117.75	7272.25	7270.70	Cs	1.55
7	108.70	7217.72	7217.00	NII	0.72
8	105.25	7196.93			
9	97.70	7151.43	7149.50	CsII	1.93
10	95.50	7138.17	7139.80	NII	-1.63
11	92.70	7121.30	7121.80	Cs	0.12
12	91.70	7115.28			
13	90.75	7109.55	7109.87	MoI	-0.32
14	81.00	7050.80			
15	69.40	6980.90	6979.67	CsII	1.23
16	65.30	6956.19	6955.50	CsII	0.69
17	54.95	6893.82			
18	51.30	6871.83	6870.45	CsI	1.38
19	47.15	6846.82			
20	40.50	6806.75			
21	36.80	6784.45			
22	32.80	6760.35	6758.60	NI ?	1.75
23	30.05	6743.78			
24	29.05	6737.75			
25	27.00	6725.40	6724.47	CsII	0.93
26	25.60	6716.96			
27	22.75	6699.79			
28	21.90	6694.67			
29	16.05	6659.42			
30	14.20	6648.27	6646.57	CsII	1.80
31	13.25	6642.54			
32	10.80	6627.78	6628.65	CsI	-0.87
33	5.55	6596.14			
34	3.75	6585.30	6586.51	CsI	-1.21
35	0	6562.70	6562.79	H_α	-0.09
36	-3.10	6544.02			
37	-4.15	6537.69	6536.44	CsII	1.25
38	-11.10	6495.81	6495.53	CsII	0.28
39	-12.30	6488.58			
40	-72.05	6128.53	6128.61	CsII	-0.08

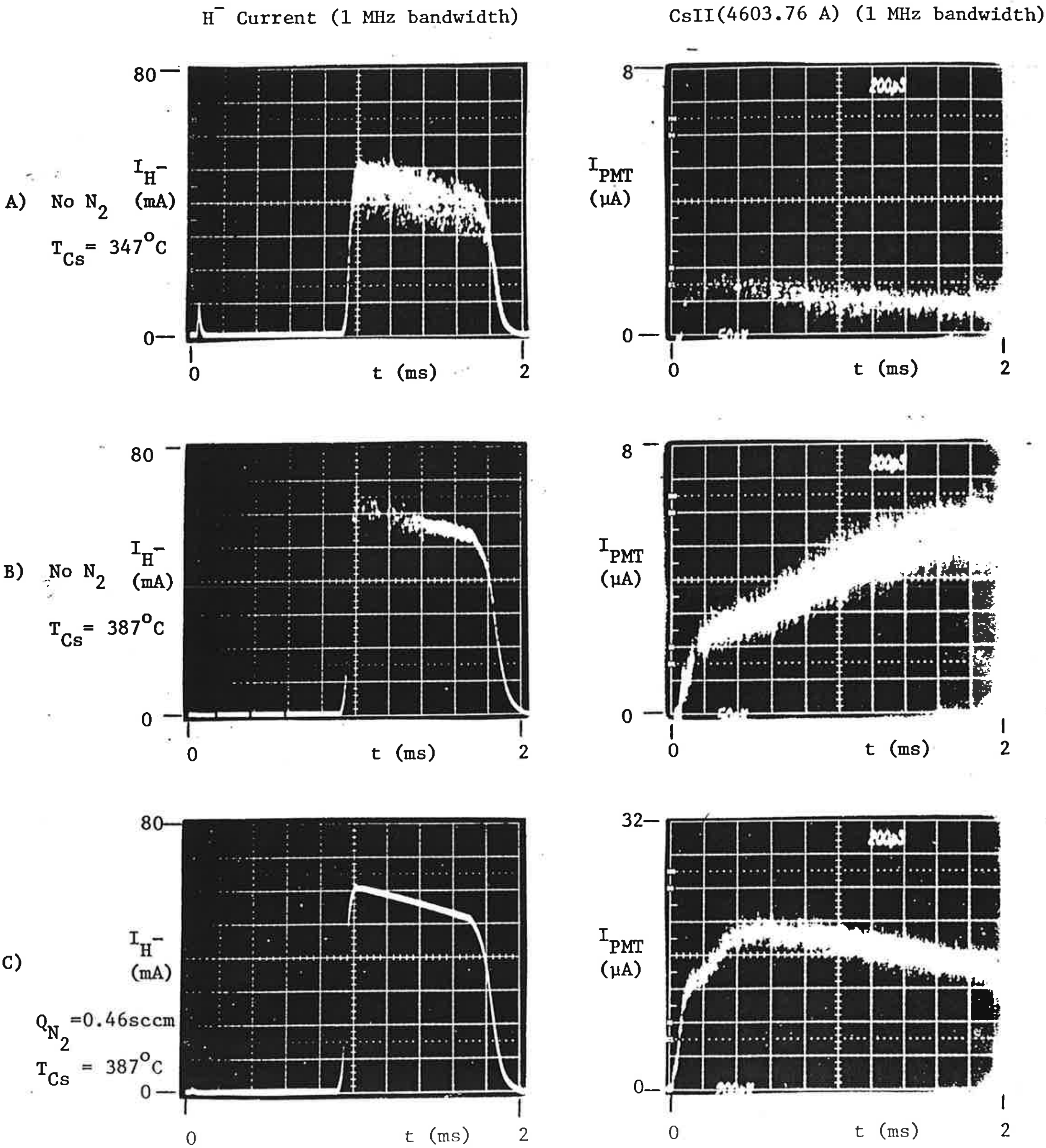
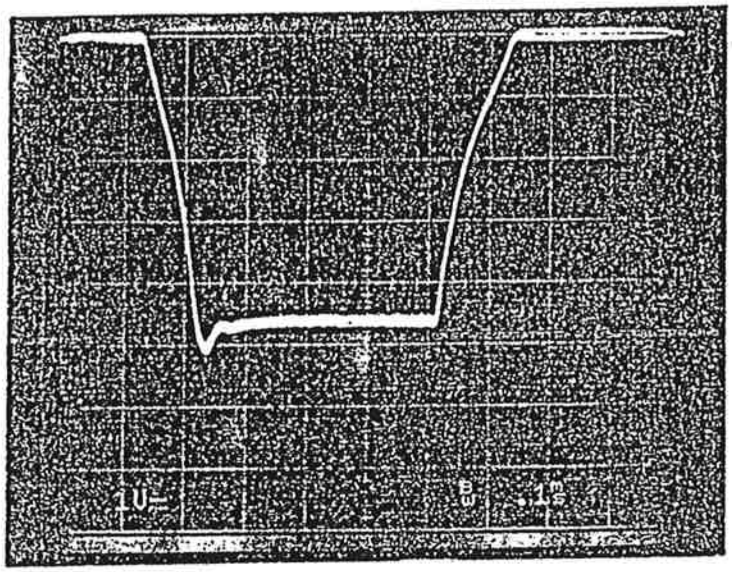
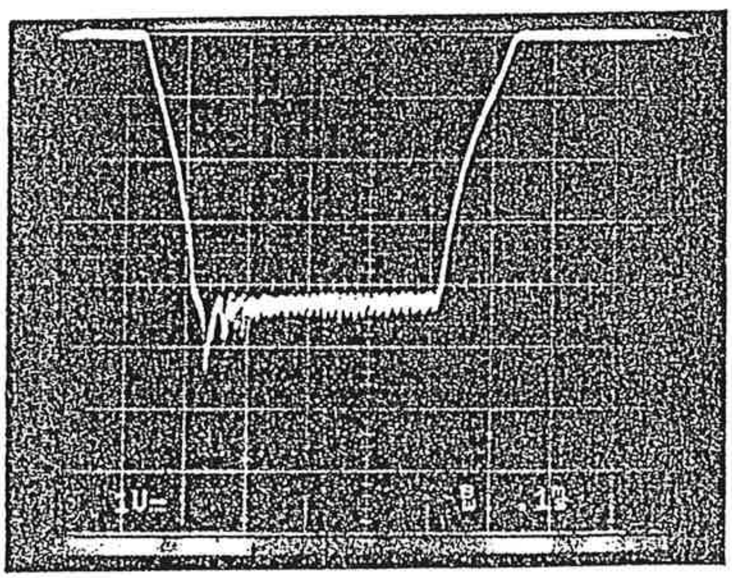


