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

PRINTED IN THE NETHERLANDS

INTRODUCTION

Energy-level and transition diagrams have been indispensable since their first appearance in the literature of atomic structure. The pioneering work by Grotrian [1] 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 Moore [2] and Kelly,[3] the spectral data in the publications by Kelly and Palumbo [4] 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 Kelly [3] 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 Kelly [3] with a certain exception noted below. In a number of systems, there are discrepancies between the designations listed by Kelly [3] 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

INTRODUCTION

Energy-level and transition diagrams have been indispensable since their first appearance in the literature of atomic structure. The pioneering work by Grotrian [1] 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 Moore [2] and Kelly,[3] the spectral data in the publications by Kelly and Palumbo [4] 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 Kelly [3] 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 Kelly [3] with a certain exception noted below. In a number of systems, there are discrepancies between the designations listed by Kelly [3] 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 ^{4}D term of Na V is listed as:

$$\begin{matrix} 797270 \\ 797060 \end{matrix} \text{———} \; 3d\,([5/2,3/2],\,1/2)\,,$$

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 fron one spectroscopic term to another are called, "Grotrian Diagrams". We have shown most of the transitions listed by Kelly and Palumbo[4] 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.

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 ^{4}D term of Na V is listed as:

$$\begin{matrix} 797270 \\ 797060 \end{matrix} \text{———} \; 3d\,([5/2,3/2],\,1/2)\,,$$

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 fron one spectroscopic term to another are called, "Grotrian Diagrams". We have shown most of the transitions listed by Kelly and Palumbo[4] 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 1928).
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.

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 1928).
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.

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 $3s\,^3P^\circ$, $2s\,2p^3\,^3D^\circ$, and $3p\,^3D$ to Higher Triplets. Quintet–Quintet Transitions.	60
	Energy Levels. Triplets and Quintets.	61
	Grotrian Diagram. Triplets. Transitions from $2s^2\,2p\,3p\,^3S$, $2s^2\,2p\,3p\,^3P$, and $2s\,2p^3\,^3P^\circ$ 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, $1s^2\,2s\,nl$ Terms.	82
	Energy levels. Triplets, $1s^2\,2s\,nl$ Terms.	83
	Grotrian Diagram. Triplets, $1s^2\,2p\,nl$ Terms.	84
	Energy Levels. Triplets, $1s^2\,2p\,nl$ Terms.	85
	Grotrian Diagram. Intercombinations. Transitions between $1s^2\,2s\,nl$ Triplets and $1s^2\,2p\,nl$ 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 $2p\,^2D^\circ$ to Higher Doublets.	100
	Energy Levels. Doublets.	101
	Grotrian Diagram. Doublets. Transitions from $2p\,^2P^\circ$ 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 $1s^2\ 2s^2\ 2p^3\ (^2D^\circ)$ *nl* Terms.	160
	Energy Levels. Triplets, $1s^2\ 2s^2\ 2p^3\ (^2D^\circ)$ *nl* Terms.	161
	Grotrian Diagram and Energy Levels. Autoionizing Triplets, $1s^2\ 2s^2\ 2p^3\ (^2P^\circ)$ *nl* Terms.	163
	Grotrian Diagram. Triplets and Quintets. Transitions between $1s^2\ 2s^2\ 2p^3\ (^4S^\circ)$ *nl* Terms.	164
	Energy Levels. Triplets and Quintets. $1s^2\ 2s^2\ 2p^3\ (^4S^\circ)$ *nl* Terms.	165
	Grotrian Diagram. Intercombinations. Transitions between Triplets with $(^4S^\circ)$, $(^2P^\circ)$, and $(^2D^\circ)$ 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 $1s^2\ 2s^2\ 2p^2\ 3p\ {}^2D^\circ$.	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, $({}^5S^\circ)$ 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 $n \geqslant 4$.	292
	Energy Levels.	293

	Grotrian Diagram. High Intermediate Coupling.	294
	Energy Levels. High Intermediate Coupling.	295
	Grotrian Diagram. Doubly-Excited Terms. ^{3}P Core.	296
	Energy Levels. Doubly-Excited Terms.	297
	Grotrian Diagram. Doubly-Excited Terms. ^{1}D, ^{1}S 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 $^2P^\circ_{1/2}$ Core.	344
	Energy Levels. Intermediate-Coupling Terms with $^2P^\circ_{1/2}$ Core.	345
	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P^\circ_{3/2}$ Core.	346
	Energy Levels. Intermediate-Coupling Terms with $^2P^\circ_{3/2}$ Core.	347
	Grotrian Diagram. Intercombinations. Transitions between $^2P^\circ_{1/2}$ and $^2P^\circ_{3/2}$ 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 $^2P^\circ_{1/2}$ Core.	394
	Energy Levels. Intermediate-Coupling Terms with $^2P^\circ_{1/2}$ Core.	395
	Grotrian Diagram. Transitions between Intermediate-Coupling Terms with $^2P^\circ_{3/2}$ Core.	396
	Energy Levels. Intermediate-Coupling Terms with $^2P^\circ_{3/2}$ 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

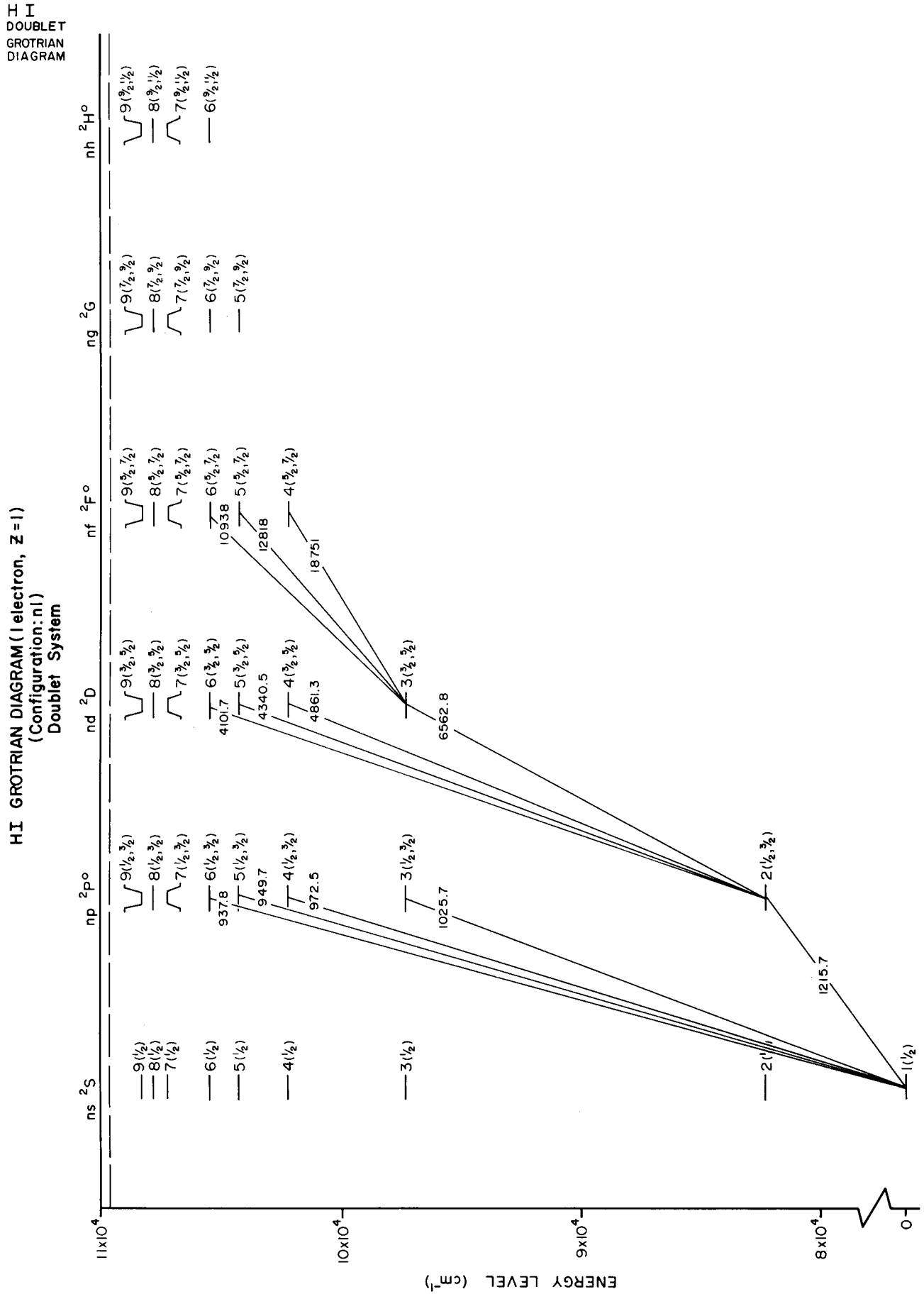
Mg VI	Grotrian Diagram. Doublets.	412
	Energy Levels. Doublets.	413
	Grotrian Diagram. Quartets.	414
	Energy Levels. Quartets.	415
Mg VII	Grotrian Diagram. Singlets.	416
	Energy Levels. Singlets.	417
	Grotrian Diagram. Triplets.	418
	Energy Levels. Triplets.	419
	Grotrian Diagram. Quintets.	420
	Energy 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 ^{1}D and Terms with $n \geqslant 5$ 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 ^{3}P or Terms $\geqslant$ 4p ^{3}P° 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 ^{1}S 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 $n \geqslant 4$.	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

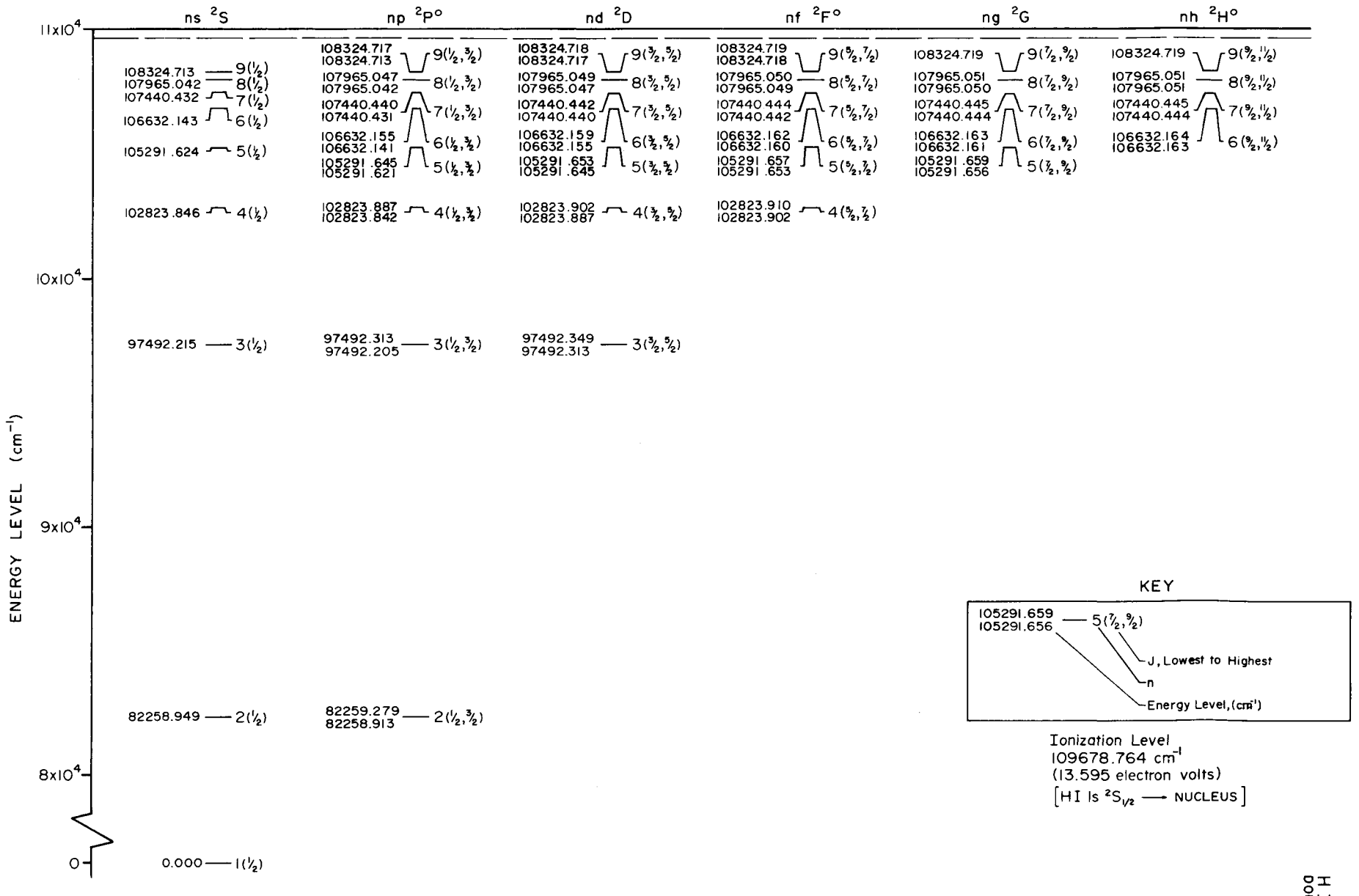
Si VI	Grotrian Diagram. Doublets.	524
	Energy Levels. Doublets.	525
	Energy Levels. Quartets.	527
Si VII	Grotrian Diagram. Singlets.	528
	Energy Levels. Singlets.	529
	Grotrian Diagram. Triplets.	530
	Energy Levels. Triplets.	531
	Grotrian Diagram. Intercombinations. Transitions between Singlets and 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

