

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 $\lambda 1050\text{\AA}$ - $\lambda 2600\text{\AA}$. Atomic nitrogen was accelerated at higher energies up to 5.5 MeV to study the wavelength region $\lambda 2000\text{\AA}$ - $\lambda 5000\text{\AA}$. Decay times of twenty-one of the stronger lines of N II to N V in both these regions were measured.

**CASE FILE
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INTRODUCTION

The beam-foil method¹ 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 $\lambda 2000\text{\AA}$ and $\lambda 6000\text{\AA}$. References 5, 6 and 9 used photoelectric detection permitting accurate ($\pm 5\%$) 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 $2000\text{\AA}$ down to $1050\text{\AA}$, 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 $\lambda 2000 - 5000\text{\AA}$ 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 $10 \mu\text{g}/\text{cm}^2$ 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 λ/mm grating blazed at $1500\text{\AA}$ 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 $\lambda 1050 - 2000\text{\AA}$ and $\lambda 1500 - 3000\text{\AA}$ 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 $2000\text{\AA}$ 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 $\lambda 1153$, 1229 , and $1176\text{\AA}$. However, $\lambda 1229$ and $1176\text{\AA}$ were also strongly excited in a 1.85 MeV beam of N_{14}^{+} . $\lambda 1208$, 1392 , 1403 , and $1466\text{\AA}$ 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 $\lambda 1335\text{\AA}$ 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 $\lambda 1372\text{\AA}$ 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 $5 - 10\text{\AA}$ with a position accuracy of $\pm 2\text{\AA}$. Several scans at energies of 3.5 to 5 MeV were made from $2000-5000\text{\AA}$. 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 $\pm 1\text{\AA}$. 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 1050-2000Å from a 0.5 MeV N_{28}^{+} beam. All but the strongest lines at 1134Å and 1200Å had disappeared at beam energies of 0.75 MeV per N_{14}^{+} ion. The strong N I line at 1243Å can be resolved from the N V resonance lines at 1238, and 1254Å 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 1843 overlaps with a possible N III transition and that at 2316Å 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 $\lambda 1276\text{\AA}$ was attributed to the $2s2p^3\ ^3D^0 - 2p3p\ ^3P$ transition of N II. At higher energies a N IV transition at $\lambda 1272\text{\AA}$ 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 $1345\text{\AA}$ is due partly to a transition in N III and the $2s2p^3\ ^3D^0 - 2p3p\ ^3D$ 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 $\lambda 1085\text{\AA}$ has been previously measured, once by Lawrence and Savage¹⁷ using a pulsed electron beam for excitation, and also by Heroux⁹ 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 $2p^3\ ^3D^0$ level through the transitions at $\lambda 1276$ and $1345\text{\AA}$ whose lifetimes are reported above. Figure 2 shows the computed corrections due to these two cascades. Just behind the foil the transitions at $\lambda 1276$ and $1345\text{\AA}$ are about 30 and 20 times weaker than that at $\lambda 1085\text{\AA}$. 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 $2p^3\ ^3D^0$ 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 $2p3s\ ^4P^0$ 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 $\lambda 2064\text{\AA}$ had been previously reported.⁸ There was good agreement. The resonance line at $\lambda 1184\text{\AA}$ agreed with theory¹⁸ to 20% but the $2p^3\ ^2D^0$ lifetime measured at $\lambda 1749\text{\AA}$ 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 $\lambda 1176\text{\AA}$ 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. Heroux¹⁹ has observed a C III transition at $1175.7\text{\AA}$ 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 $1134\text{\AA}$. 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: $2s3s\ ^3S - 2p3s\ ^3P^0$. 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 $\lambda 2318\text{\AA}$ was measured in third order where it coincides with a second order N IV line at $\lambda 3480\text{\AA}$. 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 $3000\text{\AA}$. Also the line appeared in second order at $\lambda 2318\text{\AA}$ with a similar intensity. Therefore we attribute our decay to the $\lambda 2318\text{\AA}$ 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 $\lambda 2647\text{\AA}$, 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 $\lambda 4610\text{\AA}$ is a superposition of the N IV transition at $\lambda 4606\text{\AA}$, and the N V transition $3s\ ^2S - 3p\ ^2P^o$ at $\lambda 4604, 4620\text{\AA}$. 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 $\lambda 1238, 1243\text{\AA}$ have been previously measured both unresolved²⁰ and resolved.²¹ Our measurement is in agreement with these two results. The N V 6fgh-7 dghi transition at $\lambda 4950\text{\AA}$ 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 $\lambda 1896, 1907\text{\AA}$ 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 $\lambda 1907\text{\AA}$ was blended with a N III transition.