Fig. 1. H^- current and CsII line oscillograms for A) "low" Cs and no N_2, B) "correct" Cs and no N_2, and C) "correct" Cs and 0.46 sccm of N_2 added to the 4X source discharge.

N_2 EFFECTS ON ISTS BEAM



$\sim$0.1% N_2



1 Min after N_2 Stopped

Both 20 mA, 100 μs per Division

Fig. 2. N_2 effect on SAS H^- beam.

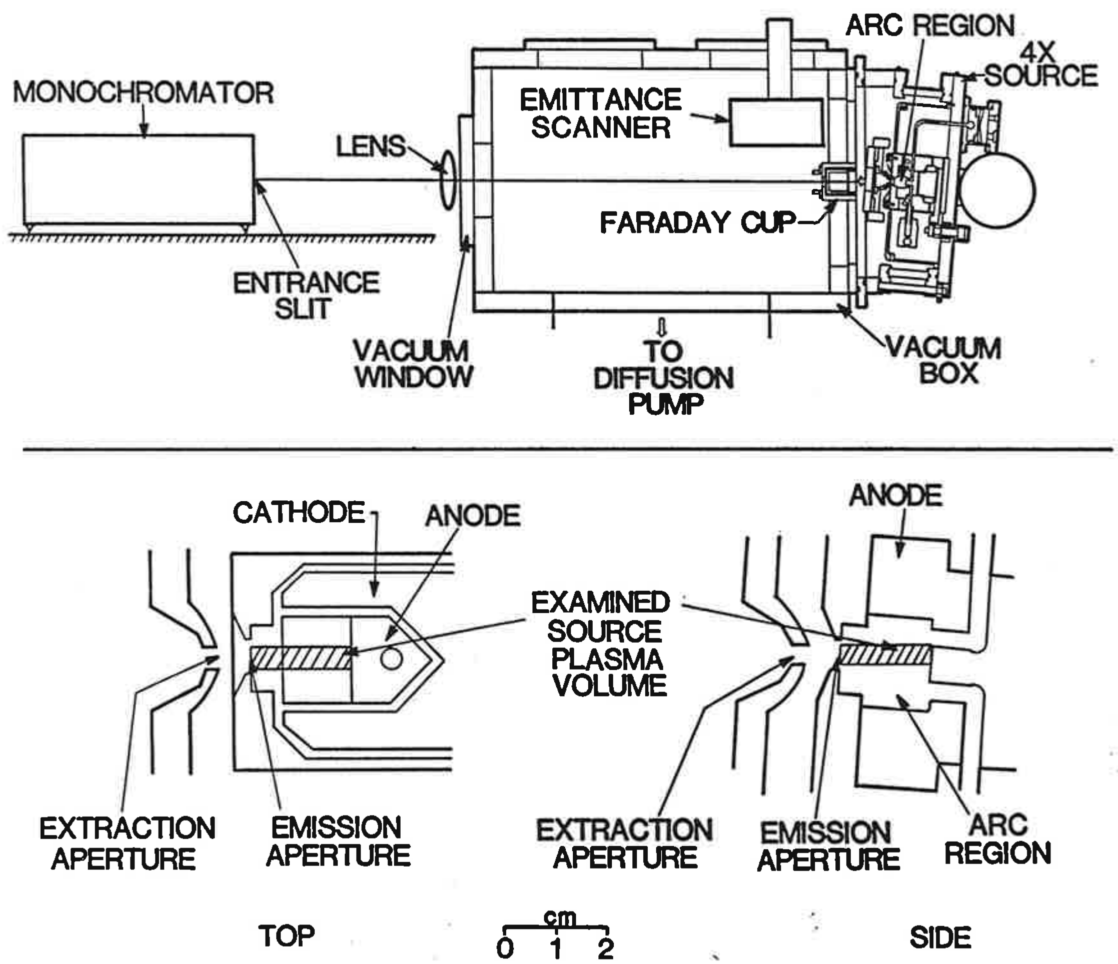
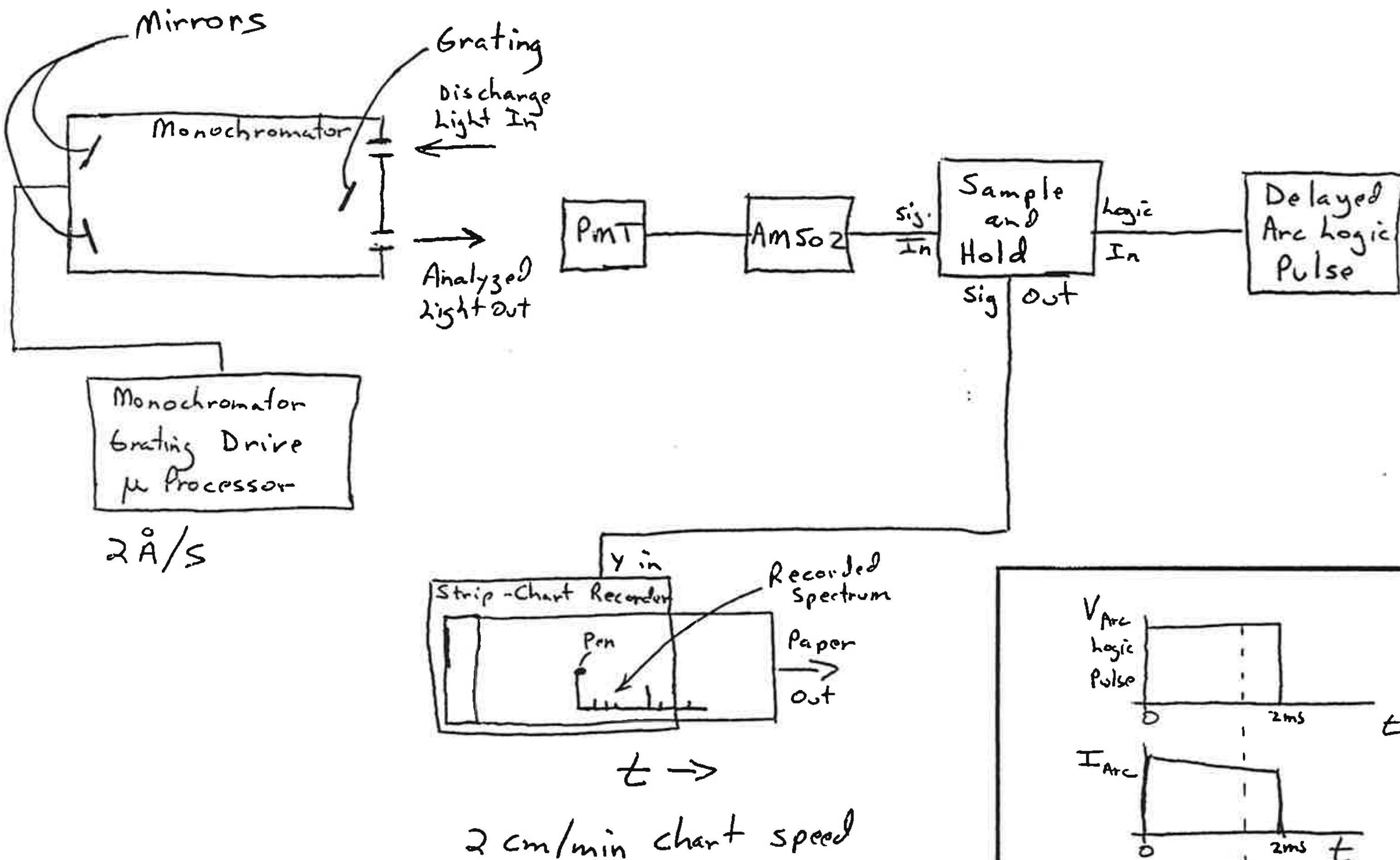


Fig. 3. Schematic of the experimental arrangement (top). The examined portion of the 4X source arc is shown at the bottom.



