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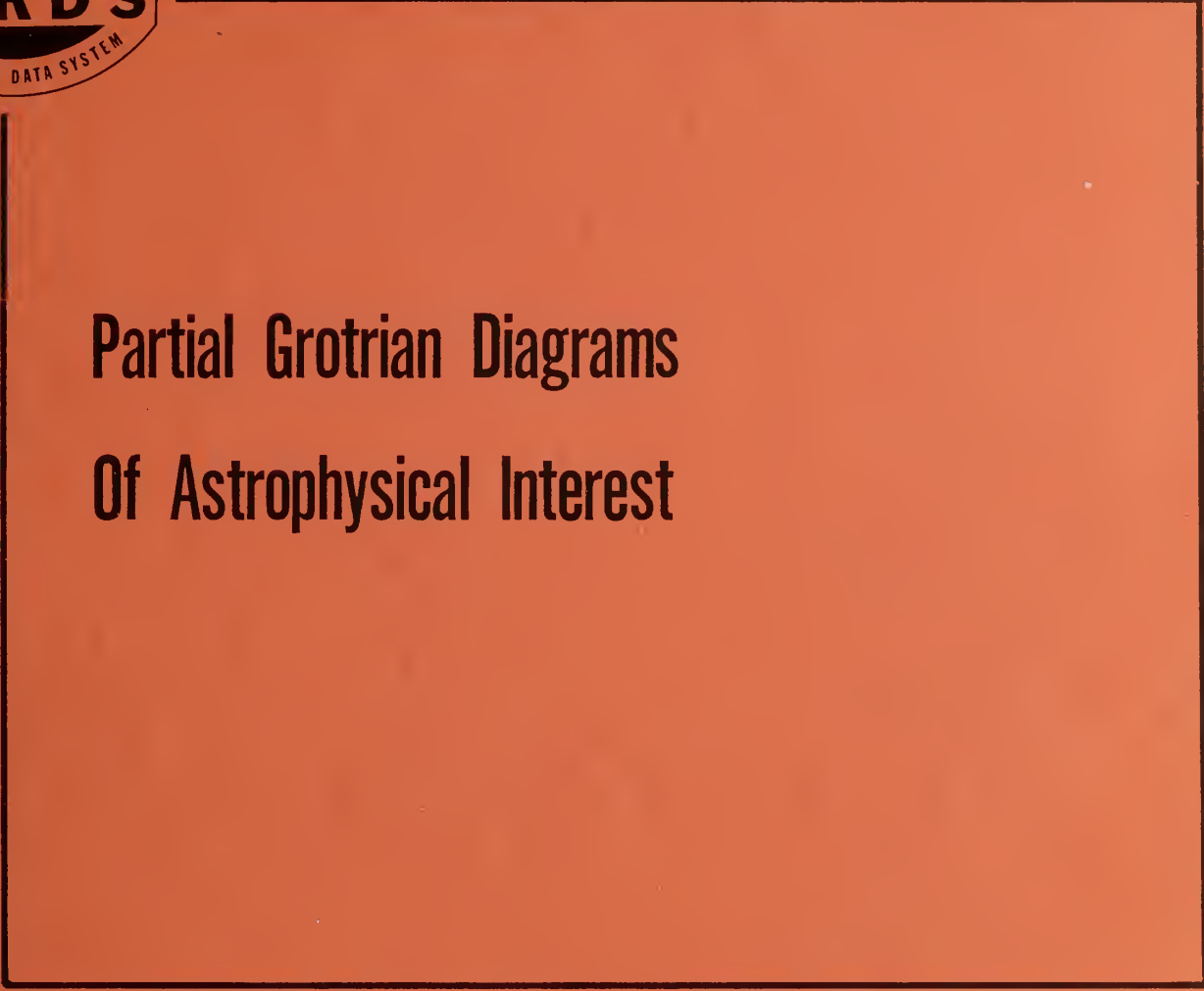
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Partial Grotrian Diagrams of Astrophysical Interest

Charlotte E. Moore

Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

and

Paul W. Merrill

Mount Wilson and Palomar Observatories

A Reprint of Appendix A from
"Lines of the Chemical Elements in Astronomical Spectra"
by Paul W. Merrill
Carnegie Institution of Washington Publication 610, 1956



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Abstract

This publication is a reprint of Appendix A of the book by Paul W. Merrill entitled, "Lines of the Chemical Elements in Astronomical Spectra" (Carnegie Inst. Wash. Publ. 610, 1956). It contains partial Grotrian Diagrams of selected spectra of astrophysical interest, which give wavelengths, multiplet numbers and key letters for the transitions shown. The diagrams are accompanied by tabular keys in which the key letters indicate related lines in spectra similar in structure to those illustrated in the diagrams. There are 39 diagrams of spectra between hydrogen and nickel and tabular keys for 90 spectra between lithium and rhenium.

Key Words: Atomic spectra, partial Grotrian diagrams; Grotrian diagrams.

Library of Congress Catalog Card Number: 68-60070

Foreword

The National Standard Reference Data System is a Government-wide effort to provide for the technical community of the United States effective access to the quantitative data of physical science, critically evaluated and compiled for convenience, and readily accessible through a variety of distribution channels. The System was established in 1963 by action of the President's Office of Science and Technology and the Federal Council for Science and Technology.

The responsibility to administer the System was assigned to the National Bureau of Standards and an Office of Standard Reference Data was set up at the Bureau for this purpose. Since 1963, this Office has developed systematic plans for meeting high-priority needs for reliable reference data. It has undertaken to coordinate and integrate existing data evaluation and compilation activities (primarily those under sponsorship of Federal agencies) into a comprehensive program, supplementing and expanding technical coverage when necessary, establishing and maintaining standards for the output of the participating groups, and providing mechanisms for the dissemination of the output as required.

The System now comprises a complex of data centers and other activities, carried on in Government agencies, academic institutions, and non-governmental laboratories. The independent operational status of existing critical data projects is maintained and encouraged. Data centers that are components of the NSRDS produce compilations of critically evaluated data, critical reviews of the state of quantitative knowledge in specialized areas, and computations of useful functions derived from standard reference data. In addition, the centers and projects establish criteria for evaluation and compilation of data and make recommendations on needed modifications or extensions of experimental techniques.

Data publications of the NSRDS take a variety of physical forms, including books, pamphlets, loose-leaf sheets and computer tapes. While most of the compilations have been issued by the Government Printing Office, several have appeared in scientific journals. Under some circumstances, private publishing houses are regarded as appropriate primary dissemination mechanisms.

The technical scope of the NSRDS is indicated by the principal categories of data compilation projects now active or being planned: nuclear properties, atomic and molecular properties, solid state properties, thermodynamic and transport properties, chemical kinetics, colloid and surface properties, and mechanical properties.

An important aspect of the NSRDS is the advice and planning assistance which the National Research Council of the National Academy of Sciences-National Academy of Engineering provides. These services are organized under an overall Review Committee which considers the program as a whole and makes recommendations on policy, long-term planning, and international collaboration. Advisory Panels, each concerned with a single technical area, meet regularly to examine major portions of the program, assign relative priorities, and identify specific key problems in need of further attention. For selected specific topics, the Advisory Panels sponsor

subpanels which make detailed studies of users' needs, the present state of knowledge, and existing data resources as a basis for recommending one or more data compilation activities. This assembly of advisory services contributes greatly to the guidance of NSRDS activities.

The NSRDS-NBS series of publications is intended primarily to include evaluated reference data and critical reviews of long-term interest to the scientific and technical community.

A. V. Astin, Director.

Preface

When the late Paul W. Merrill was planning his publication on "Lines of the Chemical Elements in Astronomical Spectra," he requested the present author (CEM) to prepare a set of selected Partial Grotrian Diagrams for inclusion as Appendix A.

In response to similar, more recent requests for Grotrian Diagrams, and in order to make them more generally available, Appendix A is being reprinted here by permission of the Director of Publications, Carnegie Institution of Washington. To facilitate the use of the material, a descriptive column is included in the index. The spectra for which partial diagrams have been made are indicated by "D". The related spectra whose leading lines are included in the tabular keys to the diagrams, are noted by "K".

In the original publication, Appendix A comprises pages 103 to 165. In the present publication the corresponding pages run from 3 to 65.

Charlotte E. Moore

Washington, D. C.
February 21, 1968.

Index to Diagrams

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3	Li I	D	8	12	Mg I	D	16	
		K	9			K	17	
4	Be I	K	15		Mg II	D	10	
		D	8			K	11	
		K	9			K	33	
5	B I	K	21	13	Al I	K	23	
						Al II	K	17
6	C I	K	25	14	Si I	D	26	
		D	20			K	27	
	K	21	Si II			D	22	
	D	14				K	23	
	K	15	Si III			K	17	
	D	8				Si IV	K	11
K	9							
7	N I	K	29	15	P I	K	31	
		D	24			P II	K	27
	K	25	16	S I	D	34		
	K	21			K	35		
	K	15			S II	D	30	
	K	9				K	31	
8	O I	D	32	17	S III	K	27	
		K	33			Cl II	K	35
	D	28	Cl III				K	31
	K	29				Cl IV	K	27
	D	24	18			A I	D	39
	K	25					A II	D	36
K	21	K		37				
K	15	A III		K	35			
K	9		A IV	K	31			
10	Ne I	D	38	A V	K	27		
		K	37					
		K	33					
		K	29					
		K	25					

* D—Diagram
K—Tabular Key

Index to Diagrams—continued

Z	Sp	Descr.*	Page	Z	Sp	Descr.*	Page
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		K	13			Rb I	K
	K IV	K	35		38		Sr I
K v	K	31	Sr II	K		13	
20	Ca I	D	18	39	Y I	K	43
	Ca II	K	19		Y II	K	41
		Ca II	D	12	40	Zr I	K
	Ca v	K	13	Zr II		K	45
21	Sc I	K	35	41	Nb I	K	51
		D	42		Nb III	K	49
	Sc II	D	40	42	Mo I	K	55
	K	41	Mo II		K	53	
22	Ti I	D	46	43	Tc I	K	59
	Ti II	K	47		Tc II	K	57
		Ti II	D	44	49	In I	K
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23	V I	D		50	56	Ba I	K
	V II	K	51	Ba II		K	13
		V II	D	48	57	La I	K
	K	49	La II	K		41	
24	Cr I	D	54	72	Hf II	K	45
	Cr II	K	55		74	W I	K	55
		Cr II	D	52		75	Re I	K	59
	K	53	Re II	K	57		
25	Mn I	D	58	26	Fe I	D	62
	Mn II	K	59		Fe II	D	61
		Mn II	D		56	Fe III	D	60
	K	57	27	Co I	D	63	
26	Fe I	D		62	28	Ni I	D	65
	Fe II	D	61	Ni I		D	64
	Fe III	D	60				

APPENDIX A

PARTIAL GROTRIAN DIAGRAMS OF ASTROPHYSICAL INTEREST

Charlotte E. Moore * and Paul W. Merrill

Introduction

Grotrian diagrams. Many years ago W. Grotrian devised a graphical representation of the relations of characteristic spectrum lines to the quantum energy levels of various atoms and ions, and gave many examples for atoms and ions with one, two, and three valence electrons. These "Grotrian diagrams" (ZZ17, 18, 20) have been of great value to astronomers as well as to physicists. A few excellent diagrams of carbon, nitrogen, and oxygen ions were prepared by B. Edlén in connection with his important laboratory work in the far ultraviolet (ZZ51). Some simplified diagrams of low-excitation lines will be found in a useful recent French monograph on flame spectra (ZZ1).

A new collection of partial diagrams of many of the lighter elements has been prepared especially for this monograph. The purpose of the Grotrian diagrams in this appendix is to exhibit, for various elements, the atomic transitions responsible for the chief lines observed in astronomical spectra. We must emphasize the astronomical bias of the diagrams and the fact that they do not, by any means, include all transitions which the atoms actually perform. It is not feasible to indicate all the multiplets, to say nothing of all the lines; it has even been necessary to omit many of the known spectroscopic terms. Hence, as representations of actual atomic structure and behavior, the diagrams of many elements are oversimplified and woe-

fully incomplete. We have tried, however, to retain enough of the important features to display the main quantum organization, especially of the lower terms.

Multiplets are represented by straight lines: the line is solid for transitions between terms of the same multiplicity, dashed for transitions between terms of different multiplicity (intersystem multiplets), and dot-dashed for transitions whose upper terms are metastable (forbidden transitions between terms of the same parity).

The wave lengths in angstroms of one or more of the strongest lines in each multiplet are given; the accompanying figure in parentheses indicates the multiplet number either (1) in the Revised Multiplet Table (A Multiplet Table of Astrophysical Interest, Revised Edition, Contributions from the Princeton University Observatory No. 20, 1945) or (2) if accompanied by the letters UV, in An Ultraviolet Multiplet Table (Circular of the National Bureau of Standards 488, 1950).

Tabular keys to Grotrian diagrams. To list important corresponding lines in spectra of various elements, and thus to make a diagram serve for more than one element, we include a number of tables showing in parallel columns analogous lines of two or more related spectra. These tables are of two kinds: they may list (1) isoelectronic sequences such as Na I, Mg II, Al III, Si IV, or (2) corresponding spectra in successive periods of the Periodic Table such as Li I, Na I, K I, Rb I, Cs I. Wave lengths greater than 2000A are IA values in air; those less than 2000A are values in vacuum.

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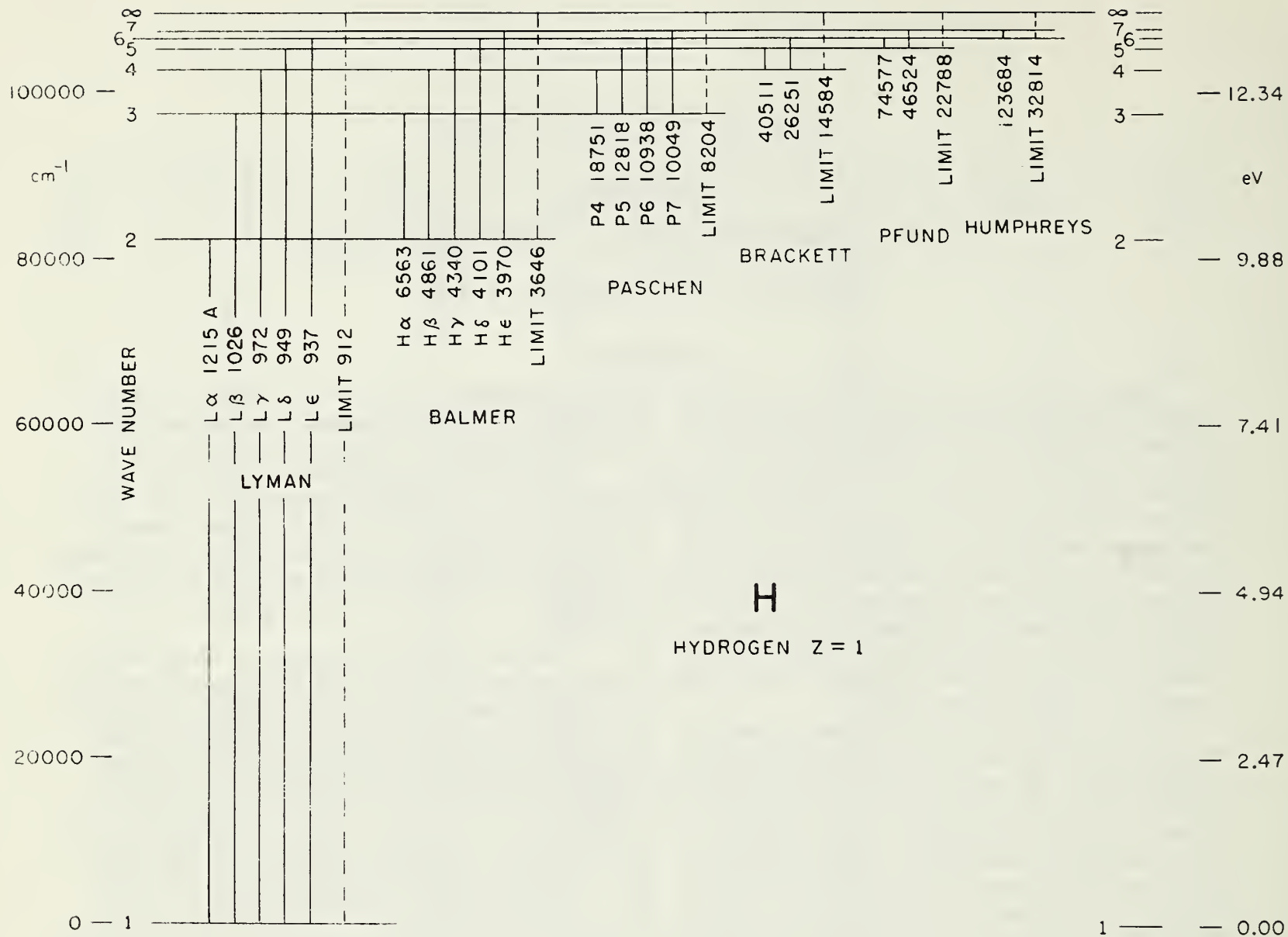
ZZ1 L'Analyse spectrale quantitative par la flamme. R. Mavrodineanu and H. Boiteux. Masson et Cie, Paris, 1954.

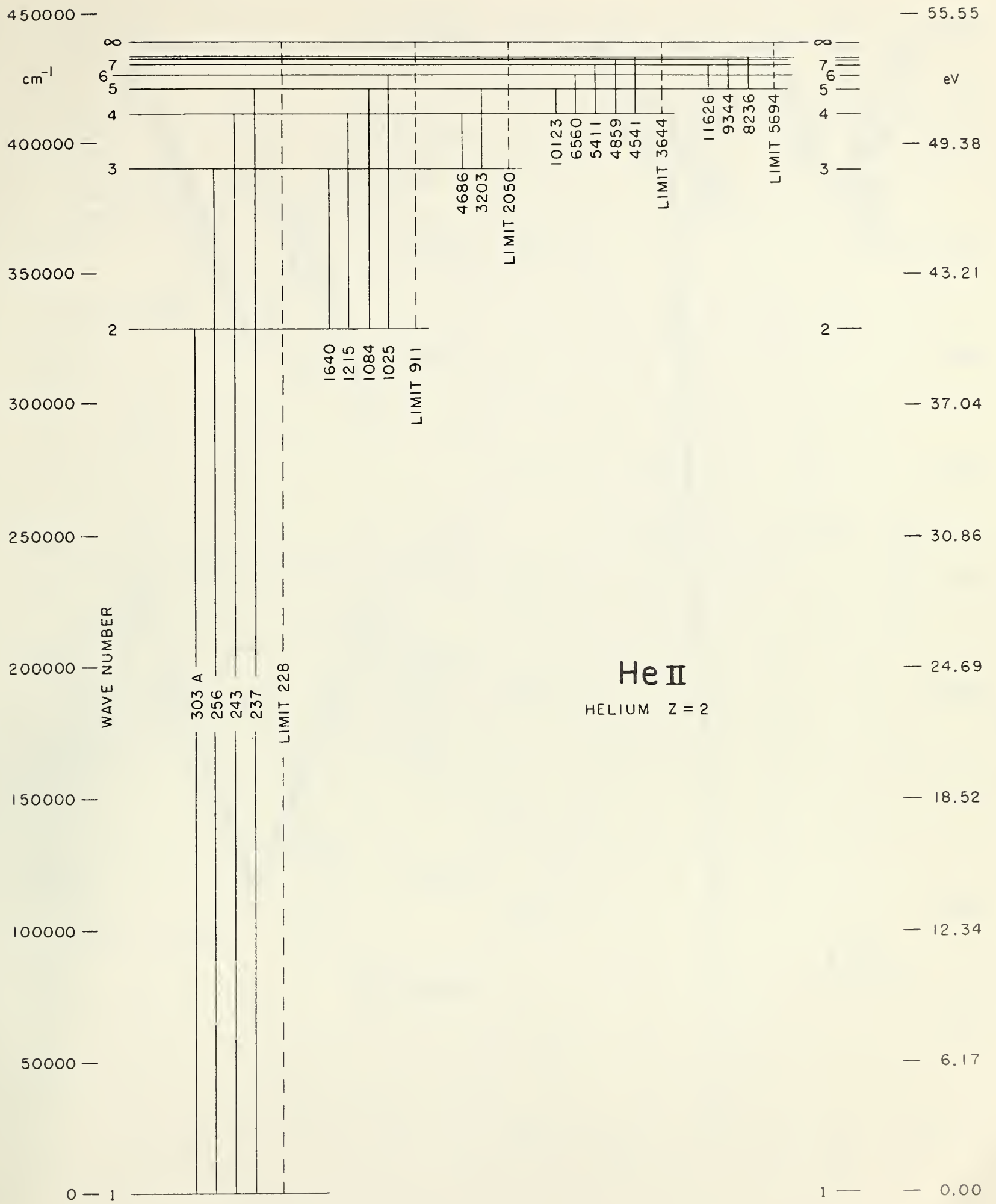
ZZ17 Graphische Darstellung der Spektren von Atomen und Ionen mit ein, zwei und drei Valenzelektronen. Volume II. W. Grotrian. Julius Springer, Berlin, 1928. Handbuch der Astrophysik. Julius Springer, Berlin.