The decay time of a transition of unknown origin is also given. The line at $\lambda 2359\text{\AA}$ 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 $\lambda 1100 - 1350\text{\AA}$, at low and high beam energies.
- Fig. 2. Decay curve for the N II $1085\text{\AA}$ $2p^2\ ^3P - 2p^3\ ^3D^0$ transition. The line through the dots $\cdot$ 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 $\lambda 1050 - 3000\text{\AA}$ at energies ≤ 2.0 MeV.

Wavelength $\text{\AA}$ ^a			Transition
<u>N I</u>	1068		$2p^3 \ ^2D^0 - 5d \ ^2F$
	1134		$2p^3 \ ^4S^0 - 2p^4 \ ^4P$
	1143		$2p^3 \ ^2P^0 - 3s'' \ ^2S$
	1152		
	1168		$2p^3 \ ^2D^0 - 3d \ ^2F$
	1200		$2p^3 \ ^4S^0 - 3s \ ^4P$
	1226		$2p^3 \ ^2P^0 - 4d \ ^2D$
	1229	Bl.	$2p^3 \ ^2P^0 - 4d \ ^2P$
	1243		$2p^3 \ ^2D^0 - 3s' \ ^2D$
	1311		$2p^3 \ ^2P^0 - 3d \ ^2D$
	1320		$2p^3 \ ^2P^0 - 3d \ ^2P$
	1330		$2p^3 \ ^2P^0 - 4s \ ^2P$
	1412	Bl.	$2p^3 \ ^2P^0 - 3s' \ ^2D$
	1744		$2p^3 \ ^2P^0 - 3s \ ^2P$
<u>N II</u>	1086	Bl.	$2p^2 \ ^3P - 2p^3 \ ^3D^0$
	1276		$2p^3 \ ^3D^0 - 3p \ ^3P$
	1345		$2p^3 \ ^3D^0 - 3p \ ^3D$
	1628		$2p^3 \ ^3P^0 - 3p \ ^3P$
	1677		$2p^3 \ ^3P^0 - 3p \ ^3S$
	1762		$2p^3 \ ^3S^0 - 3s \ ^3P$
	1844	Bl.	$3s \ ^3P^0 - 4p \ ^3P$
	1860	Bl.	$3s \ ^3P^0 - 4p \ ^3D$

Table I (continued)

