

ATOMIC ENERGY LEVELS and GROTRIAN DIAGRAMS

Volume I. Hydrogen I - Phosphorus XV

Stanley Bashkin
and
John O. Stoner, Jr.

ATOMIC ENERGY LEVELS and GROTRIAN DIAGRAMS

Volume I. Hydrogen I - Phosphorus XV

Stanley Bashkin
and
John O. Stoner, Jr.

Department of Physics, University of Arizona, Tucson, Arizona 85721



1975

NORTH-HOLLAND PUBLISHING COMPANY - AMSTERDAM. OXFORD
AMERICAN ELSEVIER PUBLISHING COMPANY, INC. - NEW YORK

© North-Holland Publishing Company - 1975.

All rights reserved. No part of this publication may be reproduced, stored in retrieval system, or transmitted, in any form of by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the copyright owner.

North-Holland ISBN: 0 7204 0322 7

American Elsevier ISBN: 0 444 10827 0

Published by:

North-Holland Publishing Company - Amsterdam

North-Holland Publishing Company, Ltd. - Oxford

Sole distributors for the U.S.A. and Canada:

American Elsevier Publishing Company, Inc.

52 Vanderbilt Avenue

New York, N.Y. 10017

INTRODUCTION

Energy-level and transition diagrams have been indispensable since their first appearance in the literature of atomic structure. The pioneering work by Grotrian¹ was so important that his name has since been associated with pictorial representations of electronic transitions. In the years following the publication of Grotrian's books, the growth of information was so rapid that subsequent compilations were restricted to special cases, such as transitions of interest to astrophysics, or transitions within a given range of wavelengths. However, our own experience suggested that a collation of all present information concerning electronic transitions in monatomic systems would be useful to the scientific community, and we have attempted to make such a collation.

Despite our concern with the entire area of atomic spectroscopy, we have found it necessary to exclude certain parts from our compilation. Thus we have largely neglected hyperfine effects, radio-frequency spectroscopy, and inner-shell transitions. We have used principally the information contained in the energy-level compilations by Moore² and Kelly,³ the spectral data in the publications by Kelly and Palumbo⁴ and by Striganov and Sventitskii,⁵ and a small number of papers not summarized in the foregoing works.

DIAGRAMS

The diagrams are of two kinds. One shows the energy levels, the other the electronic transitions and associated wavelengths.

a) Energy-Level Diagrams

The general format of these diagrams is quite standard — a level is represented by a short, horizontal line which is located by two coordinates. The ordinate is the level's energy, always given in inverse cm, and the abscissa indicates some combination of quantum numbers. With the exception of some hydrogenic and helium-like systems, the levels' energies are derived strictly from experimental spectra.

Preparation of these diagrams was hampered by the fact that there are numerous cases where different authors give different quantum numbers for the same level. We have simply used the values compiled by Kelly³ and kindly supplied by him from his unpublished work. In a few instances, Kelly himself lists two or more values for a given level. Here we have either taken the most recent data, or we have indicated by, “*see Kelly”, that a unique value has not yet been determined.

For the abscissa, we have used familiar combinations of spin and orbital angular momenta, in most cases, taking the final designation given by Kelly³ with a certain exception noted below. In a number of systems, there are discrepancies between the designations listed by Kelly³ and those used by Striganov and Sventitskii.⁵ For example, in Si I, Kelly describes many levels in terms of j, l or j, j coupling, whereas the other authors use LS coupling. We have followed Kelly and have transposed the designations of Ref. 5 into those given by Kelly.

The exception mentioned above is that we have adopted the “primed” symbols in Moore's tables,² whereas Kelly omits primes entirely. Sometimes Ref. 5 uses primes which do not conform to the pattern followed by Moore; we have used Moore's notation.

It became apparent with our first diagrams that the variety of levels is so great that no single format can serve to represent all of them. It was also clear that some level systems are too densely packed to permit inclusion of all the data. We have tried to exhibit each system

according to a format which seems best for it, sometimes avoiding any redundancy, and sometimes deliberately including duplicate information, so as to give a clear picture. When level densities are inconveniently high, we have indicated the topmost level and one or two below until the density is at such a value that all the lower levels can be shown. The level energy as derived from experiment is given to the full precision with which it is listed in the literature. However, some of the calculated levels are given with less precision than is stated in the original source.

In many ions, a number of different core configurations produce similar final configurations. Often a single diagram suffices for displaying all the levels, but there are also instances where each core contributes so many different configurations that each core is given a separate diagram. The cores are then indicated in the title and corner labels for the diagrams. Where different cores occur, they have been specifically defined on the diagrams.

Each level diagram contains a key which defines the various symbols. We include, as well, information on the ionization level, taken from Ref. 4, and the ground configurations of the ion and the next higher ion. The j,l and j,j intermediate coupling schemes are represented by different brackets, namely, $[]$ and $\{ \}$, respectively. *All level listings are in order of increasing excitation, and all j -values are in order of increasing excitation.* When intermediate coupling occurs, the intermediate-coupling angular momenta are shown in a vertical array, again, in order of increasing excitation, from bottom to top. While j -values are shown inside parentheses, we had to account for the fact that sometimes a single energy is listed for two or more different values of j . For example, the $3d\ ^4D$ term of Na V is listed as:

$$\begin{array}{l} 797270 \\ 797060 \end{array} \text{-----} 3d\ (15/2, 3/2),\ 1/2),$$

which means that the lower number is common to the first two j -values and the upper number belongs to $j = 1/2$.