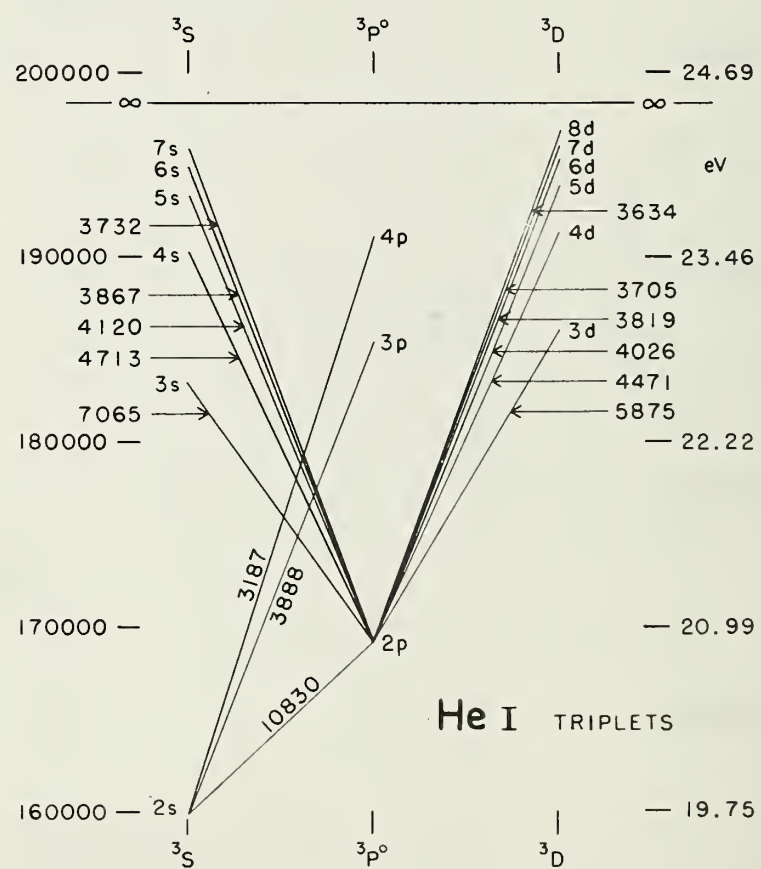
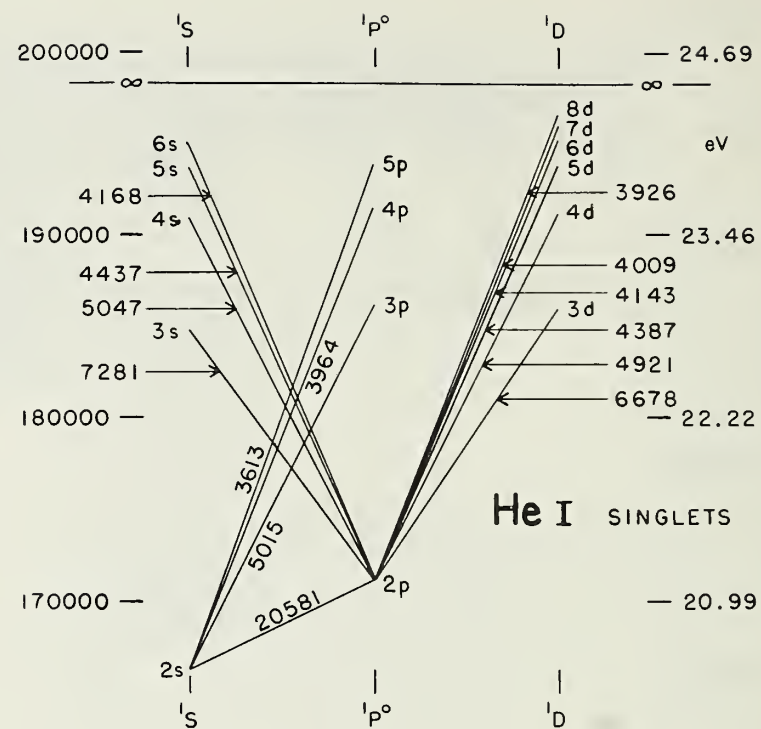
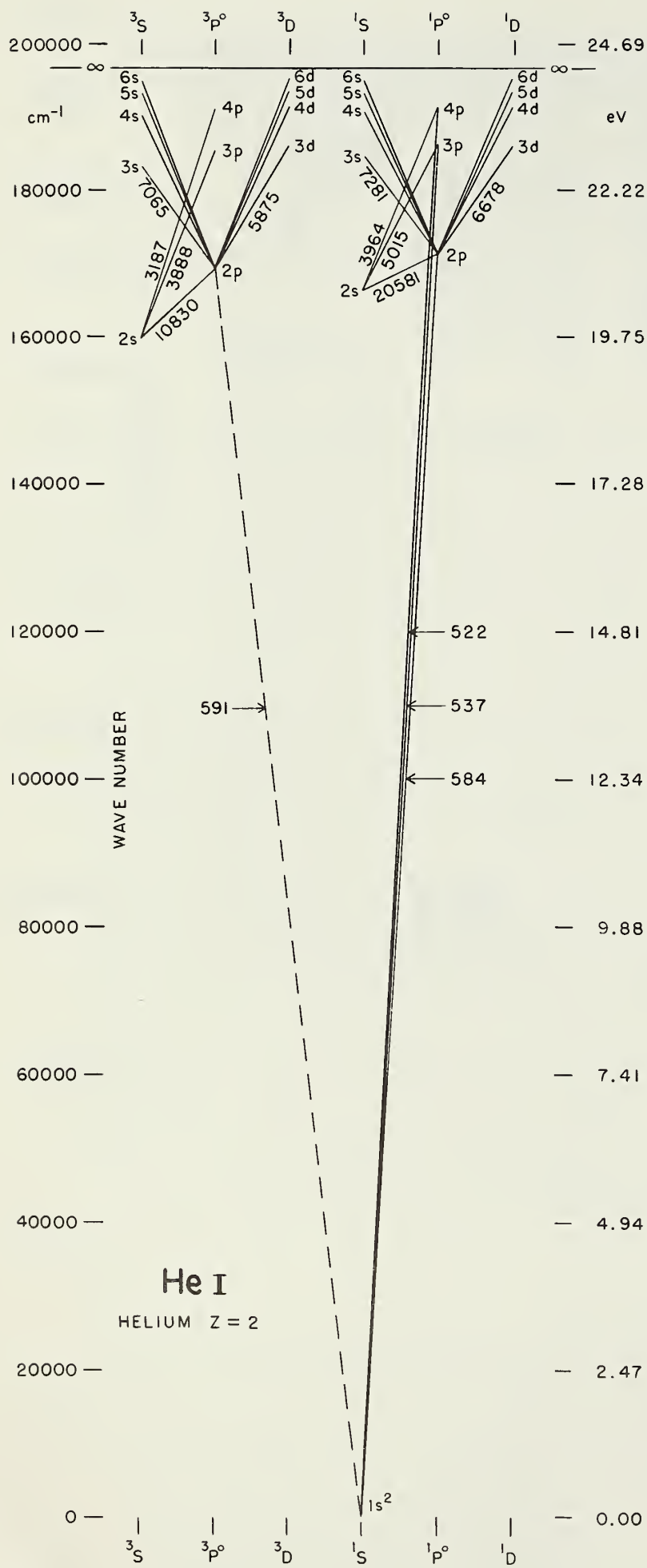
ZZ18 W. Grotrian. Gesetzmässigkeiten in den Serienspektren. Volume 3, part 2, page 475, 1930.

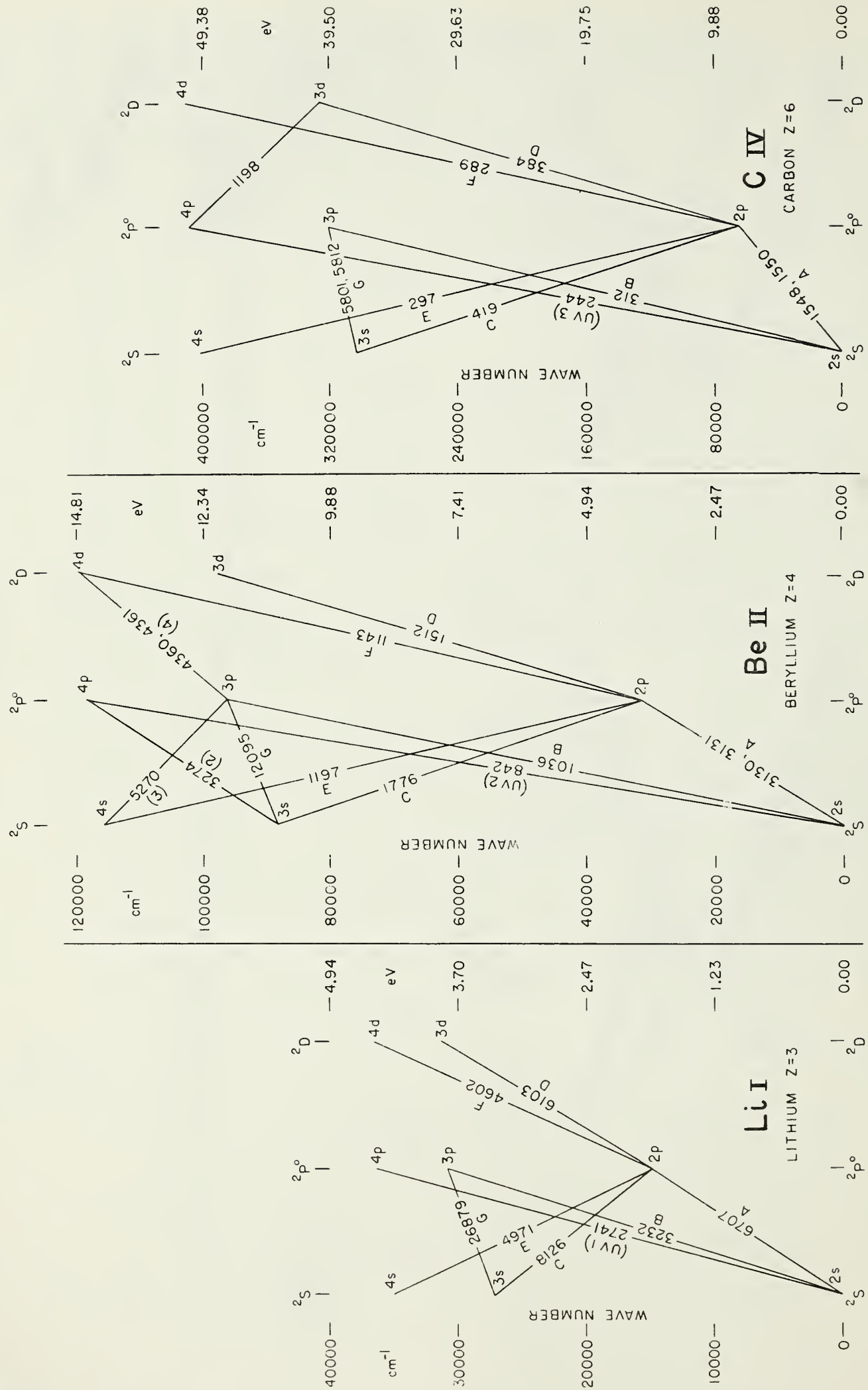
ZZ20 W. Grotrian. Gesetzmässigkeiten in den Serienspektren. Volume 7, page 250, 1936.

ZZ51 Wellenlängen und Termsysteme zu den Atom-spektren der Elemente Lithium, Beryllium, Bor, Kohlenstoff, Stickstoff und Sauerstoff. Bengt Edlén. Nova Acta Regiae Societatis Scientiarum Upsaliensis, series IV, volume 9, no. 6, 1934.





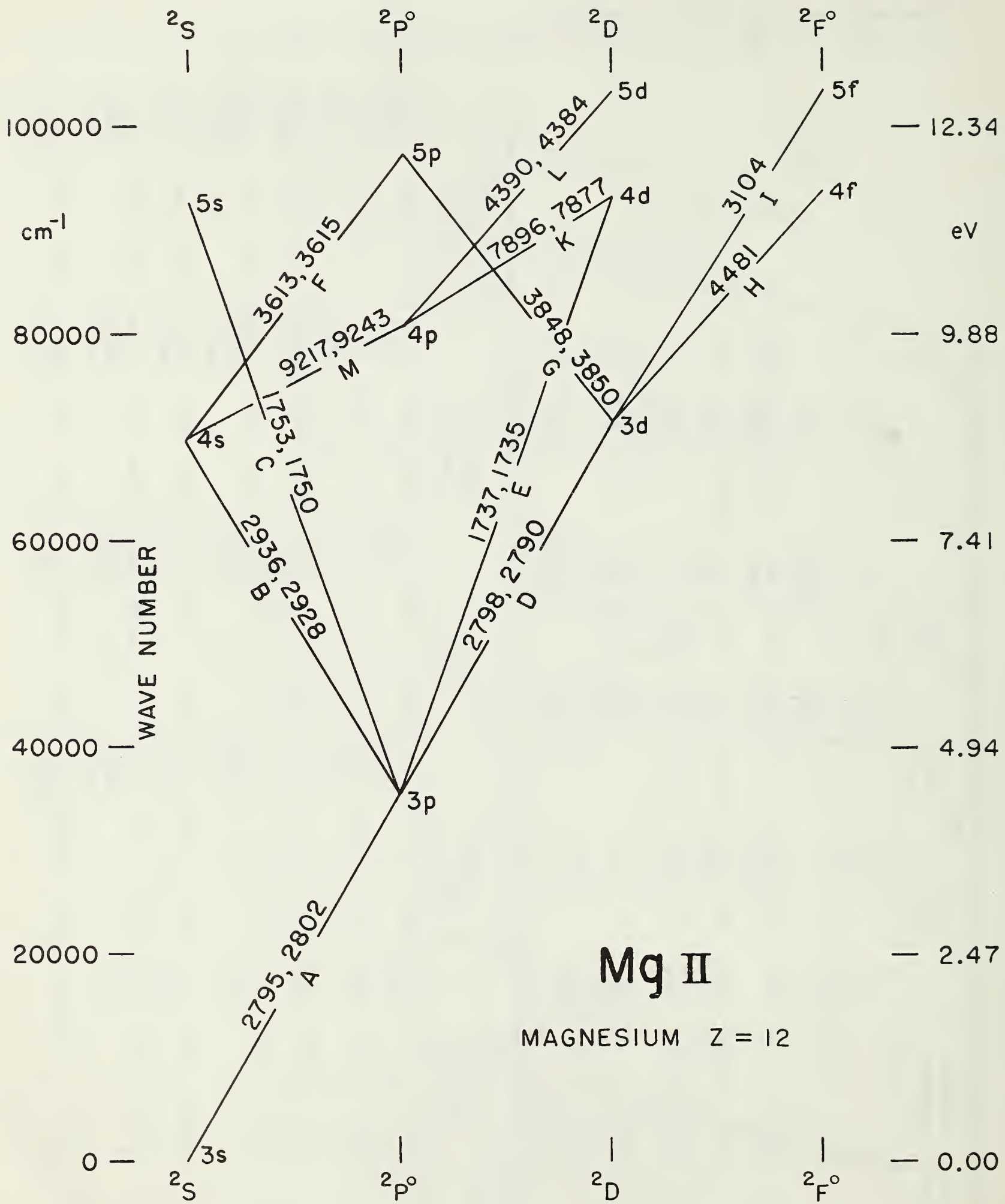




APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

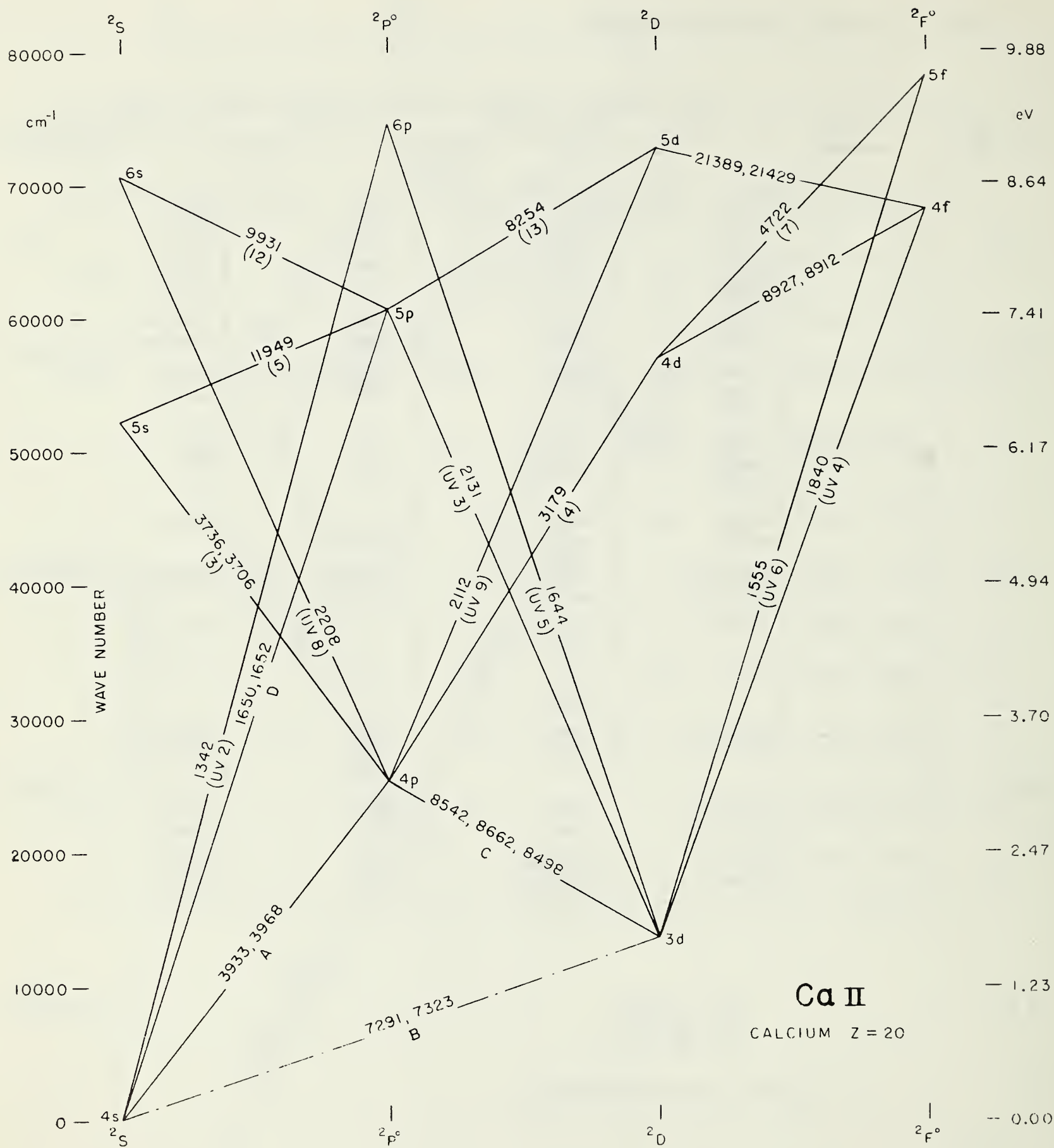
Key letter	Multiplet designation	Li I		Be II		C IV		N V		O VI	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2s^2S - 2p^2P^\circ$	6707.8 6707.9	(1)	3130.4 3131.1	(1)	1548.2 1550.8	(UV 1)	1238.8 1242.8	(UV 1)	1031.9 1037.6	(UV 1)
B	$2s^2S - 3p^2P^\circ$	3232.6	(2)	1036.3	(UV 1)	312.4 312.5	(UV 2)	209.3 209.3	(UV 2)	150.1 150.1	(UV 2)
C	$2p^2P^\circ - 3s^2S$	8126.5	(3)	1776.3 1776.1	(UV 3)	419.7 419.5	(UV 6)	266.4 266.2	(UV 4)	184.1 183.9	(UV 3)
D	$2p^2P^\circ - 3d^2D$	6103.6 6103.5	(4)	1512.5 1512.3	(UV 4)	384.2 384.0	(UV 7)	247.7 247.6	(UV 5)	173.1 172.9	(UV 4)
E	$2p^2P^\circ - 4s^2S$	4971.7 4971.7	(5)	1197.2	(UV 5)	297.0 296.9	(UV 8)	190.2 190.2	.....	132.3 132.2	.....
F	$2p^2P^\circ - 4d^2D$	4602.9 4602.8	(6)	1143.0	.....	289.2 289.1	(UV 9)	186.2 186.1	(UV 6)	129.9 129.8	(UV 5)
G	$3s^2S - 3p^2P^\circ$	26879 P	....	(12095 P)	.....	5801.5 5812.1	(1)	(4603.3P) (4619.1P)	(1)	3811.4 3834.2	(1)

Key letter	Li I		Na I		K I		Rb I		Cs I	
	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ
A	$2s^2S - 2p^2P^\circ$ (1)	6707.8 6707.9	$3s^2S - 3p^2P^\circ$ (1)	5890.0 5895.9	$4s^2S - 4p^2P^\circ$ (1)	7664.9 7699.0	$5s^2S - 5p^2P^\circ$ (1)	7800.2 7947.6	$6s^2S - 6p^2P^\circ$ (1)	8521.1 8943.5
B	$2s^2S - 3p^2P^\circ$ (2)	3232.6	$3s^2S - 4p^2P^\circ$ (2)	3302.3 3302.9	$4s^2S - 5p^2P^\circ$ (3)	4044.1 4047.2	$5s^2S - 6p^2P^\circ$ (2)	4201.9 4215.6	$6s^2S - 7p^2P^\circ$ (2)	4555.4 4593.2
C	$2p^2P^\circ - 3s^2S$ (3)	8126.5	$3p^2P^\circ - 4s^2S$ (3)	11403.6 11381.2	$4p^2P^\circ - 5s^2S$ (5)	12523.0 12434.3	$5p^2P^\circ - 6s^2S$	13663.0P 13233.3P	$6p^2P^\circ - 7s^2S$	14695.0 13588.2
D	$2p^2P^\circ - 3d^2D$ (4)	6103.6 6103.5	$3p^2P^\circ - 3d^2D$ (4)	8194.8 8183.3 8194.8	$4p^2P^\circ - 3d^2D$ (6)	11772.7 11689.8 11769.4	$5p^2P^\circ - 4d^2D$	15289.9P 14752.8P 15288.9P	$6p^2P^\circ - 5d^2D$	34897 P 30101 P 36128 P
E	$2p^2P^\circ - 4s^2S$ (5)	4971.7 4971.7	$3p^2P^\circ - 5s^2S$ (5)	6160.7 6154.2	$4p^2P^\circ - 6s^2S$	6939.0 6911.3	$5p^2P^\circ - 7s^2S$	7408.2P 7280.0P	$6p^2P^\circ - 8s^2S$	7943.9 7608.9
F	$2p^2P^\circ - 4d^2D$ (6)	4602.9 4602.8	$3p^2P^\circ - 4d^2D$ (6)	5688.2 5682.6 5688.2	$4p^2P^\circ - 4d^2D$ (7)	6964.7 6936.3 6964.2	$5p^2P^\circ - 5d^2D$	7757.6P 7618.9P 7759.4P	$6p^2P^\circ - 6d^2D$	9172.2 8761.4 9208.5
G	$3s^2S - 3p^2P^\circ$	26879 P	$4s^2S - 4p^2P^\circ$	22056 P 22083 P	$5s^2S - 5p^2P^\circ$	27068 P 27206 P	$6s^2S - 6p^2P^\circ$	27321 P 27913 P	$7s^2S - 7p^2P^\circ$	29307 P 30950 P