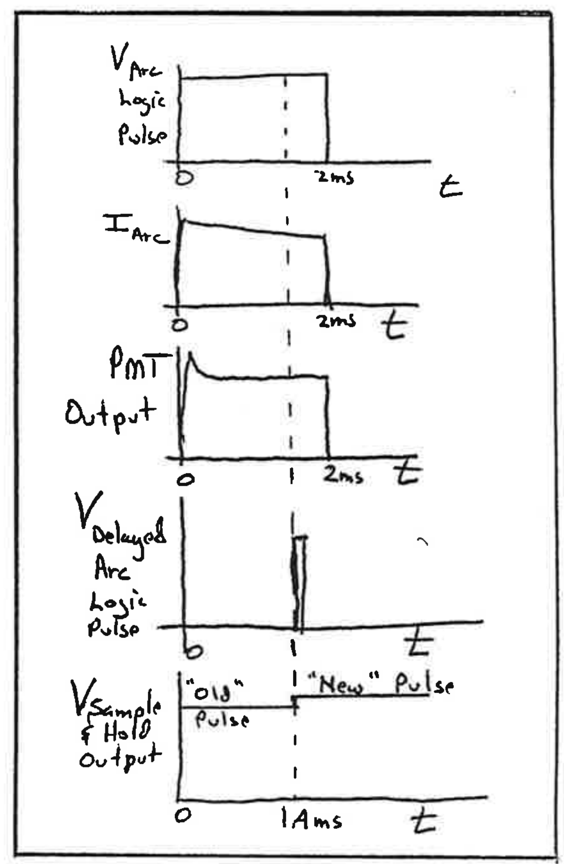


Fig. 4. Schematic of the electronics used to record the optical spectrum from the 4X source. The inset shows the timing arrangement for the sample-and-hold device, the output of which is fed into the y input of the recorder.

(a)

(b)