Hydrogen (H)

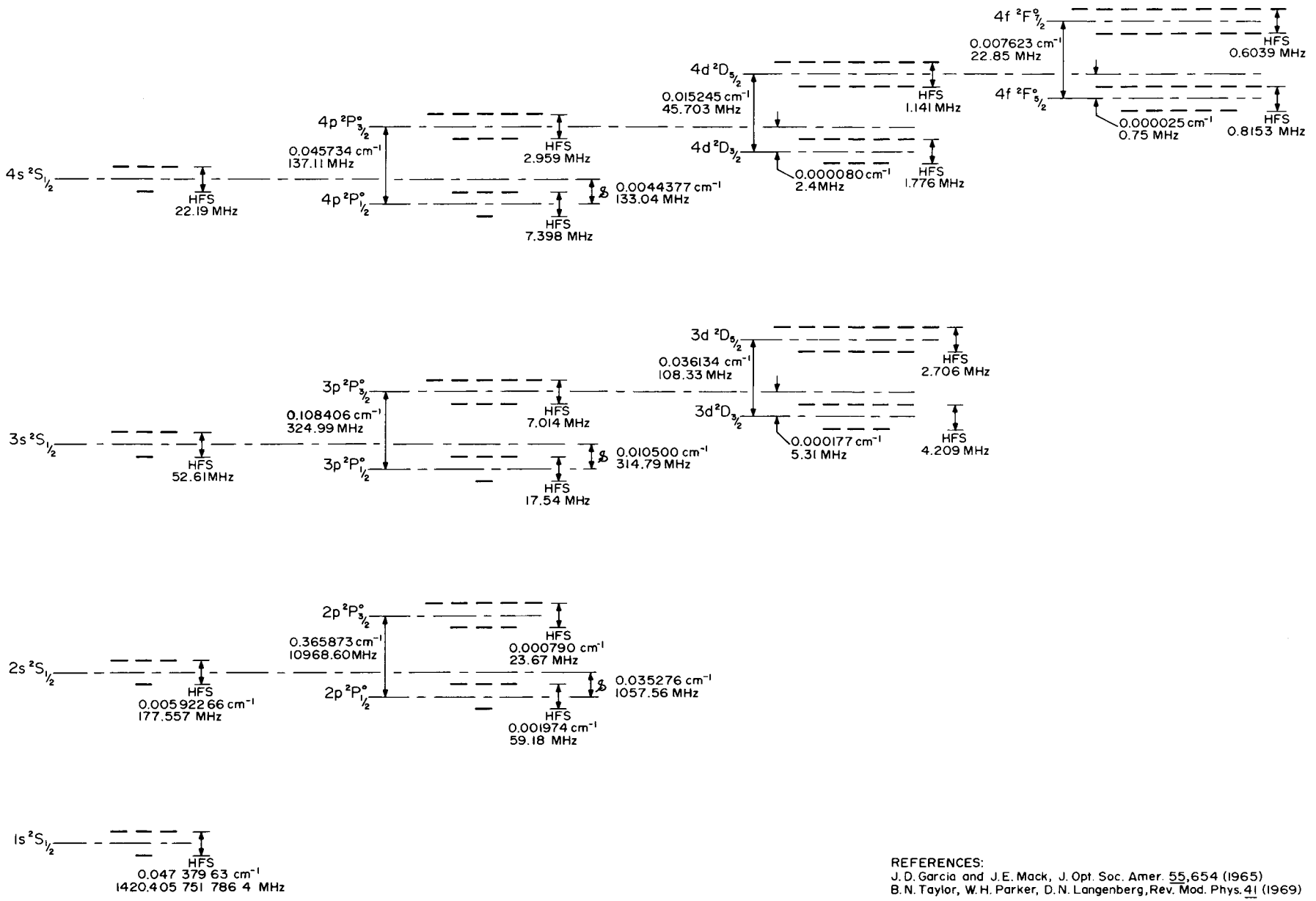

H I
DOUBLET
GROTRIAN
DIAGRAM
HI GROTRIAN DIAGRAM (1 electron, Z=1)
(Configuration: nl)
Doublet System
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
ENERGY LEVEL (cm⁻¹)
11x10⁴
10x10⁴
9x10⁴
8x10⁴
0
937.8
949.7
972.5
1025.7
4101.7
4340.5
4861.3
6562.8
10938
12818
18751
1215.7

H I ENERGY LEVELS (1 electron, Z = 1)
(Configuration: nl)
Doublet System



H I
DOUBLET

H I ENERGY LEVELS (1 electron, Z=1)
F.S., H.F.S., LAMB SHIFTS
(NOT TO SCALE)



REFERENCES:
J. D. Garcia and J. E. Mack, J. Opt. Soc. Amer. 55, 654 (1965)
B. N. Taylor, W. H. Parker, D. N. Langenberg, Rev. Mod. Phys. 41 (1969)

Bibliography

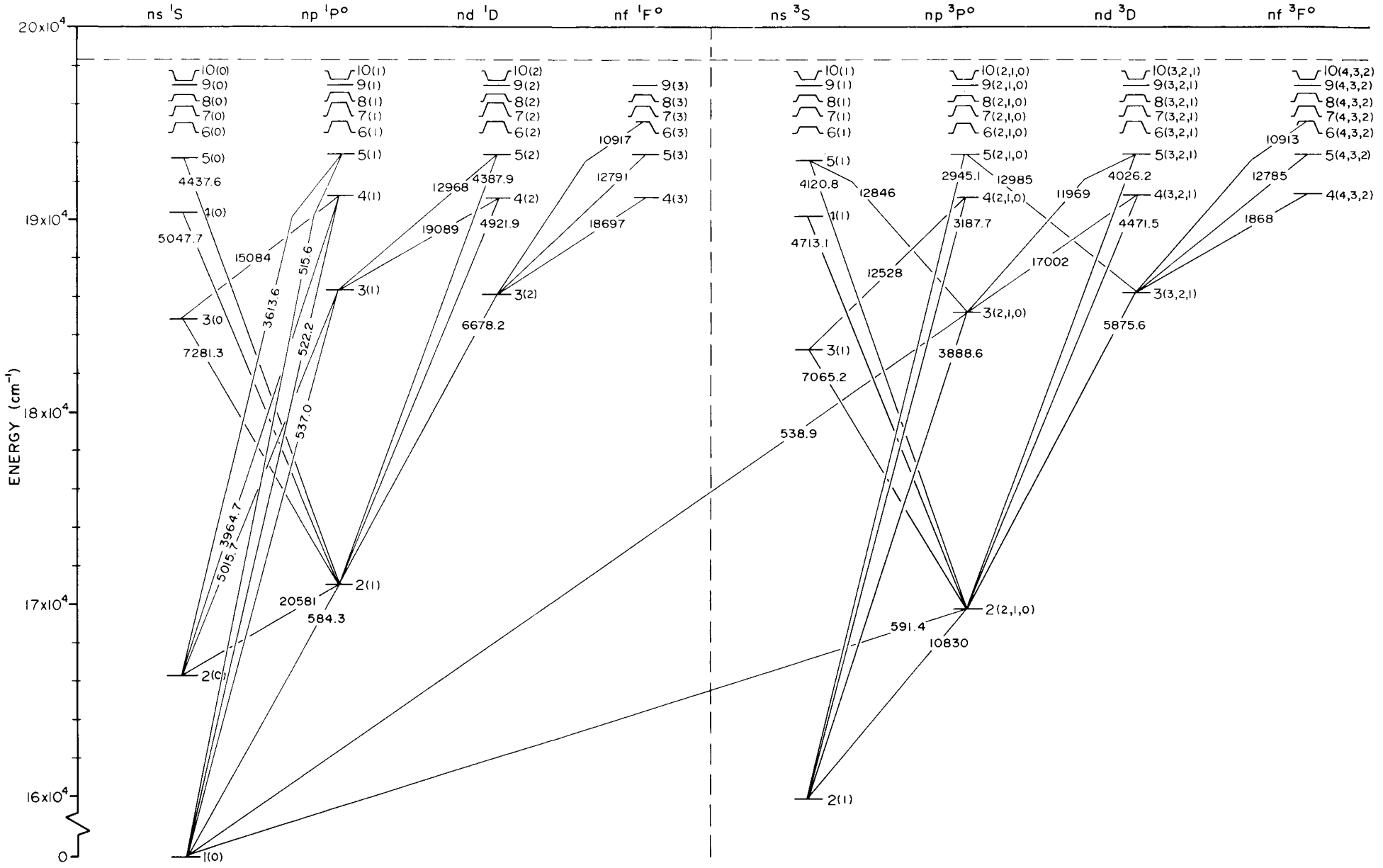
H I $Z = 1$ 1 electron

Please see the general references.

Note that levels with the same value of principal quantum number (n) but different values of l have nearly the same energies. Thus all wavelengths for transitions between $n = n_1$ and $n = n_2$ are nearly independent of the values of l involved, and only one transition is shown for any pair (n_1, n_2).

Helium (He)

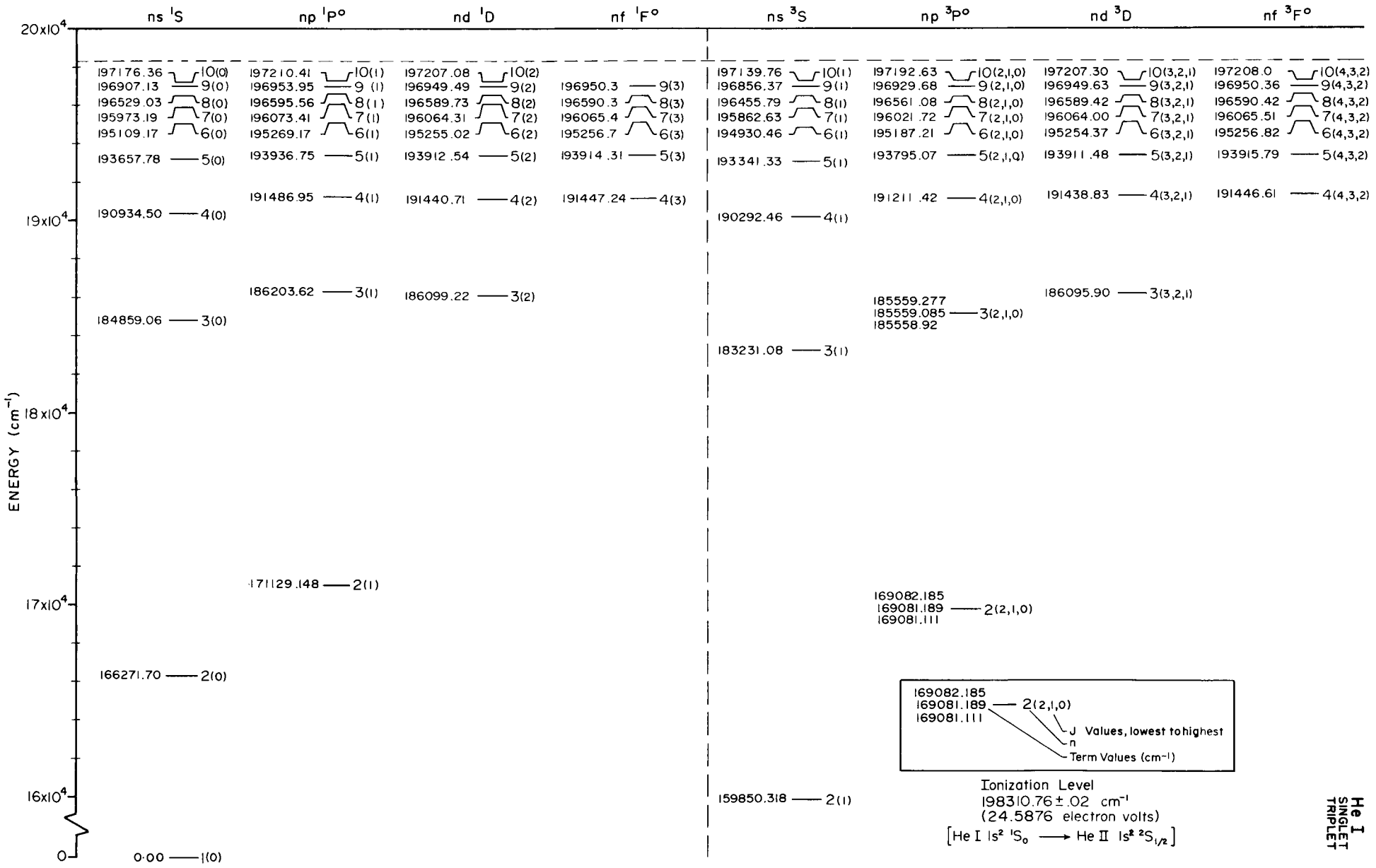
He I GROTRIAN DIAGRAM (2 electrons, Z=2)
(Configuration: 1s nl)
Singlet Triplet