The ionization level is shown as a horizontal dashed line. The ionization level is simply the energy difference between the ground term and the bottom of the continuum for the terms having the ground-term core.

b) Grotrian Diagrams

Diagrams showing transitions from one spectroscopic term to another are called, "Grotrian Diagrams". We have shown most of the transitions listed by Kelly and Palumbo⁴ and by Striganov and Sventitskii,⁵ as well as a few others taken from more recent publications. Sometimes the line density is too great for every line to be drawn with clarity. In such cases, we have shown the line of shortest wavelength, and as many of the others as could be done conveniently. The decision as to what to omit was arbitrary. In a number of instances, the Grotrian diagram was divided into two or more. In most instances, but not all, the same energy scale has been used for the Grotrian and energy-level diagrams.

The precision with which wavelengths have been measured is often gratifyingly high, but it was impossible to incorporate the full precision into our pictures. We have usually given wavelengths with one significant figure less than that in the literature, but there are a few cases, especially for systems drawn in the early days of this project, where all decimals have been omitted. When there are two lines in a multiplet, two numbers are given, separated by a comma; when there are more than two lines, the extreme wavelengths are given, separated by a dash. Wavelengths are in vacuum for values shorter than 2000 Å, and in air for longer values.

FUTURE WORK

We are extending the present work into the elements of higher atomic number. Drawings for the second volume are now in preparation. In addition, we hope to make revisions of the present drawings as corrections, new information, and other improvements are brought to our attention. We look forward to receiving comments from the scientific community.

SOURCES

The bibliography which is given for each stage of ionization is to be taken as an addition to the general references which are listed below. For those stages of ionization for which no bibliography appears, the information was taken entirely from the following references. Occasionally, a research paper has been identified on a particular energy-level or Grotrian diagram.

The general references are:

1. W. Grotrian, *Graphische Darstellung der Spektren*, J. Springer (Berlin 1923).
2. C.E. Moore, *Atomic Energy Levels*, Circular 467, National Bureau of Standards, Vol. 1 (1949), reprinted as NSRDS-NBS 35, Vol. 1.
3. R.L. Kelly, *Tabulation of Energy Levels for Atoms and Ions*, unpublished.
4. R.L. Kelly and L.J. Palumbo, *Atomic and Ionic Emission Lines Below 2000 Angstroms, Hydrogen Through Krypton*, (U.S. Govt. Printing Office, Washington, D.C., Stock No. 0851-00061, 1973).
5. A.R. Striganov and N.S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, IFI/Plenum (New York, 1968).
6. C.E. Moore and P.W. Merrill, *Partial Grotrian Diagrams of Astrophysical Interest*, Appendix A of *Lines of the Chemical Elements in Astronomical Spectra*, (Carnegie Institution of Washington Publication 610, 1958 - reprinted as NSRDS-NBS-23).

ACKNOWLEDGEMENTS

Most of the drawing and much of the assembly of bibliographies were carried out by undergraduate students and drafting assistants, nearly all of them as part-time helpers. Chief among those who had significant responsibility for the final preparation of the drawings were Christopher Hogg, John Howe, and Frank Ripley. Others in the group included: D. Abels, R. Bright, F. Camacho, A. Carlin, J. Enz, M. Ferrer, M. Gizzi, S. Heising, E. Ikeda, R. Johnson, E. Jones, G. Lim, B. Littlefield, R. Lundin, E. Meinel, R. Sherry, J. Slightom, W. Tilton, D. Toy, G. Westland, P. Wittman, R. Wong. The cover was designed by J. Howe.

We owe special thanks to the many investigators who sent us line lists and partial diagrams, often in advance of publication. Our debt to Dr. Raymond Kelly in this respect is large indeed.

Useful suggestions were also received from W.S. Bickel, J.D. Garcia, J.A. Leavitt, W.C. Martin, L.J. Radziemski, Jr., and others. All of the secretarial work was done by Mrs. Lois Davis.

Financial support was received from the U.S. Air Force, NASA, ONR, and NSF.

List of Illustrations

Please note that there has been some deliberate duplication of energy level and Grotrian diagrams. This has been done especially when the transitions have been divided among a number of Grotrian diagrams, for this arrangement permits one to see the level scheme that is appropriate for each of the Grotrian diagrams. In one case in N IV it was found convenient to use separate drawings for the singlet energy levels but one Grotrian diagram. Consequently, that Grotrian diagram appears twice.

