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Beam-Foil Spectrum of Nitrogen at Ultraviolet Wavelengths*

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Abstract

We present an analysis of the spectra seen in a foil-excited nitrogen beam accelerated by Van de Graaff accelerators. Atomic and molecular beams were accelerated to energies of 0.25 to 2.0 MeV to observe spectra in the wavelength region λ1050Å - λ2600Å. Atomic nitrogen was accelerated at higher energies up to 5.5 MeV to study the wavelength region λ2000Å - λ5000Å. Decay times of twenty-one of the stronger lines of N II to N V in both these regions were measured.

CASE FILE
COPY

INTRODUCTION

The beam-foil method[1] of measuring atomic parameters through the study of the light emitted from electronic excited states has been often applied to nitrogen.[1-9] All the above experiments detected radiation at wavelengths between λ2000Å and λ6000Å. References 5, 6 and 9 used photoelectric detection permitting accurate (± 5%) mean lives to be determined for some excited ion states, whereas photographic detection allowed only accurate wavelength studies for the remainder. Ionization states of some unidentified nitrogen lines were determined by Fink.[10]

We present here a natural extension of this work to the wavelength region below 2000Å down to 1050Å, using photoelectric detection and beam energies of 0.25 - 2.0 MeV. Also, with a 6 MV Van de Graaff, we have made measurements in the region λ2000 - 5000Å at higher energies. Mean life measurements have been made in both spectral regions, and the mean lives of 21 multiplets are given. Preliminary results were presented earlier.[11,12]

EXPERIMENT

A beam of nitrogen accelerated by a horizontal 2 MV Van de Graaff accelerator was magnetically selected to pass into a target chamber. The pressure in all parts of the system was $\leq 5 \times 10^{-6}$ torr. The beam was collimated by control slits approximately 0.5 cm apart and then passed through an 0.6 cm diameter, self-supported 10 μg/cm^2 carbon foil. Four such foils were mounted on a wheel which could be rotated about an axis parallel to the beam. Thus a new foil could be rotated into the beam when one broke. The beam current of the order of 1 μA was monitored with an unshielded Faraday cup connected to a current integrator. The cup and foil, at a fixed separation, could be moved by a screw along the beam.

Spectra were observed with a 1 meter McPherson spectrometer (600 ℓ/mm grating blazed at 1500Å in first order) which looked at 90° at a 0.5 cm length of the beam. Wavelength scans were obtained with the appropriate photomultiplier attached to the exit slit of the spectrometer, the D.C. output being amplified and recorded on a strip-chart recorder. EMR photomultipliers 542-G and 541-F were used for the wavelength regions λ1050 - 2000Å and λ1500 - 3000Å respectively. Decay time measurements for a particular spectral line were made by counting photomultiplier pulses for a fixed beam charge recorded by the current integrator as the foil was moved in steps upstream from the line of sight of the spectrometer.

The experimental arrangements for the 6 MV Van de Graaff were somewhat different. The vertical beam from the accelerator was bent 90° into a horizontal direction. The beam then passed between control slits and, finally, into a chamber containing the carbon foils. Light emitted at approximately 90° to the beam was focused with a quartz lens onto the entrance slit of a Perkin-Elmer 1/3-meter grating spectrometer. Light from the exit slit was detected with a 541-F EMR or a cooled 1P28 photomultiplier. For decay time measurements, the foil remained fixed while the spectrometer was moved stepwise downstream from the foil. Pulse counting was used as above.

At the higher energies of 3-5.0 MeV used on the 6 MV accelerator, we noticed that carbon foils did not break very quickly. Thus a single carbon foil in a 0.5 μamp beam of N_{14}^{+} would last a few hours.

RESULTS

A typical spectrum below 2000Å is shown in Fig. 1. Identifications of spectra obtained below 2 MeV are given in Table I, and spectra at 3-5 MeV in Table II.

A list of unidentified lines is given in Table III. Only those lines of intensity more than 3 times the noise level have been listed. Approximately 30 other very weakly excited lines were observed. The nine lines marked with an asterisk (*) were strongly excited in the N_{28}^+ beam at energies of 0.5 and 1.5 MeV (i.e., at 0.25 and 0.75 MeV per N_{14}^+), but were absent or weakly excited in the N_{14}^+ beam at 0.5 and 0.25 MeV. Three of these coincide with the wavelengths of N I lines at λ1153, 1229, and 1176Å. However, λ1229 and 1176Å were also strongly excited in a 1.85 MeV beam of N_{14}^+. λ1208, 1392, 1403, and 1466Å could be seen weakly excited in the 0.25 MeV N_{14}^+ beam. Although not understanding what mechanism produces better excitation in the molecular beam, we suggest that these lines belong to N I. Possible identifications of the other unknown lines, based on their energy dependence, are given in Table III. The line at λ1335Å coincides with a possible C II line which has been observed to be very strongly excited in beam-foil carbon spectra, but few of the others appear to be likely carbon lines. The beam-foil spectrum of O_{16}^+ and O_{32}^+ in this region reveals only one wavelength coincidence at λ1372Å of an O V transition. Thus the origin of these lines is suspected to be nitrogen.

The scans on the higher energy accelerator were observed at a resolution of 5 - 10Å with a position accuracy of ± 2Å. Several scans at energies of 3.5 to 5 MeV were made from 2000-5000Å. One N II line was observed.