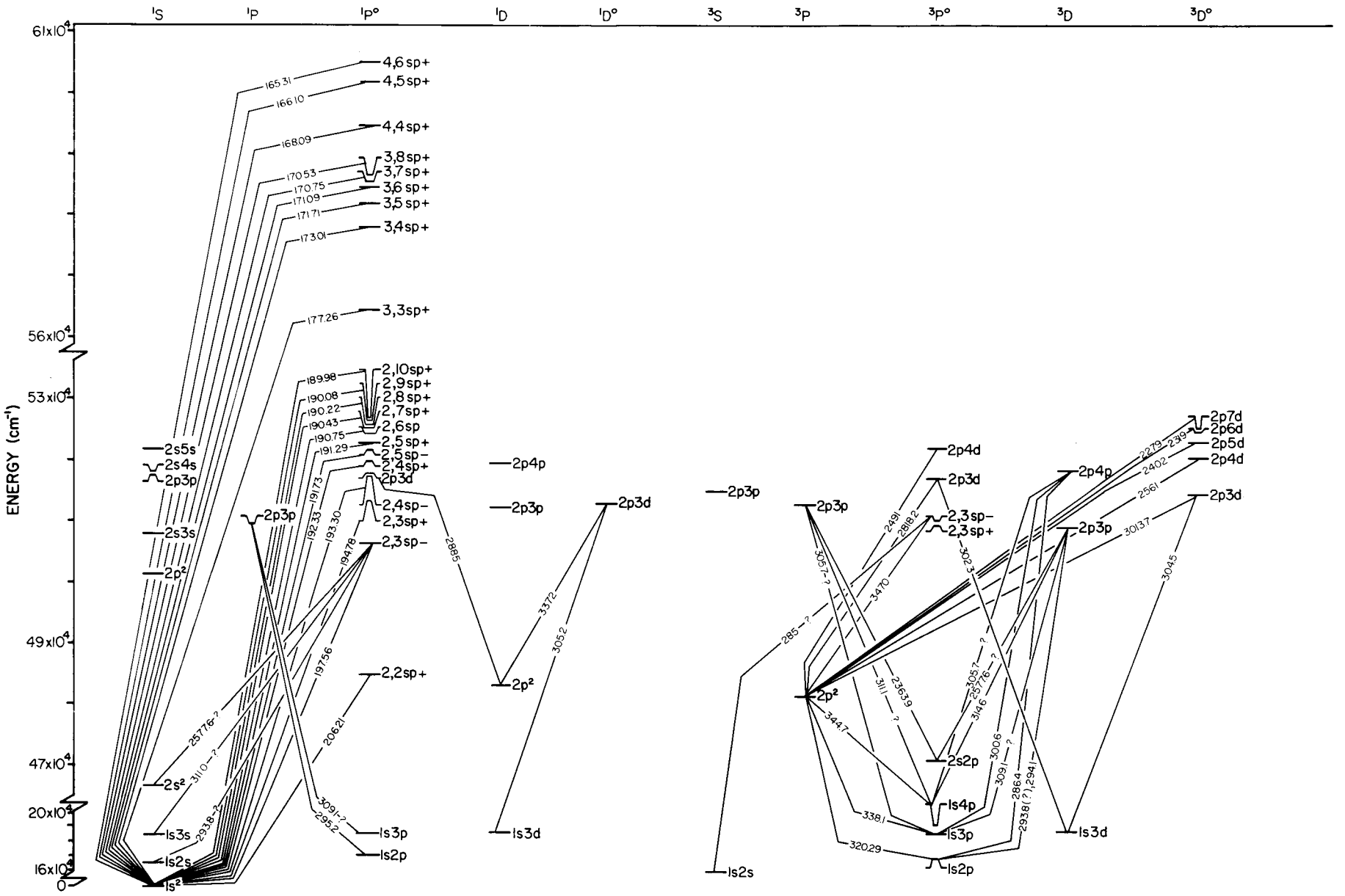
He I ENERGY LEVELS (2 electrons, Z=2)

(Configuration: 1s nl)

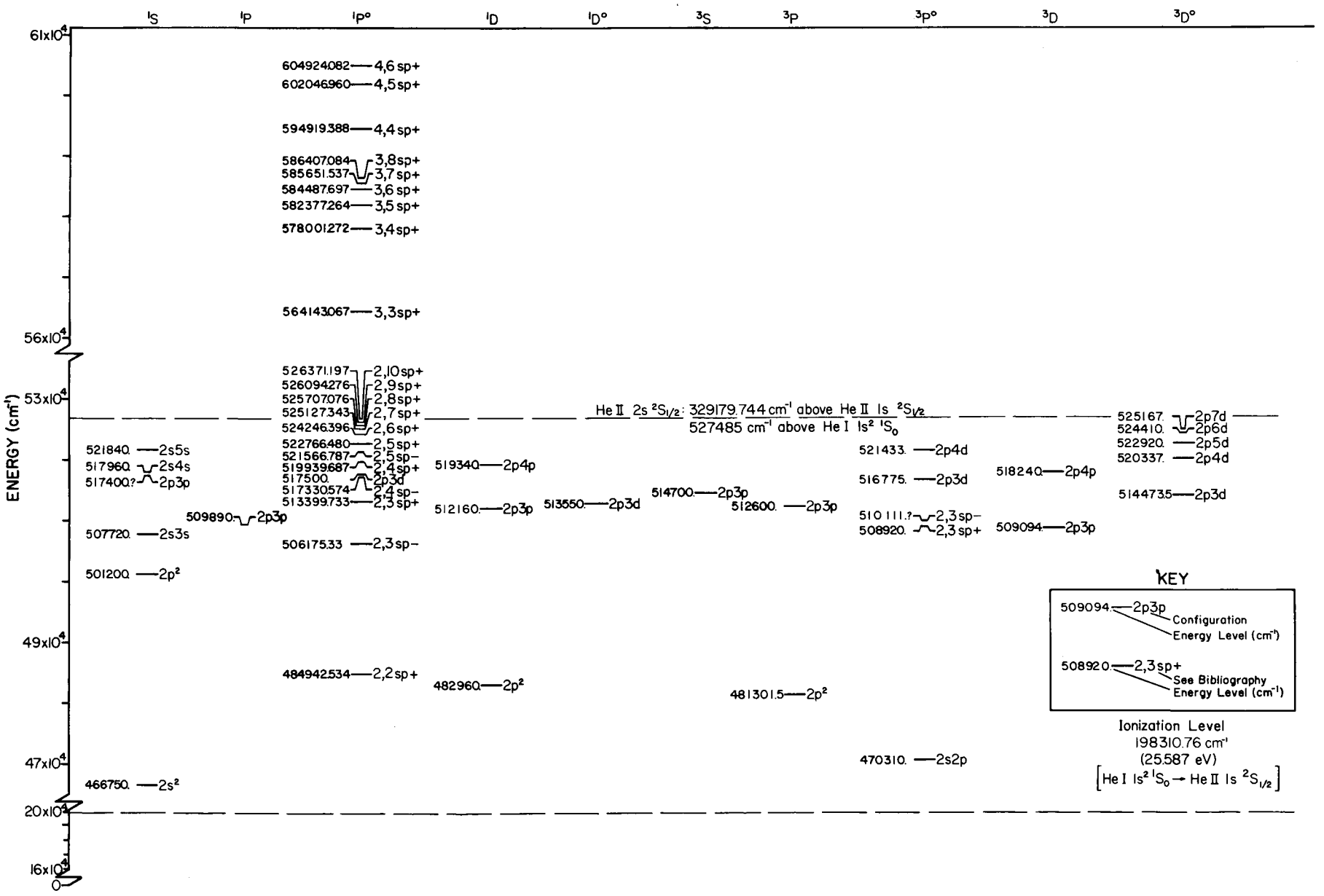
Singlet Triplet



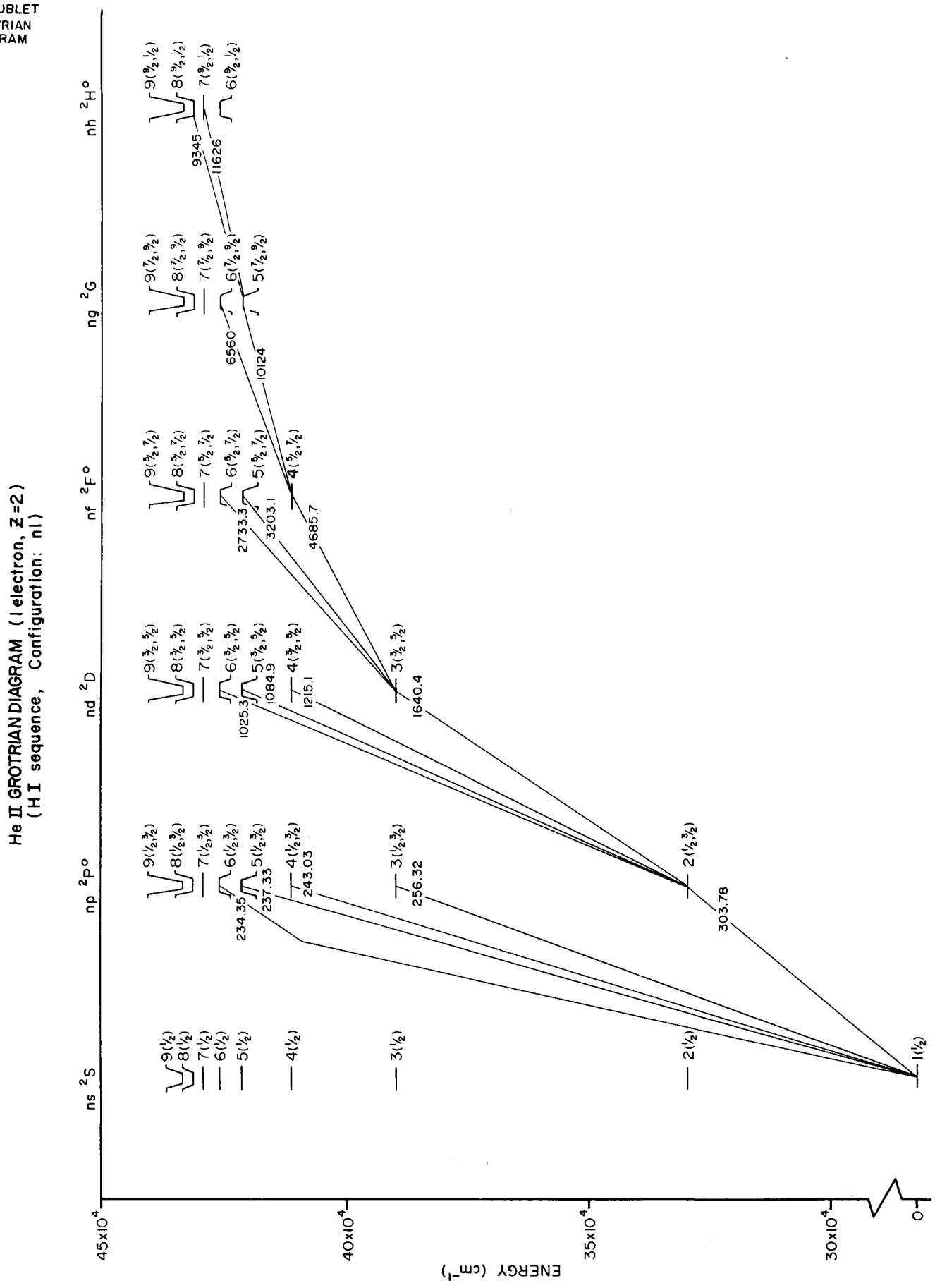
He I GROTRIAN DIAGRAM, DOUBLY-EXCITED (2 electrons, Z=2)
(Configuration: nl n'l', Singlet and Triplet Systems)



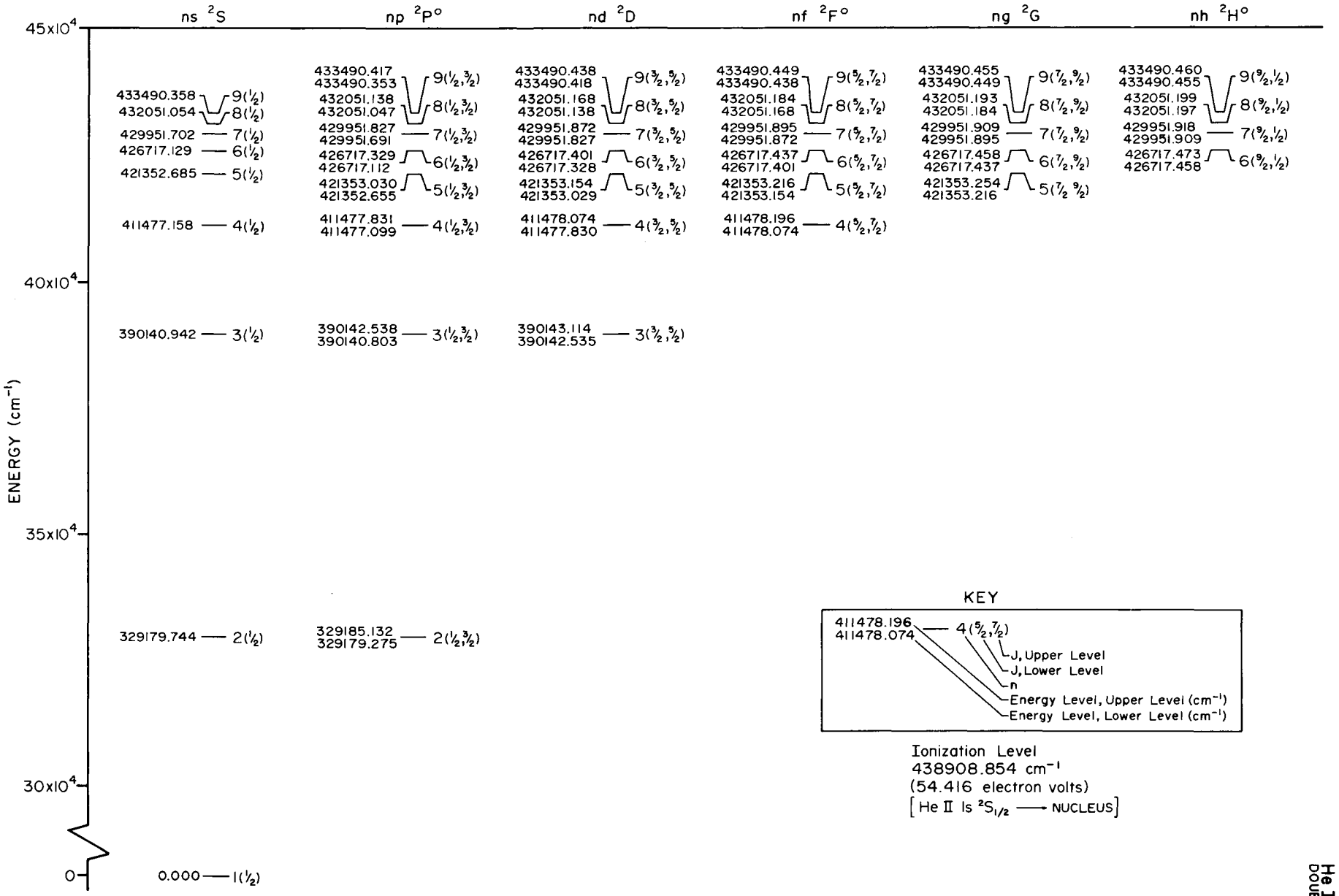
He I ENERGY LEVELS, DOUBLY-EXCITED (2 electrons, Z=2)
(Configuration: nl n'l', Singlet and Triplet Systems)



He II
DOUBLET
GROTRIAN
DIAGRAM



He II ENERGY LEVELS (1 electron, Z=2)
(H I sequence, Configuration: nl)



He II DOUBLET

He I $Z = 2$ 2 electrons

R. Arrathoon, J. Opt. Soc. Amer. **61**, 332 (1971).

Author gives transition wavelengths and probabilities.