H I	Grotrian Diagram. Doublets.	2
	Energy Levels. Doublets.	3
	Energy Levels. Fine Structure, Hyperfine Structure, Lamb Shifts, $n = 1, 2, 3, 4$.	5
He I	Grotrian Diagram. Singlets and Triplets.	8
	Energy Levels. Singlets and Triplets.	9
	Grotrian Diagram. Doubly-Excited Singlets and Triplets.	10
	Energy Levels. Doubly-Excited Singlets and Triplets.	11
He II	Grotrian Diagram. Doublets.	12
	Energy Levels. Doublets.	13
Li I	Grotrian Diagram. Doublets.	16
	Energy Levels. Doublets.	17
	Grotrian Diagram. Doubly-Excited Quartets.	18
	Energy Levels. Doubly-Excited Quartets.	19
Li II	Grotrian Diagram. Singlets and Triplets.	20
	Energy Levels. Singlets and Triplets.	21
Li III	Grotrian Diagram. Doublets.	22
	Energy Levels. Doublets.	23
Be I	Grotrian Diagram. Singlets.	28
	Energy Levels. Singlets.	29
	Grotrian Diagram. Triplets.	30
	Energy Levels. Triplets.	31
Be II	Grotrian Diagram. Doublets.	32
	Energy Levels. Doublets.	33
	Grotrian Diagram. Doubly-Excited Quartets.	34
	Energy Levels. Doubly-Excited Quartets.	35
Be III	Grotrian Diagram. Singlets and Triplets.	36
	Energy Levels. Singlets and Triplets.	37
Be IV	Grotrian Diagram. Doublets.	38
	Energy Levels. Doublets.	39
B I	Grotrian Diagram. Doublets and Quartets.	42
	Energy Levels. Doublets and Quartets.	43
B II	Grotrian Diagram. Singlets.	44
	Energy Levels. Singlets.	45
	Grotrian Diagram. Triplets.	46
	Energy Levels. Triplets.	47
B III	Grotrian Diagram. Doublets.	48
	Energy Levels. Doublets.	49
B IV	Grotrian Diagram. Singlets and Triplets.	50
	Energy Levels. Singlets and Triplets.	51
B V	Grotrian Diagram. Doublets.	52
	Energy Levels. Doublets.	53

C I	Grotrian Diagram. Singlets.	56
	Energy Levels. Singlets.	57
	Grotrian Diagram. Triplets and Quintets. Transitions from the Ground Term to Excited Triplets and Quintets.	58
	Energy Levels. Triplets and Quintets.	59
	Grotrian Diagram. Triplets and Quintets. Transitions from $3s^3P^o$, $2s2p^3D^o$, and $3p^3D$ to Higher Triplets: Quintet-Quintet Transitions.	60
	Energy Levels. Triplets and Quintets.	61
	Grotrian Diagram. Triplets. Transitions from $2s^22p3p^3S$, $2s^22p3p^3P$, and $2s2p^3P^o$ to Higher Triplets.	62
	Energy Levels. Triplets and Quintets.	63
	Energy Levels. Intermediate Coupling and Autoionizing Terms.	65
	Grotrian Diagram. Intercombinations. Transitions between Singlets and Triplets.	66
	Grotrian Diagram. Intercombinations. Transitions between Singlets and Intermediate-Coupling Terms.	68
	Grotrian Diagram. Intercombinations. Transitions from the Ground Term to Excited Singlets and Quintets.	70
	Grotrian Diagram. Intercombinations. Transitions between Excited Triplet Terms and Higher Singlets and Intermediate-Coupling Terms.	72
C II	Grotrian Diagram. Doublets.	74
	Energy Levels. Doublets.	75
	Grotrian Diagram. Quartets.	76
	Energy Levels. Quartets.	77
	Grotrian Diagram. Intercombinations. Transitions between Doublets and Quartets.	78
C III	Grotrian Diagram. Singlets.	80
	Energy Levels. Singlets.	81
	Grotrian Diagram. Triplets, $1s^22snl$ Terms.	82
	Energy levels. Triplets, $1s^22snl$ Terms.	83
	Grotrian Diagram. Triplets, $1s^22pnl$ Terms.	84
	Energy Levels. Triplets, $1s^22pnl$ Terms.	85
	Grotrian Diagram. Intercombinations. Transitions between $1s^22snl$ Triplets and $1s^22pnl$ Triplets.	86
C IV	Grotrian Diagram. Doublets.	88
	Energy Levels. Doublets.	89
	Grotrian Diagram. Doubly-Excited Quartets.	90
	Energy Levels. Doubly-Excited Quartets.	91
C V	Grotrian Diagram. Singlets.	92
	Energy Levels. Singlets.	93
	Grotrian Diagram. Triplets.	94
	Energy Levels. Triplets.	95
C VI	Grotrian Diagram. Doublets.	96
	Energy Levels. Doublets.	97
N I	Grotrian Diagram. Doublets. Transitions from $2p^2D^o$ to Higher Doublets.	100
	Energy Levels. Doublets.	101
	Grotrian Diagram. Doublets. Transitions from $2p^2P^o$ to Higher Doublets.	102
	Energy Levels. Doublets.	103
	Grotrian Diagram. Doublets. Transitions from Doublets with $n = 3$ to Higher Doublets.	104
	Energy Levels. Doublets.	105
	Grotrian Diagram. Quartets and Sextets.	106
	Energy Levels. Quartets and Sextets.	107
	Energy Levels. Intermediate Coupling.	109
	Grotrian Diagram. Intercombinations. Transitions from Doublets to Quartets.	110
	Grotrian Diagram. Intercombinations. Transitions from Quartets to Doublets.	112
	Grotrian Diagram. Intercombinations. Transitions from Doublets and Quartets to Intermediate-Coupling Terms.	114