	Wavelength Å ^a		Transition
N II (cont)	2078		$2p^3\ ^3S^0 - 4p\ ^3P$
	2093		$3p\ ^3D - 5s\ ^3P^0$
	2317	Bl.	$3p\ ^3D - 4d\ ^3F^0$
	2388		$3p\ ^3S - 4d\ ^3P^0$
	2462		$3p\ ^1D - 5s\ ^1P^0$
	2644		$3d\ ^3P^0 - 6f\ ^3D$
	2689	Bl.	$3d\ ^1F^0 - 6f\ ^1F$
	2823		$2p^3\ ^1P^0 - 4p\ ^1P$
<u>N III</u>	1105		$3s\ ^3S - 4p\ ^2P^0$
	1116		$2p^2\ ^2P^0 - 3p\ ^2D$
	1121		$3s\ ^4P^0 - 4p\ ^4D$
	1176		$3p\ ^2P^0 - 5s\ ^2S$
	1184		$2p^2\ ^2P - 2p^3\ ^2P^0$
	1229	Bl. I, IV	$3p\ ^2P^0 - 3p\ ^2S$
	1303	Bl.	$4p\ ^2P^0 - 4f\ ^2D$
	1314		$3s\ ^2S - 3s\ ^2P^0$
	1324	Bl. IV III	$\left\{ \begin{array}{l} 3p\ ^4D - 4d\ ^4D^0 \\ 3d\ ^2D - 3d\ ^2P^0 \end{array} \right.$
	1347		$3p\ ^4D - 4d\ ^4F^0$
	1360		
	1387		$3p\ ^2P^0 - 4d\ ^2D$
	1412	Bl. I	$2p^3\ ^2P^0 - 4s\ ^2S$

Table I (continued)

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

Table I (continued)

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

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 ³ S - 2p ³ P ^o
	1907	Bl. III	

^aBl. = Blend. Roman numeral indicates other charge states involved in blend.

Table II. Observed transitions above $\lambda 2000\text{\AA}$ at energies ≥ 3.5 MeV.

	Wavelength $\text{\AA}$	Transition
<u>N II</u>	2131	$3p\ ^1D - 5d\ ^1F^0$
<u>N III</u>	2064	$3d\ ^2F^0 - 4f\ ^2G$
	2188	$3d\ ^2P^0 - 4f\ ^2D$
	2315-22	$3d\ ^4P^0 - 4p\ ^4P$
	2370	$3d\ ^4P^0 - 4p\ ^4S$
	2454-68	$3d\ ^4P^0 - 4p\ ^4D$
	2688	$4d\ ^2D - 6f\ ^2F^0$
	2862	$4f\ ^2F^0 - 6g\ ^2G$
<u>N IV</u>	2080	$3d\ ^1F^0 - 5g\ ^1G$
	2318	$4d\ ^3D - 5f\ ^3F^0$
	2431	$4p\ ^3P^0 - 5s\ ^3S$
	2478	$4d\ ^1D - 5f\ ^1F^0$
	2594 Bl. V	$3p\ ^1P - ^1P^0$
	2647	$4f\ ^3F^0 - 5g\ ^3G$
	2885	$5g\ ^3G - 7h\ ^3H^0$
	3078	$4f\ ^1F^0 - 5g\ ^1G$
	3119 } 3127 }	$3p\ ^3D - 4f\ ^3F^0$
	3747	$3s\ ^1P^0 - 3p\ ^1D$
	4058	$3p\ ^1P^0 - 3d\ ^1D$
	4606 Bl. V	$5f\ ^3F^0 - 6g\ ^3G$

Table II (continued)

	Wavelength Å		Transition
N IV cont.	4707		$5f \ ^3F^0 - 6g \ ^3G$
	5814	}	$3p \ ^3P - 3d \ ^3P^0$
	5844		
<u>N V</u>	2590	Bl. IV	$5s \ ^2S - 6p \ ^2P^0$
	2859		$5p \ ^2P^0 - 6d \ ^2D$
	2975	}	$\left\{ \begin{array}{l} 5d \ ^2D - 6f \ ^2F^0 \\ 5f \ ^2F^0 - 6g \ ^2G \end{array} \right.$
	2981		
	2998		$6f, g, h - 8 \ g, i, h$
	3161		$5p \ ^2P^0 - 6s \ ^2S$
	4604	}	$3s \ ^2S - 3p \ ^2P^0$
	4620		
	4933		$6d \ ^2D - 7f \ ^2F^0$
	4944	}	$\left\{ \begin{array}{l} 6f, g, h - 7 \ g, h, i \\ 6f \ ^2F^0 - 7d \ ^2D \end{array} \right.$
	4951		

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 }	0.5 0.5	N I, II
2298	3.5	
2330	0.5	N I, II
2359	3.7	N III
2512 } 2517 }	1.5	
2585	1.5	

Table III. (continued) Footnote

^aOnly those of medium to strong intensity are included. The energy is that of maximum intensity. Those marked with an asterisk (*) are explained in the text.