H.G. Berry, J. Desesquelles, and M. Dufay, Phys. Rev. **A6**, 600 (1972).

H.G. Berry, I. Martinson, L.J. Curtis, and L. Lundin, Phys. Rev. **A3**, 1934 (1971).

Authors give energies and transitions for doubly-excited states.

J. Humphreys and H.J. Kostkowski, J. Research NBS **49**, 73 (1952).

Authors give observed infrared spectra.

A.N. Ivanova, U.I. Safronova, and V.N. Kharitonova, Opt. and Spectros. **24**, 55 (1968).

Authors give an energy level table of calculated and experimental values.

E.J. Knystautus and R. Drovin, Nucl.Instrum.Methods **110**, 95 (1973)

U. Litzén, Physica Scripta **2**, 103 (1970).

Author gives improved infrared wavelengths.

R. Madden and K. Codling, Ap. J. **141**, 364 (1965).

Authors give line and energy level tables for resonant absorption lines observed in the region 165–200 Å.

W.C. Martin, J. Opt. Soc. Amer. **50**, 174 (1960).

Author gives observed wavelengths.

W.C. Martin, J. Phys. Chem. Ref. Data **2**, 257 (1973).

This is a compilation of all levels observed to date with one and two electrons excited.

On doubly-excited terms, alternative transitions are given for some spectral lines. Thus Berry *et al.* (1972) suggest 1s 2s ^{1}S–sp23–^{1}P° and/or 1s 2p ^{3}P°–pp23–^{3}D for λ 293.8 Å, and 2s^2 ^{1}S–sp23–^{1}P and/or 2s 2p ^{3}P°–pp23–^{3}D for λ 2577.6 Å. We have shown all of these lines with question marks. Berry *et al.* (1971) assign λ 311.0 Å to 1s 3s ^{1}S–sp23 ^{1}P° whereas Knystautus and Drovin assign λ 311.1 Å to 2p 3p ^{3}P–1s 4p ^{3}P°. Knystautus and Drovin also list λ 305.7 Å as belonging to 2p 4p ^{3}D–1s 4p ^{3}P° and/or 2p 3p ^{1}D–1s 3p ^{1}P°, and λ 309.1 Å as coming from 2p 3p ^{1}P–1s 3p ^{1}P° and/or 2p 3p ^{3}D–1s 3p ^{3}P°. These possibilities are all shown with question marks.

The (±) notation comes from Madden and Codling. Briefly, the wavefunction ψ is written in terms of single-particle wavefunctions U as

$$\psi(\mathrm{sp}2n\pm) = (1/\sqrt{2})\,[U(2\mathrm{s}n\mathrm{p}) \pm U(2\mathrm{p}n\mathrm{s})]$$

He II $Z = 2$ 1 electron

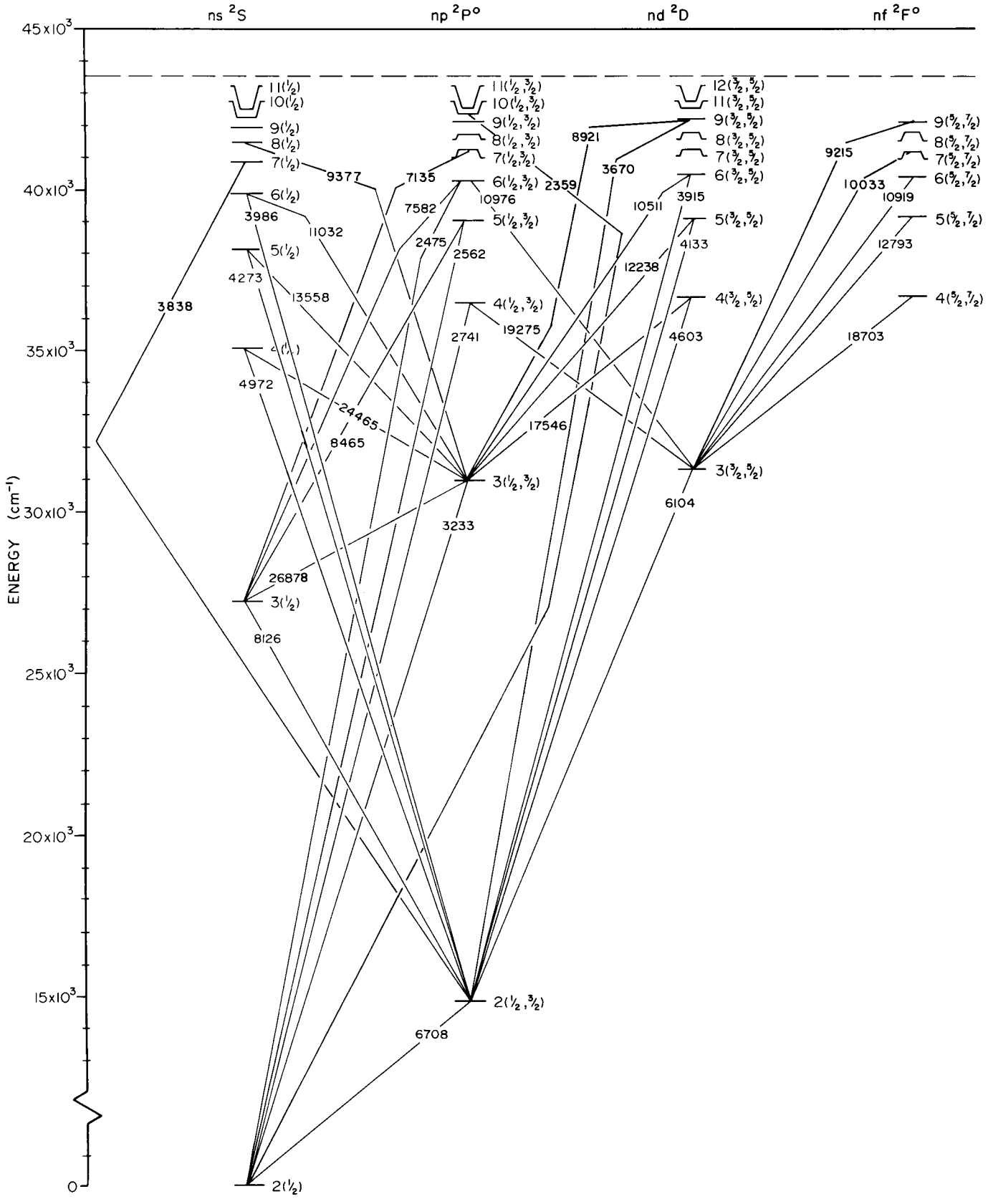
E.G. Kessler, Jr., and F.L. Roesler, J. Opt. Soc. Amer. **62**, 440 (1972).

Authors study fine structure of $n = 4$–5 and $n = 4$–6 transitions in He II at low temperature.

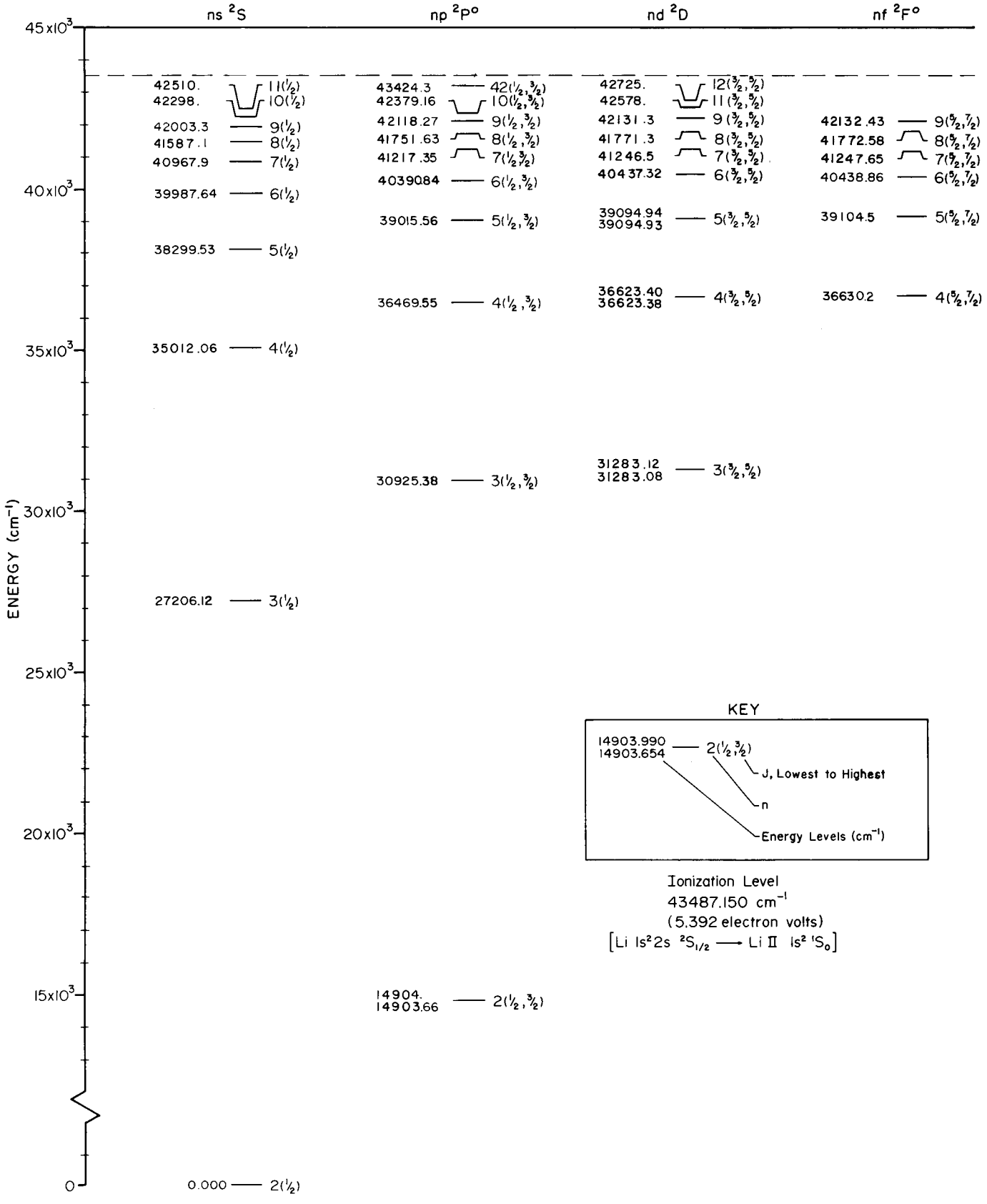
Lithium (Li)

Li I
DOUBLET
GROTRIAN
DIAGRAM

Li I GROTRIAN DIAGRAM (3 electrons, Z=3)
(Configuration: $1s^2\,nl$)
Doublet System