N II	Grotrian Diagram. Singlets.	116
	Energy Levels. Singlets.	117
	Grotrian Diagram. Triplets.	118
	Energy Levels. Triplets.	119
	Grotrian Diagram. Quintets.	120
	Energy Levels. Quintets.	121
	Grotrian Diagram. Intermediate Coupling.	122
	Energy Levels. Intermediate Coupling.	123
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Triplets.	124
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Intermediate-Coupling Terms.	126
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Singlets.	128
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Quintets and Intermediate-Coupling Terms.	130
N III	Grotrian Diagram. Doublets.	132
	Energy Levels. Doublets.	133
	Grotrian Diagram. Quartets.	134
	Energy Levels. Quartets.	135
	Grotrian Diagram. Intercombinations. Transitions between Doublets and Quartets.	136
N IV	Grotrian Diagram. Singlets. Both $1s^2 2s nl$ Terms and $1s^2 2p nl$ Terms.	138
	Energy Levels. Singlets, $1s^2 2s nl$ Terms.	139
	Grotrian Diagram. Singlets. Both $1s^2 2s nl$ Terms and $1s^2 2p nl$ Terms.	140
	Energy Levels. Singlets, $1s^2 2p nl$ Terms.	141
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s nl$ Terms.	142
	Energy Levels. Triplets, $1s^2 2s nl$ Terms.	143
	Grotrian Diagram. Triplets. Transitions between $1s^2 2p nl$ Terms.	144
	Energy Levels. Triplets, $1s^2 2p nl$ Terms.	145
	Grotrian Diagram. Intercombinations. Transitions between $1s^2 2s nl$ Triplet Terms and $1s^2 2p nl$ Triplet Terms.	146
N V	Grotrian Diagram. Doublets.	148
	Energy Levels. Doublets.	149
N VI	Grotrian Diagram. Singlets and Triplets.	150
	Energy Levels. Singlets and Triplets.	151
N VII	Grotrian Diagram. Doublets.	152
	Energy Levels. Doublets.	153
O I	Grotrian Diagram. Singlets.	158
	Energy Levels. Singlets.	159
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	160
	Energy Levels. Triplets, $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	161
	Grotrian Diagram and Energy Levels. Autoionizing Triplets, $1s^2 2s^2 2p^3 (^2P^o) nl$ Terms.	163
	Grotrian Diagram. Triplets and Quintets. Transitions between $1s^2 2s^2 2p^3 (^4S^o) nl$ Terms.	164
	Energy Levels. Triplets and Quintets. $1s^2 2s^2 2p^3 (^4S^o) nl$ Terms.	165
	Grotrian Diagram. Intercombinations. Transitions between Triplets with $(^4S^o)$, $(^2P^o)$, and $(^2D^o)$ Cores.	166
O II	Grotrian Diagram. Doublets.	168
	Energy Levels. Doublets.	169
	Grotrian Diagram. Quartets.	170
	Energy Levels. Quartets.	171
	Grotrian Diagram. Sextets.	172
	Energy Levels. Sextets.	173
	Grotrian Diagram. Intercombinations. Transitions between Doublets and Quartets.	174

O III	Grotrian Diagram. Singlets.	176
	Energy Levels. Singlets.	177
	Grotrian Diagram. Triplets.	178
	Energy Levels. Triplets.	179
	Grotrian Diagram. Quintets.	180
	Energy Levels. Quintets and Intermediate-Coupling Terms.	181
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Higher Triplets and Intermediate-Coupling Terms.	182
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Higher Singlets and Intermediate-Coupling Terms.	184
O IV	Grotrian Diagram. Doublets.	186
	Energy Levels. Doublets.	187
	Grotrian Diagram. Quartets.	188
	Energy Levels. Quartets.	189
O V	Grotrian Diagram. Singlets. Transitions between $1s^2 2s nl$ Terms.	190
	Energy Levels. Singlets, $1s^2 2s nl$ Terms.	191
	Grotrian Diagram. Singlets. Transitions between $1s^2 2p nl$ Terms.	192
	Energy Levels. Singlets, $1s^2 2p nl$ Terms.	193
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s nl$ Terms.	194
	Energy Levels. Triplets, $1s^2 2s nl$ Terms.	195
	Grotrian Diagram. Triplets. Transitions between $1s^2 2p nl$ Terms.	196
	Energy Levels. Triplets, $1s^2 2p nl$ Terms.	197
	Grotrian Diagram. Intercombinations. Transitions between $1s^2 2s nl$ Singlets and $1s^2 2p nl$ Singlets.	198
	Grotrian Diagram. Intercombinations. Transitions between $1s^2 2s nl$ Triplet Terms and $1s^2 2p nl$ Triplet Terms.	200
O VI	Grotrian Diagram. Doublets.	202
	Energy Levels. Doublets.	203
O VII	Grotrian Diagram. Singlets and Triplets.	204
	Energy Levels. Singlets and Triplets.	205
O VIII	Grotrian Diagram. Doublets.	206
	Energy Levels. Doublets.	207
F I	Grotrian Diagram. Doublets.	212
	Energy Levels. Doublets.	213
	Grotrian Diagram. Quartets.	214
	Energy Levels. Quartets.	215
	Grotrian Diagram. Intercombinations. Transitions from Doublets to Higher Quartets.	216
	Grotrian Diagram. Intercombinations. Transitions from Quartets to Higher Doublets.	218
F II	Grotrian Diagram. Singlets. Transitions between $1s^2 2s^2 2p^3 (^2P^o) nl$ Terms.	220
	Energy Levels. Singlets, $1s^2 2s^2 2p^3 (^2P^o) nl$ Terms.	221
	Grotrian Diagram. Singlets. Transitions between $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	222
	Energy Levels. Singlets, $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	223
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s^2 2p^3 (^2P^o) nl$ Terms.	224
	Energy Levels. Triplets, $1s^2 2s^2 2p^3 (^2P^o) nl$ Terms.	225
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	226
	Energy Levels. Triplets, $1s^2 2s^2 2p^3 (^2D^o) nl$ Terms.	227
	Grotrian Diagram. Triplets. Transitions between $1s^2 2s^2 2p^3 (^4S^o) nl$ Terms.	228
	Energy Levels. Triplets, $1s^2 2s^2 2p^3 (^4S^o) nl$ Terms.	229
	Grotrian Diagram. Quintets.	230
	Energy Levels. Quintets.	231
	Energy Levels. Intermediate Coupling.	233
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Higher Singlets and Triplets.	234
	Grotrian Diagram. Intercombinations. Transitions from Triplets and Quintets to Higher Singlets and Triplets.	236