Seven N III lines were observed at the lowest energy, 3.5 MeV, while the N IV lines and N V lines observed were strongest at the higher energies. All these observed lines have been seen in previous beam-foil spectra.[6-10] Below 2500Å observations with the 2 MV accelerator were made at resolutions of 1 - 2Å and line positions were known to ± 1Å. These observed spectra, and the measured decay times from both accelerators are discussed below. Spectral line identifications were made from Hallin's measurements of N IV and N V,[13,14] and also from tables.[15]

N I

Fourteen N I transitions were observed in the wavelength range λ1050-2000Å from a 0.5 MeV N_{28}^{+} beam. All but the strongest lines at λ1134Å and λ1200Å had disappeared at beam energies of 0.75 MeV per N_{14}^{+} ion. The strong N I line at λ1243Å can be resolved from the N V resonance lines at λ1238, and λ1254Å by the energy dependence in this wavelength region. At an intermediate energy the spectral intensity decreases while at low energies (less than 0.5 MeV per N_{14}^{+}) it is a strong singlet and at high energies a doublet of 4Å separation can be seen. Four measured N I mean lives have been reported in another paper.[16]

N II

Seventeen triplet and singlet transitions in N II were observed. The maximum intensity of N II lines occurred at about 0.75 MeV per N_{14}^{+}. The transition at λ1843 overlaps with a possible N III transition and that at λ2316Å with possible N III and N IV transitions. The energy dependence of the observed intensity suggests that all these transitions were present.

The decay time of a transition at λ1276Å was attributed to the $2s2p^3\ ^3D^o$ - $2p3p\ ^3P$ transition of N II. At higher energies a N IV transition at λ1272Å partially obscured it. There is no apparent cascading contribution to this double electron jump, which has a mean life measured as 6.7 ± 0.2 nsec. The transition at 1345Å is due partly to a transition in N III and the $2s2p^3\ ^3D^o$ - $2p3p\ ^3D$ transition in N II. Comparing the variations of intensity of this transition as a function of beam energy and other known N II and N III transitions, we can estimate the contributions of each multiplet. At low energy the N II contribution is evidently much larger and we attribute the fast decay to the mean life of the $2p3p\ ^3D$ multiplet of N II.

The decay time of the N II resonance line at λ1085Å has been previously measured, once by Lawrence and Savage[17] using a pulsed electron beam for excitation, and also by Heroux[9] using the beam-foil technique. Our result deduced from the straight line slope of the experimental curve of 3.15 ± 0.2 nsec was slightly higher but agreed within the estimated error. We have carefully examined the data for possible influence of cascades. The terms $3p\ ^3P$ and $2p^3\ ^3D$ can populate the $2p^3\ ^3D^o$ level through the transitions at λ1276 and 1345Å whose lifetimes are reported above. Figure 2 shows the computed corrections due to these two cascades. Just behind the foil the transitions at λ1276 and 1345Å are about 30 and 20 times weaker than that at λ1085Å. The corrections are small (about 10%) and not apparent on the experimental decay curve because the two cascading mean lives are of the same order of magnitude as the principal decay. The corrected mean life of the $2p^3\ ^3D^o$ level is 2.8 ± 0.2 nanosec.

N III

Thirty-eight transitions in N III were observed. These are shown in the Grotrian diagrams of Figs. 3a, b. Their optimum excitation was at 1.0 - 2.0 MeV per N_{14}^{+}. All 2p3p and 2p4p quartet levels were seen produced in the foil excitation (except 2p3s $^4P^o$ which has no decay transition in this wavelength region). Most doublet levels of similar energy were also seen, but with somewhat lower intensities.

Of the six N III measured decay times, only one at λ2064Å had been previously reported.[8] There was good agreement. The resonance line at λ1184Å agreed with theory[18] to 20% but the $2p^3\ ^2D^o$ lifetime measured at λ1749Å differs from theory by a factor of four.[15] No other theoretical results have been reported for levels excited in this work. The decay time measured at λ1176Å was attributed to the 5s ^2S level. However, the intensity dependence on energy of this line was unusual as noted earlier and therefore this labeling cannot be certain. Heroux[19] has observed a C III transition at 1175.7Å with the same decay time, 0.80 ± 0.04 nsec. This was strongly excited in a carbon beam-foil experiment and is another possible origin of this line.

N IV

Seventeen N IV lines were observed at energies between 1.0 and 1.85 MeV. Two decays were measured at 1134Å. One, observed at a particle energy of 0.25 MeV, was due to the strong N I line already mentioned. However, a line at this wavelength remained strong even at 1 MeV, by which energy all the other N I lines had vanished. The decay curve showed long and short components. The latter, measured to be 0.30 ± 0.05 nsec, is attributed to an inner-shell electron transition in N IV: 2s3s ^3S - 2p3s $^3P^o$. The slow decay 7.0 ± 1.0 nsec is the same as the

N I, but this is considered to be accidental, the correct source being a level in N IV which cascades into the 2p3s $^3P^o$ level, such as the 2p3p ^3P or ^3D levels.

The N IV line at λ2318Å was measured in third order where it coincides with a second order N IV line at λ3480Å. The latter has been measured by Denis et al.[6] and Pinnington and Lin,[8] who obtained mean lives 8.2 and 7.3 nsec, respectively. These are in disagreement with our decay time of 1.30 ± 0.1 nsec. However, the photomultiplier used in our experiment was an EMR 541-F, the response of which is very low above 3000Å. Also the line appeared in second order at λ2318Å with a similar intensity. Therefore we attribute our decay to the λ2318Å line originating at the 2s5f $^3P^o$ N IV state. In Refs. 6 and 8 the beam was not mass analyzed before entering the chamber which can produce some errors in identifications.

A decay time of 1.22 ± 0.1 nsec was obtained for the line at λ2647Å, in disagreement with the value of 2.3 nsec of Ref. 11. The line is strong at energies of 1.5 - 5.0 MeV and is identified as due to the N IV 4f $^3F^o$ - 5g ^3G transition. The transition observed at λ4610Å is a superposition of the N IV transition at λ4606Å, and the N V transition 3s ^2S - 3p $^2P^o$ at λ4604, 4620Å. The long lifetime of the observed decay of 7.1 ± 1.0 nsec agrees with the N IV lifetime measured in Ref. 6. We thus presume the fast decay of 0.51 ± 0.05 nsec is the mean life of the N V 3p $^2P^o$ multiplet and the longer decay is that of the N IV multiplet.