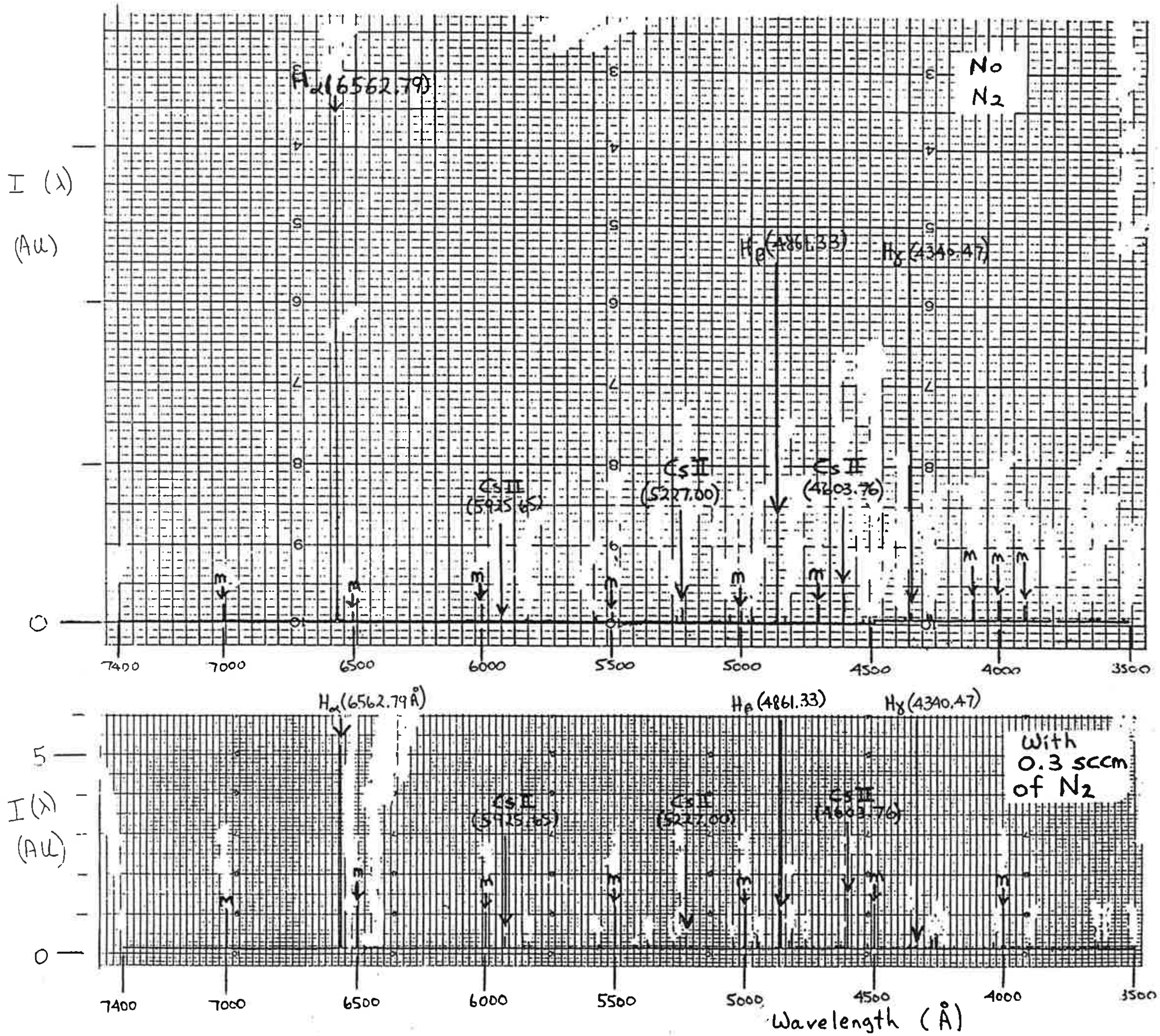


Fig. 5. (a) Lowest-PMT-gain spectrum without N_2 gas added to the source discharge. (b) Lowest-PMT-gain spectrum with N_2 gas added to the discharge. The lines labelled M are wavelength marks purposely added to the spectrum. The prominent hydrogen atom and cesium ion lines are indicated on the spectra.

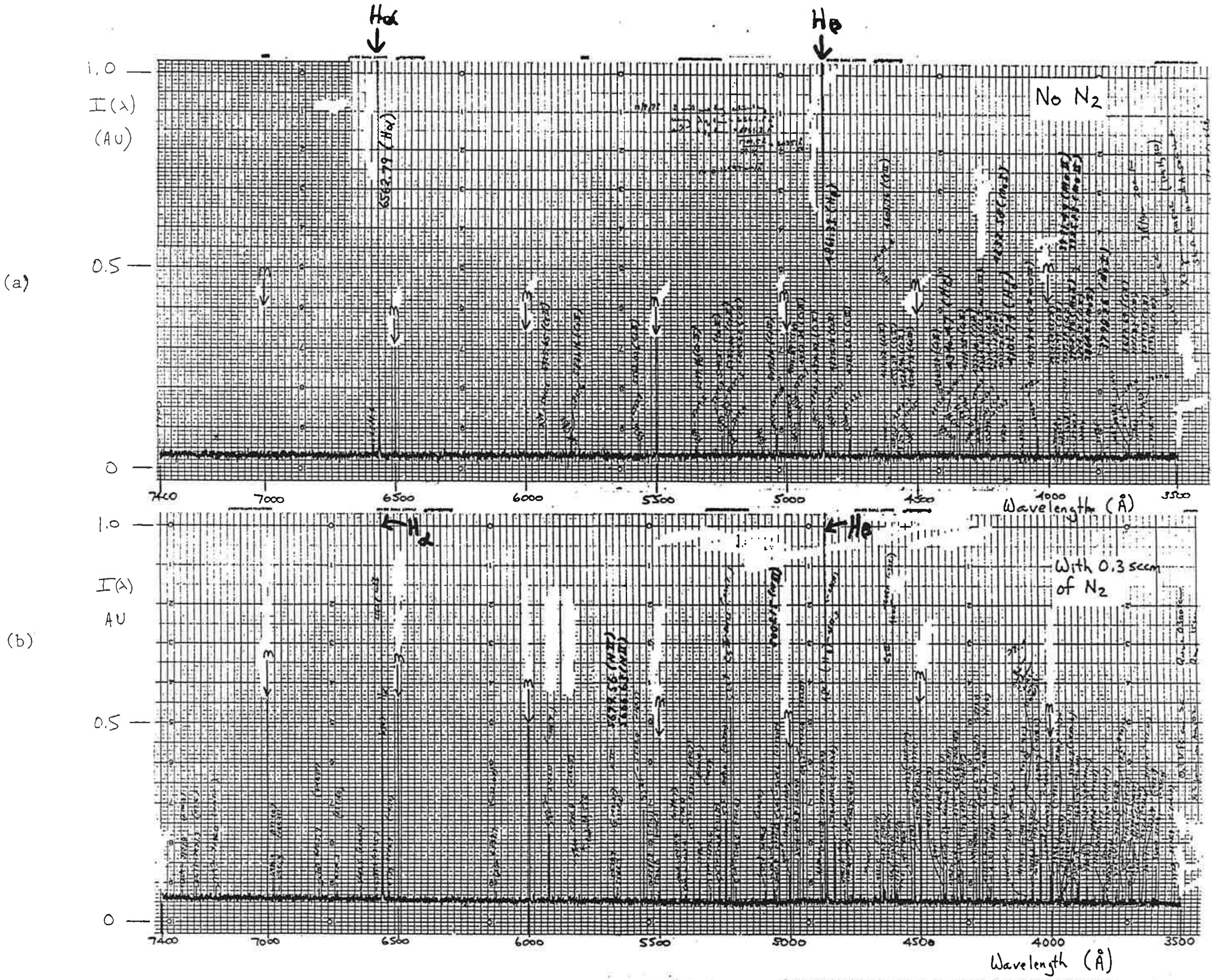


Fig. 6. Intermediate-PMT-gain spectra without (a) and with (b) N_2 gas added to the 4X source discharge.