F III	Grotrian Diagram. Doublets. Transitions from $1s^2 2s^2 2p^3$ Terms to Higher Doublets.	238
	Energy Levels. Doublets.	239
	Grotrian Diagram. Doublets. Transitions from $1s^2 2p^4$ Terms to Higher Doublets.	240
	Energy Levels. Doublets, $1s^2 2s 2p^4 {}^2S$ and above.	241
	Grotrian Diagram. Doublets. Transitions between Excited Doublets Higher than $1s^2 2s^2 2p^2 3p {}^2D^o$.	242
	Energy Levels. Doublets Higher than $1s^2 2s 2p^4 {}^2S$.	243
	Grotrian Diagram. Quartets.	244
	Energy Levels. Quartets.	245
	Grotrian Diagram. Sextets.	246
	Energy Levels. Sextets, (${}^5S^o$) Core, and Intermediate-Coupling Terms, (1L) Core.	247
	Energy Levels. Intermediate-Coupling Terms, (3P) Core.	249
	Grotrian Diagram. Sextets and Intercombination Transitions Between Doublets and Quartets.	250
	Grotrian Diagram. Intercombinations. Transitions from Doublets to Higher Intermediate-Coupling Terms.	252
	Grotrian Diagram. Intercombinations. Transitions from Quartets to Higher Intermediate-Coupling Terms.	254
F IV	Grotrian Diagram. Singlets.	256
	Energy Levels. Singlets.	257
	Grotrian Diagram. Transitions from the Two Lowest Triplets to Higher Triplets.	258
	Energy Levels. Triplets.	259
	Grotrian Diagram. Transitions between Excited Triplets Higher than the Second Term.	260
	Energy Levels. Triplets.	261
	Grotrian Diagram. Quintets.	262
	Energy Levels. Quintets and Intermediate Coupling.	263
	Grotrian Diagram. Intercombinations. Transitions among Singlets, Triplets, and Intermediate-Coupling Terms.	264
F V	Grotrian Diagram. Doublets.	266
	Energy Levels. Doublets.	267
	Grotrian Diagram. Quartets.	268
	Energy Levels. Quartets.	269
F VI	Grotrian Diagram. Singlets.	270
	Energy Levels. Singlets.	271
	Grotrian Diagram. Triplets.	272
	Energy Levels. Triplets.	273
F VII	Grotrian Diagram. Doublets.	274
	Energy Levels. Doublets.	275
F VIII	Grotrian Diagram. Singlets and Triplets.	276
	Energy Levels. Singlets and Triplets.	277
F IX	Grotrian Diagram. Doublets.	278
	Energy Levels. Doublets.	279
Ne I	Grotrian Diagram. Transitions from the Ground Term to Higher Terms.	284
	Energy Levels.	285
	Grotrian Diagram. Transitions from Two Lowest Excited Terms to Higher Terms.	286
	Energy Levels.	287
	Grotrian Diagram. Transitions from the Third Excited Term to Higher Terms.	288
	Energy Levels.	289
	Grotrian Diagram. Transitions from the Fourth Excited Term to Higher Terms.	290
	Energy Levels.	291
	Grotrian Diagram. Transitions between Terms with $n \geq 4$.	292
	Energy Levels.	293