N V

Nine N V lines were seen below 2000Å for particle energies between 1.0 and 1.75 MeV, their intensities increasing with increasing beam energy. The lifetimes of the N V 2p $^2P_{\frac{1}{2},\frac{3}{2}}$ levels at λ1238, 1243Å have been previously measured both unresolved[20] and resolved.[21] Our measurement is in agreement with these two results. The N V 6fgh-7 dghi transition at λ4950Å was previously measured photographically by Fink *et al.*[7] and agrees with our result of 1.6 ± 0.1 nsec.

None of the other N V lifetimes had been previously measured. No theoretical estimates for the transition probabilities are known to ascertain whether the long or short-lived component of some of these decays is the lifetime of the upper state.

N VI

One N VI transition was observed at λ1896, 1907Å with a 1.55 MeV N_{14}^+ beam. It is the triplet resonance transition 1s2s ^3S - 1s2p $^3P^0$ and has been observed in a theta-pinch plasma by Bockasten *et al.*[22] The two components were resolved, but the component at λ1907Å was blended with a N III transition.

The decay time of a transition of unknown origin is also given. The line at λ2359Å appeared strongly excited in the higher energy range 3.5 to 5 MeV with energy behavior similar to that of other N IV lines, and hence is probably a N IV transition.

CONCLUSION

It has been observed that the beam-foil excitation produces a large number of nitrogen lines in the vacuum ultraviolet. More than 90% of the stronger lines have been identified. Neutral nitrogen and ions up to N^{5+} were excited at beam energies up to 5 MeV. The decay times of 21 of the strongest of these transitions were measured.

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FIGURE CAPTIONS

Fig. 1. Beam-foil spectra of nitrogen in the wavelength region λ1100 - 1350Å, at low and high beam energies.

Fig. 2. Decay curve for the N II 1085Å $2p^2\ {}^3P - 2p^3\ {}^3D^0$ transition. The line through the dots • is the fit to the original data; that through the pluses + is the fit after correction for the two cascades from the $3p\ {}^3P$ and $3p\ {}^3D$ levels.

Fig. 3. The energy levels of N III listed in Ref. 23. The doublet and quartet wavelengths observed in the beam foil spectrum are indicated in (a) and (b) respectively.

Table I. Observed transitions λ1050 - 3000Å at energies ≤ 2.0 MeV.

	Wavelength Å[a]		Transition
N I	1068		$2p^3\ ^2D^o - 5d\ ^2F$
	1134		$2p^3\ ^4S^o - 2p^4\ ^4P$
	1143		$2p^3\ ^2P^o - 3s''\ ^2S$
	1152		
	1168		$2p^3\ ^2D^o - 3d\ ^2F$
	1200		$2p^3\ ^4S^o - 3s\ ^4P$
	1226		$2p^3\ ^2P^o - 4d\ ^2D$
	1229	Bl.	$2p^3\ ^2P^o - 4d\ ^2P$
	1243		$2p^3\ ^2D^o - 3s'\ ^2D$
	1311		$2p^3\ ^2P^o - 3d\ ^2D$
	1320		$2p^3\ ^2P^o - 3d\ ^2P$
	1330		$2p^3\ ^2P^o - 4s\ ^2P$
	1412	Bl.	$2p^3\ ^2P^o - 3s'\ ^2D$
	1744		$2p^3\ ^2P^o - 3s\ ^2P$
N II	1086	Bl.	$2p^2\ ^3P - 2p^3\ ^3D^o$
	1276		$2p^3\ ^3D^o - 3p\ ^3P$
	1345		$2p^3\ ^3D^o - 3p\ ^3D$
	1628		$2p^3\ ^3P^o - 3p\ ^3P$
	1677		$2p^3\ ^3P^o - 3p\ ^3S$
	1762		$2p^3\ ^3S^o - 3s\ ^3P$
	1844	Bl.	$3s\ ^3P^o - 4p\ ^3P$
	1860	Bl.	$3s\ ^3P^o - 4p\ ^3D$

Table I (continued)

	Wavelength Å^a			Transition
N II (cont)	2078			$2p^3\ ^3S^o - 4p\ ^3P$
	2093			$3p\ ^3D - 5s\ ^3P^o$
	2317	Bl.		$3p\ ^3D - 4d\ ^3F^o$
	2388			$3p\ ^3S - 4d\ ^3P^o$
	2462			$3p\ ^1D - 5s\ ^1P^o$
	2644			$3d\ ^3P^o - 6f\ ^3D$
	2689	Bl.		$3d\ ^1F^o - 6f\ ^1F$
	2823			$2p^3\ ^1P^o - 4p\ ^1P$
N III	1105			$3s\ ^3S - 4p\ ^2P^o$
	1116			$2p^2\ ^2P^o - 3p\ ^2D$
	1121			$3s\ ^4P^o - 4p\ ^4D$
	1176			$3p\ ^2P^o - 5s\ ^2S$
	1184			$2p^2\ ^2P - 2p^3\ ^2P^o$
	1229	Bl.	I, IV	$3p\ ^2P^o - 3p\ ^2S$
	1303	Bl.		$4p\ ^2P^o - 4f\ ^2D$
	1314			$3s\ ^2S - 3s\ ^2P^o$
	1324	Bl.	IV	$3p\ ^4D - 4d\ ^4D^o$
			III	$3d\ ^2D - 3d\ ^2P^o$
	1347			$3p\ ^4D - 4d\ ^4F^o$
	1360			
	1387			$3p\ ^2P^o - 4d\ ^2D$
	1412	Bl.	I	$2p^3\ ^2P^o - 4s\ ^2S$