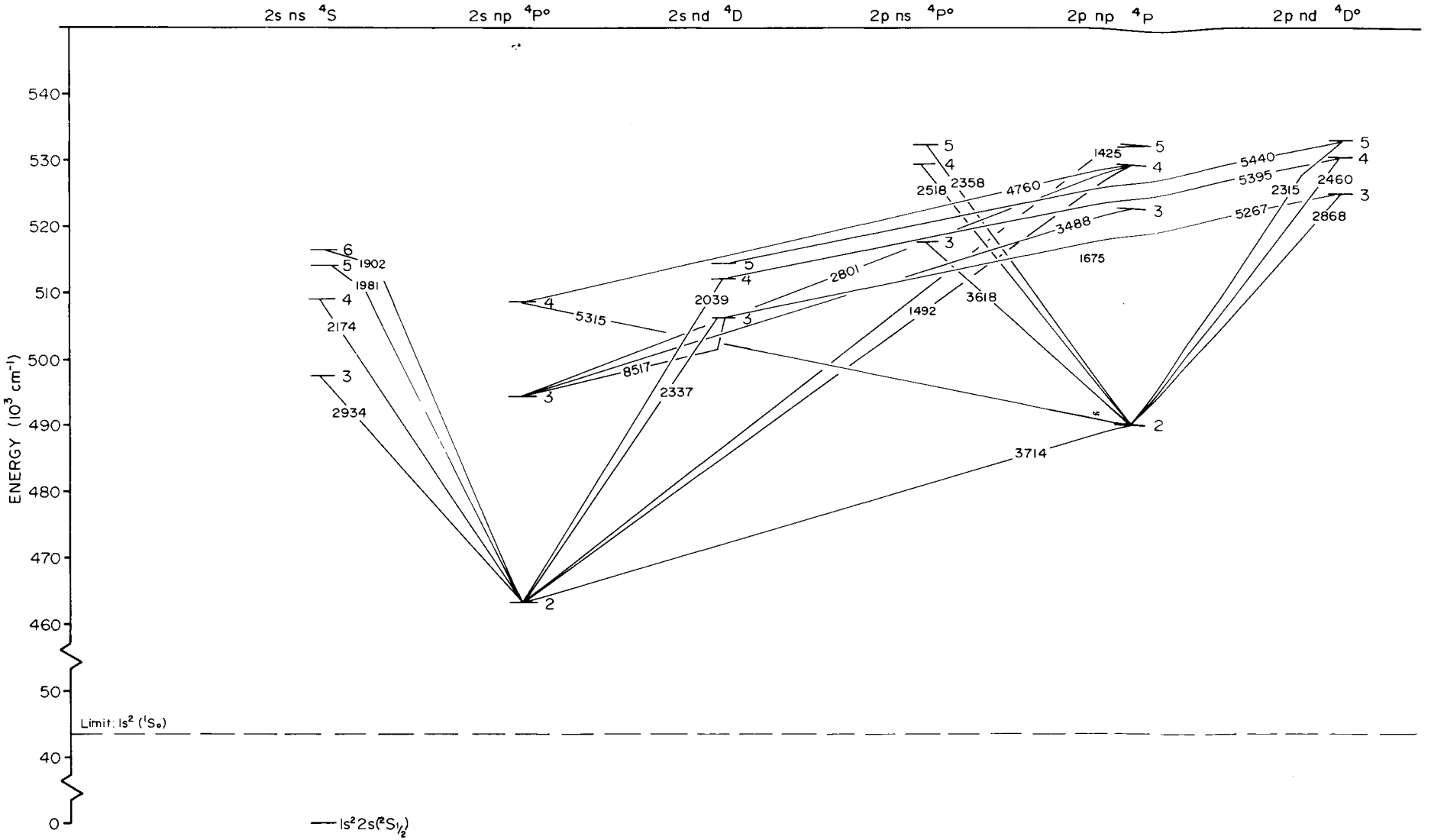


Li I ENERGY LEVELS (3 electrons, Z=3)
(Configuration $1s^2\,nl$)
Doublet System

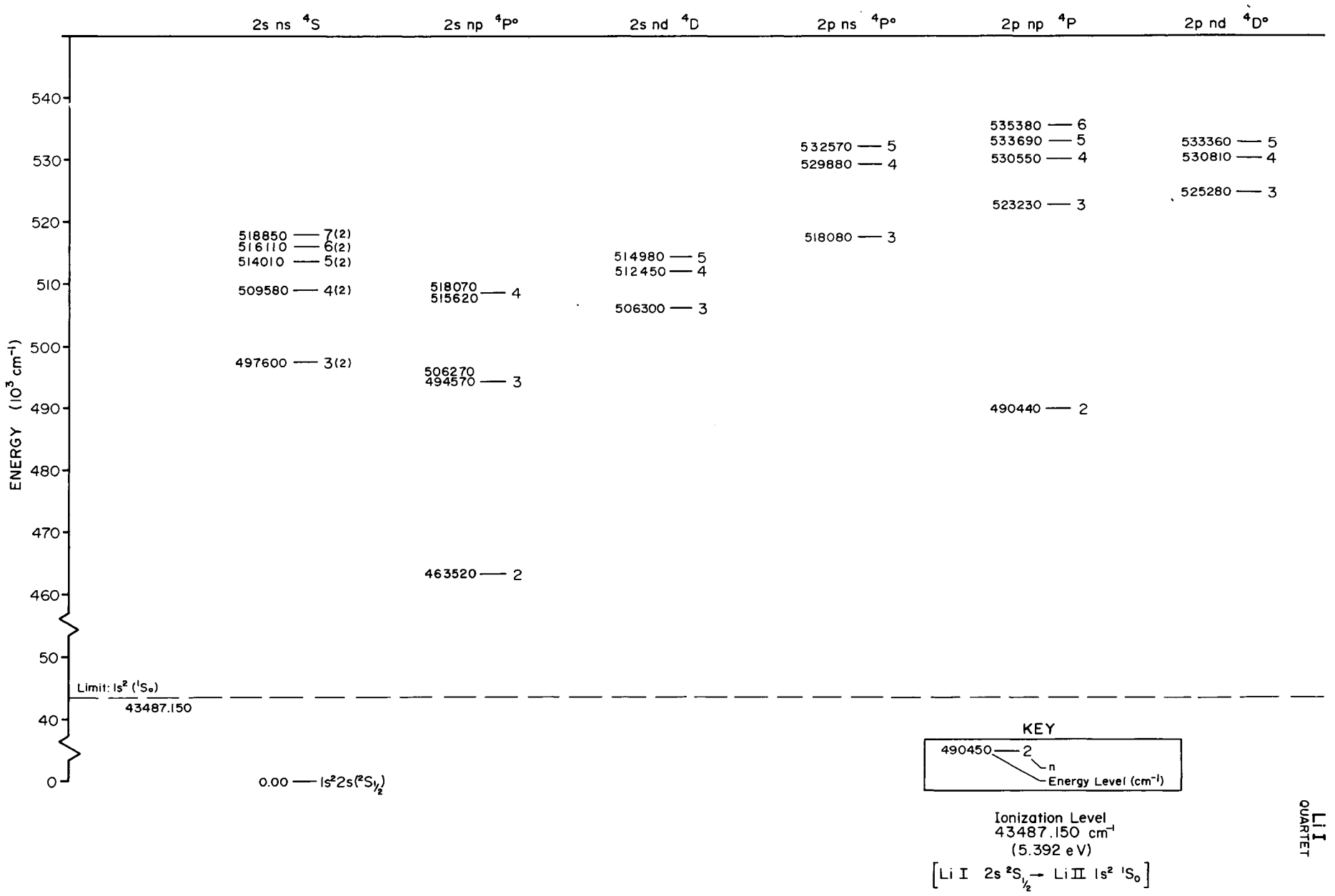


Ionization Level
43487.150 cm^{-1}
(5.392 electron volts)
[Li $1s^2 2s\ ^2S_{1/2} \longrightarrow$ Li II $1s^2\ ^1S_0$]

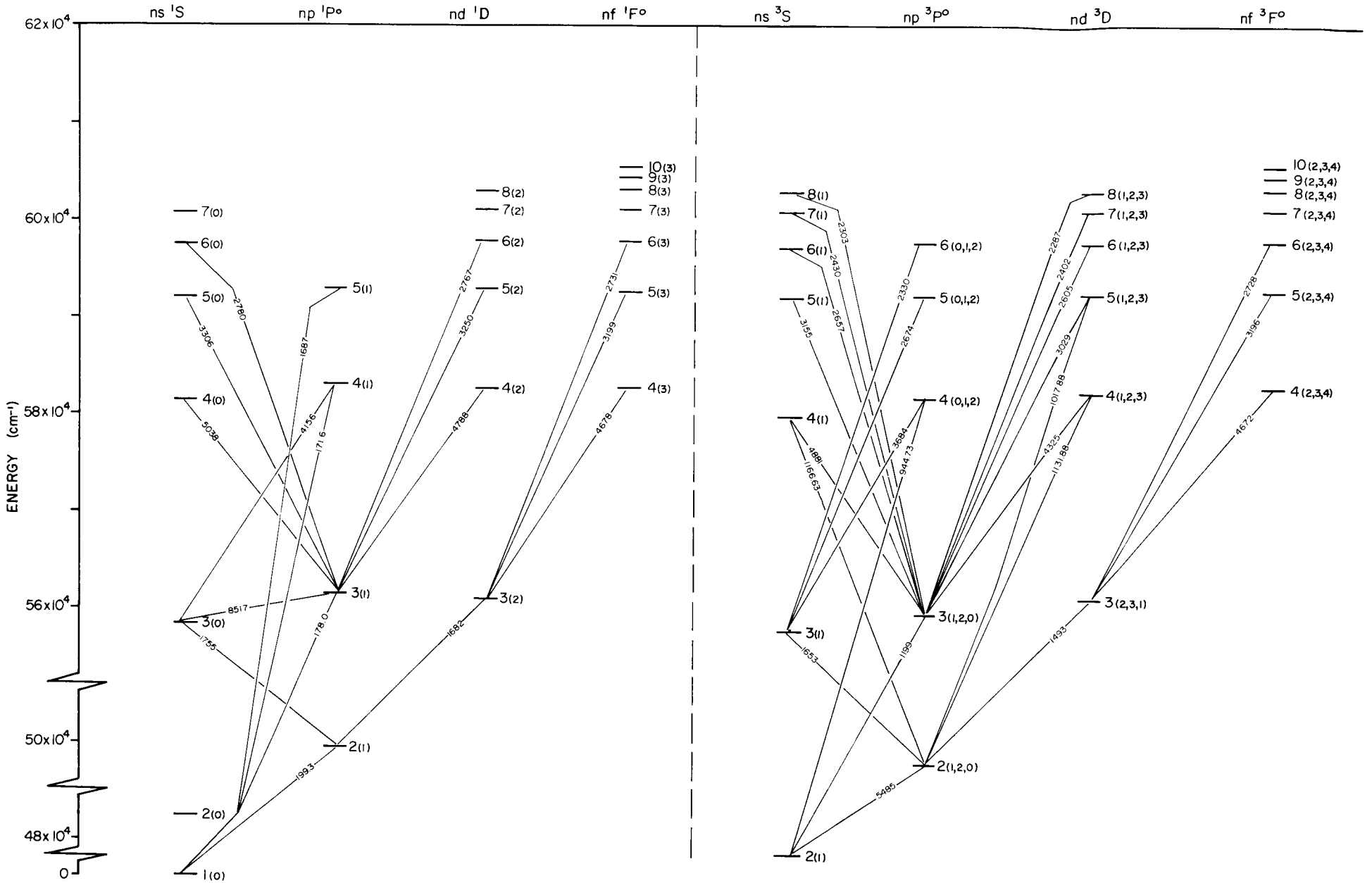
Li I DOUBLY EXCITED GROTRIAN DIAGRAM (3 electrons, Z = 3)
(Configuration: 1s nl n'l', Quartet Term System)



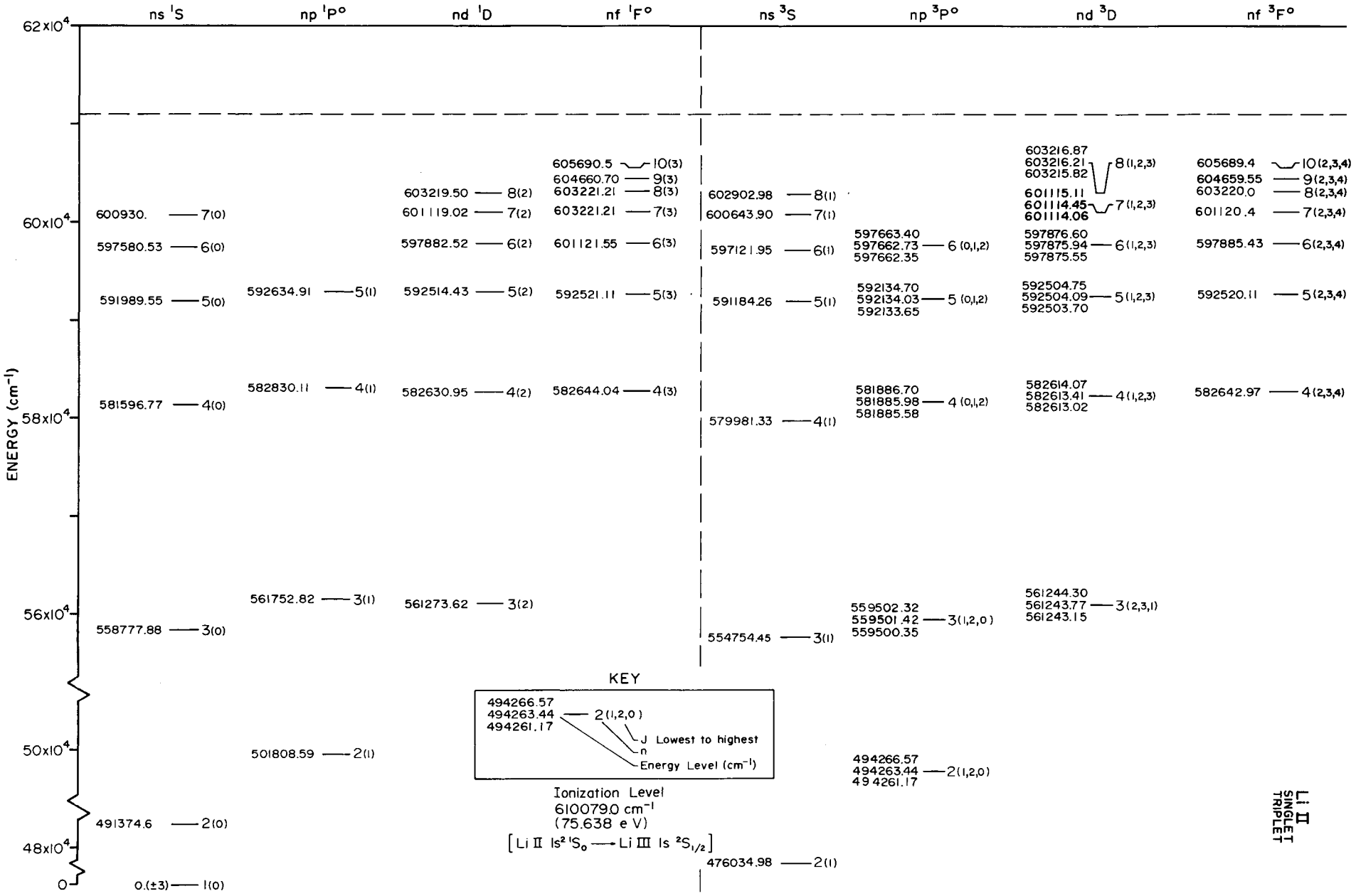
Li I DOUBLY EXCITED ENERGY LEVELS (3 electrons, Z=3)
(Configuration: 1s nl n'l', Quartet Term System)