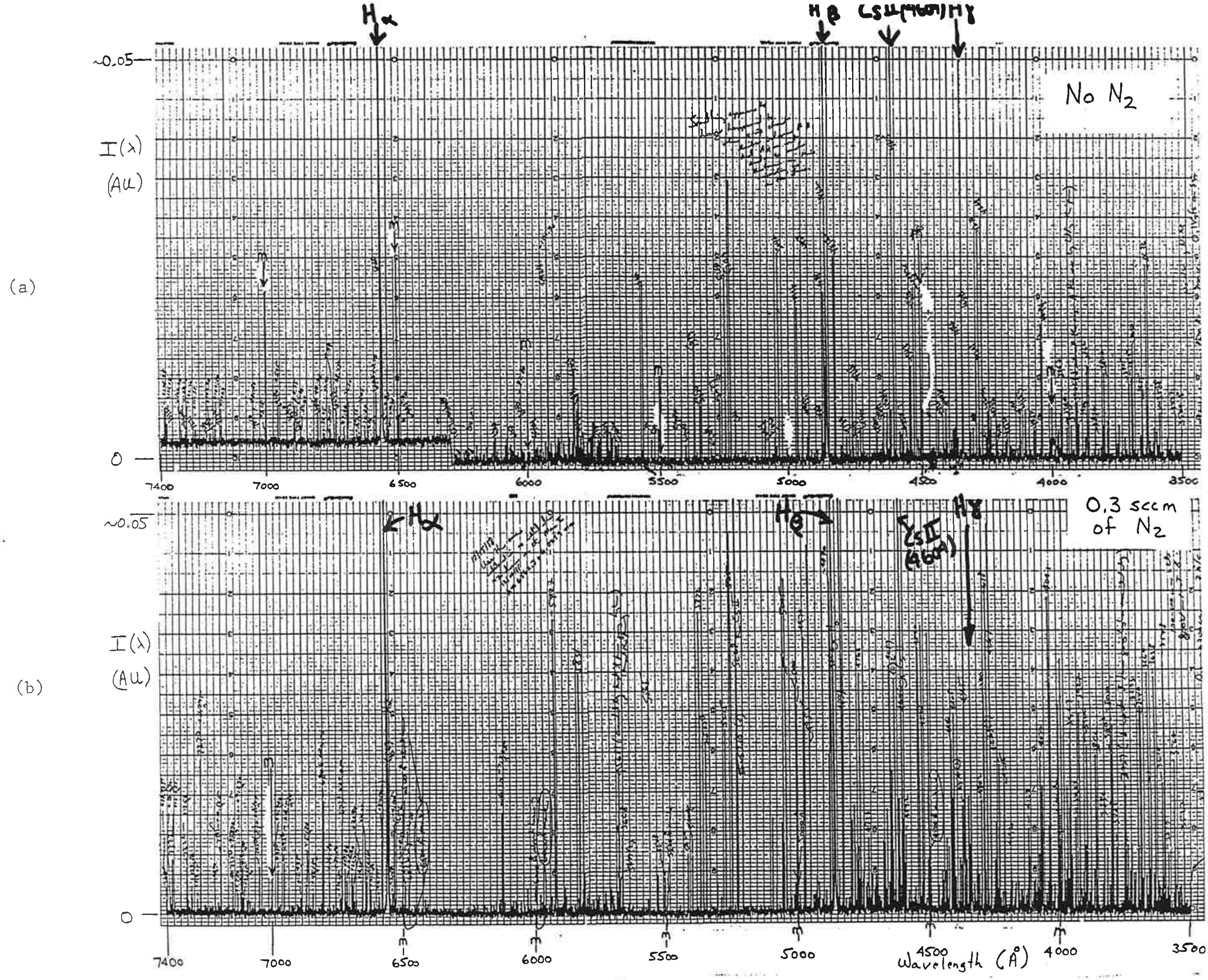


Fig. 7 Highest-PMT-gain spectra without (a) and with (b) N_2 gas added to the 4X source discharge.