Table I (continued)

	Wavelength Å^a		Transition
N III cont.	1465		4f $^2F^o$ - 4f ^2D
	1470		3p ^4P - 4d $^4D^o$
	1507	?	4p $^2P^o$ - 4p ^2D
	1560	?	2p^3 $^2D^o$ - 3d ^2D
	1698	Bl. V	3p ^4D - 4s $^4P^o$
	1722		3d $^4F^o$ - 4f ^4D
	1729		3d $^4F^o$ - 4f ^4G
	1750		2p^2 ^2P - 2p^3 $^2D^o$
	1804		3p $^2P^o$ - 4s ^2S
	1847		3d $^4D^o$ - 4f ^4F
	1884		3d ^2D - 4f $^2F^o$
	1908	Bl. VI	3d $^2D^o$ - 4f ^2F
	1920		3d $^4P^o$ - 4f ^4D
	1948		3p ^4P - 4s $^4P^o$
	2060		3d $^2F^o$ - 4f ^2D
	2065		3d $^2F^o$ - 4f ^2G
	2147		3d $^4D^o,F^o$ - 4p $^4P,D$
	2248		3d ^2D - 4p $^2P^o$
	2273		3d $^4D^o$ - 4p ^4D
	2317	Bl. II, IV	3d $^4D^o$ - 4p ^4P
	2369		3d $^4P^o$ - 4p ^4S
	2454		3d $^4P^o$ - 4p ^4D
	2689	Bl. II	4d ^2D - 6f $^2F^o$
	2866		4f $^2F^o$ - 6g ^2G

Table I (continued)

	Wavelength Å[a]		Transition
N IV	1086	Bl. II	$3p\ ^3P^o - 4s\ ^3S$
	1134	Bl. I	$3s\ ^3S - 3s\ ^3P^o$
	1170		$3d\ ^3D - 3d\ ^3D^o$
	1229	Bl. I, III	$2p^3\ ^3P^o - 4d\ ^3D$
	1248	?	$3d\ ^3F^o - 6g\ ^3G$
	1272		$3p\ ^3P^o - 3p\ ^3P$
	1299	Bl. III	$3d\ ^1D - 3d\ ^1F^o$
	1324	Bl. III	$3d\ ^3D - 3d\ ^3F^o$
	1439		$3d\ ^1F^o - 6g\ ^1G$
	1446		$3d\ ^1D - 3d\ ^1D^o$
	1687		$4f\ ^3F^o - 6g\ ^3G$
	1719		$2p\ ^1P^o - 2p^2\ ^1D$
	2080		$3d\ ^1F^o - 5g\ ^1G$
	2317	Bl. II, III	$4d\ ^3D - 5f\ ^3F^o$
	2430		$4p\ ^3P^o - 5s\ ^3S$
	2476		$4d\ ^1D - 5f\ ^1F^o$
	2646		$4f\ ^3F^o - 5g\ ^3G$
N V	1238		$\left\{ 2s\ ^2S_{\frac{1}{2}} - 2p\ ^2P^o_{\frac{1}{2},\frac{3}{2}} \right.$
	1243	Bl. I	
	1389		$4s\ ^2S - 5p\ ^2P^o$
	1498		5f,g - 8 fgh
	1549		$4p\ ^2P^o - 5d\ ^2D$

Table I (continued)

	Wavelength Å[a]		Transition
N V cont.	1617		4d,f - 5dfg
	1698	Bl. III	5s,4p - 7p,5s
	1860	Bl. II	5dfg - 7 fgh
N VI	1896		$2s\ ^3S - 2p\ ^3P^o$
	1907	Bl. III	

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[a] Bl. = Blend. Roman numeral indicates other charge states involved in blend.

Table II. Observed transitions above λ2000Å at energies ≥ 3.5 MeV.

	Wavelength Å		Transition
N II	2131		$3p\ ^1D - 5d\ ^1F^o$
N III	2064		$3d\ ^2F^o - 4f\ ^2G$
	2188		$3d\ ^2P^o - 4f\ ^2D$
	2315-22		$3d\ ^4P^o - 4p\ ^4P$
	2370		$3d\ ^4P^o - 4p\ ^4S$
	2454-68		$3d\ ^4P^o - 4p\ ^4D$
	2688		$4d\ ^2D - 6f\ ^2F^o$
	2862		$4f\ ^2F^o - 6g\ ^2G$
N IV	2080		$3d\ ^1F^o - 5g\ ^1G$
	2318		$4d\ ^3D - 5f\ ^3F^o$
	2431		$4p\ ^3P^o - 5s\ ^3S$
	2478		$4d\ ^1D - 5f\ ^1F^o$
	2594	Bl. V	$3p\ ^1P - {}^1P^o$
	2647		$4f\ ^3F^o - 5g\ ^3G$
	2885		$5g\ ^3G - 7h\ ^3H^o$
	3078		$4f\ ^1F^o - 5g\ ^1G$
	3119		$3p\ ^3D - 4f\ ^3F^o$
	3127		
	3747		$3s\ ^1P^o - 3p\ ^1D$
	4058		$3p\ ^1P^o - 3d\ ^1D$
	4606	Bl. V	$5f\ ^3F^o - 6g\ ^3G$

Table II (continued)