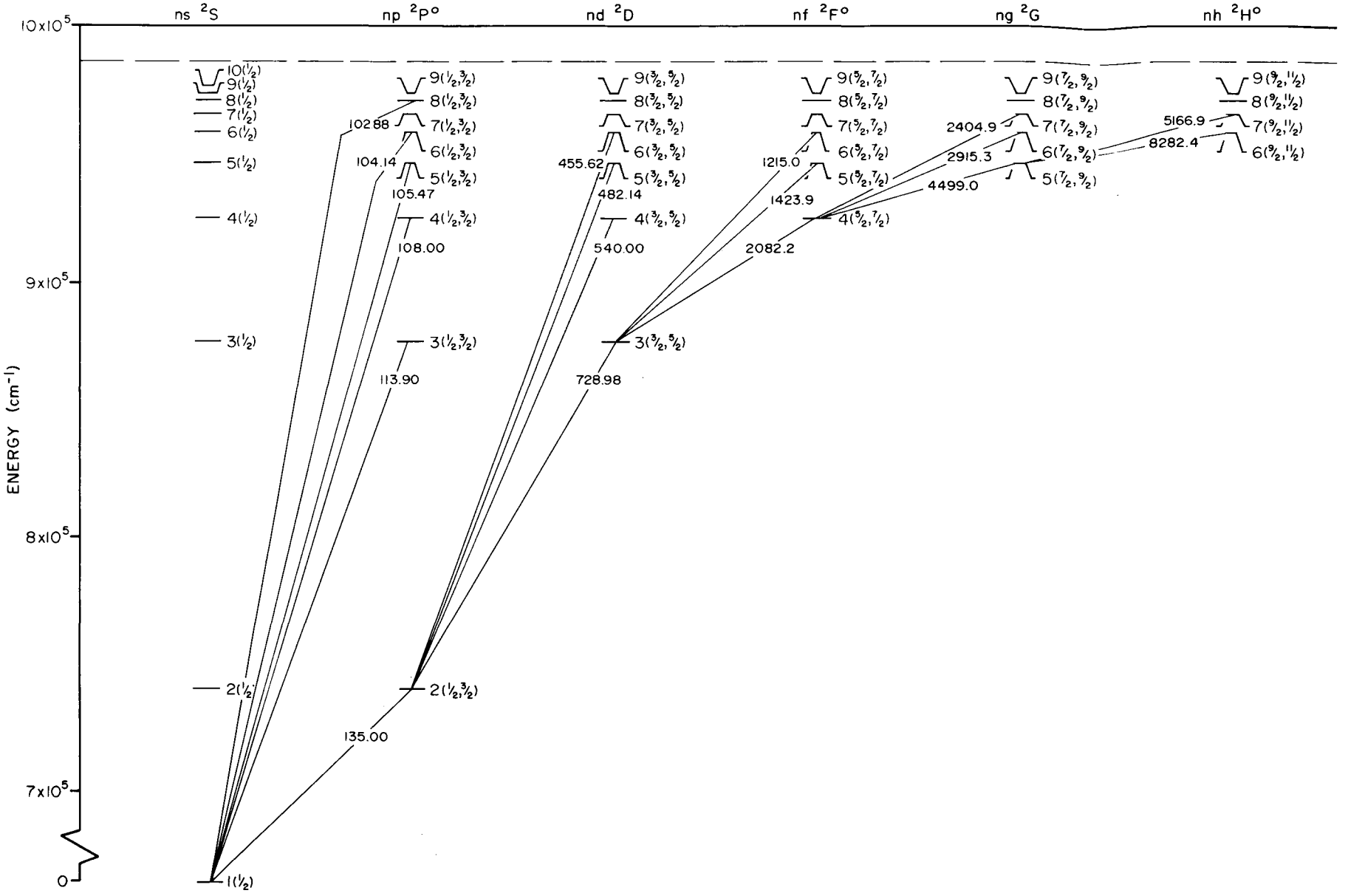
Li II GROTRIAN DIAGRAM (2 electrons, Z=3, A=7)
(He I sequence, Configuration: 1s nl)
Singlet Triplet System



Li II ENERGY LEVELS (2 electrons, Z=3, A=7)
(He I sequence, Configuration: 1s nl)
Singlet Triplet System

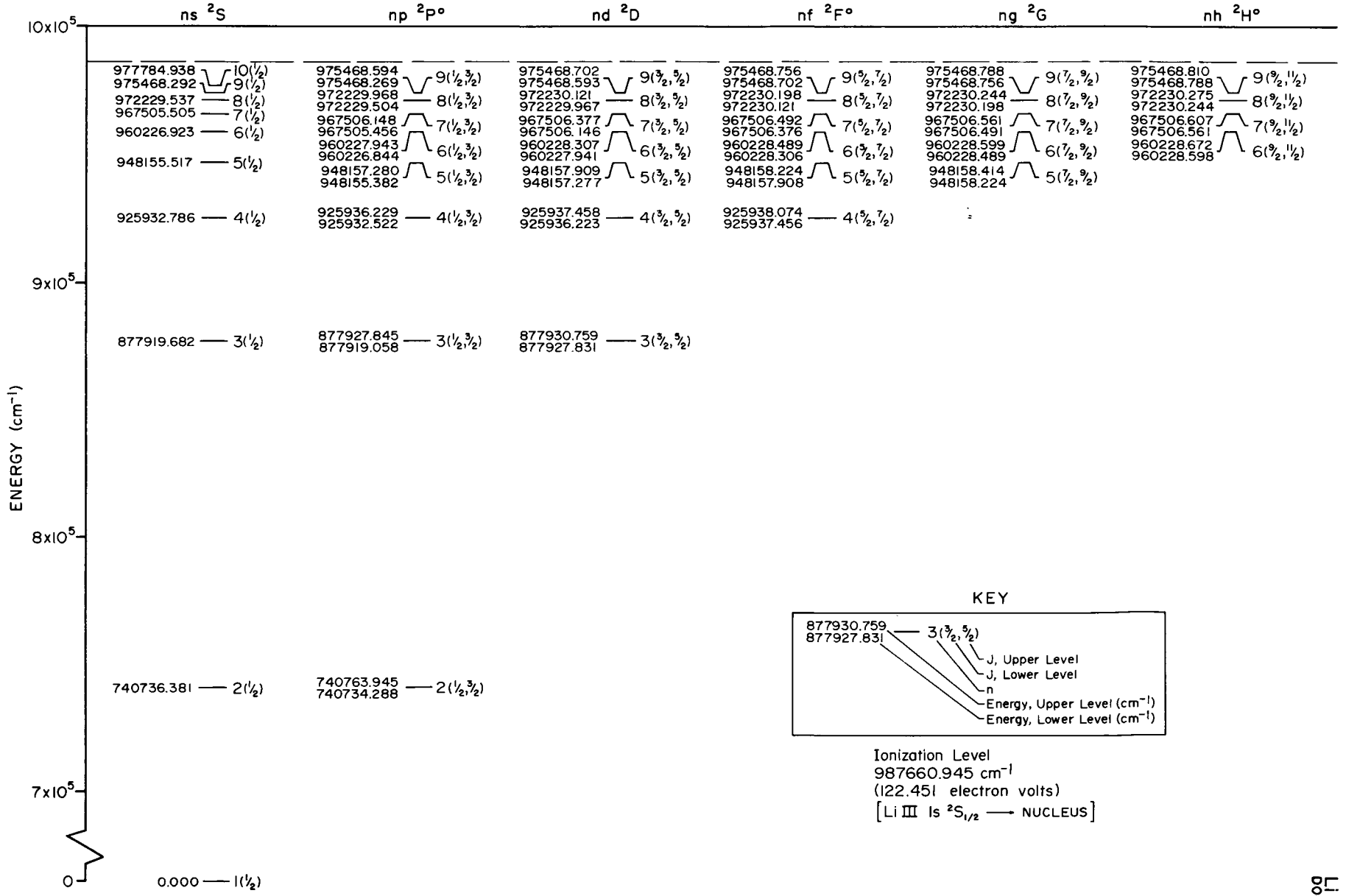


Li III GROTRIAN DIAGRAM (1 electron, Z = 3)
(H I sequence, Configuration: nl)
Doublet



Li III ENERGY LEVELS (1 electron, Z = 3) Mass Number 7)
(H I sequence, Configuration: nl) Doublet

(NOTE: MAGNETIC HYPERFINE STRUCTURE HAS BEEN IGNORED)



Ionization Level
987660.945 cm^{-1}
(122.451 electron volts)
[Li III 1s $^2S_{1/2}$ ⟶ NUCLEUS]

Li I $Z = 3$ 3 electrons

N. Andersen, W.S. Bickel, G.W. Carriveau, K. Jensen, and E. Veje, Physica Scripta **4**, 113 (1971).

Authors extend the spectra of Li I and Li II.

H.G. Berry, J. Bromander, I. Martinson, and R. Buchta, Physica Scripta **3**, 63 (1971).

Authors give observed energy levels and wavelengths of doubly-excited Li.

H.G. Berry, E.H. Pinnington, and J.L. Subtil, J. Opt. Soc. Amer. **62**, 767 (1972).

Authors give a line table and a Grotrian diagram from lines observed in doubly-excited lithium.

J.P. Buchet, M.C. Buchet-Poulizac, and H.G. Berry, Phys. Rev. **A7**, 922 (1973).

Authors present classifications of transitions in doubly-excited Li and Li II.

J.P. Buchet, A. Denis, J. Désesquelles, and M. Dufay, Phys. Letters **28A**, 529 (1969).

Authors treat new lines plausibly attributed to doubly-excited states of lithium.

J.W. Cooper, M.J. Conneely, K. Smith, and S. Ormonde, Phys. Rev. Letters **25**, 1540 (1970).

Authors calculate resonant energy levels above the 2 ^{3}S threshold and compare values to observed values.

D.L. Ederer, T. Lucatorto, and R.P. Madden, Phys. Rev. Letters **25**, 1537 (1970).

Authors give line and energy level tables for observed resonance lines due to an excitation of a K-shell electron or due to a K-shell electron and an outer electron.

D.L. Ederer, T. Lucatorto, and R.P. Madden, Journal de Physique **32**, C4 (1971).

Authors compare energy level values from observations and calculations for resonances due to an excitation of a K-shell electron or due to a K-shell electron and an outer electron.

P. Feldman, M. Levitt, and R. Novick, Phys. Rev. Letters **21**, 331 (1968).

Authors use energy values for definitive identification of lithium spectral lines.

J.D. Garcia and J.E. Mack, Phys. Rev. **138A**, 987 (1965).

Authors give energy levels and spectral lines of doubly-excited lithium.

Li II $Z = 3$ 2 electrons

H.G. Berry, E.H. Pinnington, and J.L. Subtil, J. Opt. Soc. Amer. **62**, 767 (1972).

Authors give a table of lines observed in doubly-excited lithium.

J.P. Buchet, A. Denis, J. Desesquelles, and M. Dufay, Phys. Letters **28A**, 529 (1969).

Authors treat new lines plausibly attributed to doubly-excited states of lithium.

E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculate energy levels nonrelativistically for He I isoelectronic sequence.

C.L. Pekeris, Phys. Rev. **126**, 143 (1962).

Author presents calculations of energies of some states in Li II.

Y.G. Turesson and B. Edlén, Ark. Fys. **23**, 117 (1962).

Authors identify the transition at 9581 Å.