Table IV. Mean Lives.

Ion	States		Lifetimes (nanosec)			Cascade Lifetime (nsec)	Wave- length Å	Energy Observed (MeV)
	Lower	Upper	Our Expt.	Other Expts.	Theory ^a			
N II	$2p^3\ ^3P - 2s2p^3\ ^3D^0$		2.8 ± 0.1	2.7 ± 0.3^b 2.8 ± 0.2^c	1.7^c	-	1085	1.0
	$2s2p^3\ ^3D^0 - 2s^22p3p\ ^3P$		6.73 ± 0.2		-	-	1275	0.5
	$2p^3\ ^3D^0 - 2p3p\ ^3D$		2.12 ± 0.1		-	17.9 ± 5.0	1346	0.5
N III	$2s2p^2\ ^2P - 2p^3\ ^2P^0$		0.45 ± 0.1		1.2^d	1.03 ± 0.1	1184	1.0
	$3p\ ^4D - 4d\ ^4D^0$		1.56 ± 0.1		-	8.93 ± 2.0	1324	0.75
	$2p3d\ ^4F^0 - 2p4f\ ^4G$		0.86 ± 0.1		-	6.96 ± 1.0	1730	1.55
	$2p^2\ ^2P - 2p^3\ ^2D^0$		0.97 ± 0.1		3.8^d	-	1749	1.5
	$3d\ ^4F - 4f\ ^2G$		2.6 ± 0.2	2.4 ± 0.1^e	0.88^d	-	2064	3.7
	$3p\ ^2P^0 - 5s\ ^2S$		0.83 ± 0.05		-	6.79 ± 1.0	1176	1.85
N IV	$2s3s\ ^3S - 2p3s\ ^3P^0$		0.30 ± 0.05		-	7.0 ± 1.0	1134	1.0
	$2s4d\ ^3D - 2s5f\ ^3F^0$		1.30 ± 0.1	$7.3 \pm 0.5^{e,g}$	-	-	2318, 3480 ^e	3.7
	$2s4f\ ^3F^0 - 2s5g\ ^3G$		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 ² S - 2p ² P ^o		3.30 ± 0.2	3.30 ^h	2.96		1238, 43	1.5
	4p ² P ^o - 5d ² D		0.95 ± 0.1		-	4.31 ± 1.0	1550	1.55
	4f ² F ^o - 5d, g		0.76 ± 0.1		-	5.34 ± 1.0	1619	1.55
	5s ² S - 6p ² P ^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 ² S - 3p ² P ^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

^aThe theoretical lifetimes given are the inverse of the calculated transition probability for the upper state.

^bReference 17

^cReference 19

^dReference 18

^eReference 8

^fReference 7

Table IV (continued)

^gReference 5 identifies a line at $\lambda 2316\text{\AA}$ as the $3p\ ^3D - 4d\ ^3F^0$ 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 $\lambda 3480\text{\AA}$.