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

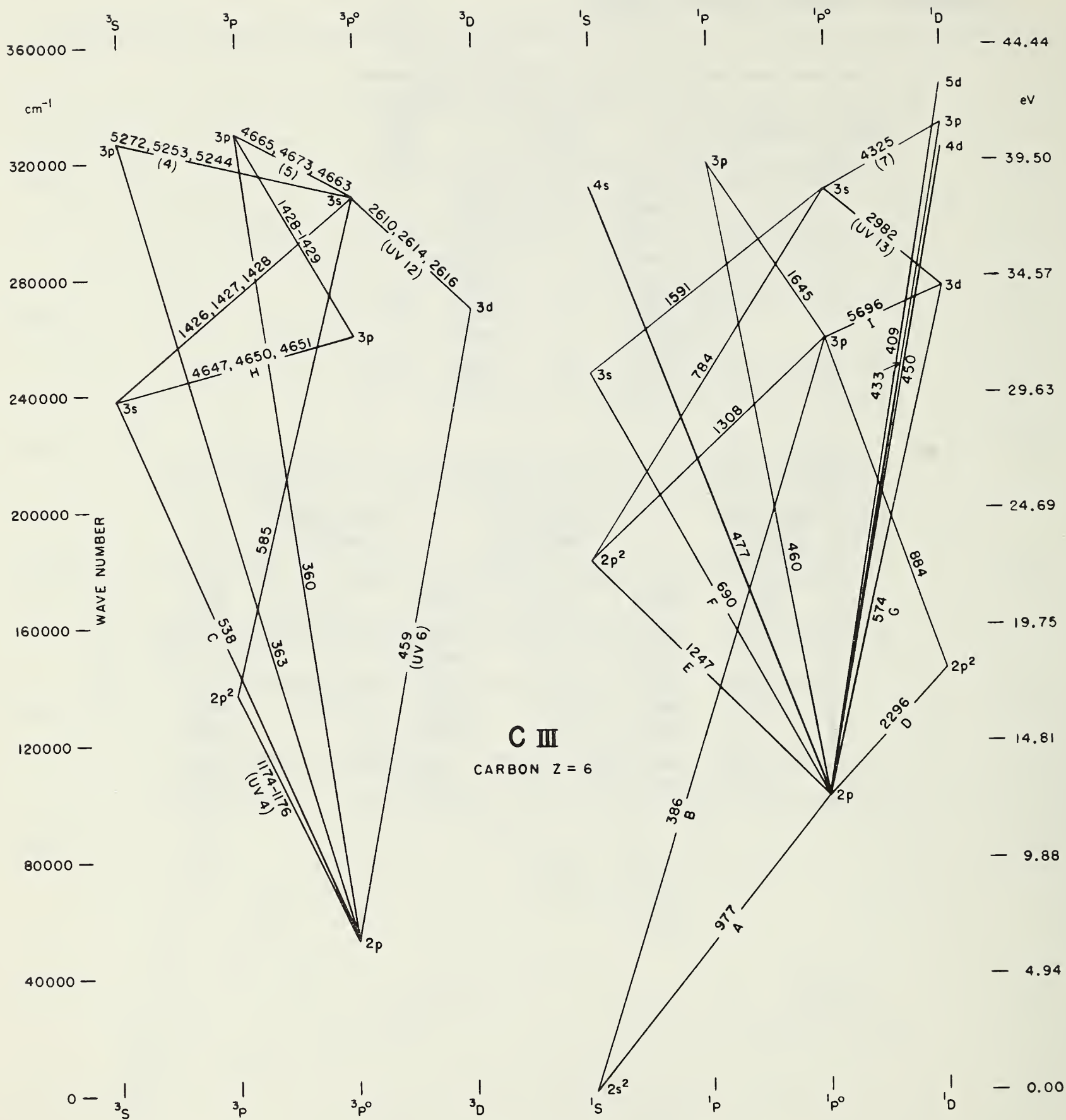
Key letter	Multiplet designation	Na I		Mg II		Al III		Si IV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$3s^2S - 3p^2P^\circ$	5890.0 5895.9	(1)	2795.5 2802.7	(UV 1)	1854.7 1862.8	(UV 1)	1393.7 1402.7	(UV 1)
B	$3p^2P^\circ - 4s^2S$	11403.6 11381.2	(3)	2936.5 2928.6	(UV 2)	1384.1 1379.7	.....	818.1 815.1	(UV 4)
C	$3p^2P^\circ - 5s^2S$	6160.7 6154.2	(5)	1753.6 1750.9	.....	856.8 855.0	.....	(516.3P) (517.8P)	.....
D	$3p^2P^\circ - 3d^2D$	8194.8 8183.3 8194.8	(4)	2798.0 2790.8	(UV 3)	1611.8 1605.8	.....	1128.3 1122.5	(UV 3)
E	$3p^2P^\circ - 4d^2D$	5688.2 5682.6 5688.2	(6)	1737.8 1735.0	.....	893.9 892.1	.....	561.1	.....
F	$4s^2S - 5p^2P^\circ$	10745.9 10748.7	(18)	3613.8 3615.6	(2)	(1911.8P) (1913.2P)	.....	1210.5	.....
G	$3d^2D - 5p^2P^\circ$	(17031.3P) (17038.7P)	.....	3848.2 3850.4	(5)	(1599.6P) (1600.7P)	.....	(860.5P)	.....
H	$3d^2D - 4f^2F^\circ$	18459.7P	.....	4481.1 4481.3	(4)	1935.8	.....	1066.6	.....
I	$3d^2D - 5f^2F^\circ$	12679.0	(21)	3104.7 3104.8	(6)	1352.9	.....	749.7	.....
K	$4p^2P^\circ - 4d^2D$	23378.4P 23347.5P	.....	7896.4 7877.1	(8)	4529.2 4512.5 4528.9	(3)	3165.7 3149.6	.....
L	$4p^2P^\circ - 5d^2D$	(14779.5P) (14767.1P)	.....	4390.6 4384.6	(10)	2213.6 2209.7	.....	1365.0 1369.1	.....
M	$4s^2S - 4p^2P^\circ$	22056 P 22084 P	.....	(9217.3P) (9243.4P)	(1)	5696.5 5722.6	(2)	4088.9 4116.1	(1)



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

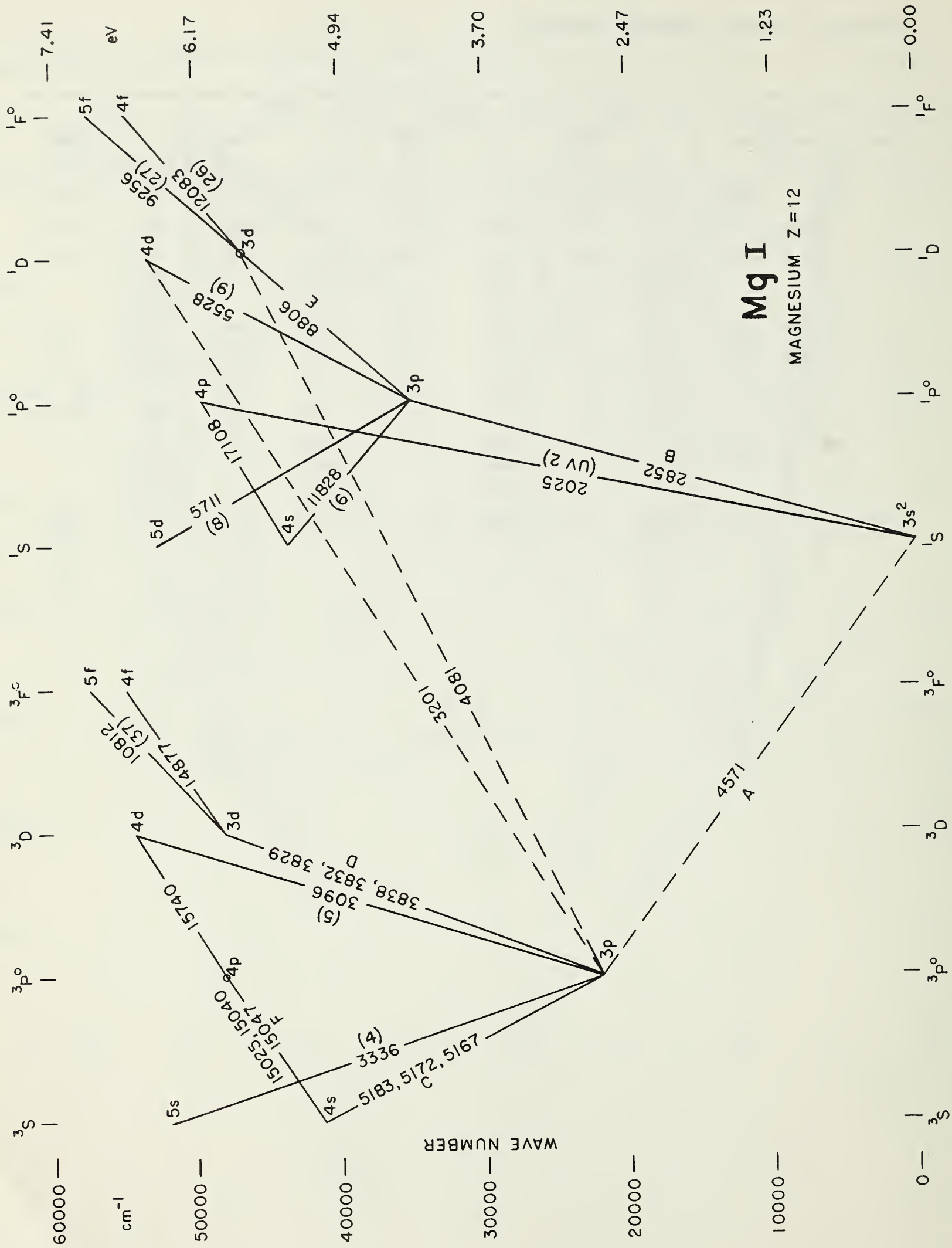
Key letter	Multiplet designation	KI		Ca II	
		λ	Mult. no.	λ	Mult. no.
A	$4s^2S - 4p^2P^\circ$	7664.9 7699.0	(1)	3933.7 3968.5	(1)
B	$4s^2S - 3d^2D$	4642.4P 4641.9P	.....	7291.5P 7323.9P	(1F)
C	$3d^2D - 4p^2P^\circ$	-11772.7 -11689.8 -11769.4	(6)	8542.1 8662.1 8498.0	(2)
D	$4s^2S - 5p^2P^\circ$	4044.1 4047.2	(3)	1650.0 1652.0	(UV 1)

Key letter	Ca II		Sr II		Ba II	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	$4s^2S - 4p^2P^\circ$ (1)	3933.7 3968.5	$5s^2S - 5p^2P^\circ$ (1)	4077.7 4215.5	$6s^2S - 6p^2P^\circ$ (1)	4554.0 4934.1
B	$4s^2S - 3d^2D$ (1F)	7291.5P 7323.9P	$5s^2S - 4d^2D$ (1F)	(6738.4P) (6868.2P)	$6s^2S - 5d^2D$ (17616.8P) (20511.9P)	
C	$3d^2D - 4p^2P^\circ$ (2)	8542.1 8662.1 8498.0	$4d^2D - 5p^2P^\circ$ (2)	10327.3 10914.9 10036.7	$5d^2D - 6p^2P^\circ$ (2)	6141.7 6496.9 5853.7
D	$4s^2S - 5p^2P^\circ$ (UV 1)	1650.0 1652.0	$5s^2S - 6p^2P^\circ$ (UV 1)	1784.0 1793.1	$6s^2S - 7p^2P^\circ$	1999.4 2024.0



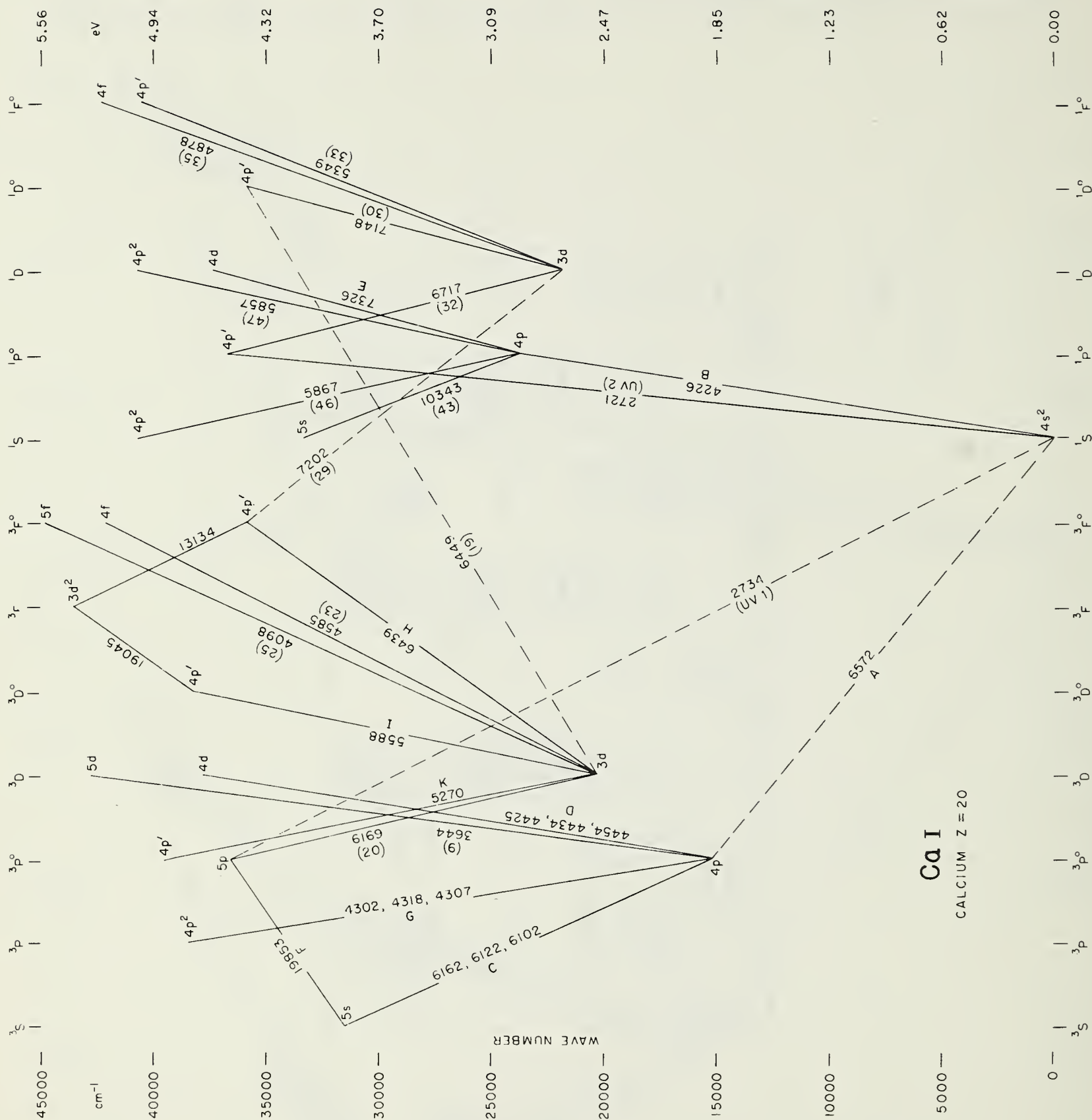
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	Be I		C III		NIV		OV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2s^2 1S - 2p^1 1P^\circ$	2348.6	(UV 1)	977.0	(UV 1)	765.1	(UV 1)	629.7	(UV 1)
B	$2s^2 1S - 3p^1 1P^\circ$	————	————	386.2	(UV 2)	247.2	(UV 2)	172.2	(UV 2)
C	$2p^3 3P^\circ - 3s^3 3S$	3321.3	(1)	538.3	(UV 5)	322.7	(UV 4)	215.2	(UV 4)
		3321.1		538.2		322.6		215.1	
		3321.0		538.1		322.5		215.0	
D	$2p^1 1P^\circ - 2p^2 1D$	7209.3	.....	2296.9	(UV 3)	1718.5	(UV 7)	1371.3	(UV 7)
E	$2p^1 1P^\circ - 2p^2 1S$	3455.2	.....	1247.4	.....	955.3	(UV 8)	774.5	(UV 8)
F	$2p^1 1P^\circ - 3s^1 1S$	8254.1	(2)	690.5	(UV 10)	387.4	(UV 9)	248.5	(UV 9)
G	$2p^1 1P^\circ - 3d^1 1D$	4572.7	(3)	574.3	(UV 11)	335.0	(UV 10)	220.4	(UV 10)
H	$3s^3 3S - 3p^3 3P^\circ$	14904.3	.....	4647.4	(1)	3478.7	(1)	2781.0	.....
				4650.2		3483.0		2787.0	
				4651.4		3484.9		2789.9	
I	$3p^1 1P^\circ - 3d^1 1D$	————	————	5696.0	(2)	4057.8	(3)	3144.7	(2)



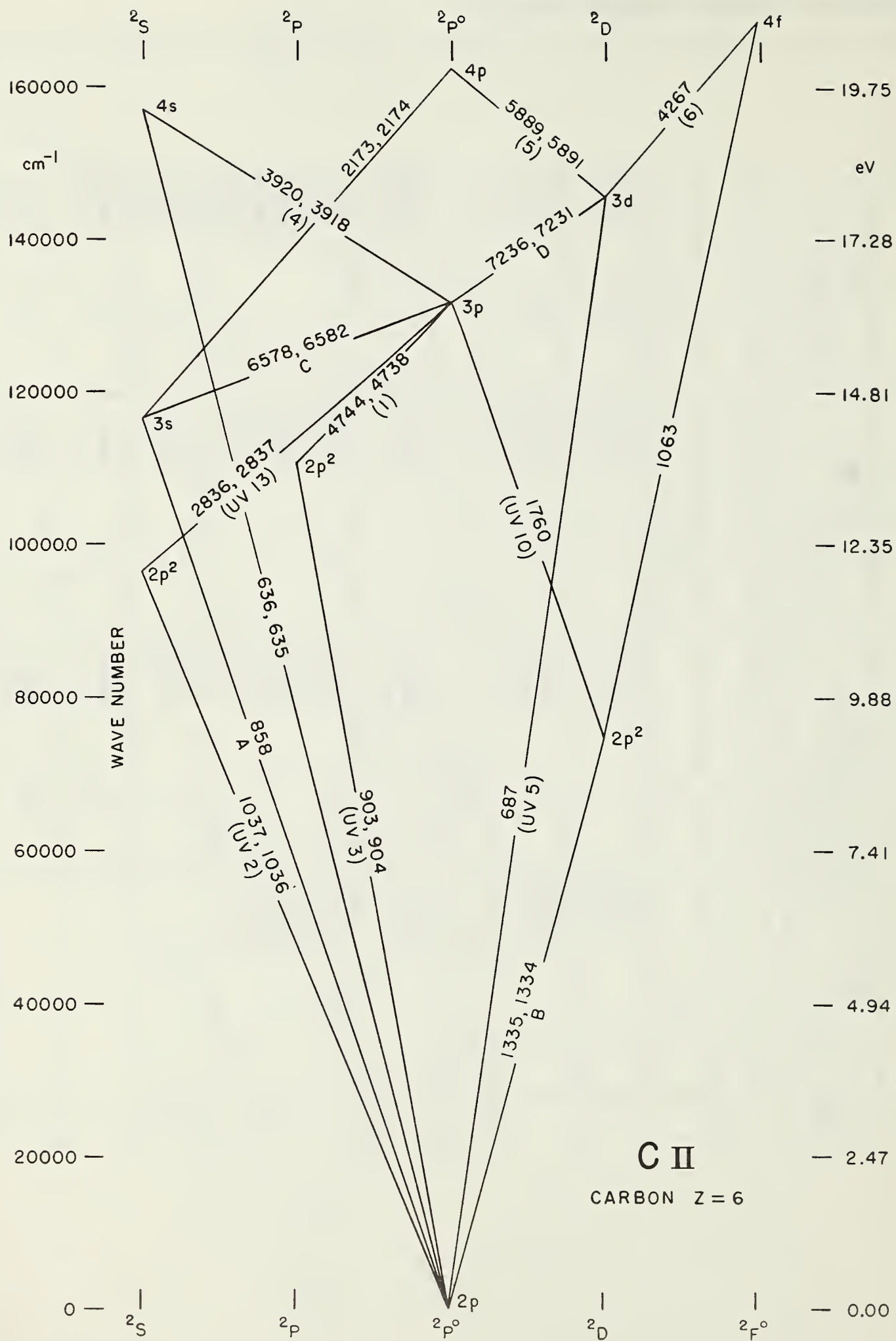
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	Mg I		Al II		Si III	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$3s^2 1S - 3p^3 P^{\circ}$	4571.1	(1)	2669.2	(UV 1)	1895.5	(UV 1)
B	$3s^2 1S - 3p^1 P^{\circ}$	2852.1	(UV 1)	1670.8	(UV 2)	1206.5	(UV 2)
C	$3p^3 P^{\circ} - 4s^3 S$	5183.6	(2)	1862.3	(UV 4)	997.4	(UV 6)
		5172.7		1858.0		994.8	
		5167.3		1856.0		993.5	
D	$3p^3 P^{\circ} - 3d^3 D$	3838.3	(3)	1725.0	(UV 6)	1113.2	(UV 5)
		3832.3		1721.3		1110.0	
		3829.4		1719.5		1108.4	
E	$3p^1 P^{\circ} - 3d^1 D$	8806.8	(7)	3900.7	(1)	2541.8	(UV 8)
		15025.0	.....	7042.1	(3)	4552.7	(2)
F	$4s^3 S - 4p^3 P^{\circ}$	15040.1		7056.6		4567.9	
		15047.4		7063.6		4574.8	