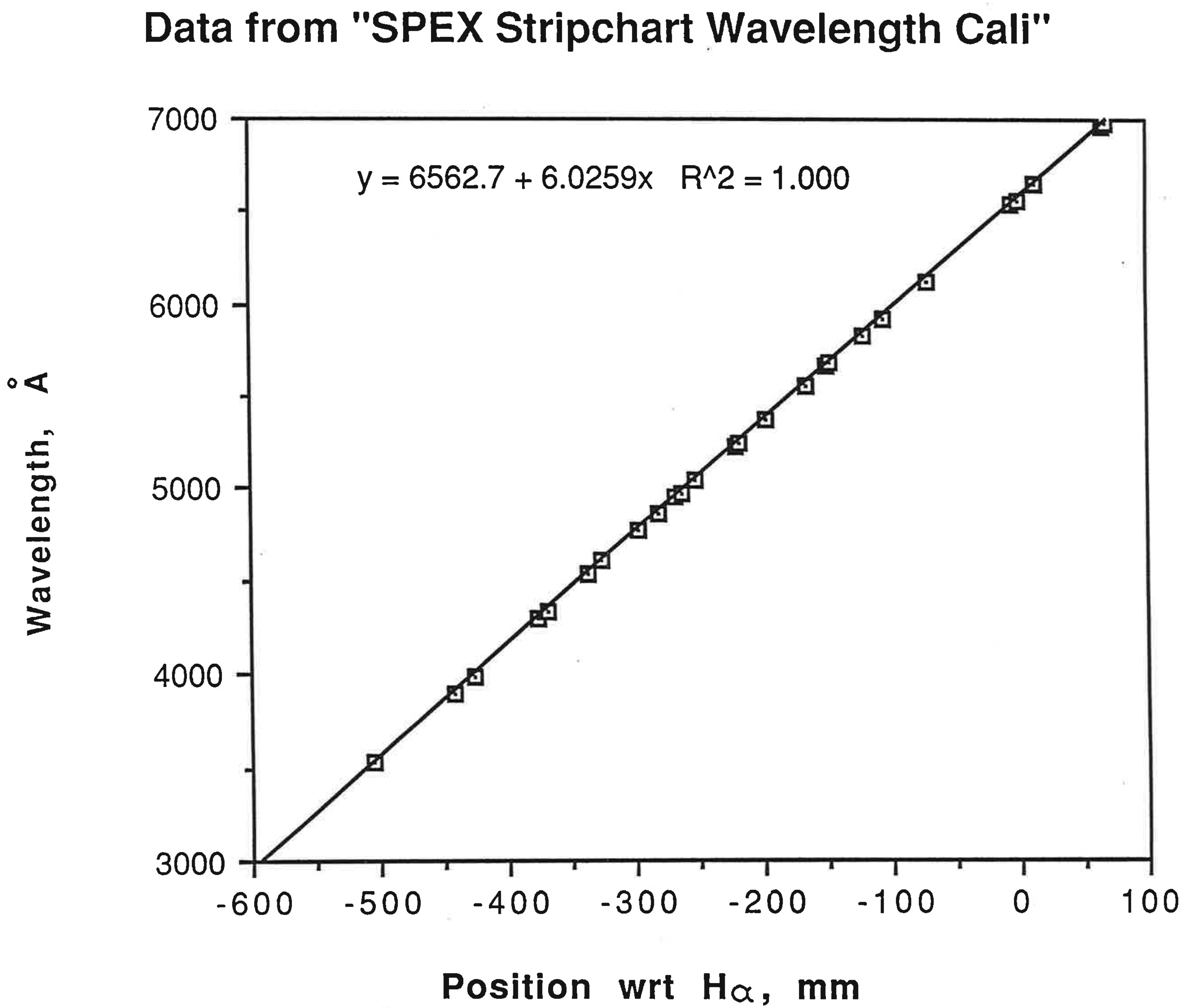


Fig. 8. Wavelength calibration curve for the intermediate-PMT-gain scan with N_2 gas (fig. 6b).