	Wavelength Å		Transition
N IV cont.	4707		5f $^3F^o$ - 6g ^3G
	5814		3p ^3P - 3d $^3P^o$
	5844		
<u>N V</u>	2590	Bl. IV	5s ^2S - 6p $^2P^o$
	2859		5p $^2P^o$ - 6d ^2D
	2975		5d ^2D - 6f $^2F^o$
	2981		5f $^2F^o$ - 6g ^2G
	2998		6f,g,h - 8 g,i,h
	3161		5p $^2P^o$ - 6s ^2S
	4604	Bl. IV	3s ^2S - 3p $^2P^o$
	4620		
	4933		6d ^2D - 7f $^2F^o$
	4944		6f,g,h - 7 g,h,i
	4951		6f $^2F^o$ - 7d ^2D

Table III. Unidentified transitions.[a]

Wavelength Å	Energy MeV	Possible Identification
1112	1.85	N III, IV
1126	1.85	N IV, V
1130 *	0.25	
1176 *	0.25	N I
1195	1.85	N IV, V
1208 *	0.25	N I
1252 *	0.75	
1269 *	0.75	
1290	1.0	
1334 *	0.25	C II
1372	1.5	O V
1394 *	0.25	
1403 *	0.25	
1524	0.5	N I, II
1535	0.5	N I, II
1591	0.5	N I, II
1654 1659 } d	0.5 0.5	N I, II
2298	3.5	
2330	0.5	N I, II
2359	3.7	N III
2512 2517 } d	1.5	
2585	1.5	

Table III. (continued) Footnote

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[a] Only those of medium to strong intensity are included. The energy is that of maximimum intensity. Those marked with an asterisk (*) are explained in the text.

Table IV. Mean Lives.

Ion	States Lower	 Upper	Lifetimes (nanosec) Our Expt.	 Other Expts.	 Theory[a]	Cascade Lifetime (nsec)	Wave-length Å	Energy Observed (MeV)
N II	$2p^2\ ^3P$	$2s2p^3\ ^3D^o$	2.8 ± 0.1	2.7 ± 0.3[b] 2.8 ± 0.2[c]	1.7[c]	-	1085	1.0
	$2s2p^3\ ^3D^o$	$2s^22p3p\ ^3P$	6.73 ± 0.2		-	-	1275	0.5
	$2p^3\ ^3D^o$	$2p3p\ ^3D$	2.12 ± 0.1		-	17.9 ± 5.0	1346	0.5
N III	$2s2p^2\ ^2P$	$2p^3\ ^2P^o$	0.45 ± 0.1		1.2[d]	1.03 ± 0.1	1184	1.0
	$3p\ ^4D$	$4d\ ^4D^o$	1.56 ± 0.1		-	8.93 ± 2.0	1324	0.75
	$2p3d\ ^4F^o$	$2p4f\ ^4G$	0.86 ± 0.1		-	6.96 ± 1.0	1730	1.55
	$2p^2\ ^2P$	$2p^3\ ^2D^o$	0.97 ± 0.1		3.8[d]	-	1749	1.5
	$3d\ ^2F$	$4f\ ^2G$	2.6 ± 0.2	2.4 ± 0.1[e]	0.88[d]	-	2064	3.7
	$3p\ ^2P^o$	$5s\ ^2S$	0.83 ± 0.05		-	6.79 ± 1.0	1176	1.85
N IV	$2s3s\ ^3S$	$2p3s\ ^3P^o$	0.30 ± 0.05		-	7.0 ± 1.0	1134	1.0
	$2s4d\ ^3D$	$2s5f\ ^3F^o$	1.30 ± 0.1	7.3 ± 0.5[e,g]	-	-	2318, 3480[e]	3.7
	$2s4f\ ^3F^o$	$2s5g\ ^3G$	1.22 ± 0.2	2.3[f]	-	-	2647	4.5
			2.40 ± 0.2				2359	3.7

Table IV (continued)

Ion	States		Lifetimes (nanosec)			Cascade Lifetime (nsec)	Wave-length Å	Energy Observed (MeV)
	Lower	Upper	Our Expt.	Other Expts.	Theory[a]			
N V	2s ^2S -	2p $^2P^o$	3.30 ± 0.2	3.30[h]	2.96		1238, 43	1.5
	4p $^2P^o$ -	5d ^2D	0.95 ± 0.1		-	4.31 ± 1.0	1550	1.55
	4f $^2F^o$ -	5d, g	0.76 ± 0.1		-	5.34 ± 1.0	1619	1.55
	5s ^2S -	6p $^2P^o$	0.51 ± 0.05		-	2.86 ± 1.0	2590	3.7
	5d, f -	6f, g	0.61 ± 0.1		-	1.26, 8.4[j]	2975	3.7
	6 fgh -	8 ghi	0.85 ± 0.05		-	6.4 ± 1.0	2998	3.7
	3s ^2S -	3p $^2P^o$	0.51 ± 0.05		-	7.1 ± 1.0	4610	4.4
	6 fgh -	7 dghi	1.67 ± 0.1	1.28[i]	6.2[d]	-	4950	4.4

[a] The theoretical lifetimes given are the inverse of the calculated transition probability for the upper state.