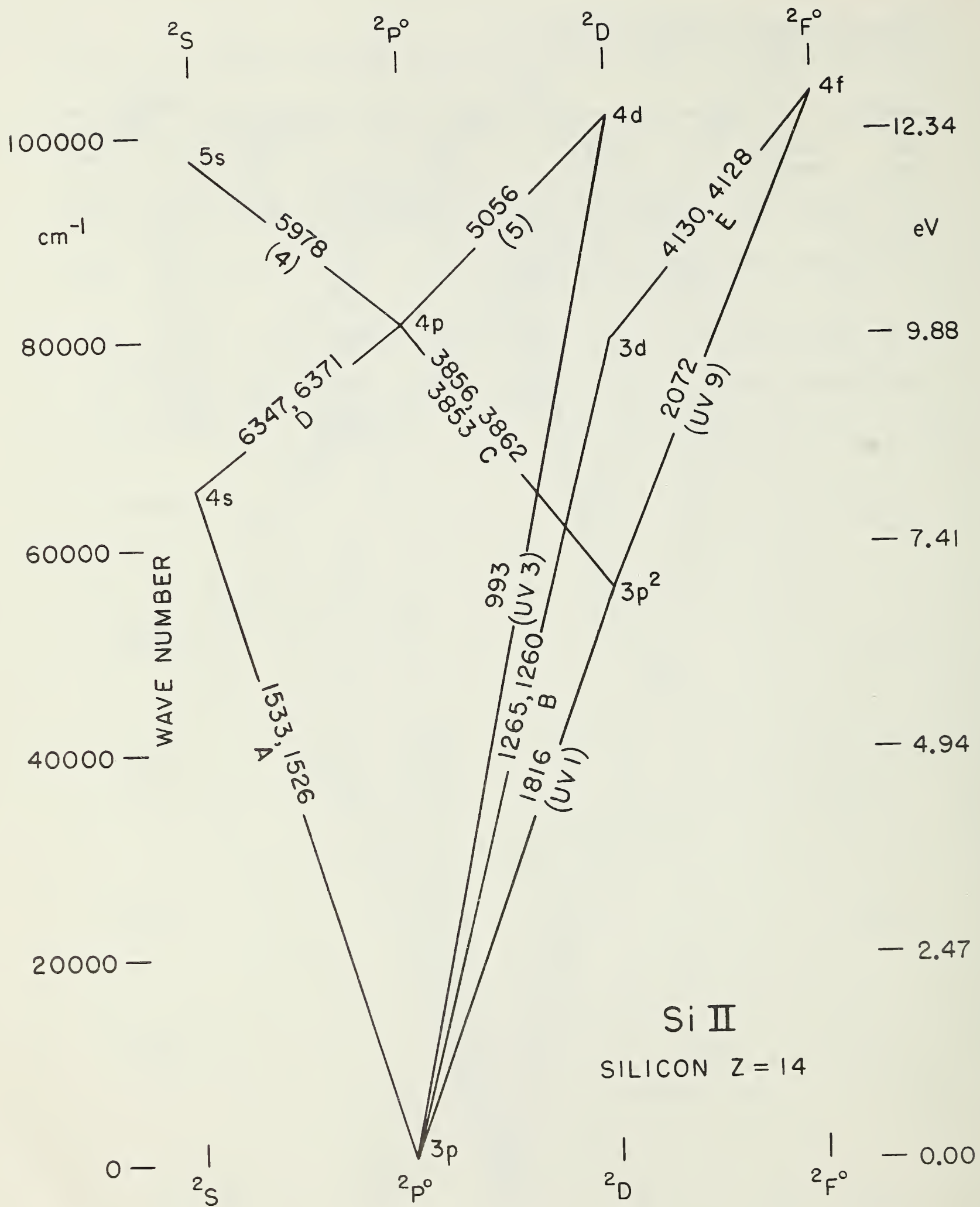
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Mg I		Ca I		Sr I		Ba I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	$3s^2 1S - 3p^3 3P^\circ$ (1)	4571.1	$4s^2 1S - 4p^3 3P^\circ$ (1)	6572.8	$5s^2 1S - 5p^3 3P^\circ$ (1)	6592.6	$6s^2 1S - 6p^3 3P^\circ$ (1)	7911.3
B	$3s^2 1S - 3p^1 1P^\circ$ (UV 1)	2852.1	$4s^2 1S - 4p^1 1P^\circ$ (2)	4226.7	$5s^2 1S - 5p^1 1P^\circ$ (2)	4607.3	$6s^2 1S - 6p^1 1P^\circ$ (2)	5535.5
C	$3p^3 3P^\circ - 4s^3 3S$ (2)	5183.6 5172.7 5167.3	$4p^3 3P^\circ - 5s^3 3S$ (3)	6162.2 6122.2 6102.7	$5p^3 3P^\circ - 6s^3 3S$ (3)	7070.1 6878.3 6791.0	$6p^3 3P^\circ - 7s^3 3S$ (10)	7905.8 7392.4 7195.2
D	$3p^3 3P^\circ - 3d^3 3D$ (3)	3838.3 3832.2 3829.4	$4p^3 3P^\circ - 4d^3 3D$ (4)	4454.8 4435.0 4425.4	$5p^3 3P^\circ - 5d^3 3D$ (4)	4962.3 4872.5 4832.1	$6p^3 3P^\circ - 6d^3 3D$ (9)	5777.6 5519.0 5424.6
E	$3p^1 1P^\circ - 3d^1 1D$ (7)	8806.8	$4p^1 1P^\circ - 4d^1 1D$ (44)	7326.1	$5p^1 1P^\circ - 5d^1 1D$	7673.1	$6p^1 1P^\circ - 6d^1 1D$	8210.2
F	$4s^3 3S - 4p^3 3P^\circ$ 15040.1 15047.4	15025.0 15040.1 15047.4	$5s^3 3S - 5p^3 3P^\circ$ 19933.9 19962.0	19853.1 19933.9 19962.0	$6s^3 3S - 6p^3 3P^\circ$ 20700.2P 20764.2	20260.7P 20700.2P 20764.2	$7s^3 3S - 7p^3 3P^\circ$ 21475.0P (21812.5P)	20711.0P 21475.0P (21812.5P)
G	$3p^3 3P^\circ - 3p^2 3P$ (UV 6)	2779.8 2779.8 2783.0 2781.4 2776.7 2778.3	$4p^3 3P^\circ - 4p^2 3P$ (5)	4302.5 4299.0 4318.7 4307.7 4283.0 4289.4	$5p^3 3P^\circ - 5p^2 3P$ (5)	4811.9 4784.3 4876.3 4832.1 4722.3 4741.9	$6p^3 3P^\circ - 6p^2 3P$	4523.2 4505.9 4691.6 4573.9 4350.3 4431.9
H	—	—	$3d^3 3D - 4p^3 3F^\circ$ (18)	6439.1 6462.6 6493.8	$4d^3 3D - 5p^3 3F^\circ$ (8)	6408.5 6504.0 6617.3	$5d^3 3D - 6p^3 3F^\circ$ (5)	7059.9 7280.3 7672.1
I	—	—	$3d^3 3D - 4p^3 3D^\circ$ (21)	5588.8 5594.5 5598.5	$4d^3 3D - 5p^3 3D^\circ$ (9)	5480.9 5504.2 5521.8	$5d^3 3D - 6p^3 3D^\circ$ (6)	6498.8 6527.3 6595.3
K	—	—	$3d^3 3D - 4p^3 3P^\circ$ (22)	5270.3 5265.6 5262.2	$4d^3 3D - 5p^3 3P^\circ$	5256.9 5238.5 5225.1	$5d^3 3D - 6p^3 3P^\circ$ (7)	6110.8 6063.1 6019.5



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	B I		C II		N III		O IV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2p^2P^\circ - 3s^2S$	2497.7 2496.8	(UV 1)	858.6 858.1	(UV 4)	452.2 451.9	(UV 4)	279.9 279.6	(UV 4)
B	$2p^2P^\circ - 2p^2D$	2089.6 2088.8	(UV 2)	1335.7 1334.5	(UV 1)	991.6 989.8 991.5	(UV 1)	790.2 787.7 790.1	(UV 1)
C	$3s^2S - 3p^2P^\circ$	————	————	6578.0 6582.8	(2)	4097.3 4103.4	(1)	3063.5 3071.7	(1)
D	$3p^2P^\circ - 3d^2D$	————	————	7236.2 7231.1	(3)	4640.6 4634.2 4641.9	(2)	3411.8 3403.6 3413.7	(2)

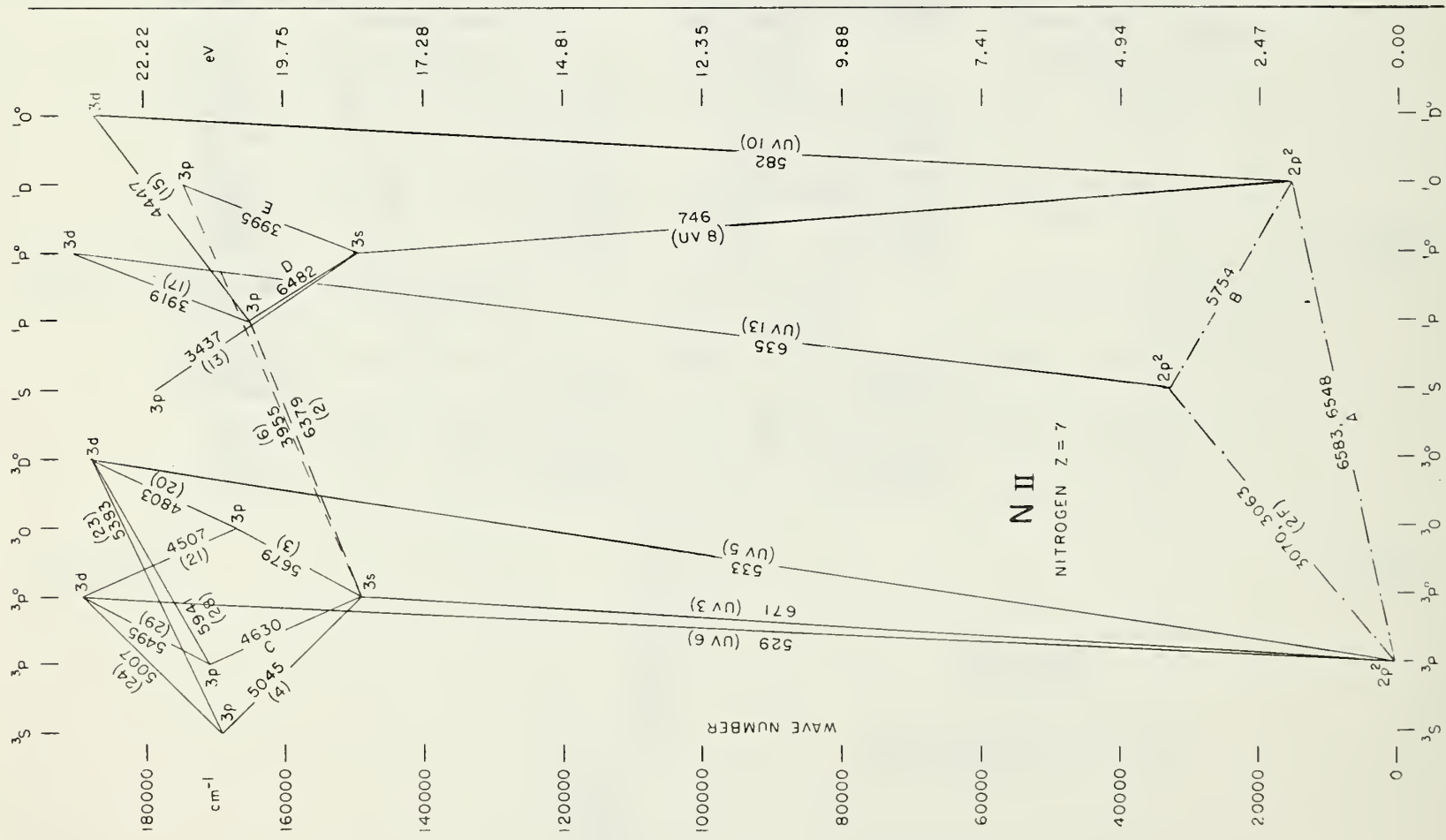
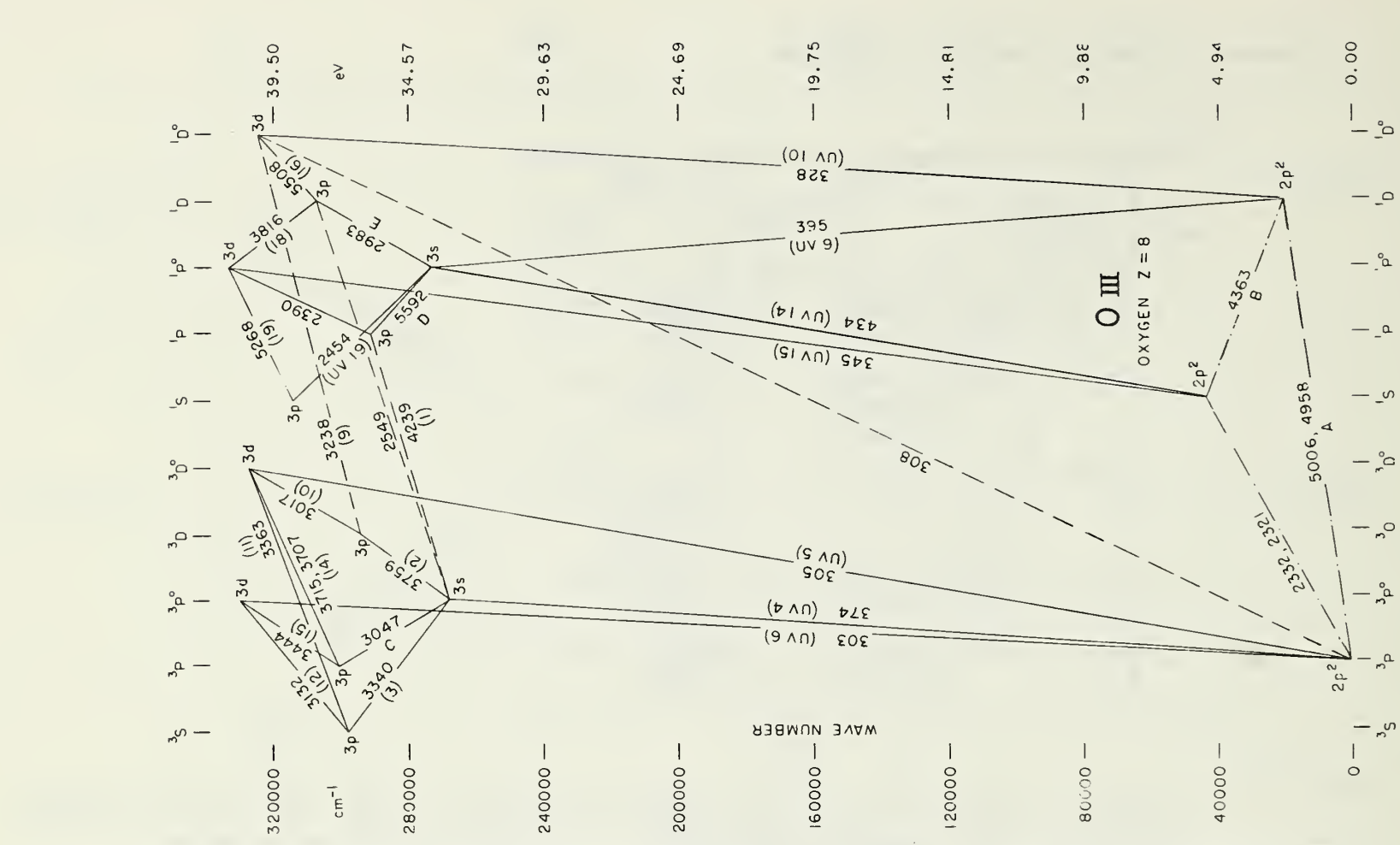


Si II
SILICON Z = 14

APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

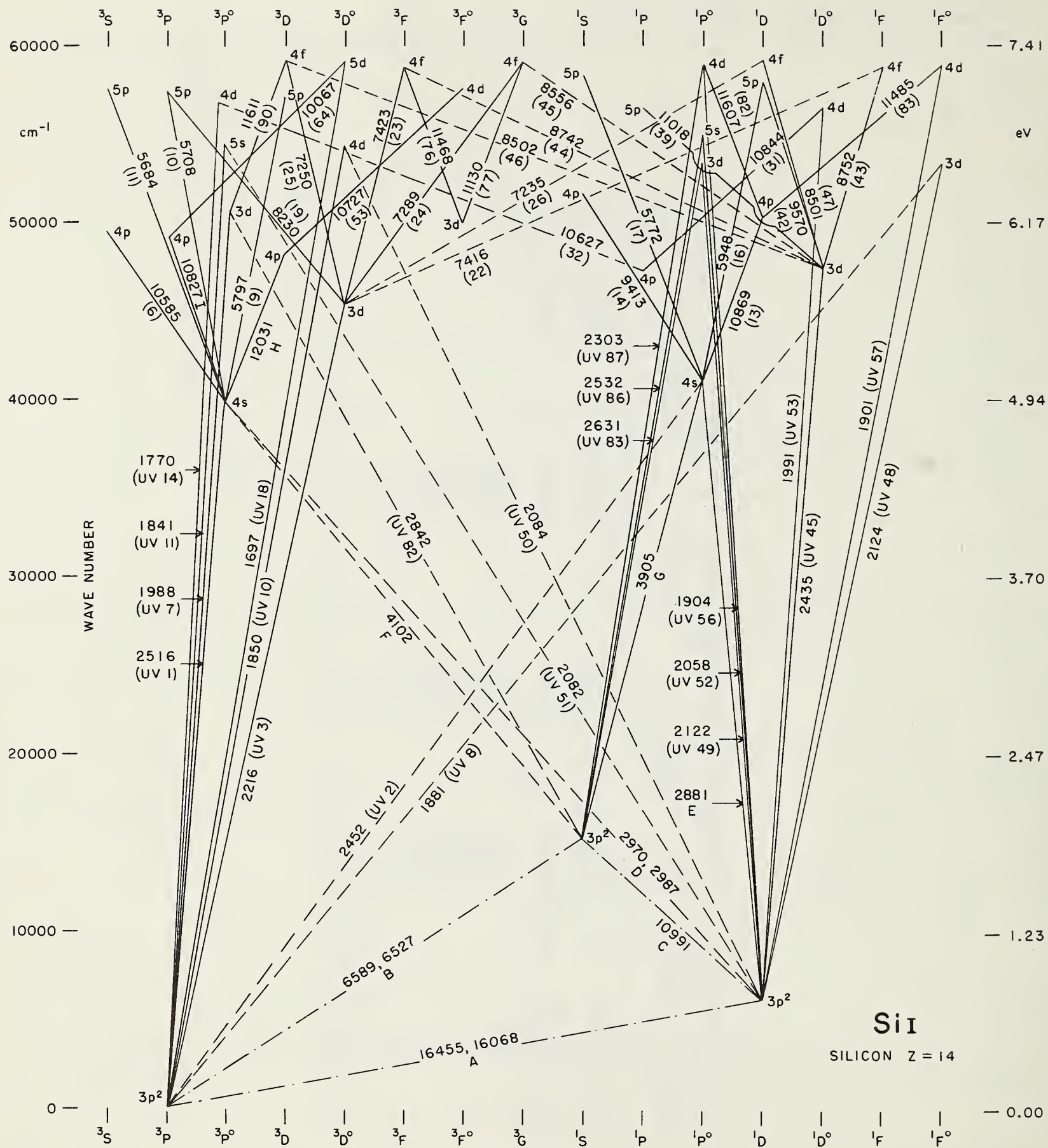
Key letter	Multiplet designation	Al I		Si II	
		λ	Mult. no.	λ	Mult. no.
A	$3p \ ^2P^\circ - 4s \ ^2S$	3961.5 3944.0	(1)	1533.4 1526.7	(UV 2)
B	$3p \ ^2P^\circ - 3d \ ^2D$	3092.7 3082.2 3092.8	(3)	1265.0 1260.7	(UV 4)
C	$3p^{22}D - 4p \ ^2P^\circ$	—	—	3856.0 3862.6 3853.7	(1)
D	$4s \ ^2S - 4p \ ^2P^\circ$	13123.2P 13150.6P	(4)	6347.1 6371.4	(2)
E	$3d \ ^2D - 4f \ ^2F^\circ$	11255.7P 11254.0P	(8)	4130.9 4128.1	(3)

Key letter	Al I		Ga I		In I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	$3p \ ^2P^\circ - 4s \ ^2S$ (1)	3961.5 3944.0	$4p \ ^2P^\circ - 5s \ ^2S$ (1)	4172.0 4033.0	$5p \ ^2P^\circ - 6s \ ^2S$ (1)	4511.3 4101.8
B	$3p \ ^2P^\circ - 3d \ ^2D$ (3)	3092.7 3082.2 3092.8	$4p \ ^2P^\circ - 4d \ ^2D$ (UV 1)	2943.6 2874.2 2944.2	$5p \ ^2P^\circ - 5d \ ^2D$	3256.1 3039.4 3258.6
C	—	—	—	—	$5p^{22}D - 6p \ ^2P^\circ$	-(13266.1P) -(12669.7P)
D	$4s \ ^2S - 4p \ ^2P^\circ$	13123.2P 13150.6P	$5s \ ^2S - 5p \ ^2P^\circ$	11949.2 12109.9	$6s \ ^2S - 6p \ ^2P^\circ$	12912.6 (13430.4P)
E	$3d \ ^2D - 4f \ ^2F^\circ$	11255.7P 11254.0P	$4d \ ^2D - 5f \ ^2F^\circ$	8813.7 8808.9	$5d \ ^2D - 6f \ ^2F^\circ$	9370.4 9350.0



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	CI		NII		OIII		NeV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2p^2\ ^3P - 2p^2\ ^1D$	(9849.3P)	(1F)	6583.4	(1F)	5006.9	(1F)	3425.9	(1F)
		(9823.1P)		6548.1		4958.9		3345.8	
B	$2p^2\ ^1D - 2p^2\ ^1S$	(8727.6P)	(3F)	5754.6	(3F)	4363.2	(2F)	(2974.8P)	(2F)
			(3)	4630.5	(5)	3047.1	(4)		
C	$3s\ ^3P^\circ - 3p\ ^3P$	9094.9		4613.9		3035.4			
		9078.3		4643.1		3059.3			
		9111.8		4621.4		3043.0			
		9088.6		4601.5		3023.4			
		9061.5		4607.2		3024.6			
		9062.5							
D	$3s\ ^1P^\circ - 3p\ ^1P$	14540.2		6482.1	(8)	5592.4	(5)		
E	$3s\ ^1P^\circ - 3p\ ^1D$	9405.8	(9)	3995.0	(12)	2983.8	(6)		

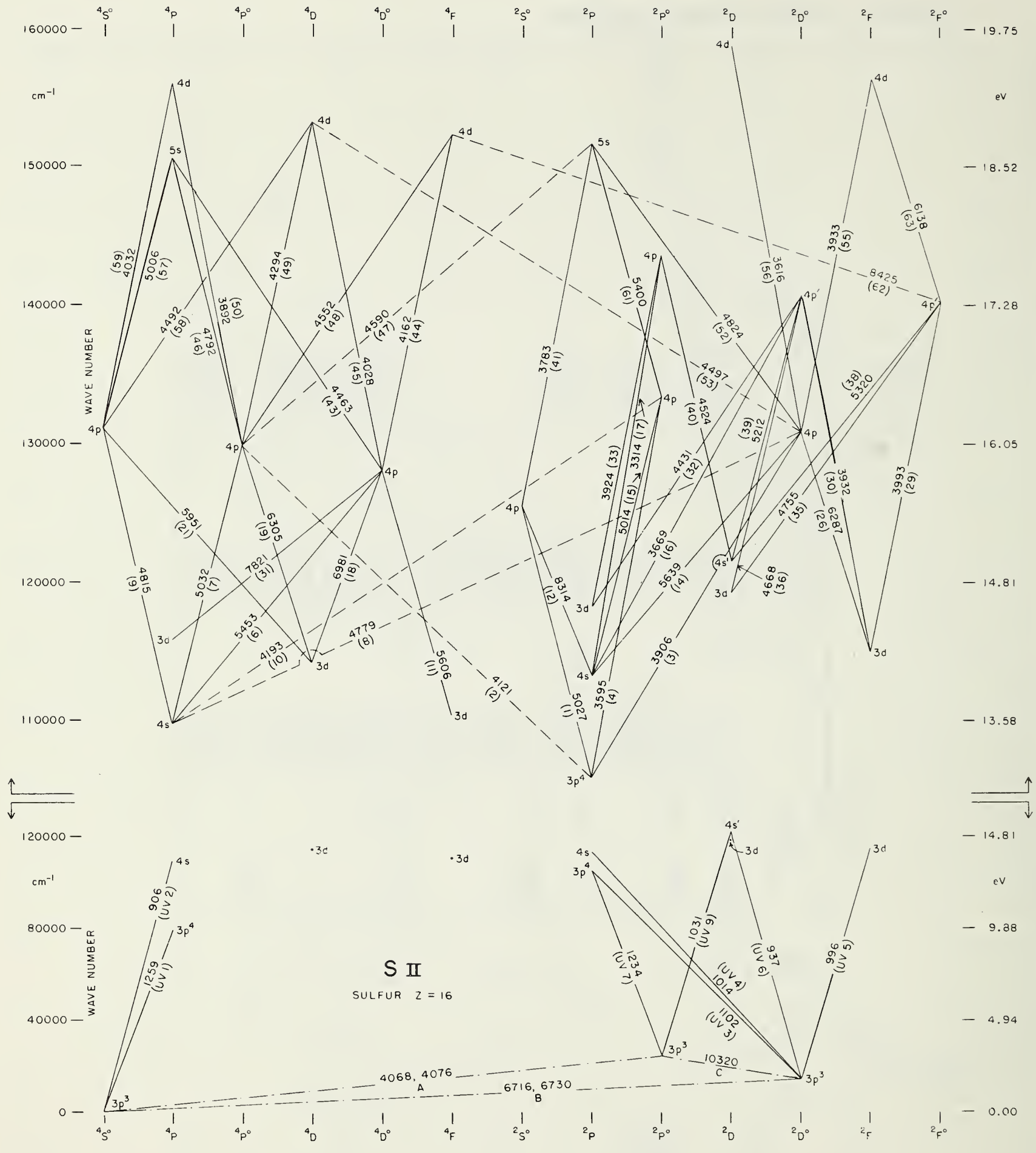


APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	Si I		P II		S III		Cl IV		A V	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$3p^{23}P - 3p^{21}D$	(16455.0P) (16068.4P)		(11884.1P) (1F) (11470.0P)		(9532.1P) (1F) (9069.6P)		8045.6 (1F) 7530.5		7005.7 (1F) 6435.1	
B	$3p^{23}P - 3p^{21}S$	(6589.7P) (1F) 6527.1		(4736.6P) (2F) (4669.5P)		(3796.8P) (2F) 3721.8		(3203.6P) (2F) (3118.7P)		(2785.2P) (2691.1P)	
C	$3p^{21}D - 3p^{21}S$	(10991.5P) (2F)		(7875.7P) (3F)		6312.1 (3F)		5323.3 (3F)		4625.5 (2F)	
D	$3p^{21}D - 4s^3P^{\circ}$	2970.4 (1) 2987.6		1278.1 1284.4		736.2 (UV 11) 738.5		(493.3P) (496.0P)		-----	-----
E	$3p^{21}D - 4s^1P^{\circ}$	2881.6 (UV 43)		1249.8		729.5 (UV 12)		486.2		350.9 (UV 8)	
F	$3p^{21}S - 4s^3P^{\circ}$	4102.9 (2)		1534.5?		836.3 (UV 13)		(546.9P)		-----	-----
G	$3p^{21}S - 4s^1P^{\circ}$	3905.5 (3)		1485.5		824.9 (UV 14)		535.0		-----	-----
H	$4s^3P^{\circ} - 4p^3D$	12031.5 (4) 11984.2 11991.6		6043.1 (5) 6024.2 6034.0		4253.6 (4) 4285.0 4332.7		3076.7 3063.1 3071.4		-----	-----
I	$4s^3P^{\circ} - 4p^3P$	10827.1 (5) 10749.4 10979.3 10786.9 10603.4 10661.0		5425.9 (6) 5386.9 5499.7 5409.7 5316.1 5344.7		3838.3 (5) 3837.8 (3899.1P) 3860.6 3778.9 3831.8		2782.5 2751.2 2835.4 2770.6 2701.4 2724.0		-----	-----