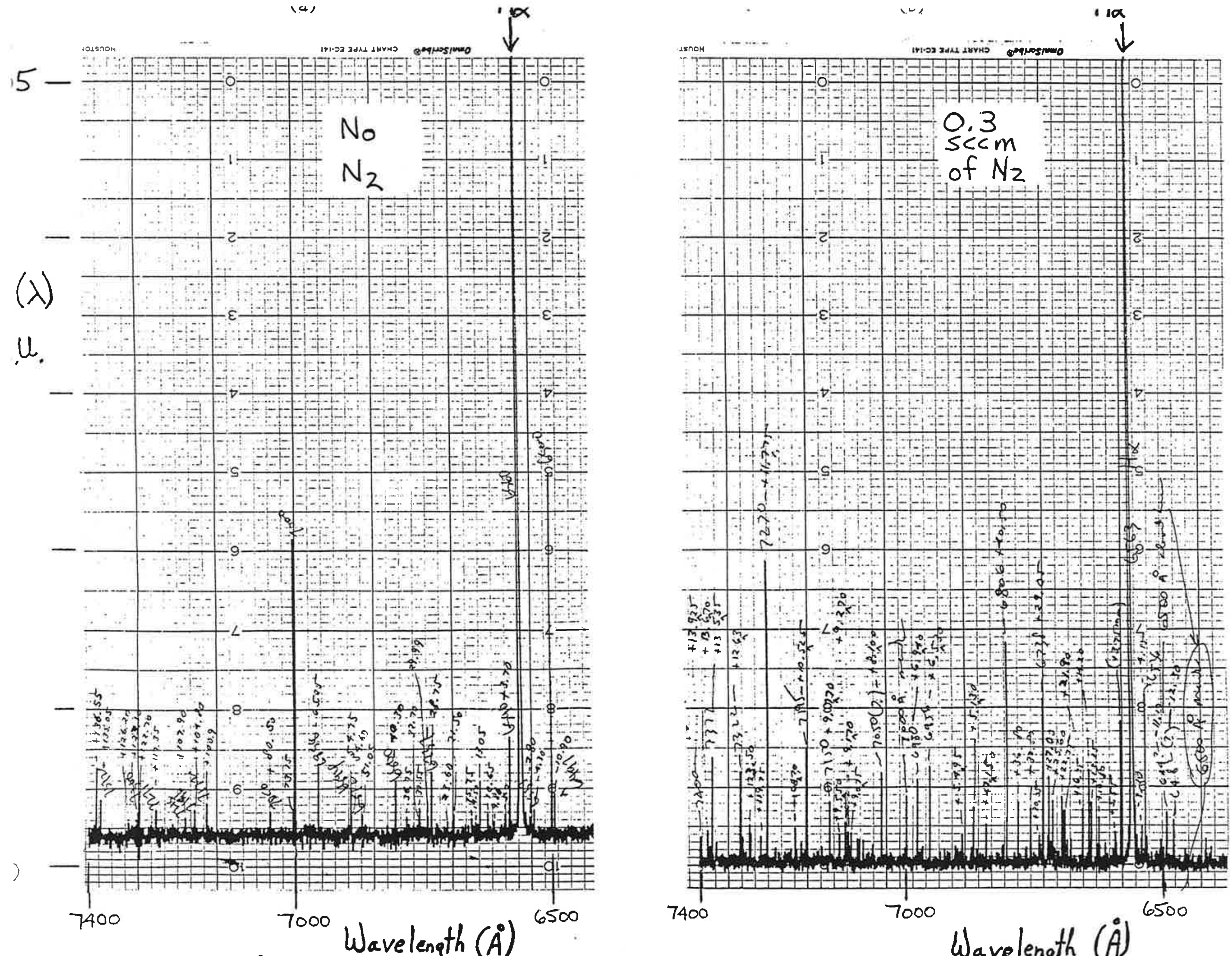


Fig. 9 Upper 1000 Å of figs. 7a and 7b a) without N_2 and b) with 0.3 sccm of N_2 gas added to the arc.

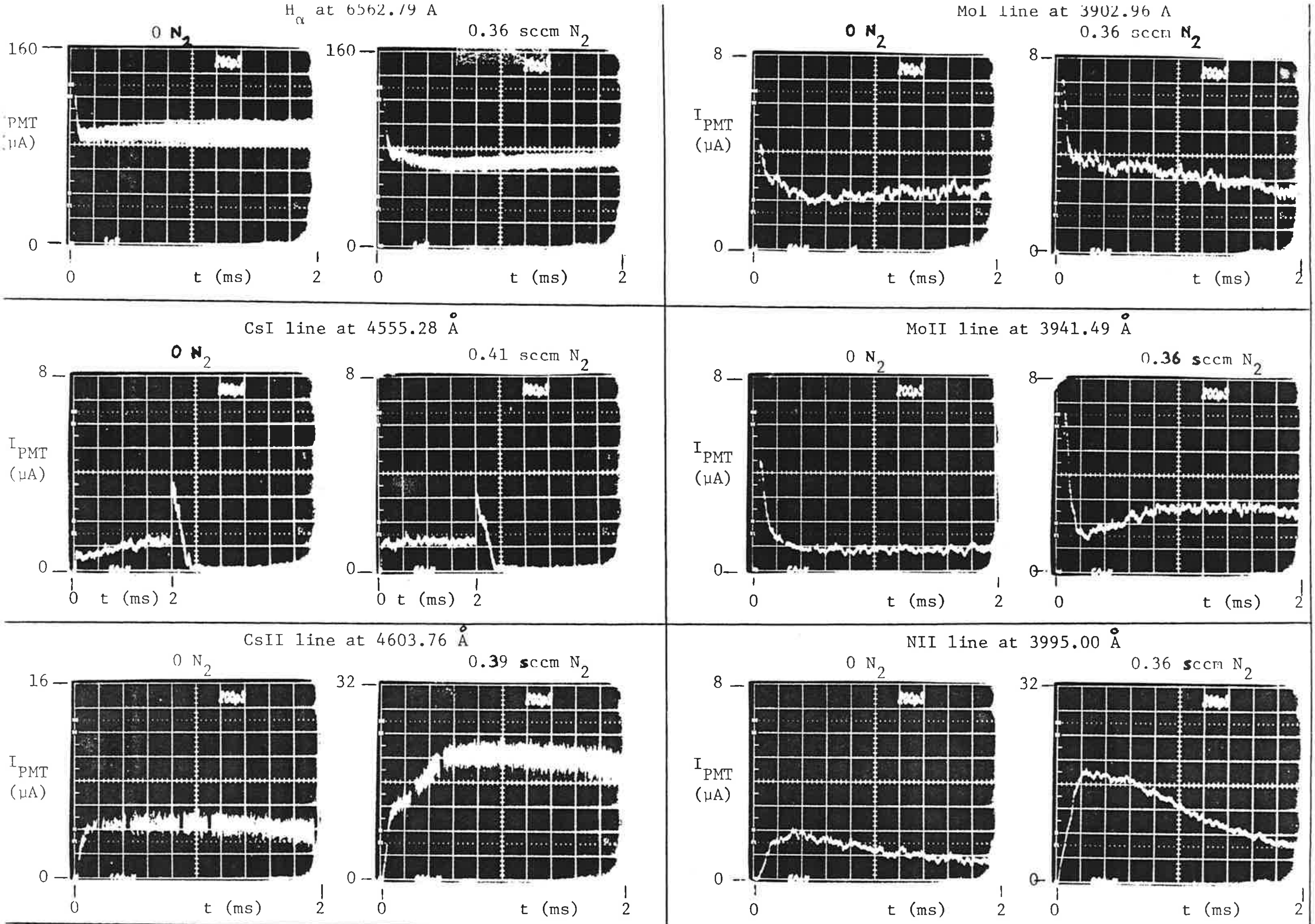


Fig. 10. Sample emission line shapes for H_α, CsI, CsII, MoI, MoII, and NII for the 4X source discharge with and without N_2 gas. The bandwidth for H_α and CsII is 1 MHz and 10 kHz for the others.