	Grotrian Diagram. High Intermediate Coupling.	294
	Energy Levels. High Intermediate Coupling.	295
	Grotrian Diagram. Doubly-Excited Terms. 3P Core.	296
	Energy Levels. Doubly-Excited Terms.	297
	Grotrian Diagram. Doubly-Excited Terms. 1D , 1S Cores.	298
	Energy Levels. Doubly-Excited Terms.	299
Ne II	Grotrian Diagram. Doublets.	300
	Energy Levels. Doublets.	301
	Grotrian Diagram. Quartets.	302
	Energy Levels. Quartets.	303
	Energy Levels. Intermediate-Coupling Terms.	305
	Grotrian Diagram. Intercombinations. Transitions from Doublets to Quartets.	306
	Grotrian Diagram. Intercombinations. Transitions from Quartets to Doublets and Intermediate-Coupling Terms.	308
Ne III	Grotrian Diagram. Singlets and Quintets.	310
	Energy Levels. Singlets and Quintets.	311
	Grotrian Diagram. Triplets.	312
	Energy Levels. Triplets.	313
Ne IV	Grotrian Diagram. Doublets.	314
	Energy Levels. Doublets.	315
	Grotrian Diagram. Quartets and Sextets.	316
	Energy Levels. Quartets and Sextets.	317
Ne V	Grotrian Diagram. Singlets.	318
	Energy Levels. Singlets.	319
	Grotrian Diagram. Triplets.	320
	Energy Levels. Triplets.	321
	Grotrian Diagram. Quintets.	322
	Energy Levels. Quintets.	323
Ne VI	Grotrian Diagram. Doublets.	324
	Energy Levels. Doublets.	325
	Grotrian Diagram. Quartets.	326
	Energy Levels. Quartets.	327
Ne VII	Grotrian Diagram. Singlets.	328
	Energy Levels. Singlets.	329
	Grotrian Diagram. Triplets.	330
	Energy Levels. Triplets.	331
Ne VIII	Grotrian Diagram. Doublets.	332
	Energy Levels. Doublets.	333
Ne IX	Grotrian Diagram. Singlets and Triplets.	334
	Energy Levels. Singlets and Triplets.	335
Ne X	Grotrian Diagram. Doublets.	336
	Energy Levels. Doublets.	337
Na I	Grotrian Diagram. Doublets.	342
	Energy Levels. Doublets.	343
Na II	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P_{1/2}^o$ Core.	344
	Energy Levels. Intermediate-Coupling Terms with $^2P_{1/2}^o$ Core.	345
	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P_{3/2}^o$ Core.	346
	Energy Levels. Intermediate-Coupling Terms with $^2P_{3/2}^o$ Core.	347
	Grotrian Diagram. Intercombinations. Transitions between $^2P_{1/2}^o$ and $^2P_{3/2}^o$ Cores.	348
Na III	Grotrian Diagram. Doublets.	350
	Energy Levels. Doublets.	351
	Grotrian Diagram. Quartets.	352
	Energy Levels. Quartets.	353
	Grotrian Diagram. Intercombinations. Transitions between Doublets and Quartets.	354

Na IV	Grotrian Diagram. Singlets.	356
	Energy Levels. Singlets.	357
	Grotrian Diagram. Triplets.	358
	Energy Levels. Triplets.	359
Na V	Grotrian Diagram. Doublets.	360
	Energy Levels. Doublets.	361
	Grotrian Diagram. Quartets.	362
	Energy Levels. Quartets.	363
Na VI	Grotrian Diagram. Singlets.	364
	Energy Levels. Singlets.	365
	Grotrian Diagram. Triplets.	366
	Energy Levels. Triplets.	367
	Grotrian Diagram. Quintets.	368
	Energy Levels. Quintets.	369
Na VII	Grotrian Diagram. Doublets.	370
	Energy Levels. Doublets.	371
	Grotrian Diagram. Quartets.	372
	Energy Levels. Quartets.	373
Na VIII	Grotrian Diagram. Singlets.	374
	Energy Levels. Singlets.	375
	Grotrian Diagram. Triplets.	376
	Energy Levels. Triplets.	377
Na IX	Grotrian Diagram. Doublets.	378
	Energy Levels. Doublets.	379
Na X	Grotrian Diagram. Singlets and Triplets.	380
	Energy Levels. Singlets and Triplets.	381
Na XI	Grotrian Diagram. Doublets.	382
	Energy Levels. Doublets.	383
Mg I	Grotrian Diagram. Singlets and Triplets.	388
	Energy Levels. Singlets and Triplets.	389
Mg II	Grotrian Diagram. Doublets.	390
	Energy Levels. Doublets.	391
Mg III	Grotrian Diagram. Singlets and Triplets.	392
	Energy Levels. Singlets and Triplets.	393
	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P_{1/2}^{\circ}$ Core.	394
	Energy Levels. Intermediate-Coupling Terms with $^2P_{1/2}^{\circ}$ Core.	395
	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P_{3/2}^{\circ}$ Core.	396
	Energy Levels. Intermediate-Coupling Terms with $^2P_{3/2}^{\circ}$ Core.	397
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Intermediate-Coupling Terms.	398
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Intermediate-Coupling Terms.	400
Mg IV	Grotrian Diagram. Doublets.	402
	Energy Levels. Doublets.	403
	Grotrian Diagram. Quartets.	404
	Energy Levels. Quartets.	405
	Grotrian Diagram. Intercombinations. Transitions between Doublets and Quartets.	406
Mg V	Grotrian Diagram. Singlets.	408
	Energy Levels. Singlets.	409
	Grotrian Diagram. Triplets.	410
	Energy Levels. Triplets.	411