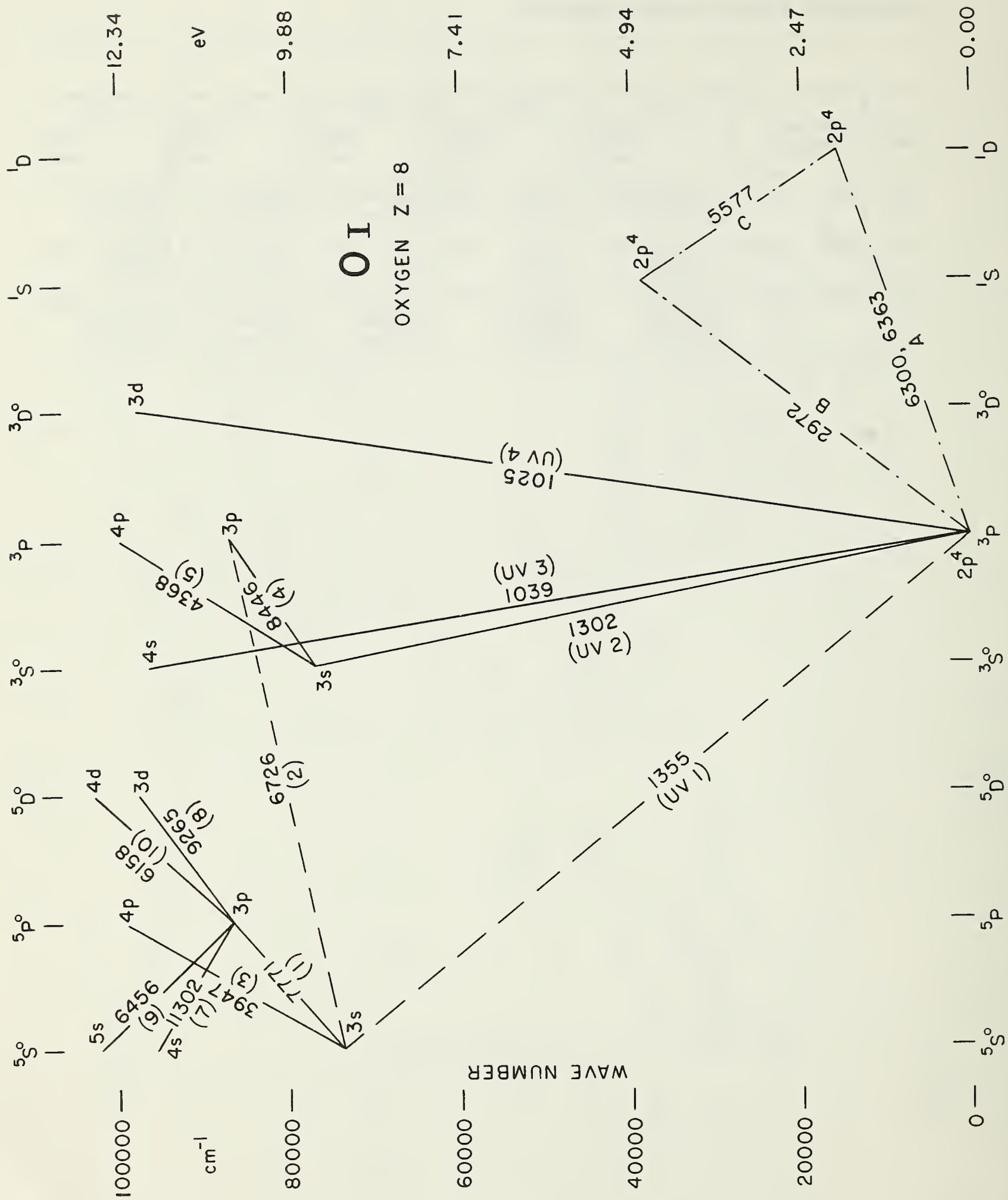
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	NI		O II		Ne IV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2p^3 4S^\circ - 2p^3 2D^\circ$	5200.4	(1F)	3728.8	(1F)	(2441±P)	.....
		5197.9		3726.0		(2438±P)	
B	$2p^3 2D^\circ - 2p^3 2P^\circ$	(10396.5P)	(3F)	7319.9	(2F)	4714.2	(1F)
		(10406.2P)		7330.2		4725.6	
		(10396.5P)		7319.9		4715.6	
		(10406.2P)		7330.2		4724.2	
C	$2p^3 4S^\circ - 2p^3 2P^\circ$	(3466.4P)	(2F)	(2470.4P)	.....	(1609±P)	.....
		(3466.4P)		(2470.3P)		(1609±P)	
D	$3s^2 4P - 3p^2 4D^\circ$	8680.2	(1)	4649.1	(1)	-----	-----
		8683.4		4641.8		-----	-----
		8686.1		4638.9		-----	-----
		8718.8		4676.2		-----	-----
		8711.7		4661.6		-----	-----
		8703.2		4650.8		-----	-----
		8216.3	(2)	4349.4	(2)	(2203.6P)	.....
		8210.6		4336.9		(2192.4P)	
E	$3s^2 4P - 3p^2 4P^\circ$	8200.3		4325.8		(2188.0P)	
		8242.3		4367.0		(2220.3P)	
		8223.1		4345.6		(2206.2P)	
		8184.8		4319.6		(2176.1P)	
		8188.0		4317.1		(2174.4P)	
		7468.3	(3)	3749.5	(3)	(1875.2P)	.....
F	$3s^2 4P - 3p^2 4S^\circ$	7442.3		3727.3		(1855.3P)	
		7423.6		3712.8		(1842.4P)	



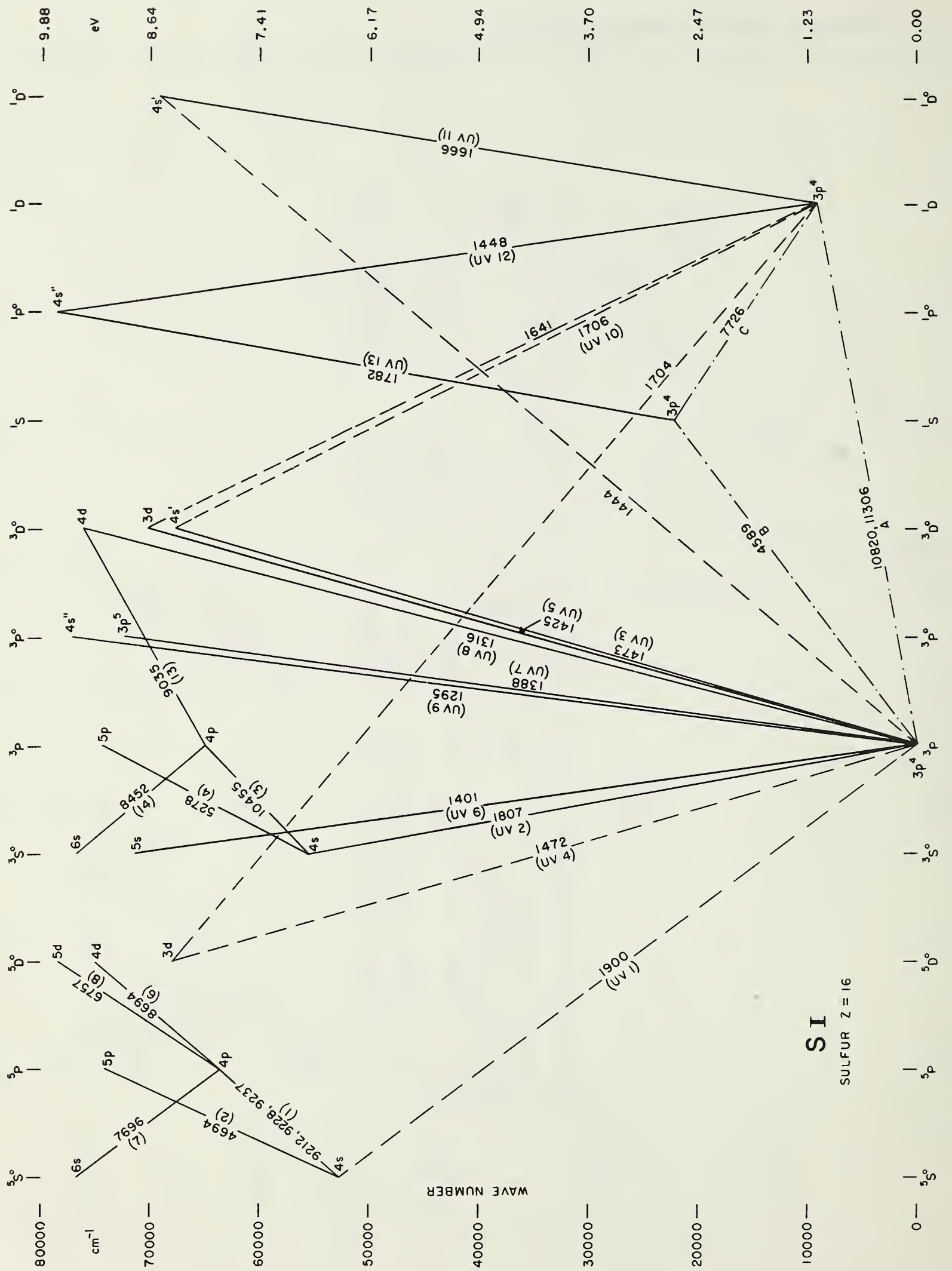
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	PI		SII		CI III		AIV		KV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A....	$3p^{34}S^{\circ} - 3p^{32}P^{\circ}$	(5332.4P)	(2F)	4068.6	(1F)	(3342.7P)	(2F)	(2853.6P)	.....	(2495.3P)	.....
		(5339.7P)		4076.4		(3353.4P)		(2868.2P)		(2515.3P)	
B....	$3p^{34}S^{\circ} - 3p^{32}D^{\circ}$	(8787.6P)	(1F)	6716.4	(2F)	5517.7	(1F)	4711.3	(1F)	4122.63	(1F)
		(8799.1P)		6730.8		5537.6		4740.2		4163.30	
C....	$3p^{32}D^{\circ} - 3p^{32}P^{\circ}$	(13561.8P)	.....	(10320.4P)	(3F)	(8480.9P)	(3F)	7237.3	(2F)	(6321.8P)	(2F)
		(13581.9P)		(10336.4P)		(8501.8P)		7262.8		(6354.7P)	
		(13534.7P)		(10286.7P)		(8433.7P)		7170.6		(6228.4P)	



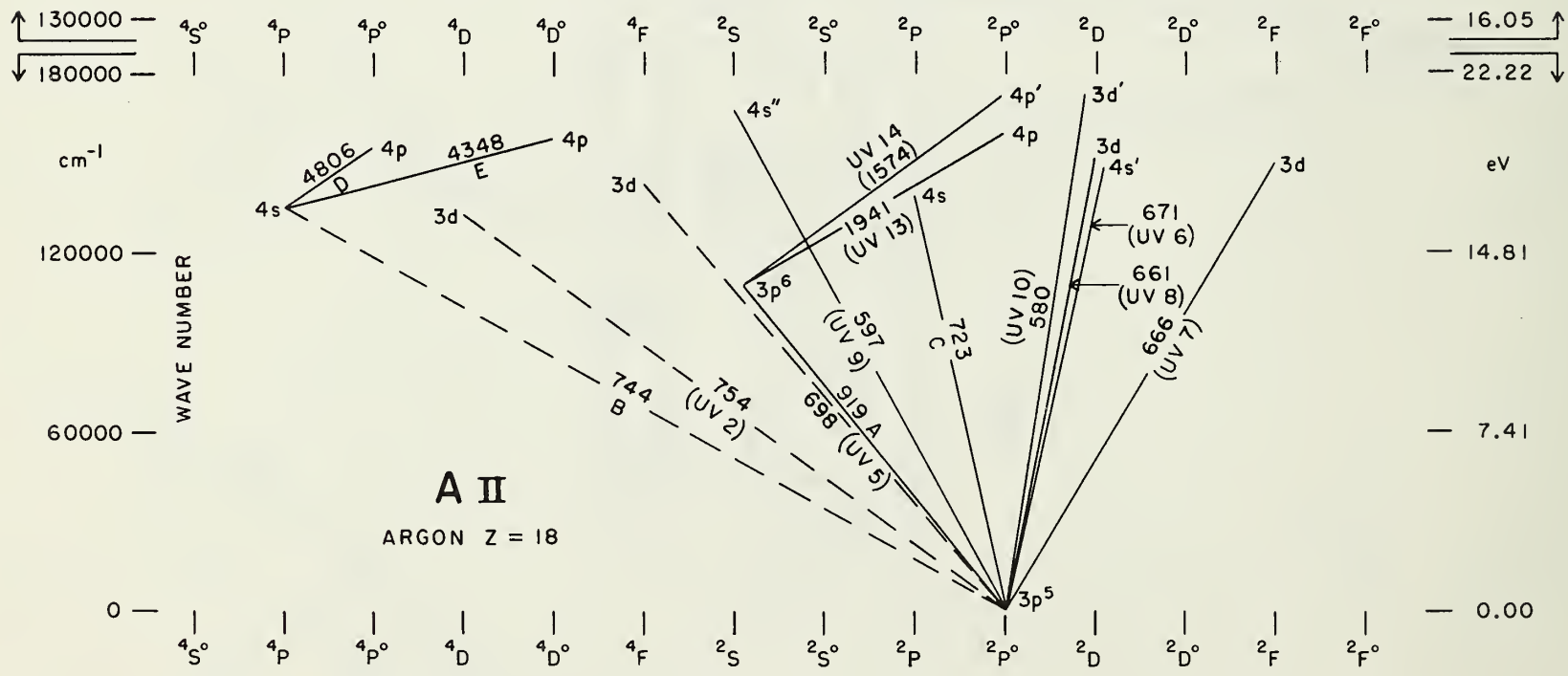
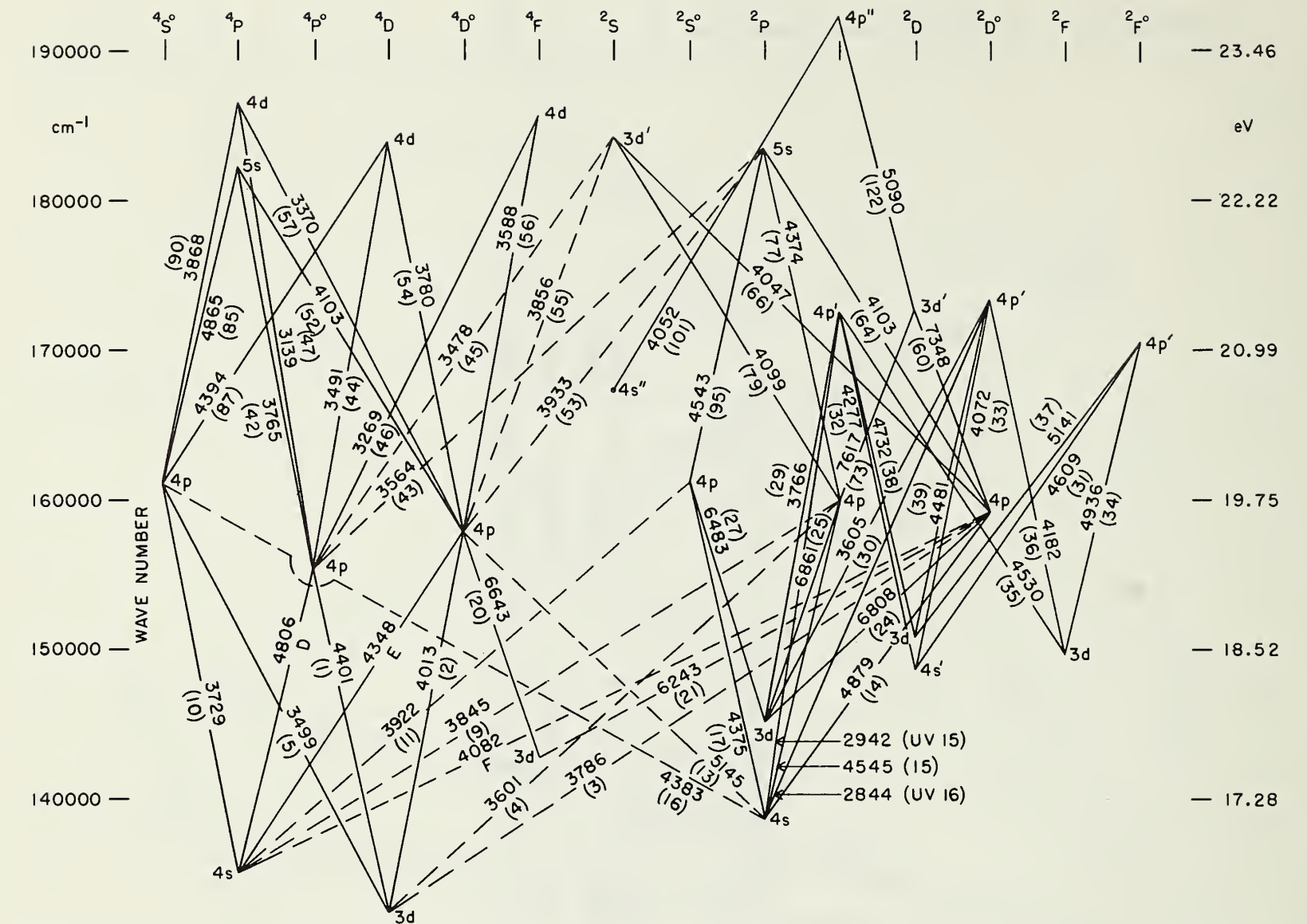
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Multiplet designation	O I		Ne III		Na IV		Mg V	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A	$2p^{43}P - 2p^{41}D$	6300.3 6363.8	(1F)	3868.8 3967.5	(1F)	(3212.6±P) (3331.0±P)	(1F)	(2750.4±P) (2892.0±P)	.....
B	$2p^{43}P - 2p^{41}S$	(2972.3P)	(2F)	(1815.0P)	.....	(1522.7±P)	.....	(1317.0±P)	.....
C	$2p^{41}D - 2p^{41}S$	5577.4	(3F)	(3342.9P)	(2F)	(2803.3P)	.....	(2416.8P)	.....



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

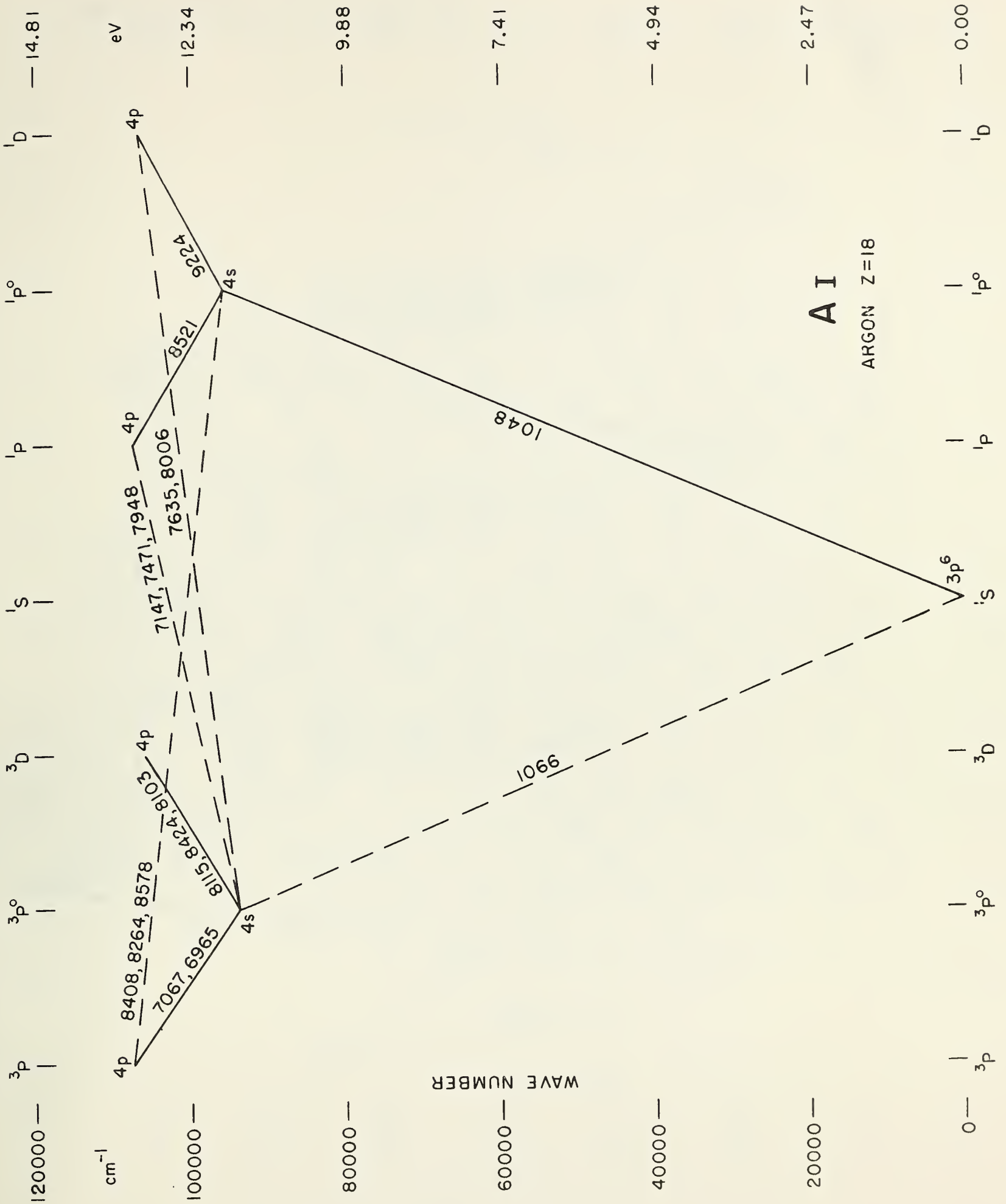
Key letter	Multiplet designation	SI		CII		AIII		KIV		CaV	
		λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.	λ	Mult. no.
A....	3p ⁴ 3P - 3p ⁴ 1D	(10820.7P) (11306.3P)	(1F)	(8579.9P) (9125.7P)	(1F)	7135.8 7751.1	(1F)	6101.8 (6795.8P)	(1F)	5309.2 6086.9	(1F)
B....	3p ⁴ 3P - 3p ⁴ 1S	(4589.1P)	(2F)	—	—	(3109.2P) .....	.....	(2711.1P) .....	.....	(2412.3P) .....	.....
C....	3p ⁴ 1D - 3p ⁴ 1S	7726.5	(3F)	—	—	5191.8 (3F)	(3F)	4510.9 (2F)	(2F)	(3996.2P) (2F)	(2F)