^hReference 22

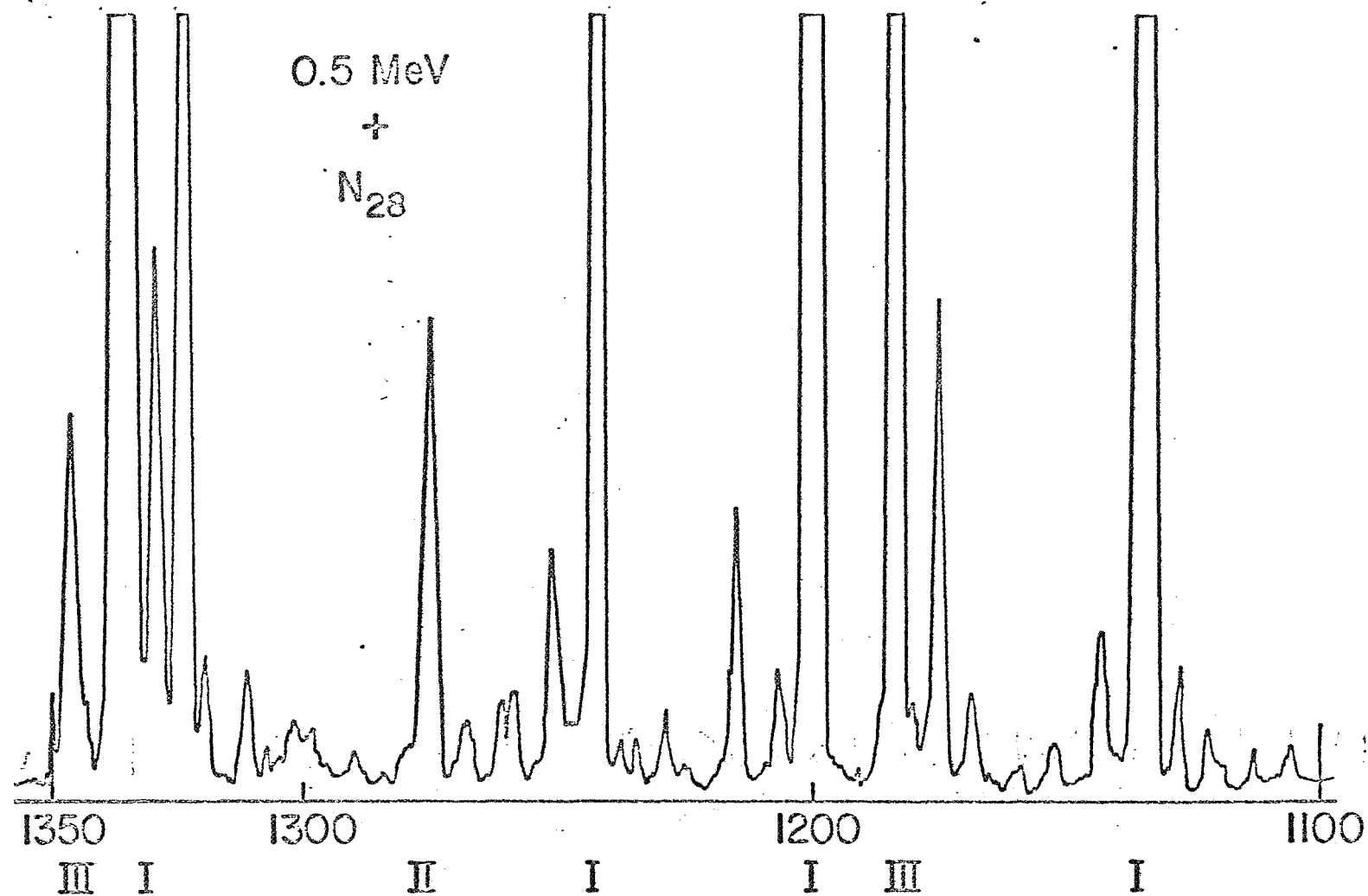
ⁱReference 5

^jReference 5 identifies a line at $\lambda 2983\text{\AA}$ as the $3p\ ^2P - 3d\ ^2P^0$ transition in N III. Their lifetime of 1.24 ± 0.1 nsec agrees with our primary cascade lifetime.