Mg VI	Grotrian Diagram. Doublets.	412
	Energy Levels. Doublets.	413
	Grotrian Diagram. Quartets.	414
	Energy Levels. Quartets.	415
Mg VII	Grotrian Diagram. Singlets.	416
	Energy Levels. Singlets.	417
	Grotrian Diagram. Triplets.	418
	Energy Levels. Triplets.	419
	Grotrian Diagram. Quintets.	420
	Energy Levels. Quintets.	421
Mg VIII	Grotrian Diagram. Doublets.	422
	Energy Levels. Doublets.	423
	Grotrian Diagram. Quartets.	424
	Energy Levels. Quartets.	425
Mg IX	Grotrian Diagram. Singlets.	426
	Energy Levels. Singlets.	427
	Grotrian Diagram. Triplets.	428
	Energy Levels. Triplets.	429
Mg X	Grotrian Diagram. Doublets.	430
	Energy Levels. Doublets.	431
Mg XI	Grotrian Diagram. Singlets and Triplets.	432
	Energy Levels. Singlets and Triplets.	433
Mg XII	Grotrian Diagram. Doublets.	434
	Energy Levels. Doublets.	435
Al I	Grotrian Diagram. Doublets and Quartets. Transitions from the Two Lowest Terms to Higher Terms.	440
	Energy Levels. Doublets and Quartets.	441
	Grotrian Diagram. Doublets and Quartets. Transitions from the Lowest Quartet to Higher Terms.	442
	Energy Levels. Doublets and Quartets.	443
Al II	Grotrian Diagram. Singlets. Transitions from the Three Lowest Singlets to Higher Terms.	444
	Energy Levels. Singlets.	445
	Grotrian Diagram. Singlets. Transitions from Singlets with $n = 4$ to Higher Singlets.	446
	Energy Levels. Singlets.	447
	Grotrian Diagram. Singlets. Transitions from $3d\ ^1D$ and Terms with $n \geq 5$ to Higher Singlets.	448
	Energy Levels. Singlets.	449
	Grotrian Diagram. Triplets. Transitions from the First, Second, and Fourth Lowest Triplets to Higher Triplets.	450
	Energy Levels. Triplets.	451
	Grotrian Diagram. Triplets. Transitions from $3p\ ^3P$ or Terms $\geq 4p\ ^3P^o$ to Higher Terms.	452
	Energy Levels. Triplets.	453
Al III	Grotrian Diagram. Doublets.	454
	Energy Levels. Doublets.	455
Al IV	Grotrian Diagram. Intermediate-Coupling and Autoionizing Terms.	456
	Energy Levels. Intermediate-Coupling and Autoionizing Terms.	457
Al V	Grotrian Diagram. Doublets and Quartets.	458
	Energy Levels. Doublets and Quartets.	459
Al VI	Grotrian Diagram. Singlets.	460
	Energy Levels. Singlets.	461
	Grotrian Diagram. Triplets.	462
	Energy Levels. Triplets.	463

Al VII	Grotrian Diagram. Doublets.	464
	Energy Levels. Doublets.	465
	Grotrian Diagram. Quartets.	466
	Energy Levels. Quartets.	467
Al VIII	Grotrian Diagram. Singlets and Quintets.	468
	Energy Levels. Singlets and Quintets.	469
	Grotrian Diagram. Triplets.	470
	Energy Levels. Triplets.	471
Al IX	Grotrian Diagram. Doublets.	472
	Energy Levels. Doublets.	473
	Grotrian Diagram. Quartets.	474
	Energy Levels. Quartets.	475
Al X	Grotrian Diagram. Singlets.	476
	Energy Levels. Singlets.	477
	Grotrian Diagram. Triplets.	478
	Energy Levels. Triplets.	479
Al XI	Grotrian Diagram. Doublets.	480
	Energy Levels. Doublets.	481
Al XII	Grotrian Diagram. Singlets and Triplets.	482
	Energy Levels. Singlets and Triplets.	483
Al XIII	Grotrian Diagram. Doublets.	484
	Energy Levels. Doublets.	485
Si I	Grotrian Diagram. Singlets.	490
	Energy Levels. Singlets.	491
	Grotrian Diagram. Triplets and Quintets. Transitions from the Ground to Excited Terms.	492
	Energy Levels. Triplets and Quintets.	493
	Grotrian Diagram. Triplets and Quintets. Transitions between Excited Terms.	494
	Energy Levels. Triplets and Quintets.	495
	Energy Levels. Intermediate-Coupling Terms.	496
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Triplets.	498
	Grotrian Diagram. Intercombinations. Transitions from Singlets to Intermediate-Coupling Terms.	500
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Singlets.	502
	Grotrian Diagram. Intercombinations. Transitions from Triplets to Intermediate-Coupling Terms.	504
Si II	Grotrian Diagram. Doublets.	506
	Energy Levels. Doublets.	507
	Grotrian Diagram. Quartets.	508
	Energy Levels. Quartets.	509
Si III	Grotrian Diagram. Singlets. Transitions from the Lowest Four Singlets to Higher Singlets.	510
	Energy Levels. Singlets.	511
	Grotrian Diagram. Transitions from the $4s^1S$ Term to Higher Singlets.	512
	Energy Levels. Singlets.	513
	Grotrian Diagram. Triplets. Transitions from Triplets with $n = 3$ to Higher Triplets.	514
	Energy Levels. Triplets.	515
	Grotrian Diagram. Triplets. Transitions between Triplets with $n \geq 4$.	516
	Energy Levels. Triplets.	517
	Grotrian Diagram. Intermediate-Coupling Terms.	518
	Energy Levels. Intermediate-Coupling Terms.	519
Si IV	Grotrian Diagram. Doublets.	520
	Energy Levels. Doublets.	521
Si V	Grotrian Diagram. Intermediate Coupling.	522
	Energy Levels. Intermediate Coupling.	523