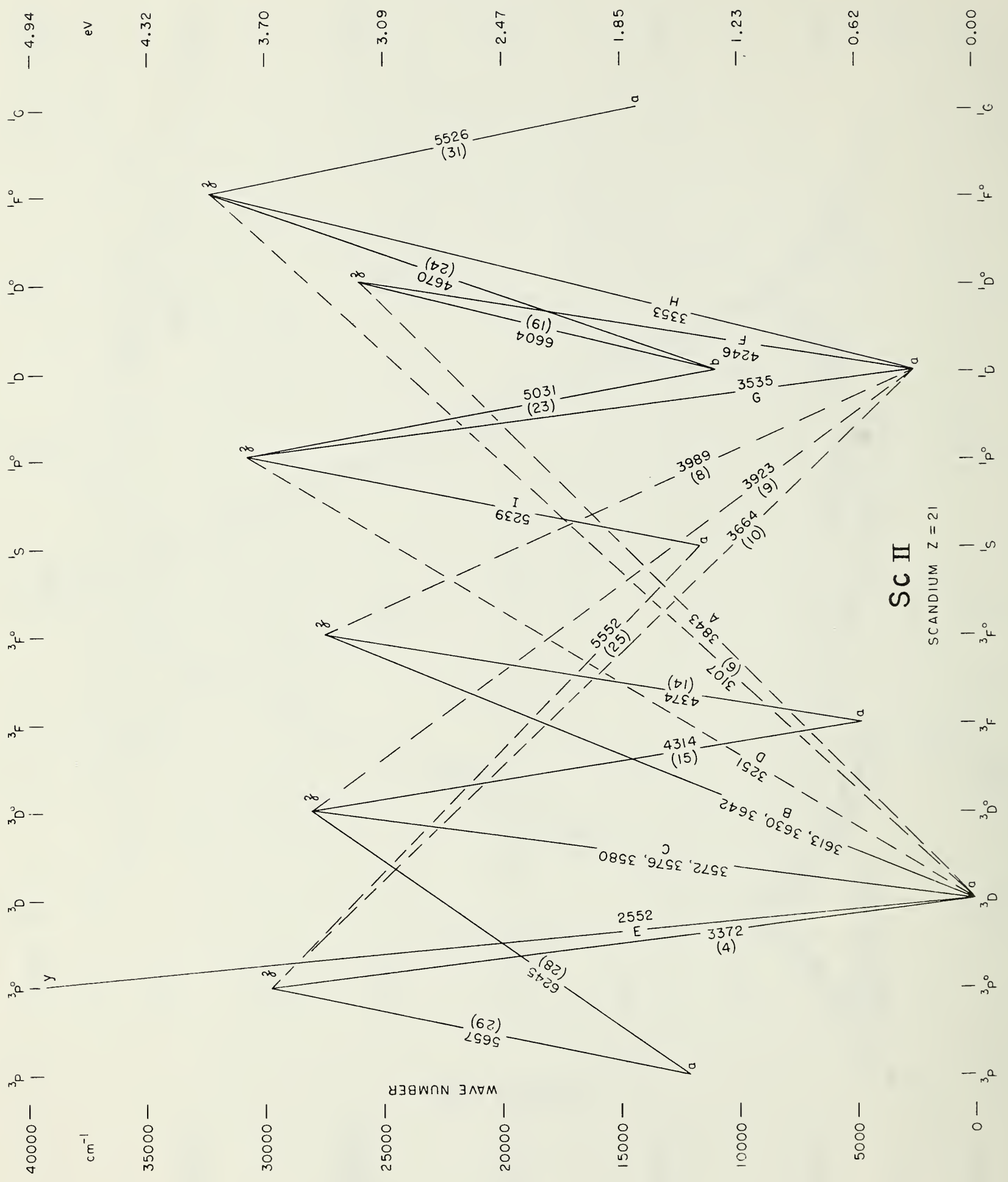
A II
ARGON Z = 18

APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Ne II		A II	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	$2p^{52}P^{\circ} - 2p^{62}S$	460.7	$3p^{52}P^{\circ} - 3p^{62}S$	919.8
	(UV 1)	462.4	(UV 1)	932.0
B	$2p^{52}P^{\circ} - 3s\ 4P$	456.3	$3p^{52}P^{\circ} - 4s\ 4P$	744.9
	(UV 2)	456.9	(UV 3)	748.2
		455.3		740.3
		454.6		745.3
C	$2p^{52}P^{\circ} - 3s\ 2P$	446.3	$3p^{52}P^{\circ} - 4s\ 2P$	723.4
	(UV 3)	446.6	(UV 4)	725.5
		445.0		718.1
		447.8		730.9
D	$3s\ 4P - 3p\ 4P^{\circ}$	3694.2	$4s\ 4P - 4p\ 4P^{\circ}$	4806.1
	(1)	3734.9	(6)	4933.2
		3751.3		4972.2
		3664.1		4735.9
		3709.6		4847.9
		3766.3		5009.4
		3777.2		5062.1
E	$3s\ 4P - 3p\ 4D^{\circ}$	3334.9	$4s\ 4P - 4p\ 4D^{\circ}$	4348.1
	(2)	3355.0	(7)	4426.0
		3360.6		4430.2
		3297.7		4266.5
		3327.2		4331.2
F	$3s\ 4P - 3p\ 2D^{\circ}$	3135.8	$4s\ 4P - 4p\ 2D^{\circ}$	4082.4
	(3)	(3136.5P)	(8)	4112.8
		(3086.3P)		3974.8
		3187.6		4228.2



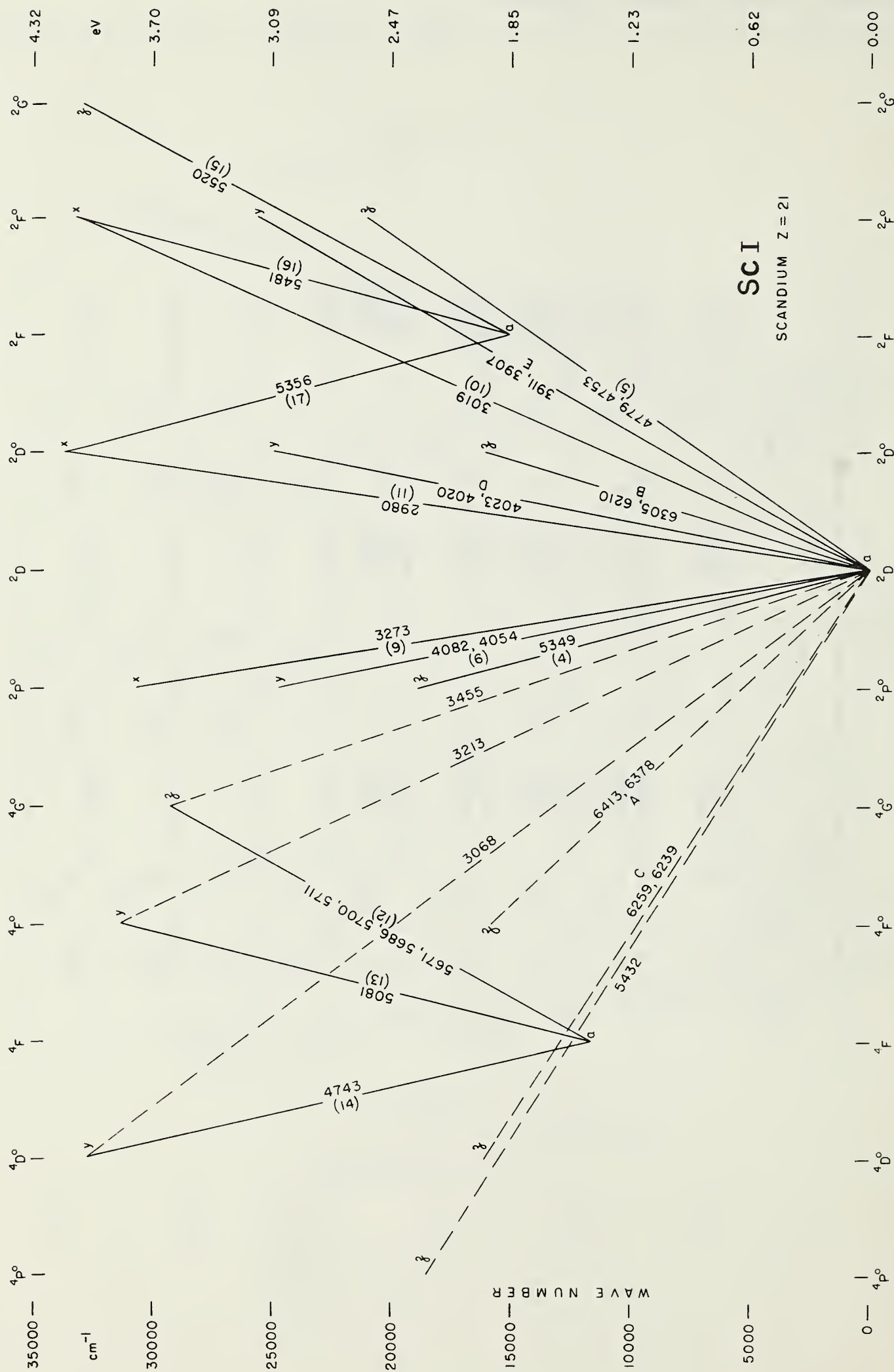
Ar
ARGON Z=18



Sc II
SCANDIUM Z = 21

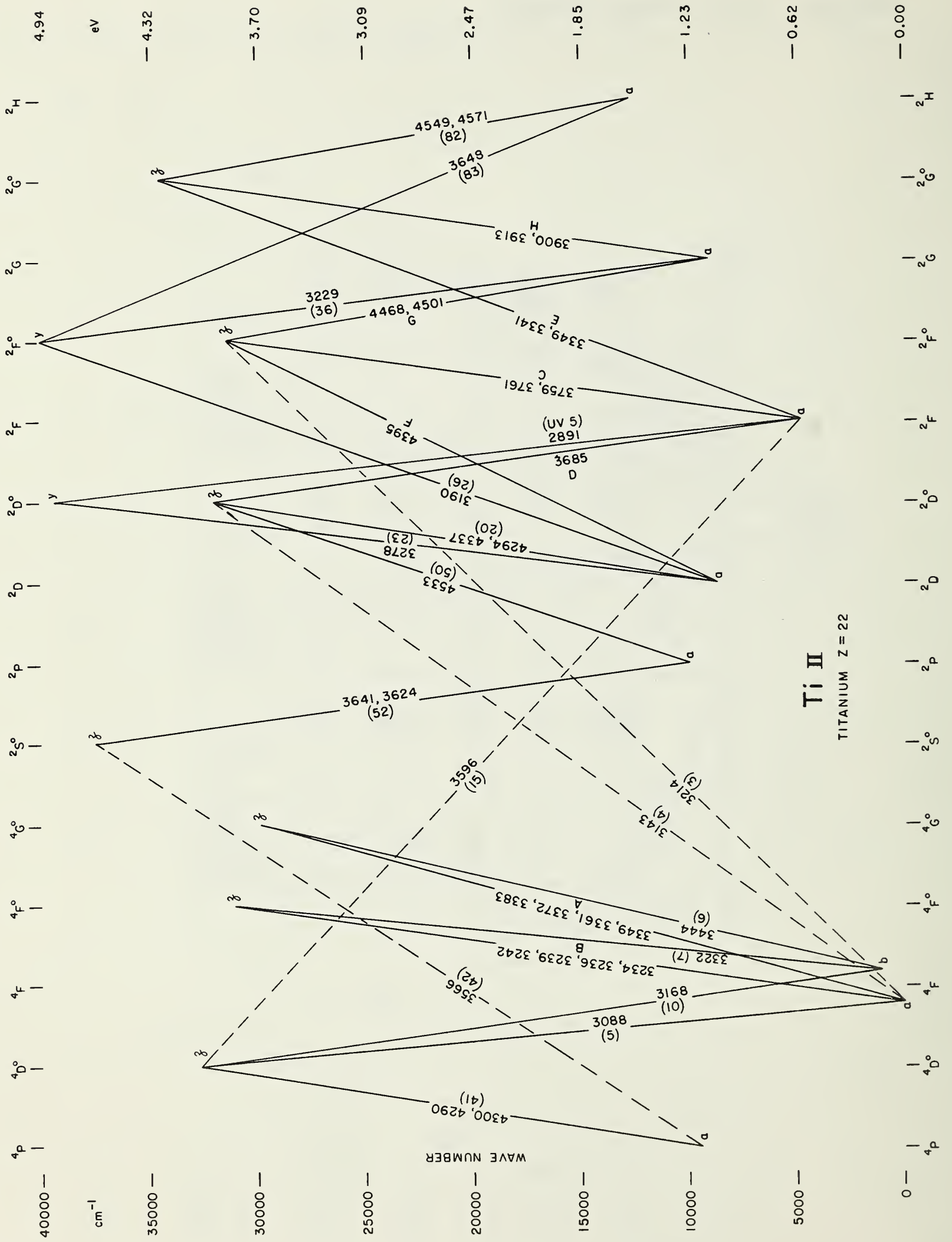
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Sc II		Y II		La II	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a ³ D - z ¹ D° 4s 4p (1)	3843.0 3833.1	a ³ D - z ¹ D° 5s 5p (6)	3982.6 3950.4	a ³ D - y ¹ D° 6s 6p (38)	4571.0 4429.9
B	a ³ D - z ³ F° 4s 4p (2)	3613.8 3630.7 3642.8	a ³ D - z ³ F° 5s 5p (7)	3710.3 3774.3 3788.7	a ³ D - x ³ F° 6s 6p (41)	3949.1 4123.2 4077.4
C	a ³ D - z ³ D° 4s 4p (3)	3572.5 3576.3 3580.9	a ³ D - z ³ D° 5s 5p (9)	3600.7 3611.1 3601.9	a ³ D - y ³ D° 6s 6p (40)	3988.5 4031.7 4152.0
D	a ³ D - z ¹ P° 4s 4p (5)	3251.3 3244.2P	a ³ D - z ¹ P° 5s 5p (8)	3776.6 3747.6	a ³ D - y ¹ P° 6s 6p (44)	3601.1 3512.9
E	a ³ D - y ³ P° 4s 4p' (UV 1)	2552.4 2560.3 2563.2	a ³ D - z ³ P° 5s 5p' (5)	4309.6 4398.0 4422.6	a ³ D - x ³ P° 6s 6p' (45)	3337.5 3380.9 3344.6
F	a ¹ D - z ¹ D° 4s 4p (7)	4246.8	a ¹ D - z ¹ D° 5s 5p (13)	4374.9	a ¹ D - y ¹ D° 6s 6p (24)	4333.8
G	a ¹ D - z ¹ P° 4s 4p (11)	3535.7	a ¹ D - z ¹ P° 5s 5p (15)	4127.6	a ¹ D - y ¹ P° 6s 6p (30)	3452.2
H	a ¹ D - z ¹ F° 4s 4p (12)	3353.7	a ¹ D - z ¹ F° 5s 5p (18)	3327.9	a ¹ D - x ¹ F° 6s 6p (32)	3245.1
I	a ¹ S - z ¹ P° 4s ² 4p (26)	5239.8	a ¹ S - z ¹ P° 5s ² 5p (2)	3633.1	a ¹ S - y ¹ P° 6s ² 6p (58)	4354.4



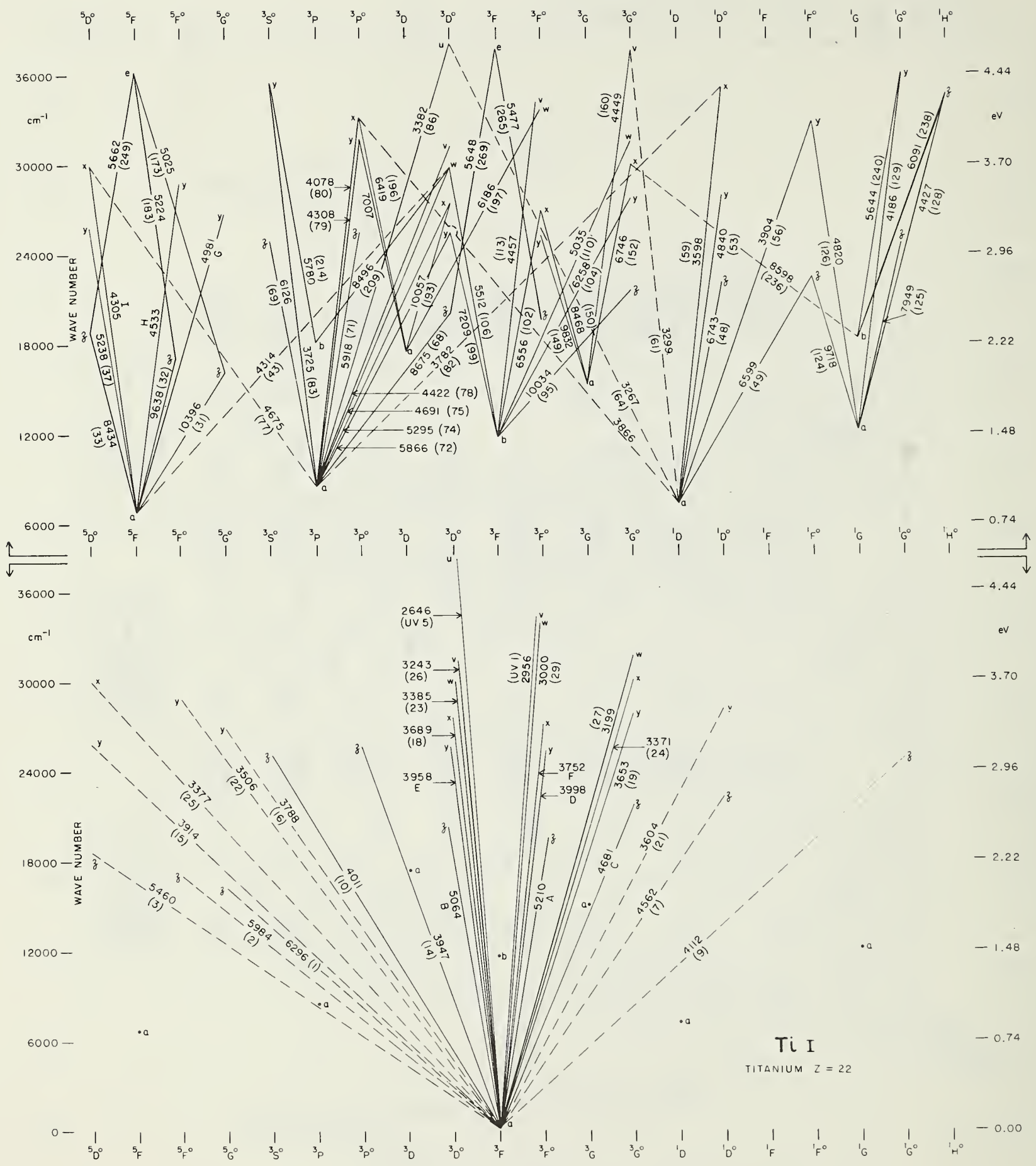
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Sc I		Y I		La I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	$a^2D - z^4F^\circ$ 4s ² 4p (1)	6413.4 6378.8	$a^2D - z^4F^\circ$ 5s ² 5p' (1)	6793.7 6687.6	$a^2D - z^4F^\circ$ 6s ² 6p'' (1)	7948.3 7539.2
E	$a^2D - z^2D^\circ$ 4s ² 4p' (2)	6305.7 6210.7	$a^2D - y^2D^\circ$ 5s ² 5p'' (5)	4128.3 4142.9	$a^2D - z^2D^\circ$ 6s ² 6p' (2)	7270.3 6650.8
C	$a^2D - z^4D^\circ$ 4s ² 4p (3)	6259.0 6239.8	$a^2D - z^4D^\circ$ 5s ² 5p' (3)	6138.4 6023.4	$a^2D - z^4D^\circ$ 6s ² 6p'' (3)	6918.3 6796.7
D	$a^2D - y^2D^\circ$ 4s ² 4p (7)	4023.7 4020.4	$a^2D - z^2D^\circ$ 5s ² 5p' (2)	6435.0 6191.7	$a^2D - y^2D^\circ$ 6s ² 6p'' (3)	5455.1 5501.3
E	$a^2D - y^2F^\circ$ 4s ² 4p (8)	3911.8 3907.5	$a^2D - z^2F^\circ$ 5s ² 5p' (4)	4674.8 4643.7	$a^2D - y^2F^\circ$ 6s ² 6p'' (2)	5930.6 5930.7
	3d 4s ² 3d 4s(a ³ D)4p = 4p 3d 4s(a ¹ D)4p = 4p'	= 4s ²	4d 5s ² 4d 5s(a ³ D)5p = 5p' 4d 5s(a ¹ D)5p = 5p''	= 5s ²	5d 6s ² 5d 6s(a ³ D)6p = 6p'' 5d 6s(a ¹ D)6p = 6p'	= 6s ²