0.5 MeV

+

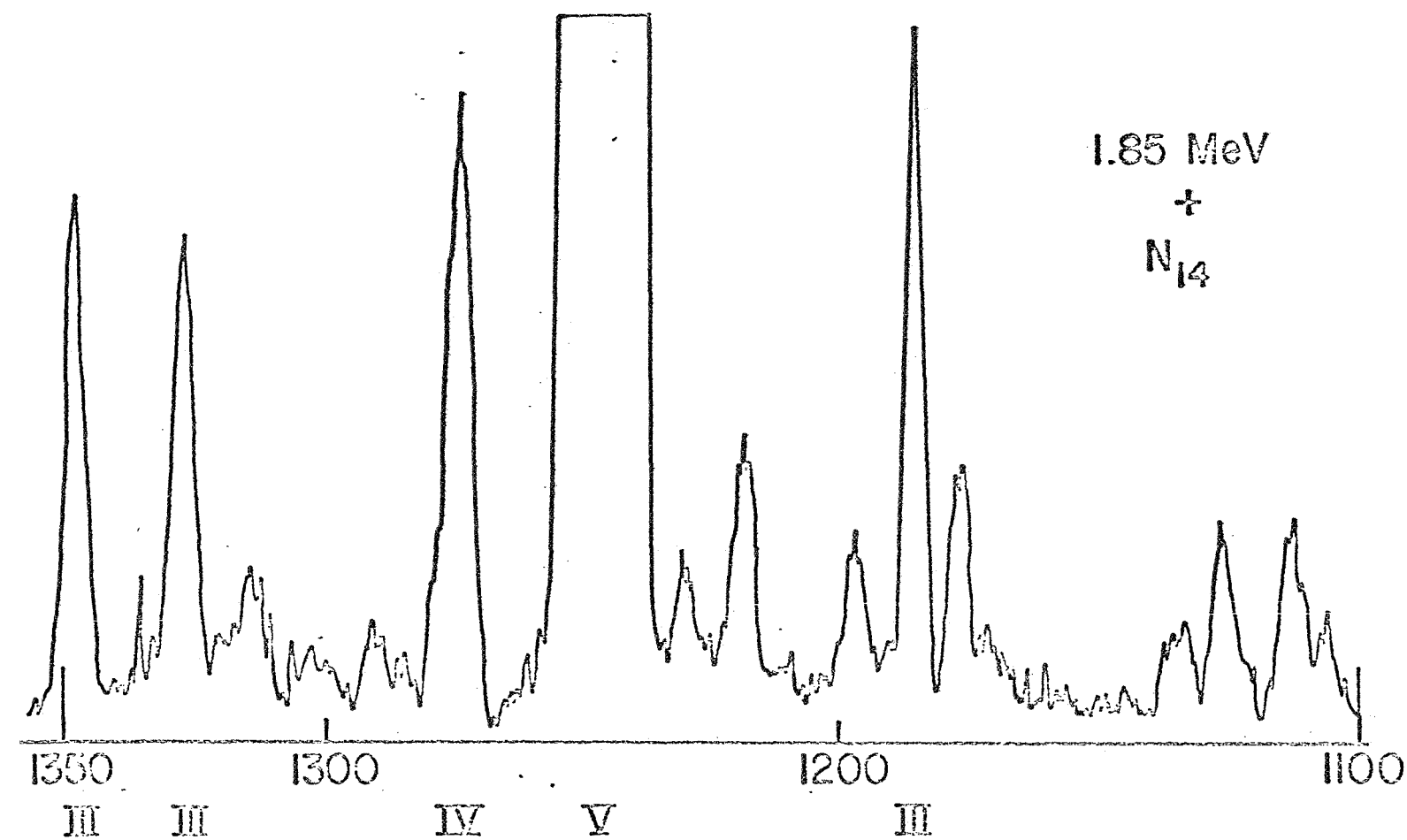
N_{28}

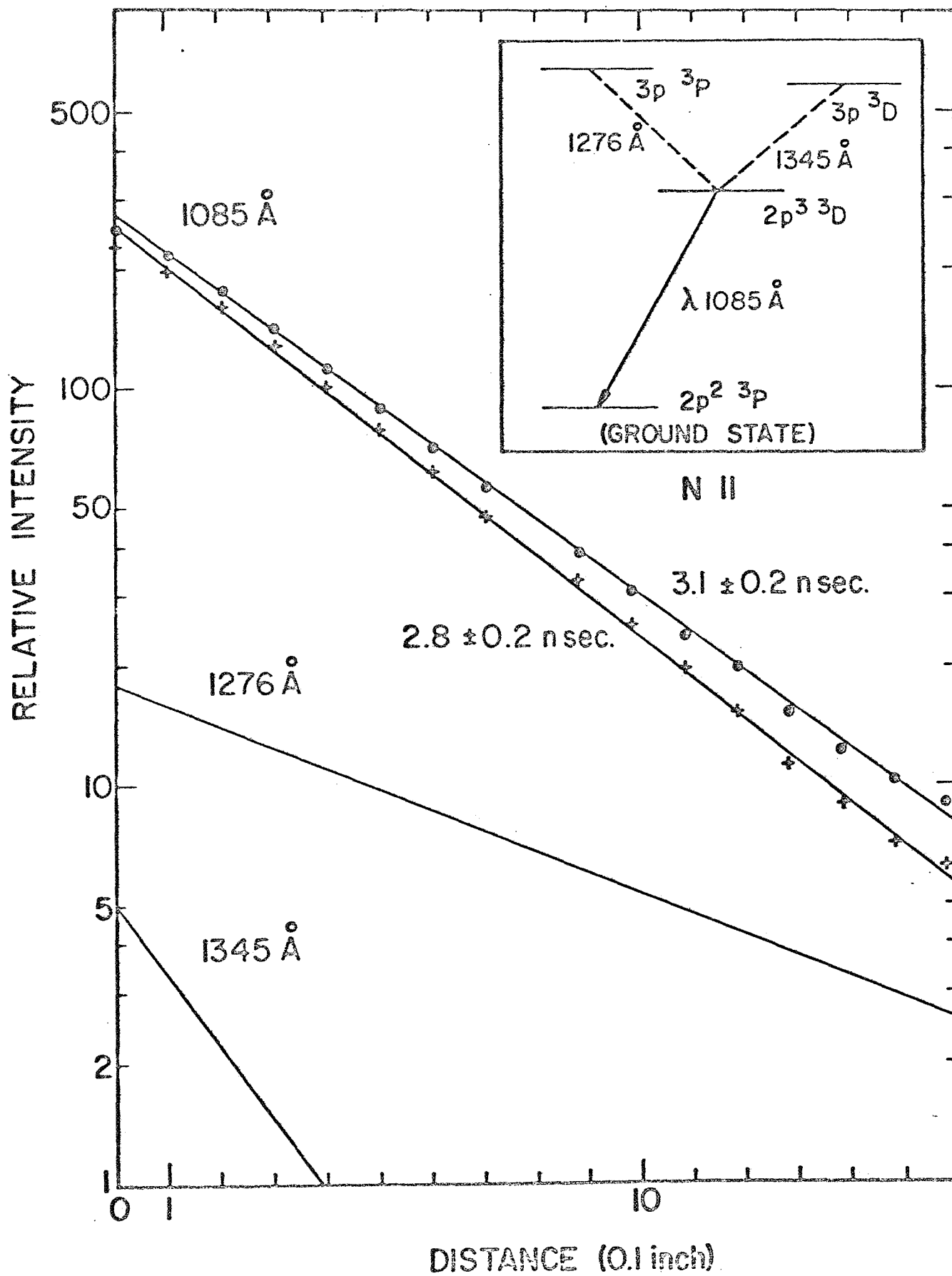