Si VI	Grotrian Diagram, Doublets.	524
	Energy Levels, Doublets.	525
	Energy Levels, Quartets.	527
Si VII	Grotrian Diagram, Singlets.	528
	Energy Levels, Singlets.	529
	Grotrian Diagram, Triplets.	530
	Energy Levels, Triplets.	531
	Grotrian Diagram, Intercombinations, Transitions between Singlets and Triplets.	532
Si VIII	Grotrian Diagram, Doublets.	534
	Energy Levels, Doublets.	535
	Grotrian Diagram, Quartets.	536
	Energy Levels, Quartets.	537
Si IX	Grotrian Diagram, Singlets and Quintets.	538
	Energy Levels, Singlets and Quintets.	539
	Grotrian Diagram, Triplets.	540
	Energy Levels, Triplets.	541
Si X	Grotrian Diagram, Doublets.	542
	Energy Levels, Doublets.	543
	Grotrian Diagram, Quartets.	544
	Energy Levels, Quartets.	545
Si XI	Grotrian Diagram, Singlets.	546
	Energy Levels, Singlets.	547
	Grotrian Diagram, Triplets.	548
	Energy Levels, Triplets.	549
Si XII	Grotrian Diagram, Doublets.	550
	Energy Levels, Doublets.	551
Si XIII	Grotrian Diagram, Singlets and Triplets.	552
	Energy Levels, Singlets and Triplets.	553
Si XIV	Grotrian Diagram, Doublets.	554
	Energy Levels, Doublets.	555
P I	Grotrian Diagram, Doublets.	560
	Energy Levels, Doublets.	561
	Grotrian Diagram, Quartets.	562
	Energy Levels, Quartets.	563
	Grotrian Diagram, Intercombinations, Transitions from Doublets to Quartets.	564
	Grotrian Diagram, Intercombinations, Transitions from Quartets to Doublets.	566
P II	Grotrian Diagram, Singlets and Quintets.	568
	Energy Levels, Singlets and Quintets.	569
	Grotrian Diagram, Triplets.	570
	Energy Levels, Triplets.	571
	Grotrian Diagram, Intercombinations, Transitions between Singlets and Triplets.	572
P III	Grotrian Diagram, Doublets.	574
	Energy Levels, Doublets.	575
	Grotrian Diagram, Quartets.	576
	Energy Levels, Quartets.	577
P IV	Grotrian Diagram, Singlets.	578
	Energy Levels, Singlets.	579
	Grotrian Diagram, Triplets.	580
	Energy Levels, Triplets.	581
P V	Grotrian Diagram, Doublets.	582
	Energy Levels, Doublets.	583
P VI	Grotrian Diagram, Singlets, Triplets, and Intermediate-Coupling Terms.	584
	Energy Levels, Singlets, Triplets, and Intermediate-Coupling Terms.	585
P VII	Grotrian Diagram, Doublets and Quartets.	586
	Energy Levels, Doublets and Quartets.	587

P VIII	Grotrian Diagram. Singlets.	588
	Energy Levels. Singlets.	589
	Grotrian Diagram. Triplets.	590
	Energy Levels. Triplets.	591
P IX	Grotrian Diagram. Doublets.	592
	Energy Levels. Doublets.	593
	Grotrian Diagram. Quartets.	594
	Energy Levels. Quartets.	595
P X	Grotrian Diagram. Singlets.	596
	Energy Levels. Singlets.	597
	Grotrian Diagram. Triplets.	598
	Energy Levels. Triplets.	599
	Grotrian Diagram. Quintets.	600
	Energy Levels. Quintets.	601
P XI	Grotrian Diagram. Doublets.	602
	Energy Levels. Doublets.	603
	Grotrian Diagram. Quartets.	604
	Energy Levels. Quartets.	605
P XII	Grotrian Diagram. Singlets and Triplets.	606
	Energy Levels. Singlets and Triplets.	607
P XIII	Grotrian Diagram. Doublets.	608
	Energy Levels. Doublets.	609
P XIV	Grotrian Diagram. Singlets and Triplets.	610
	Energy Levels. Singlets and Triplets.	611
P XV	Grotrian Diagram. Doublets.	612
	Energy Levels. Doublets.	613