[b] Reference 17

[c] Reference 19

[d] Reference 18

[e] Reference 8

[f] Reference 7

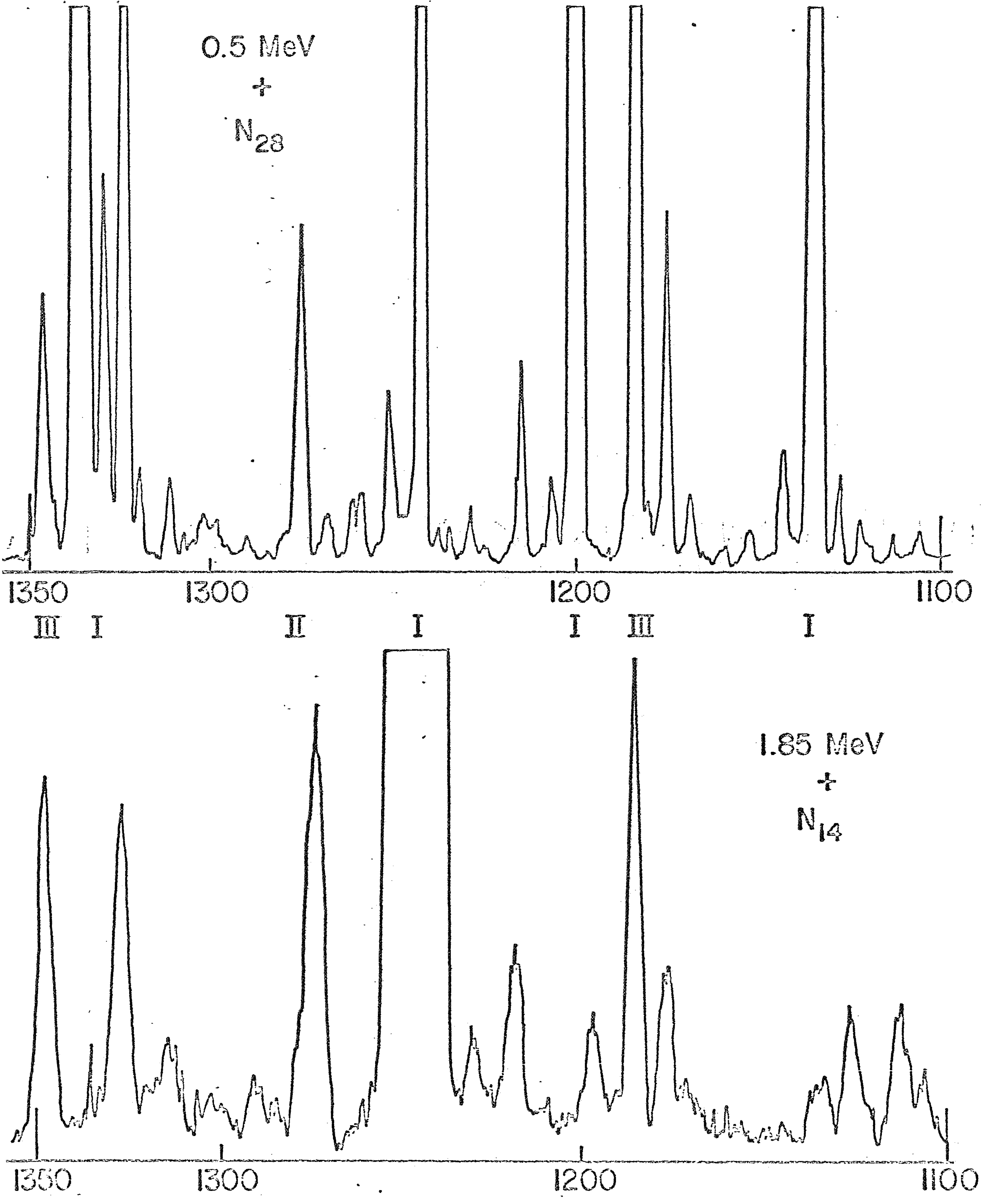
Table IV (continued)

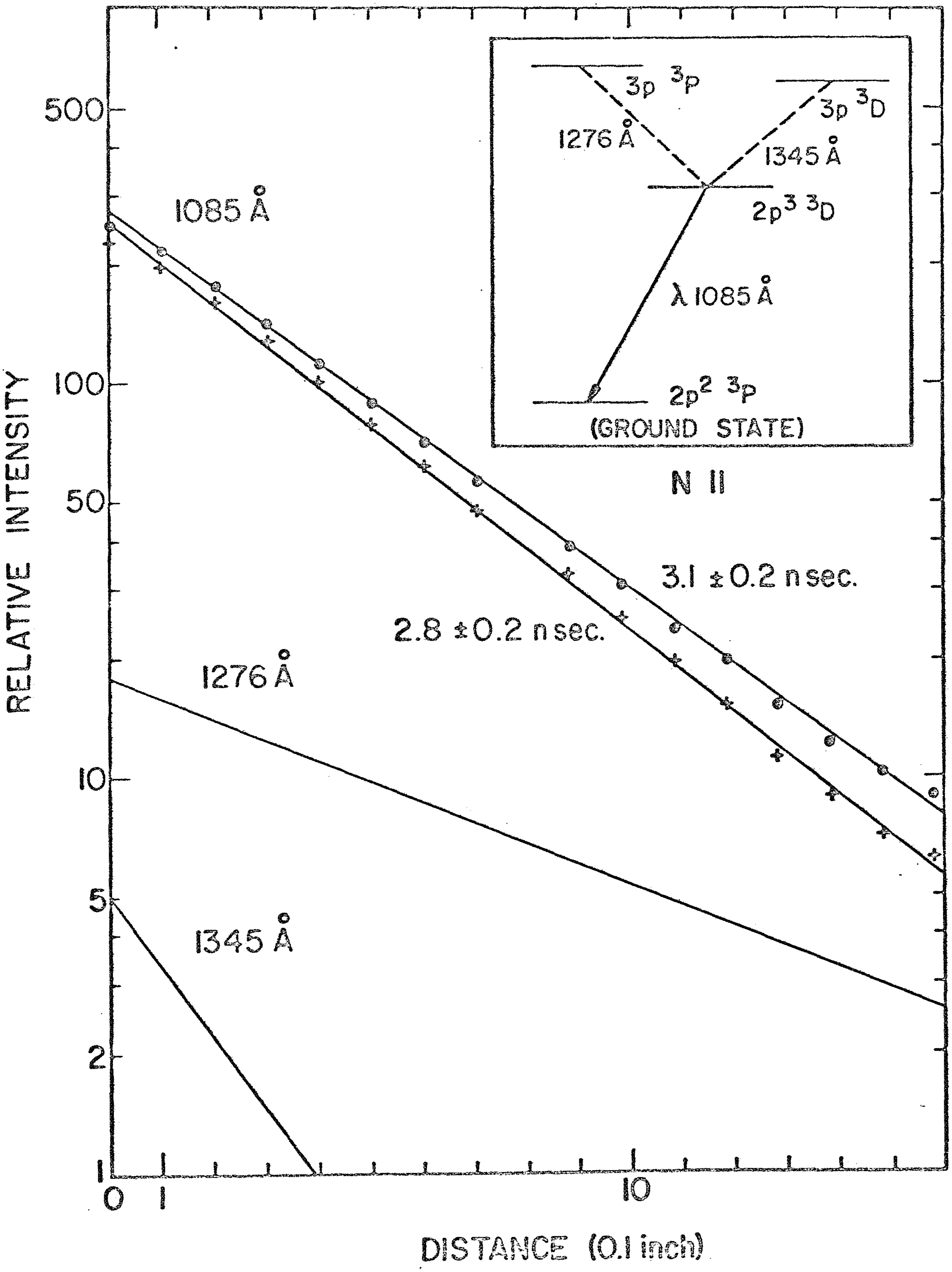
[g] Reference 5 identifies a line at λ2316Å as the 3p ^3D - 4d $^3F^o$ transition in N II with a lifetime $\tau = 0.7 \pm 0.05$ nsec. They also observe a lifetime of 9.8 ± 0.1 nsec for the line at λ3480Å.