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

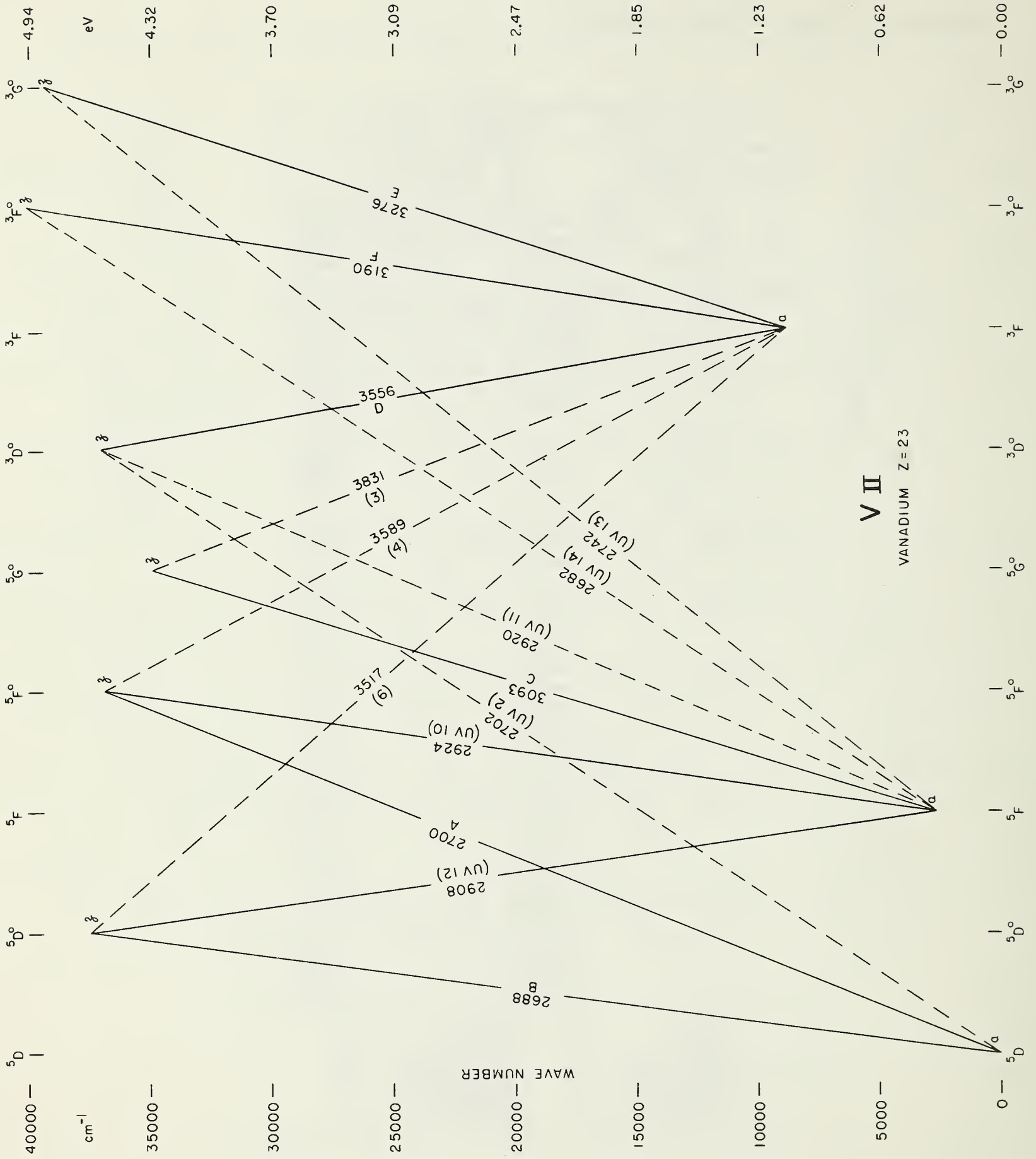
Key letter	Ti II		Zr II		Hf II	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a ⁴ F - z ⁴ G° 4s	3349.4 3361.2 3372.8 3383.8	a ⁴ F - z ⁴ G° 5s	3392.0 3438.2 3496.2 3572.5	a ⁴ F - z ⁴ G° 6s	2641.4 2773.4 2975.9 3194.2
B	a ⁴ F - z ⁴ F° 4s	3234.5 3236.6 3239.0 3242.0	a ⁴ F - z ⁴ F° 5s	3273.0 3279.3 3306.3 3357.3	a ⁴ F - y ⁴ F° 6s	2647.3 2627.0 2578.2 2571.7
C	a ² F - z ² F° 4s	3759.3 3761.3 (13)	a ² F - z ² F° 5s	4149.2 4209.0 (41)	a ² F - x ² F° 6s	2683.4 2573.9
D	a ² F - z ² D° 4s	3685.2 3685.2 (14)	a ² F - z ² D° 5s	4048.7 4050.3 (43)	a ² F - w ² D° 6s	2657.5 2559.2
E	a ² F - z ² G° 4s	3349.0 3341.9 (16)	a ² F - z ² G° 5s	3481.1 3479.4 (46)	a ² F - z ² G° 6s	2876.3 2849.2
F	a ² D - z ² F° 4s'	4395.0 4443.8 (19)	a ² D - z ² F° 5s'	3836.8 3958.2 (16)	b ² D - x ² F° 6s'	2858.7 2735.1
G	a ² G - z ² F° 3d ³	4468.5 4501.3 (31)	a ² G - z ² F° 4d ³	4461.2 4614.0 (67)	b ² G - x ² F° 5d ³	4125.1 4452.7 (94)
H	a ² G - z ² G° 3d ³	3900.5 3913.5 (34)	a ² G - z ² G° 4d ³	3698.2 3751.6 (71)	b ² G - z ² G° 5d ³	4599.5 5346.3 (92)
	3d ² (a ³ F)4s = 4s 3d ² (a ¹ D)4s = 4s' 3d ² (a ³ F)4p = 4p		4d ² (a ³ F)5s = 5s 4d ² (a ¹ D)5s = 5s' 4d ² (a ³ F)5p = 5p		5d ² (³ F)6s = 6s 5d ² (¹ D)6s = 6s' 5d ² (³ F)6p = 6p	



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

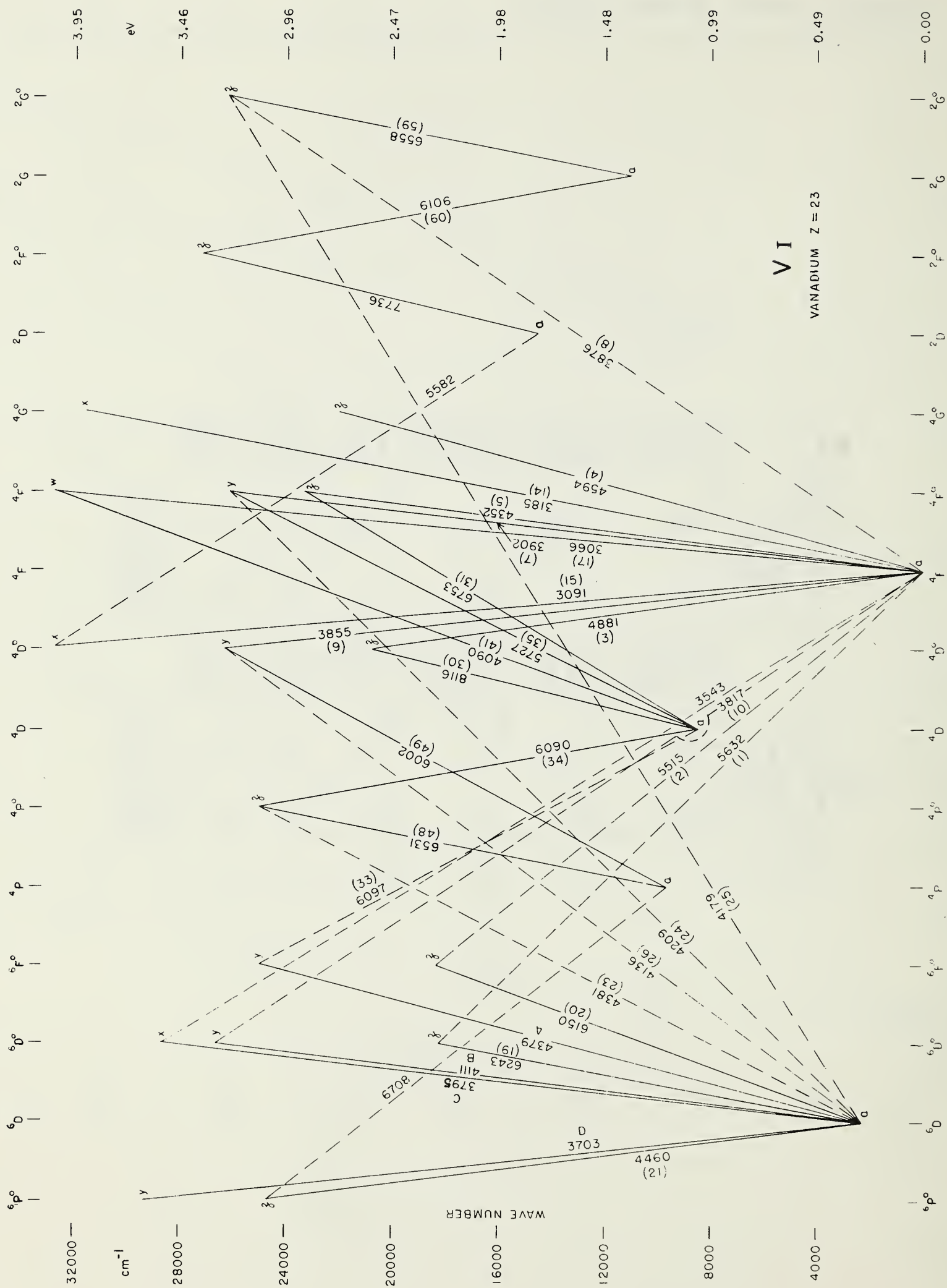
Key letter	Ti I		Zr I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a 3F - z $^3F^\circ$ 4s ² 4p'' (4)	5210.4 5193.0 5173.7	a 3F - w $^3F^\circ$ 5s ² 5p ^{IV} (12)	3663.6 3623.9 3586.3
B	a 3F - z $^3D^\circ$ 4s ² 4p'' (5)	5064.7 5040.0 5014.2	a 3F - u $^3D^\circ$ 5s ² 5p ^{IV} (22)	3029.5 3011.7 2985.4
C	a 3F - z $^3G^\circ$ 4s ² 4p'' (6)	4681.9 4667.6 4656.5	a 3F - x $^3G^\circ$ 5s ² 5p ^{IV} (13)	3601.2 3547.7 3519.6
D	a 3F - y $^3F^\circ$ 4s ² 4p (12)	3998.6 3989.8 3981.8	a 3F - z $^3F^\circ$ 5s ² 5p (2)	6127.5 6143.2 6134.6
E	a 3F - y $^3D^\circ$ 4s ² 4p (13)	3958.2 3956.3 3948.7	a 3F - z $^3D^\circ$ 5s ² 5p (4)	5879.8 5797.8 5735.7
F	a 3F - x $^3F^\circ$ 4s ² 4p' (17)	3752.9 3741.1 3729.8	a 3F - y $^3F^\circ$ (4391.4P) 5s ² 5p' (43)	4347.2 4236.6
G	a 5F - y $^5G^\circ$ 4s' 4p' (38)	4981.7 4991.1 4999.5 5007.2 5014.3	a 5F - y $^5G^\circ$ 5s' 5p' (43)	4687.8 4710.1 4739.5 4772.3 4815.6
H	a 5F - y $^5F^\circ$ 4s' 4p' (42)	4533.2 4534.8 4535.6 4535.9 4536.1	a 5F - y $^5F^\circ$ 5s' 5p' (45)	4227.8 4239.3 4241.7 4241.2 4240.4
I	a 5F - x $^5D^\circ$ 4s' 4p' (44)	4305.9 4301.1 4300.6 4298.7 4295.8	a 5F - x $^5D^\circ$ 5s 5p' (46)	4081.2 4072.7 4064.2 4055.0 4044.6
	3d ² 4s ² = 4s ² 3d ³ (b ⁴ F)4s = 4s' 3d ² 4s(a ² F)4p = 4p'' 3d ² 4s(a ⁴ F)4p = 4p 3d ³ (b ⁴ F)4p = 4p'		4d ² 5s ² = 5s ² 4d ³ (b ⁴ F)5s = 5s' 4d ² 5s(a ² F)5p = 5p ^{IV} 4d ² 5s(a ⁴ F)5p = 5p 4d ³ (b ⁴ F)5p = 5p'	

V II
VANADIUM Z = 23



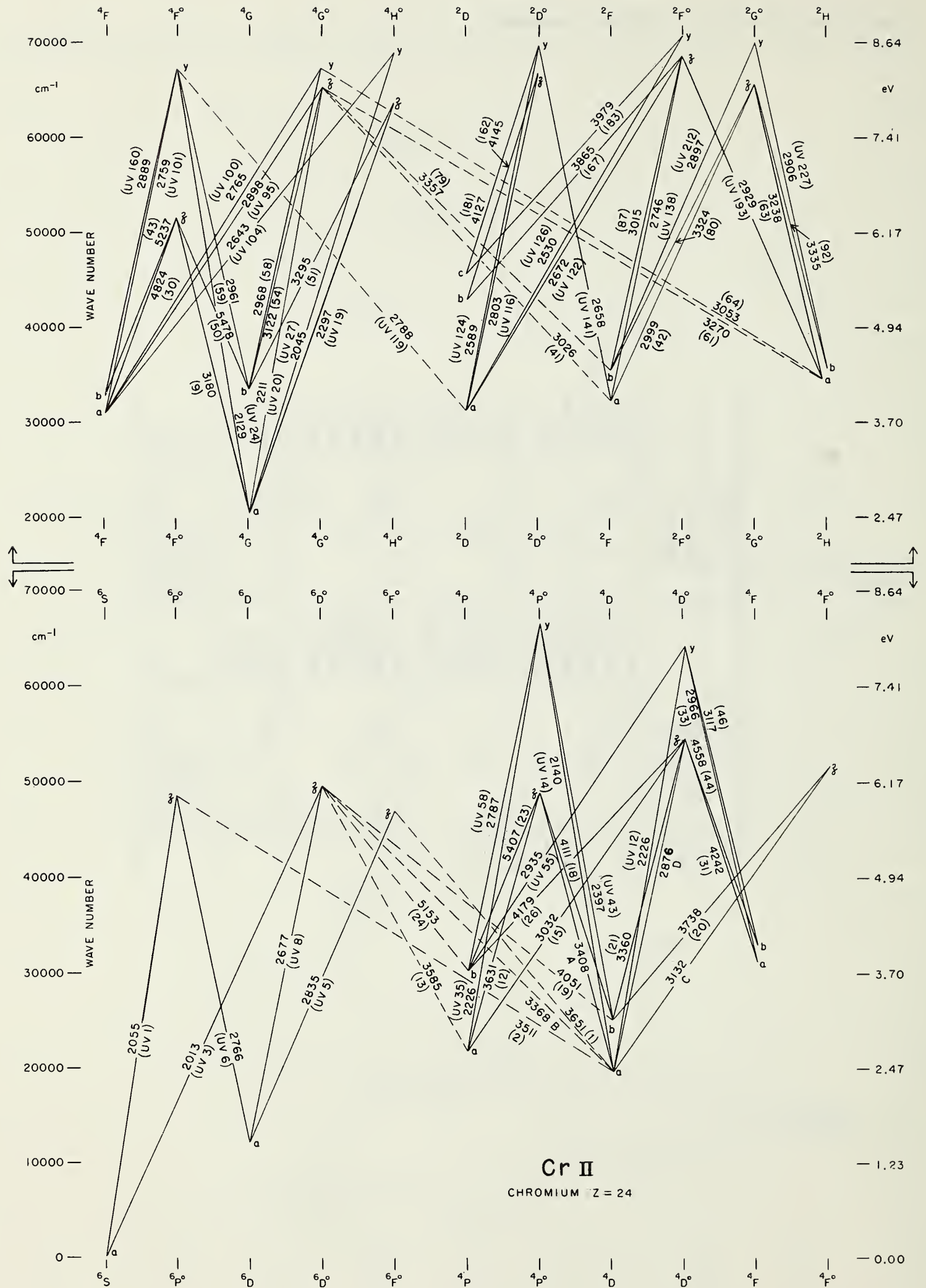
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	VII		NbII	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a ⁵ D - z ⁵ F° 3d ⁴ (UV 1)	2700.9 2706.2 2715.7 2728.6 2739.7	a ⁵ D - z ⁵ F° 4d ⁴ (UV 2)	2716.6 2722.0 2706.4 2716.3 2721.6
B	a ⁵ D - z ⁵ D° 3d ⁴ (UV 3)	2688.0 2679.3 2682.9 2685.7	a ⁵ D - z ⁵ D° 4d ⁴ (UV 3)	2697.1 2671.9 2675.9 2678.7
C	a ⁵ F - z ⁵ G° 4s (1)	3093.1 3102.3 3110.7 3118.4 3125.3	a ⁵ F - z ⁵ G° 4d ⁴ (1)	3094.2 3130.8 3163.4 3195.0 3225.5
D	a ³ F - z ³ D° 4s (5)	3556.8 3545.2 3530.8	a ³ F - z ³ D° 4s (4)	3541.0 3619.5 3651.2
E	a ³ F - z ³ G° 4s (7)	3276.1 3271.1 3267.7	a ³ F - z ³ G° 4s (5)	3145.4 3180.3 3206.4
F	a ³ F - z ³ F° 4s (8)	3190.7 3188.5 3187.7	a ³ F - z ³ F° 4s (5)	3100.8 3135.9 3175.9
	3d ³ (a ⁴ F)4s = 4s 3d ³ (a ⁴ F)4p = 4p		4d ³ (a ⁴ F)5s = 5s 4d ³ (a ⁴ F)5p = 5p	



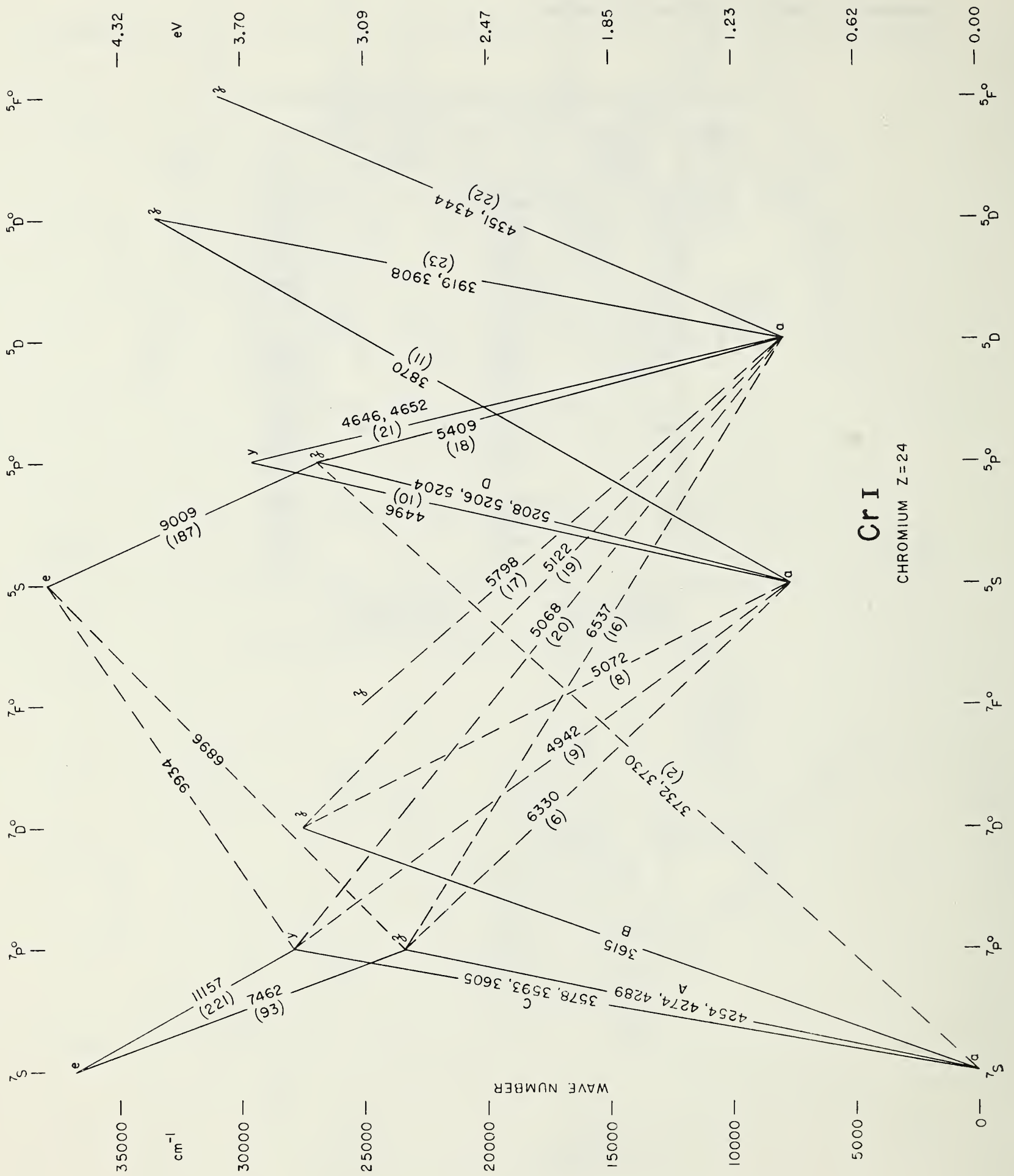
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	VI		Nb I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a 6D - y ${}^6F^\circ$	4379.2	a 6D - y ${}^6F^\circ$	4058.9
	4s 4p	4384.7	5s 5p	4079.7
	(22)	4390.0	(1)	4100.9
		4395.2		4123.8
B		4400.6		4137.1
	a 6D - y ${}^6D^\circ$	4111.8	a 6D - x ${}^6D^\circ$	3713.0
	4s 4p	4115.2	5s 5p	3739.8
	(27)	4116.5	(3)	3759.6
		4116.7		3764.1
		(4116.6P)		3765.1
C	a 6D - x ${}^6D^\circ$	3795.0	a 6D - y ${}^6D^\circ$	3791.2
	4s 4pVI	3803.5	5s 5pVI	3824.9
	(28)	3809.6	(2)	3845.9
		(3813.5P)		3858.0
		3815.5		3862.9
D	a 6D - y ${}^6P^\circ$	3703.6	a 6D - y ${}^6P^\circ$	3580.3
	4s 4pVI	3704.7	5s 5pVI	3575.9
	(29)	3705.0	(4)	3585.0
	3d ⁴ (a ⁵ D)4s = 4s		4d ⁴ (a ⁵ D)5s = 5s	
	3d ⁴ (a ⁵ D)4p = 4p		4d ⁴ (a ⁵ D)5p = 5p	
	3d ³ 4s(a ⁵ P)4p = 4pVI		4d ³ 5s(a ⁵ P)5p = 5pVI	