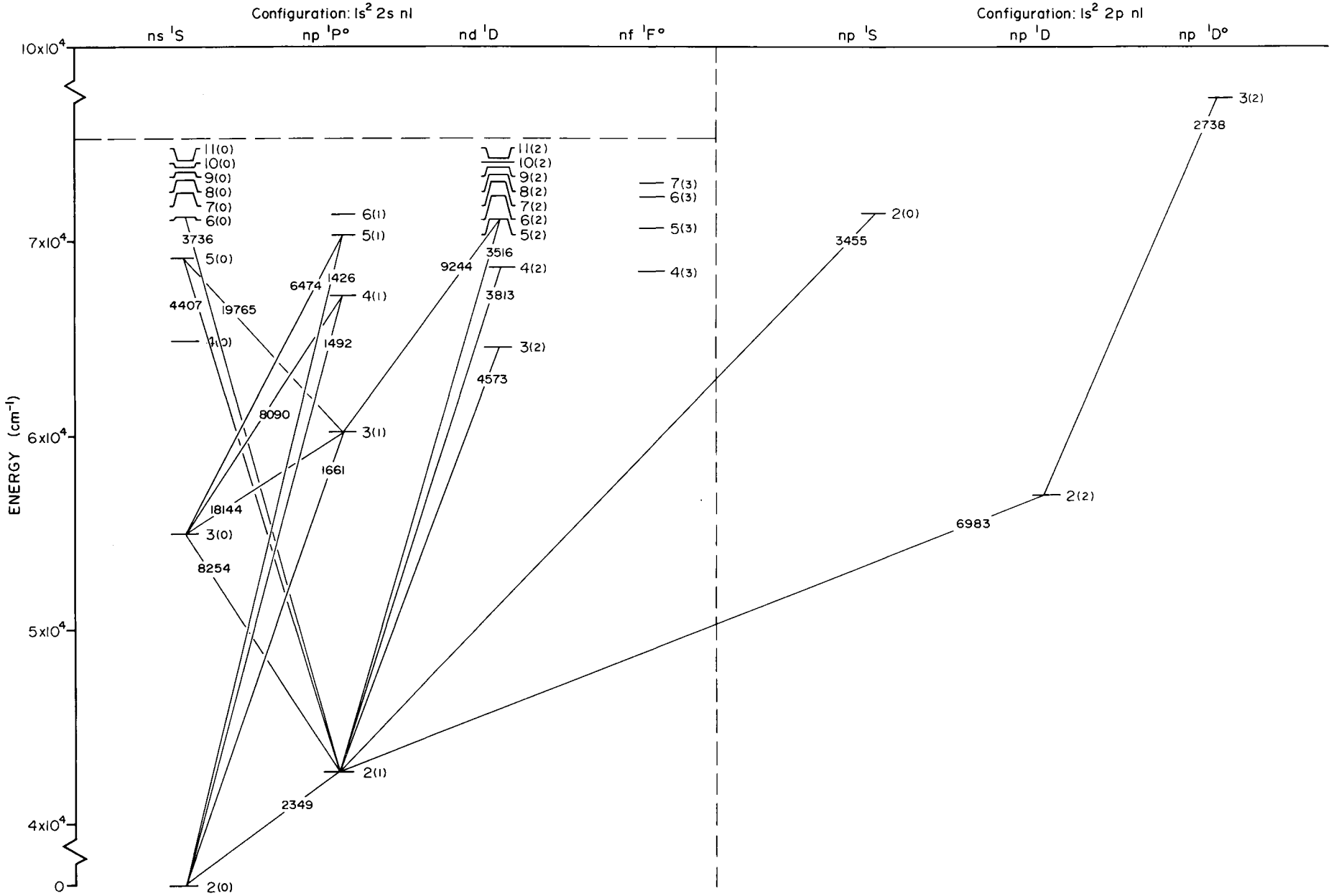
Note that a few doubly-excited states are known in Li II; these are described by J.P. Buchet, M.C. Buchet-Poulizac, H.G. Berry, and G.W.F. Drake, Phys. Rev. A **7**, 922 (1973).

Li III $Z = 3$ 1 electron

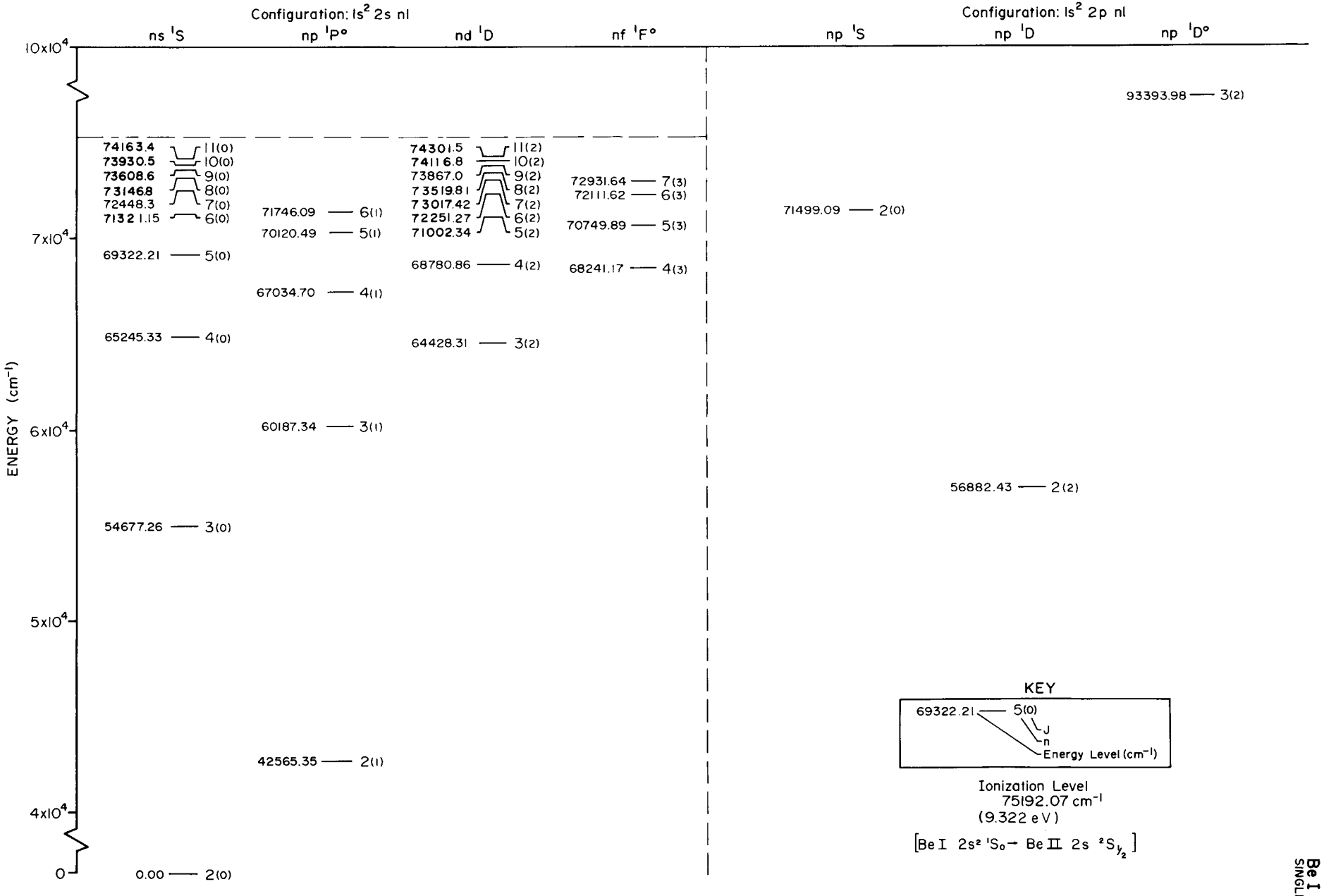
Please see the general references.

Beryllium (Be)

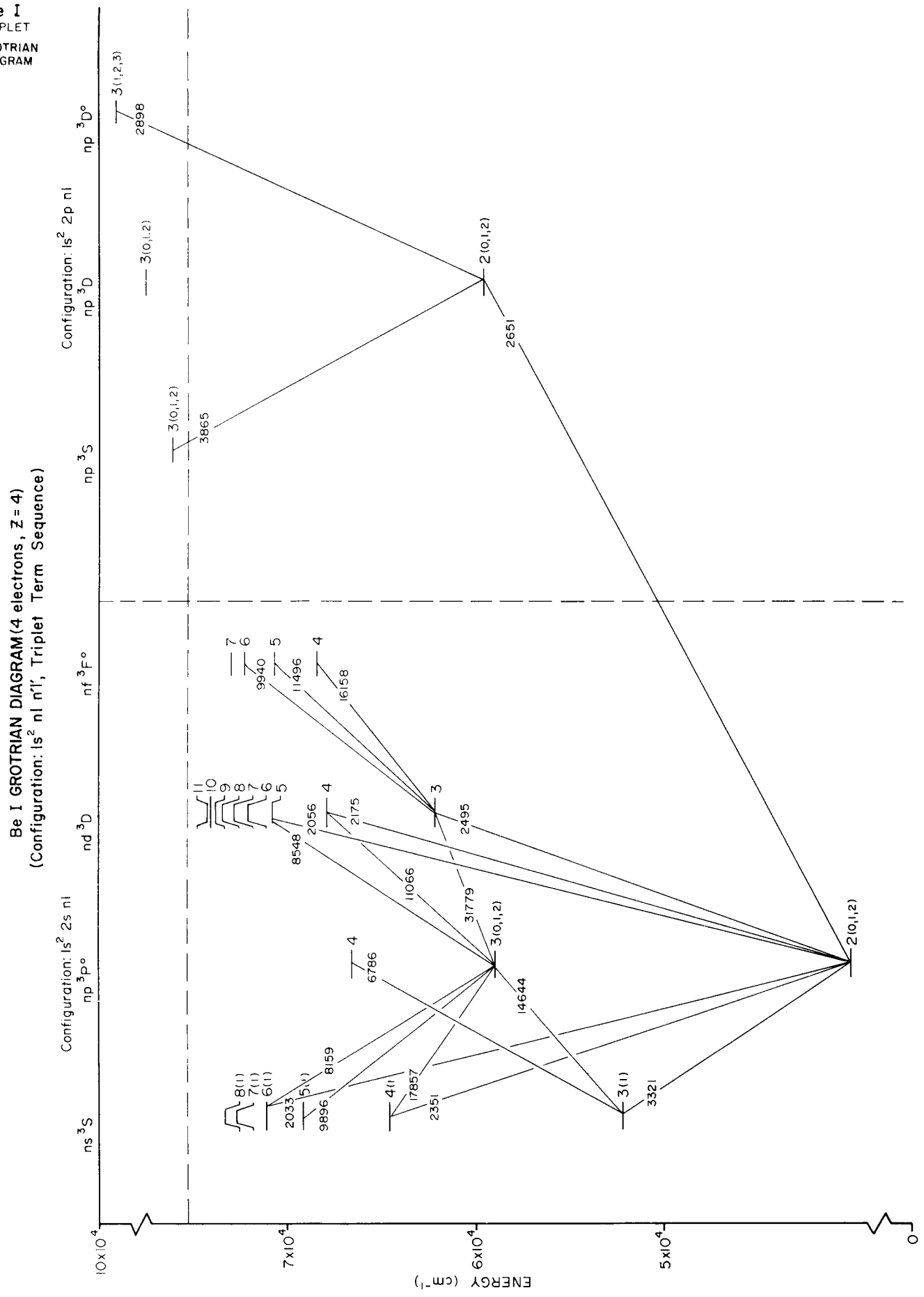
Be I GROTRIAN DIAGRAM (4 electrons, Z = 4)
(Configuration: $1s^2$ nl n'l', Singlet Term Sequence)



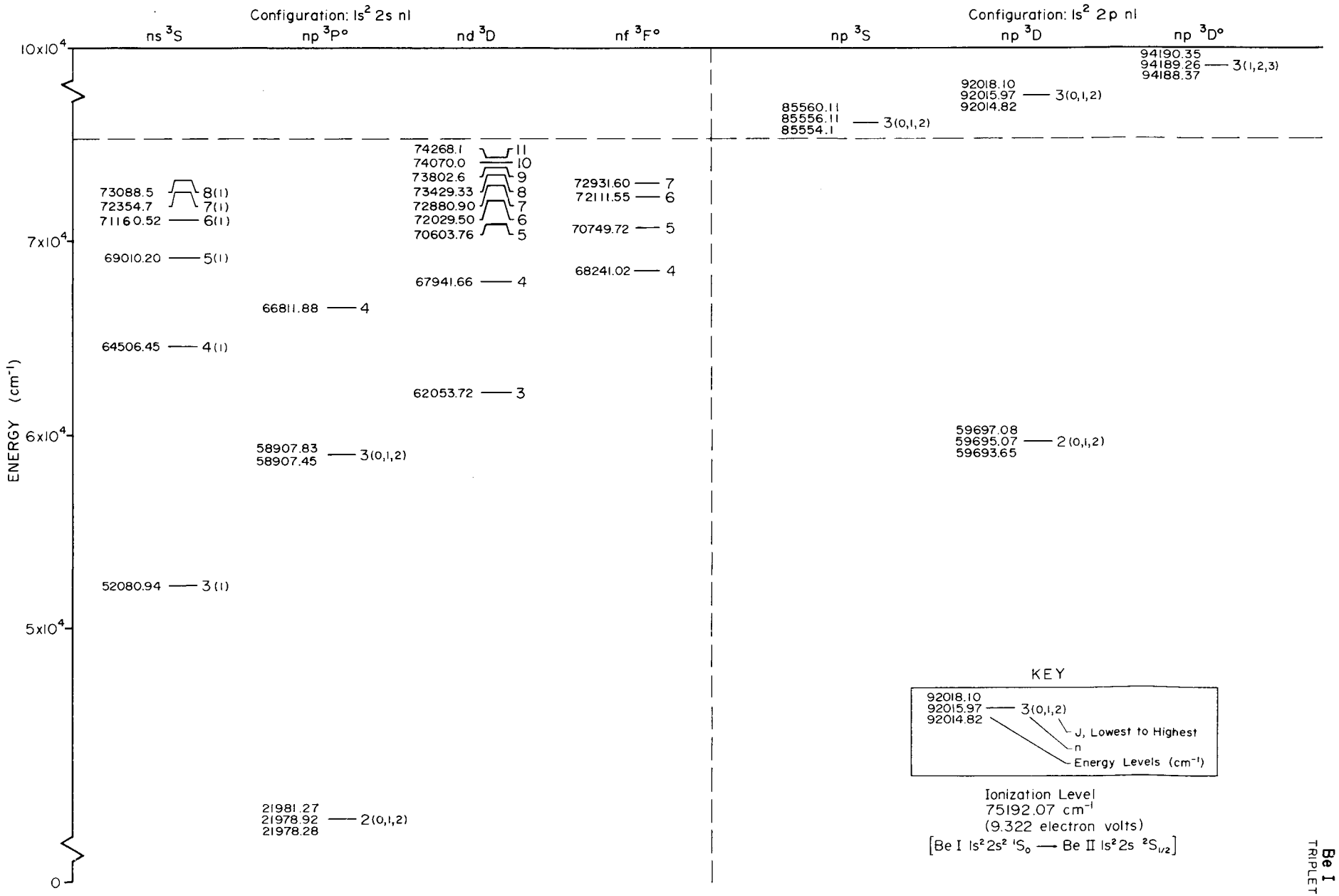
Be I ENERGY LEVELS (4 electrons, Z=4)
(Configuration: $1s^2$ nl n′l′, Singlet Term Sequence)