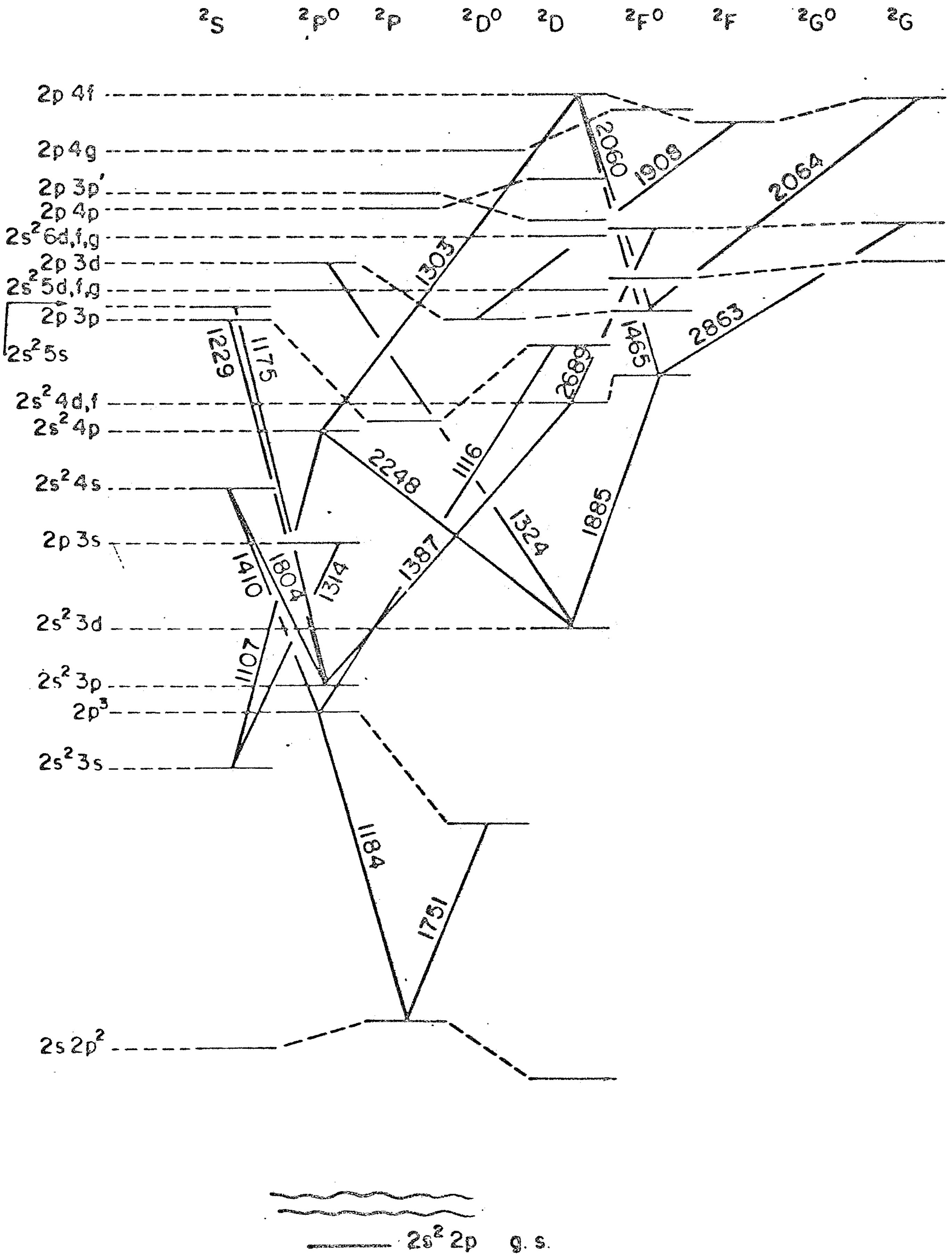
[h] Reference 22

[i] Reference 5

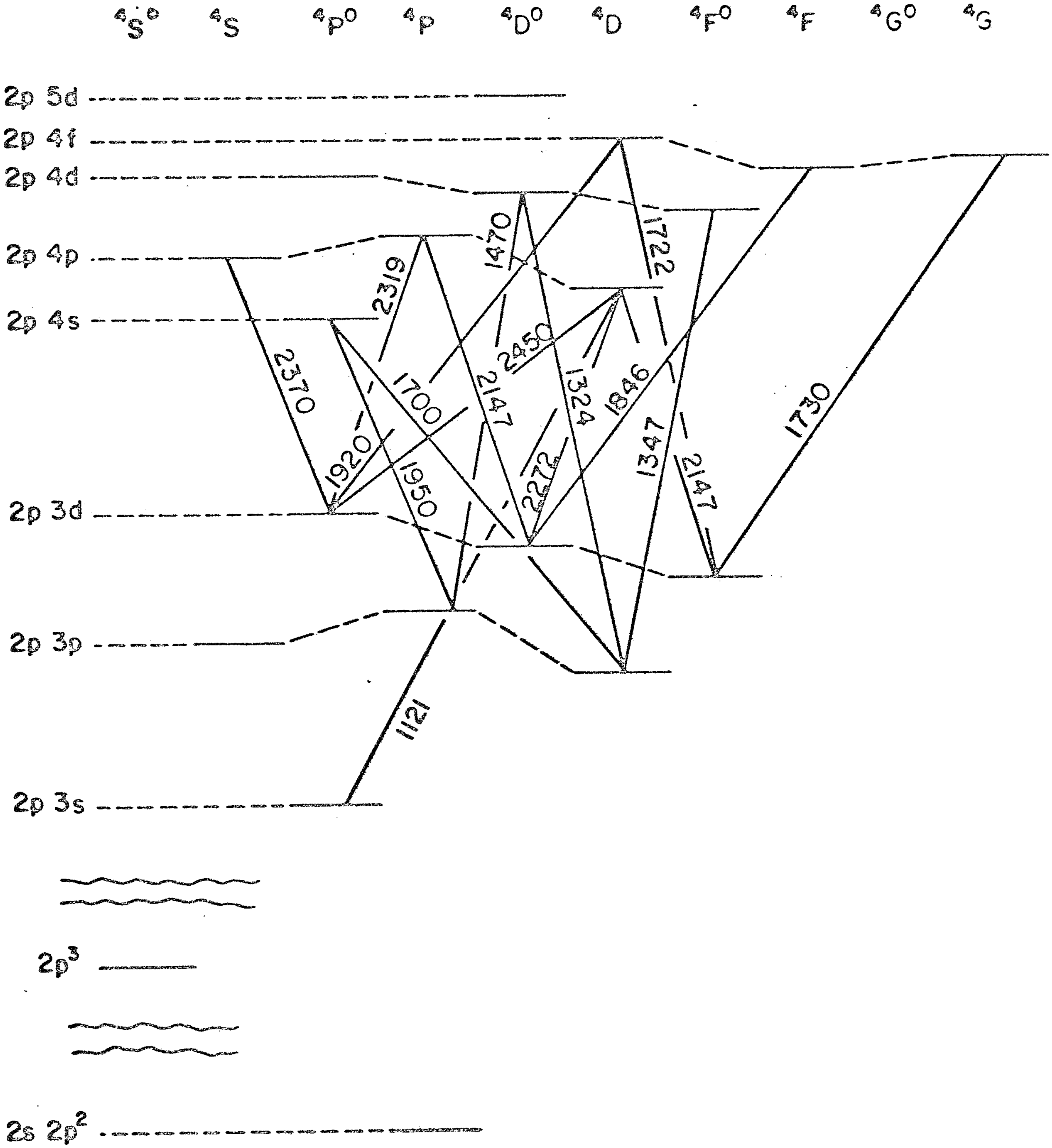
[j] Reference 5 identifies a line at λ2983Å as the 3p ^2P - 3d $^2P^o$ transition in N III. Their lifetime of 1.24 ± 0.1 nsec agrees with our primary cascade lifetime.


0.5 MeV
+
N_{28}
1350
1300
1200
1100
III
I
II
I
I
III
I
1.85 MeV
+
N_{14}
1350
1300
1200
1100
III
III
IV
V
III


500
100
50
10
5
2
1
0
1
10
RELATIVE INTENSITY
DISTANCE (0.1 inch)
1085 Å
1276 Å
1345 Å
3.1 ± 0.2 n sec.
2.8 ± 0.2 n sec.
N II
3p ^{3}P
3p ^{3}D
1276 Å
1345 Å
2p^3 ^{3}D
λ 1085 Å
2p^2 ^{3}P
(GROUND STATE)



^2S
$^2P^0$
^2P
$^2D^0$
^2D
$^2F^0$
^2F
$^2G^0$
^2G
2p 4f
2p 4g
2p 3p'
2p 4p
$2s^2$ 6d,f,g
2p 3d
$2s^2$ 5d,f,g
2p 3p
$2s^2$ 5s
$2s^2$ 4d,f
$2s^2$ 4p
$2s^2$ 4s
2p 3s
$2s^2$ 3d
$2s^2$ 3p
$2p^3$
$2s^2$ 3s
$2s\,2p^2$
$2s^2$ 2p g. s.
2060
1909
2064
1303
1465
2863
2689
1229
1175
2248
1116
1324
1885
1387
1410
1804
1314
1107
1184
1751


$^4S^o$
^4S
$^4P^o$
^4P
$^4D^o$
^4D
$^4F^o$
^4F
$^4G^o$
^4G
2p 5d
2p 4f
2p 4d
2p 4p
2p 4s
2p 3d
2p 3p
2p 3s
$2p^3$
$2s\ 2p^2$
1470
1722
2319
2450
2370
1700
2147
1324
1846
1920
1950
2272
1347
2147
1730
1121