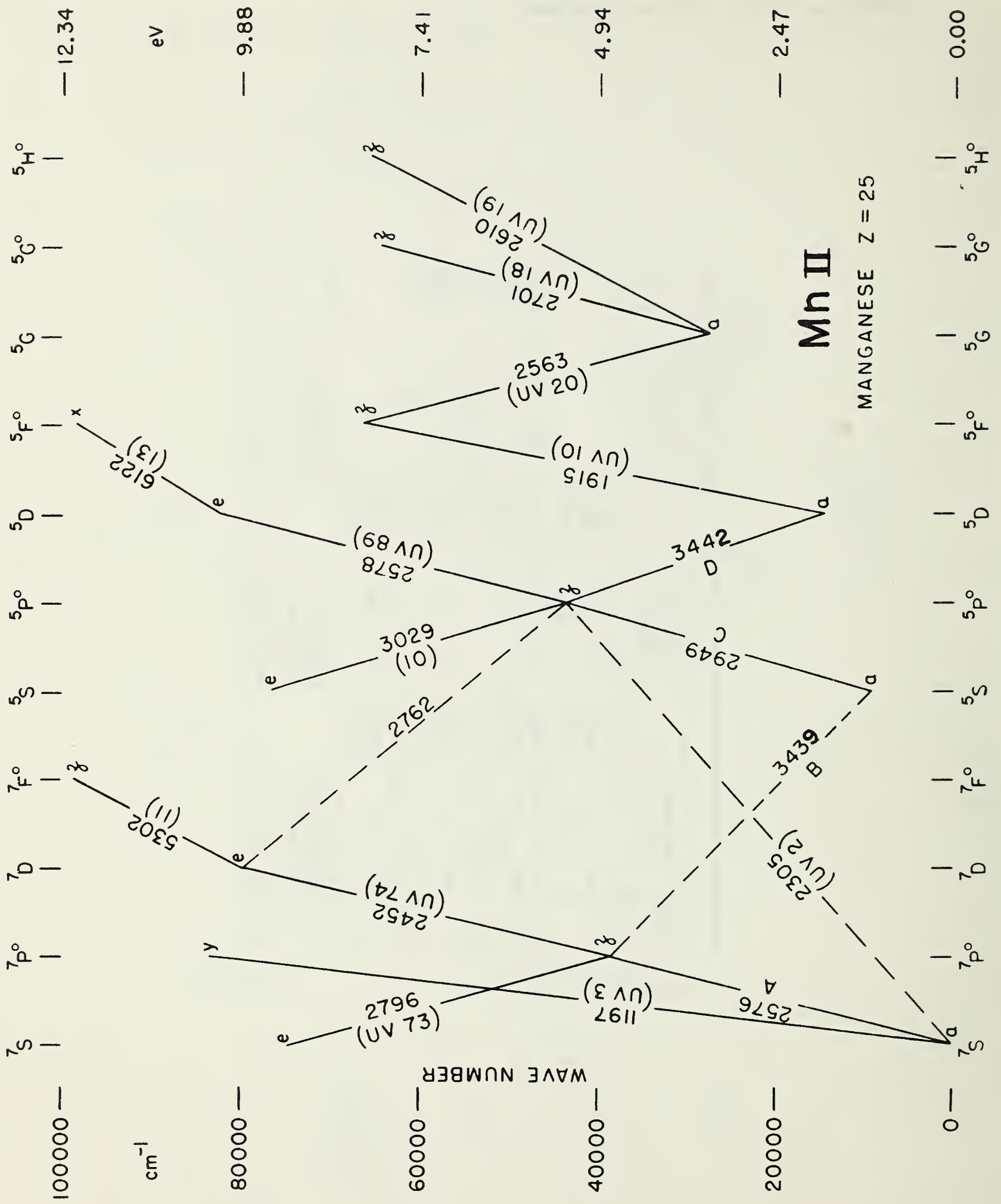
APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Cr II		Mo II	
	Mult. no.	Mult. desig.	Mult. no.	Mult. desig.
A.....	a	4D	z	$^4P^\circ$
	4s	4p		
	(3)		(3)	
B	a	4D	z	$^6D^\circ$
	4s	4p	5s	5p
	(4)		(4)	
C	a	4D	z	$^4F^\circ$
	4s	4p	5s	5p
	(5)		(5)	
D	a	4D	z	$^4D^\circ$
	4s	4p	5s	5p
	(UV 11)		(6)	
	$3d^4(a^5D)4s = 4s$		$4d^4(a^5D)5s = 5s$	
	$3d^4(a^5D)4p = 4p$		$4d^4(a^5D)5p = 5p$	



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

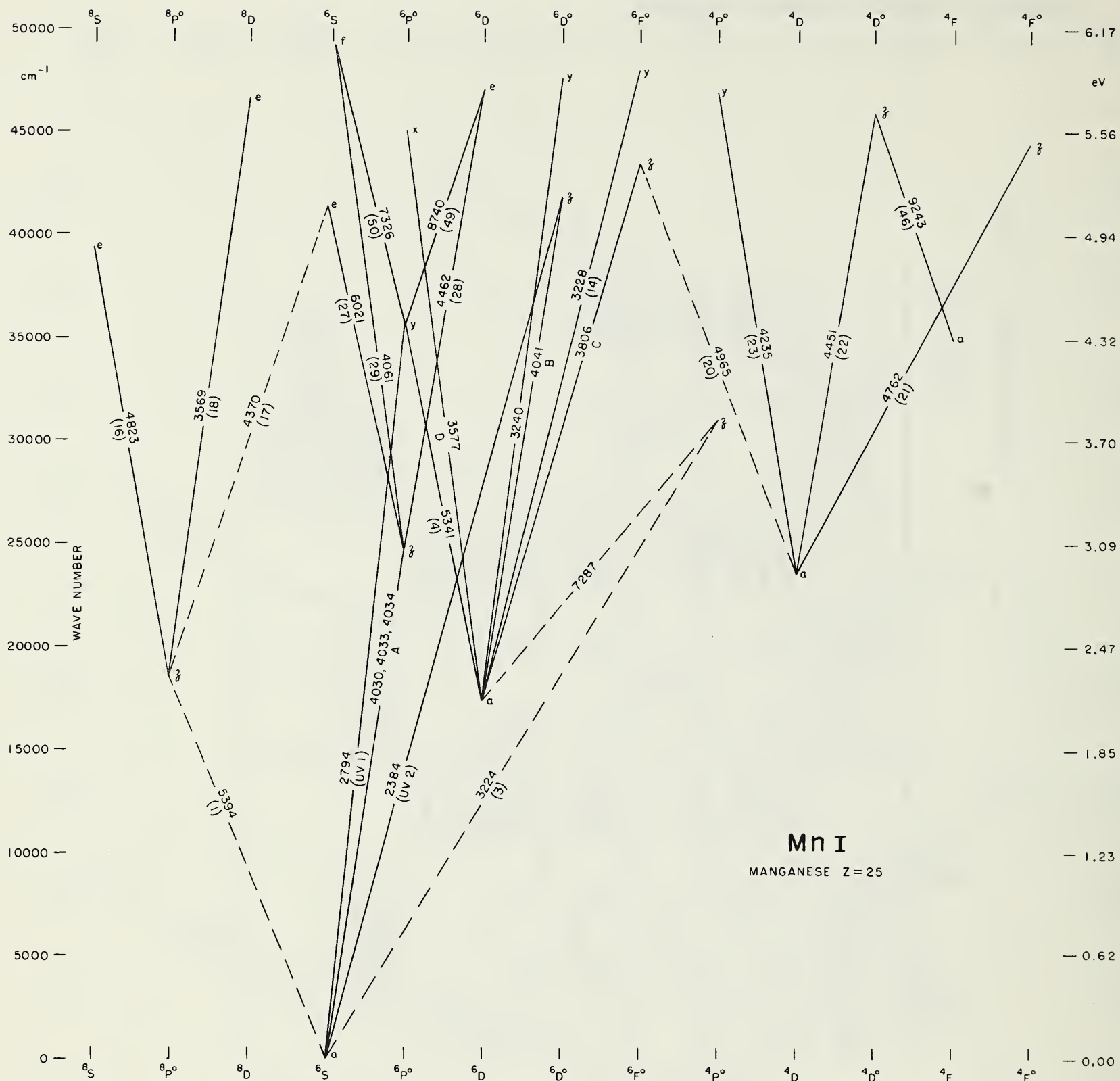
Key letter	Cr I		Mo I		W I	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a $7S - z$ $7P^\circ$ 4s 4p (1)	4254.3 4274.8 4289.7	a $7S - z$ $7P^\circ$ 5s 5p (1)	3798.3 3864.1 3903.0		
B	a $7S - z$ $7D^\circ$ 4s 4p' (3)	3615.6 3635.3 (3651.0P)	a $7S - z$ $7D^\circ$ 5s 5p' (2)	3112.1 3158.2 3208.8	d^5s $7S - d^4sp$ $7D^\circ$ 6s' 6p (7)	3868.0 4302.1 4757.6
C	a $7S - y$ $7P^\circ$ 4s 4p' (4)	3578.7 3593.5 3605.3	a $7S - y$ $7P^\circ$ 5s 5p' (3)	3132.6 3170.3 3194.0	d^5s $7S - d^4sp$ $7P^\circ$ 6s' 6p (6)	4008.8 4074.4 4294.6
D	a $5S - z$ $5P^\circ$ 4s 4p (7)	5208.4 5206.0 5204.5	a $5S - z$ $5P^\circ$ 5s 5p (4)	5506.5 5533.0 5570.5		
	$3d^5(a^6S)4s = 4s$ $3d^5(a^6S)4p = 4p$ $3d^44s(a^6D)4p = 4p'$		$4d^5(a^6S)5s = 5s$ $4d^5(a^6S)5p = 5p$ $4d^45s(a^6D)5p = 5p'$		$5d^5(a^6S)6s = 6s'$ $5d^46s(a^6D)6p = 6p$	



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

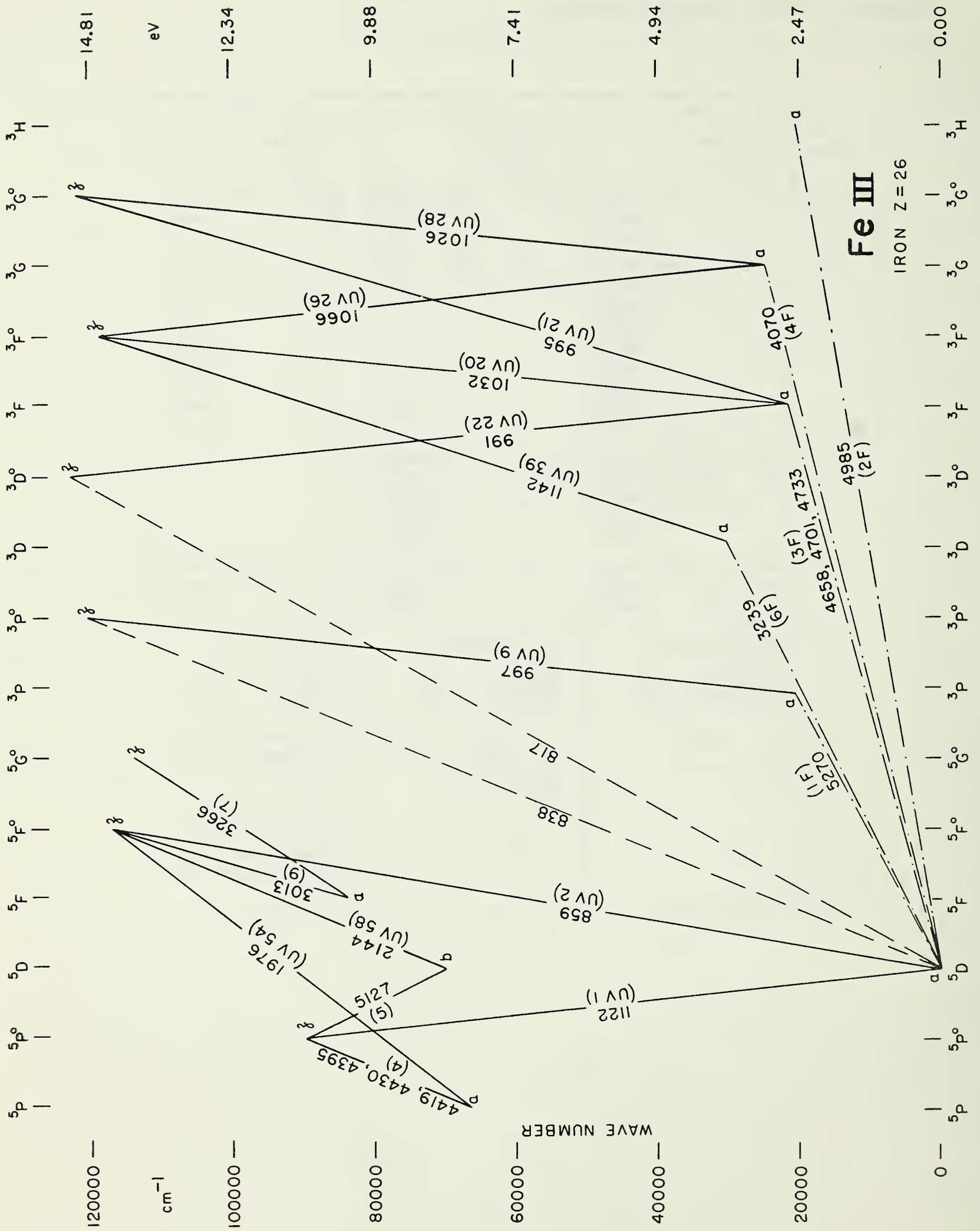
Key letter	Mn II		Tc II		Re II *	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a $7S - z 7p^\circ$ 4s (UV 1)	2576.1 2593.7 2605.7	a $7S - z 7p^\circ$ 5s	2543.2 2610.0 2647.0	a $7S - z 7p^\circ$ 6s	1973.1 2214.3 2275.2
B	a $5S - z 7p^\circ$ 4s (1)	3439.0 3460.0	a $5S - z 7p^\circ$ 5s	3892.1 3975.0	a $5S - z 7p^\circ$ 6s	3580.2 3742.3
C	a $5S - z 5p^\circ$ 4s (UV 5)	2949.2 2939.3 2933.1	a $5S - z 5p^\circ$ 5s	3237.0 3212.0 3195.2	a $5S - z 5p^\circ$ 6s	2733.0 2819.8 3103.2
D	a $5D - z 5p^\circ$ 3d ⁶ 4p (3)	3442.0 3460.3 3474.1 3474.0 3482.9 3488.7	a $5D - z 5p^\circ$ 4d ⁶ 5p	2496.8 2529.3 2547.9 2544.8 2558.6 2567.0		
	3d ⁵ (a $6S$)4s = 4s 3d ⁵ (a $6S$)4p = 4p		4d ⁵ ($6S$)5s = 5s 4d ⁵ ($6S$)5p = 5p		5d ⁵ ($6S$)6s = 6s 5d ⁵ ($6S$)6p = 6p	

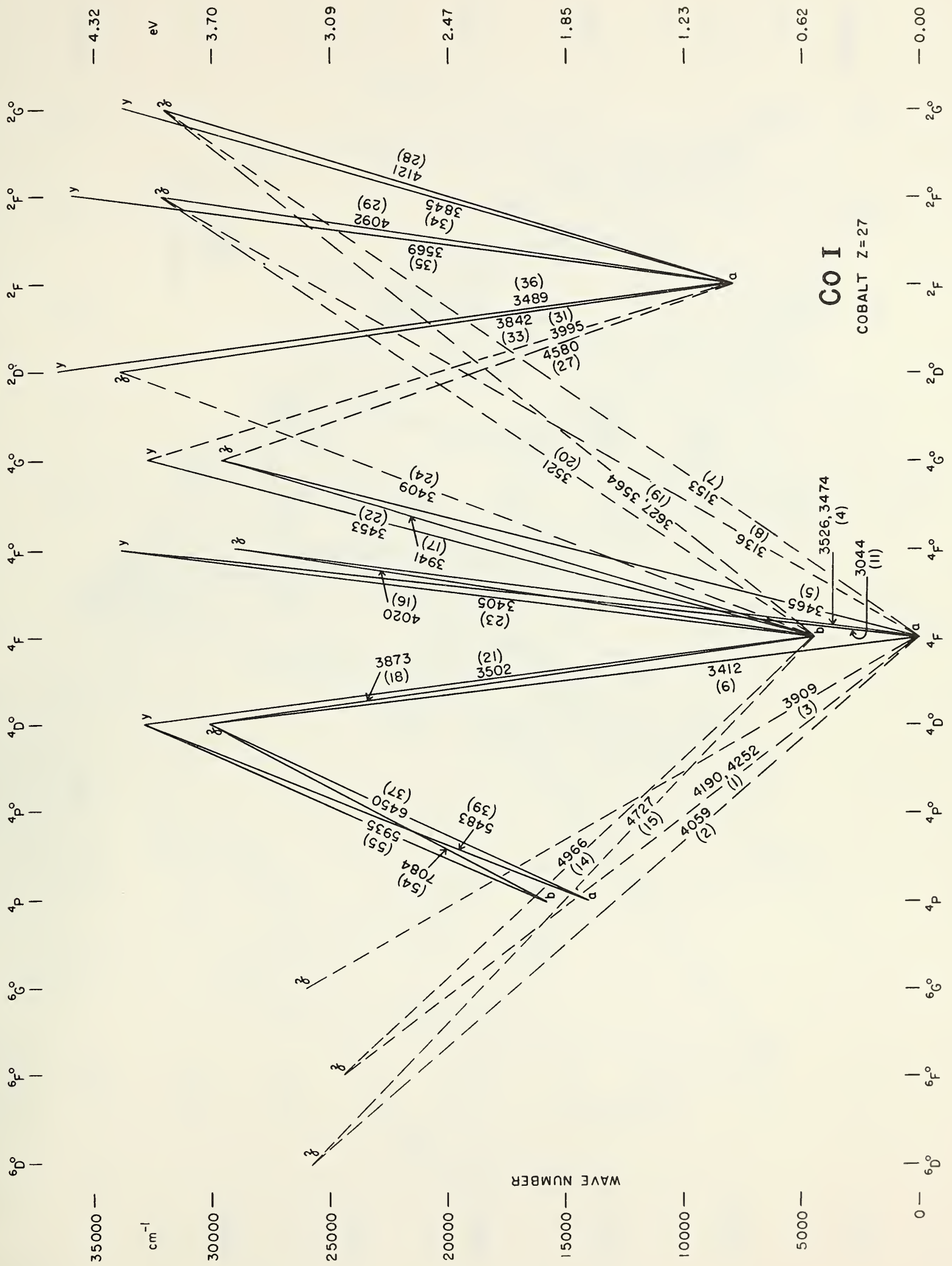
* Unpublished analysis by
W. F. Meggers, M. A.
Catalán, and M. Sales,
Dec. 1954.



APPENDIX A: PARTIAL GROTRIAN DIAGRAMS

Key letter	Mn I		Tc I #		Re I *	
	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ	Mult. desig. Mult. no.	λ
A	a 6S - z $^6P^\circ$ 4s ² 4p (2)	4030.8 4033.1 4034.5	a 6S - z $^6P^\circ$ 5s ² 5p	4297.1 4262.3 4238.2	a 6S - z $^6P^\circ$ 6s ² 6p	3460.5 3464.7 3451.9
B	a 6D - z $^6D^\circ$ 4s'' 4p'' (5)	4041.4 4055.5 4063.5 4018.1 4035.7 4048.8 4079.2 4083.6 4082.9	a 6D - z $^6D^\circ$ 5s'' 5p''	4031.6 4095.7 4124.2 3985.0 4049.1 4088.7 4145.0 4172.5 4176.3	a 6D - z $^6D^\circ$ 6s'' 6p''	4136.4 4923.9 5667.9 4391.3 (5209.1P) 5943.2 4605.7 5331.9 5852.8
C	a 6D - z $^6F^\circ$ 4s'' 4p'' (6)	3806.7 3823.5 3834.4 3841.1 3844.0	a 6D - z $^6F^\circ$ 5s'' 5p''	3636.1 3718.9 3746.9 3768.8 3779.4		
D	a 6D - x $^6P^\circ$ 4s'' 4p'' (8)	3577.9 3586.5 3595.1	a 6D - x $^6P^\circ$ 5s'' 5p''	3466.3 3550.7 3595.7	a 6D - x $^6P^\circ$ 6s'' 6p''	3399.3 3689.5 3876.9
	3d ⁵ 4s(a ⁷ S)4p = 4p 3d ⁶ (a ⁵ D)4s = 4s'' 3d ⁶ (a ⁵ D)4p = 4p''		4d ⁵ 5s(a ⁷ S)5p = 5p 4d ⁶ (a ⁵ D)5s = 5s'' 4d ⁶ (a ⁵ D)5p = 5p''		5d ⁵ 6s(a ⁷ S)6p = 6p 5d ⁶ (⁵ D)6s = 6s'' 5d ⁶ (⁵ D)6p = 6p''	
			# Tc I analysis from: W. F. Meggers, J. Res. Nat. Bur. Std. <u>47</u> , 7, RP 2221, 1951.		* Re I analysis from: W. F. Meggers, Bur. Std. J. Res. <u>6</u> , 1027, RP 322, 1931. P. F. A. Klinkenberg, Physica <u>13</u> , 581, 1947. R. Velasco, An. real. soc. esp. fis. y quim. <u>45</u> , 215, 1949.	





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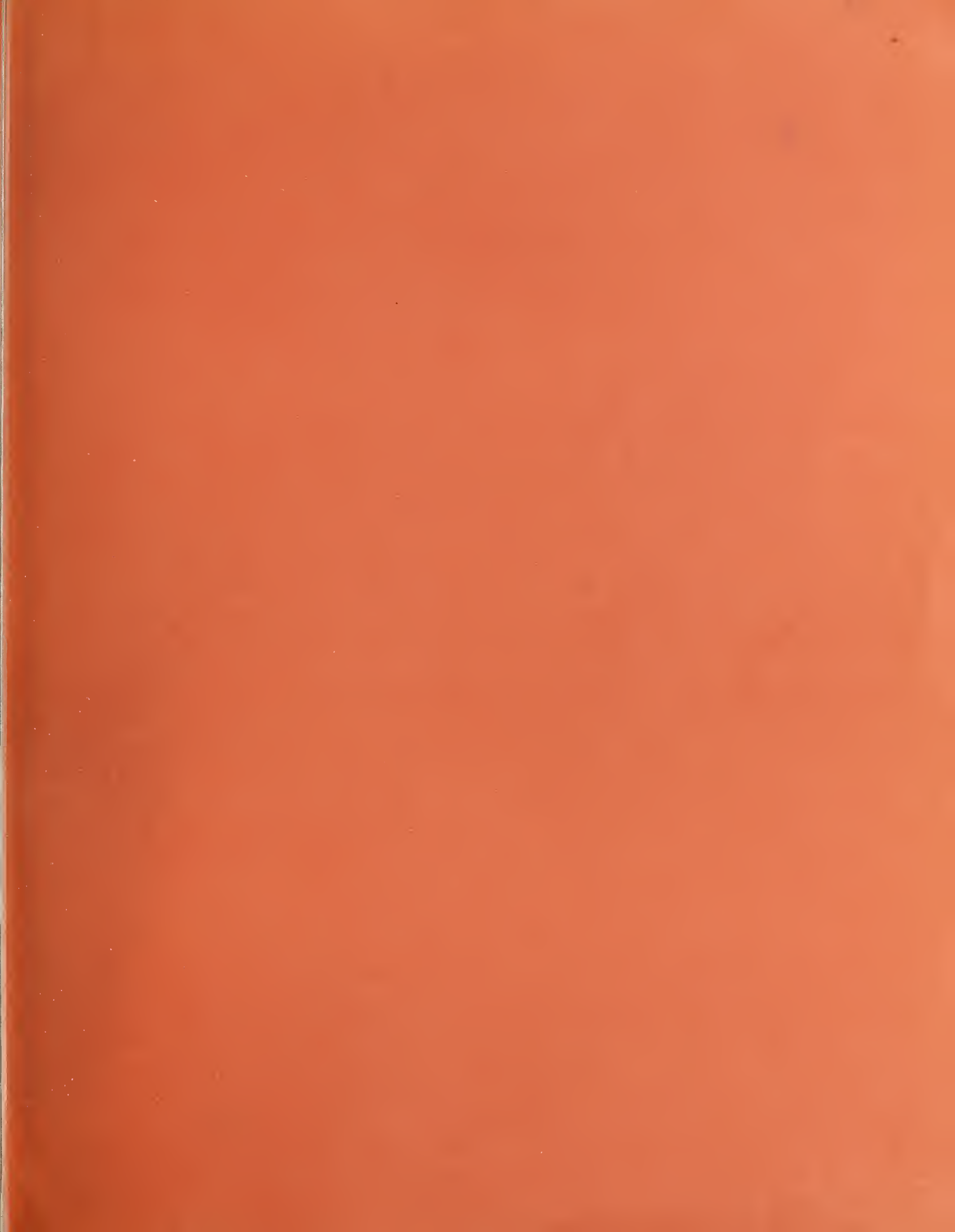
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