1.85 MeV

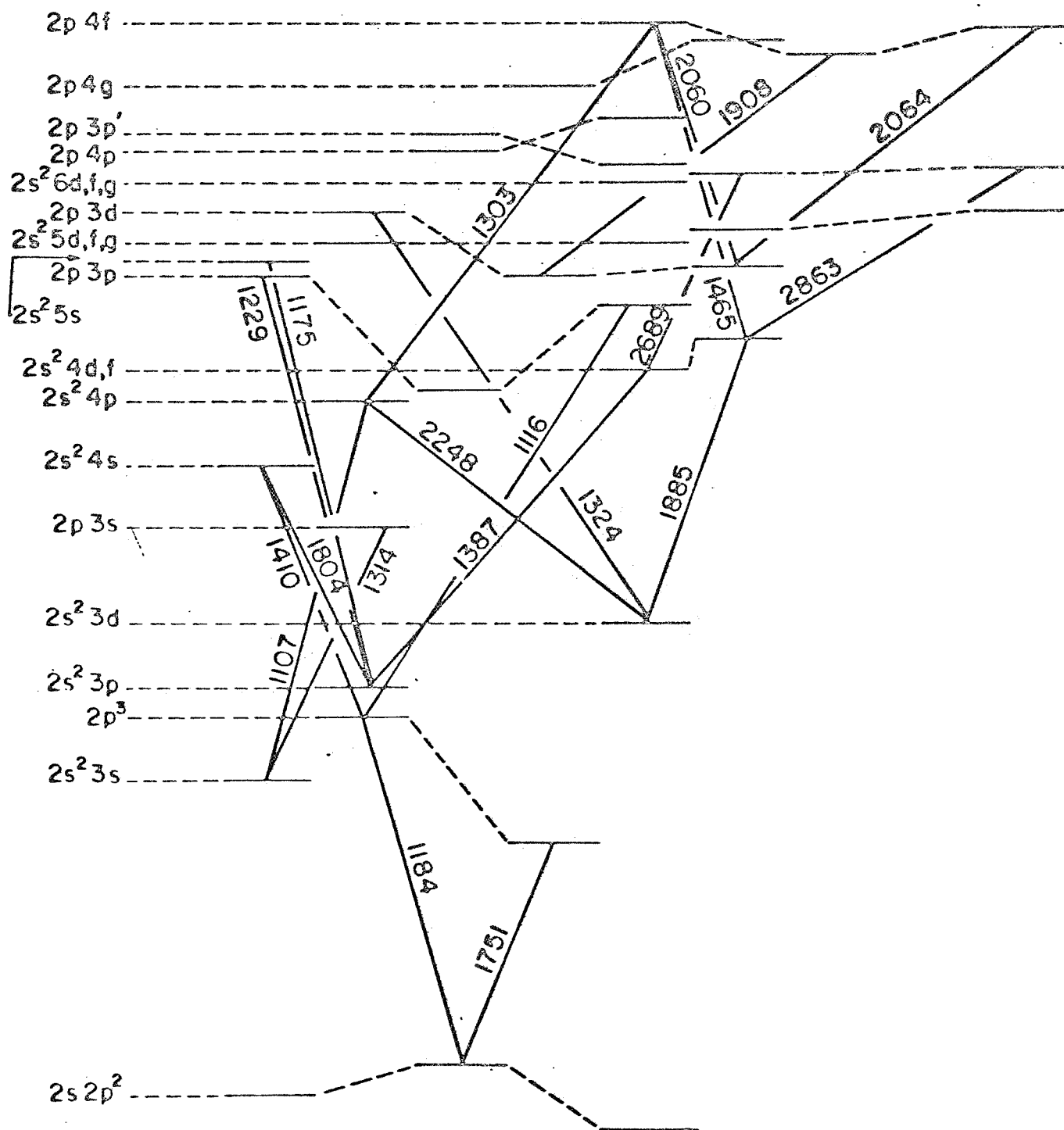
+

N_{14}





2S $^2P^0$ 2P $^2D^0$ 2D $^2F^0$ 2F $^2G^0$ 2G



~~~~~  
~~~~~  
—— $2s^2 2p$ g. s.