Be I
TRIPLET
GROTRIAN DIAGRAM

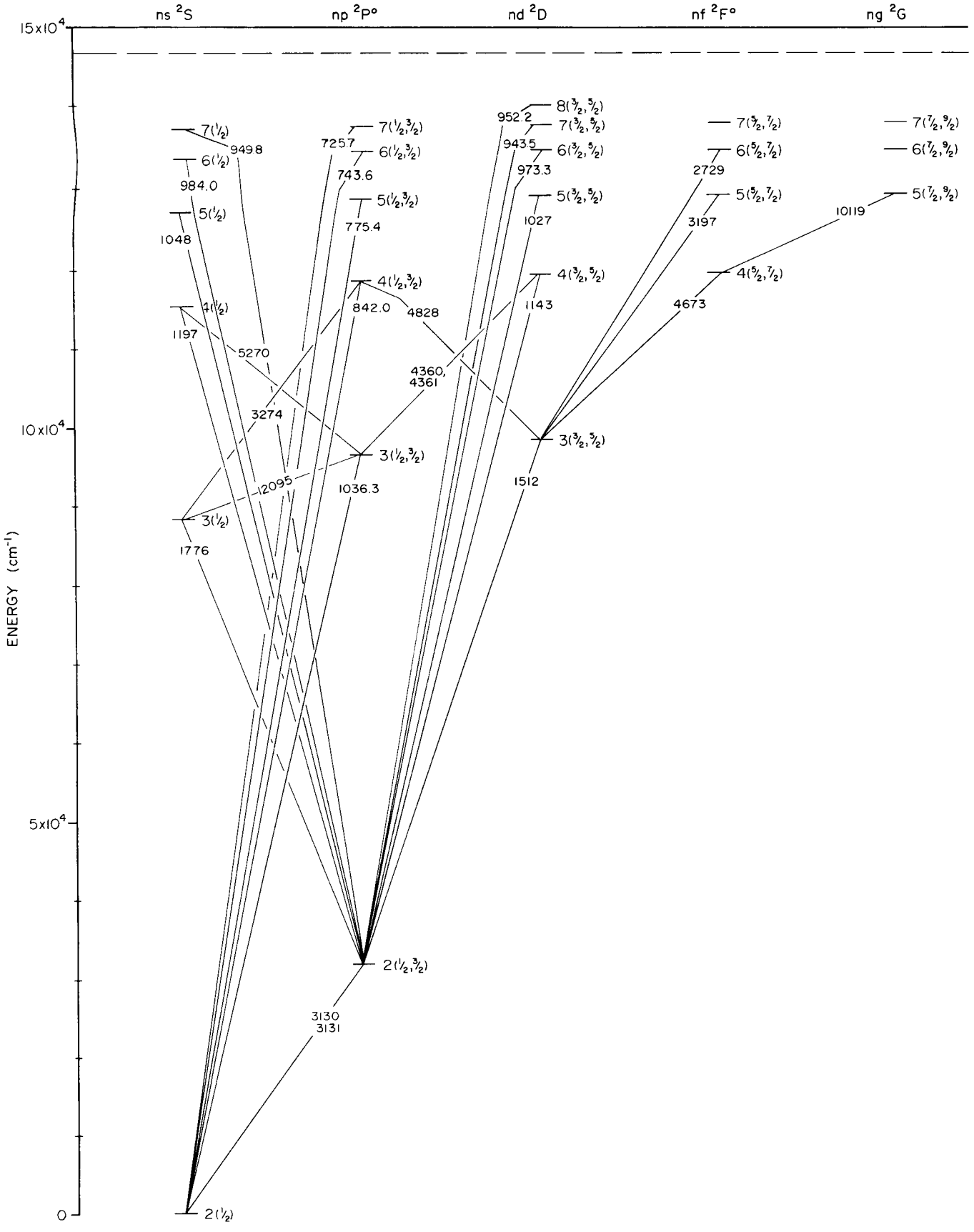


Be I ENERGY LEVELS (4 electrons, Z = 4)
(Configuration: $1s^2$ nl n′l′, Triplet Term Sequence)

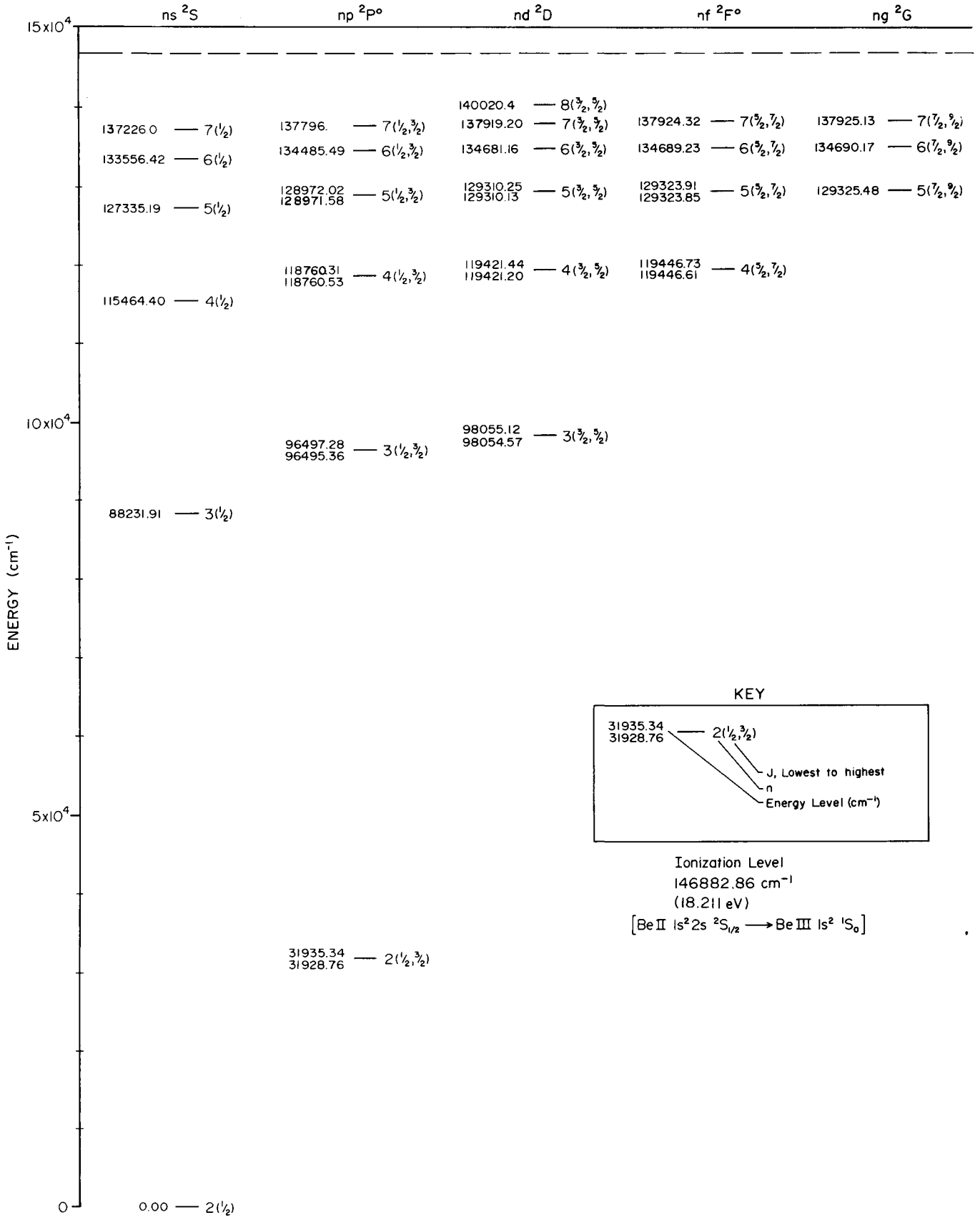


Be II
DOUBLET
GROTRIAN
DIAGRAM

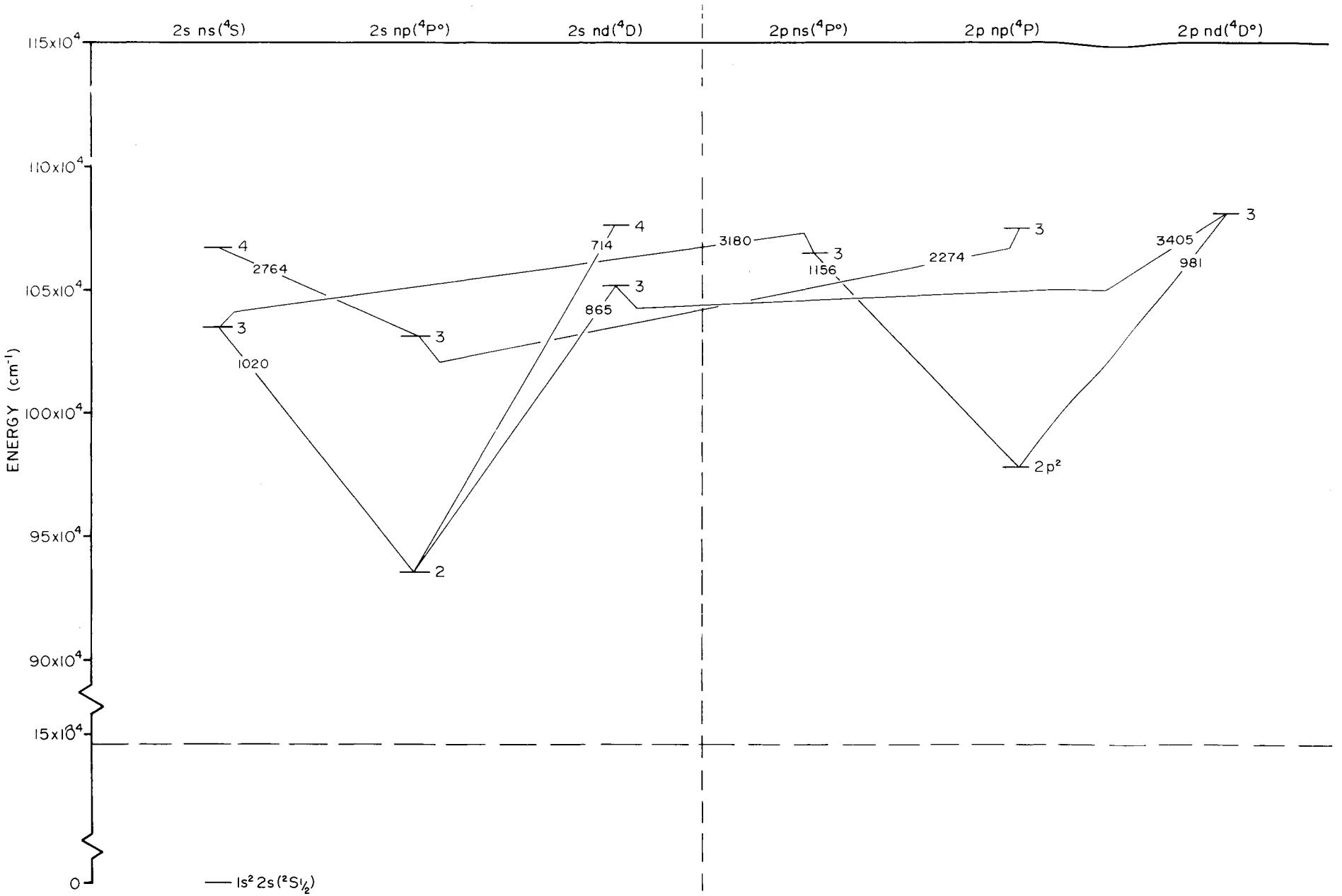
Be II GROTRIAN DIAGRAM (3 electrons, Z=3)
(Li I sequence, Configuration: $1s^2$ nl)
Doublet System



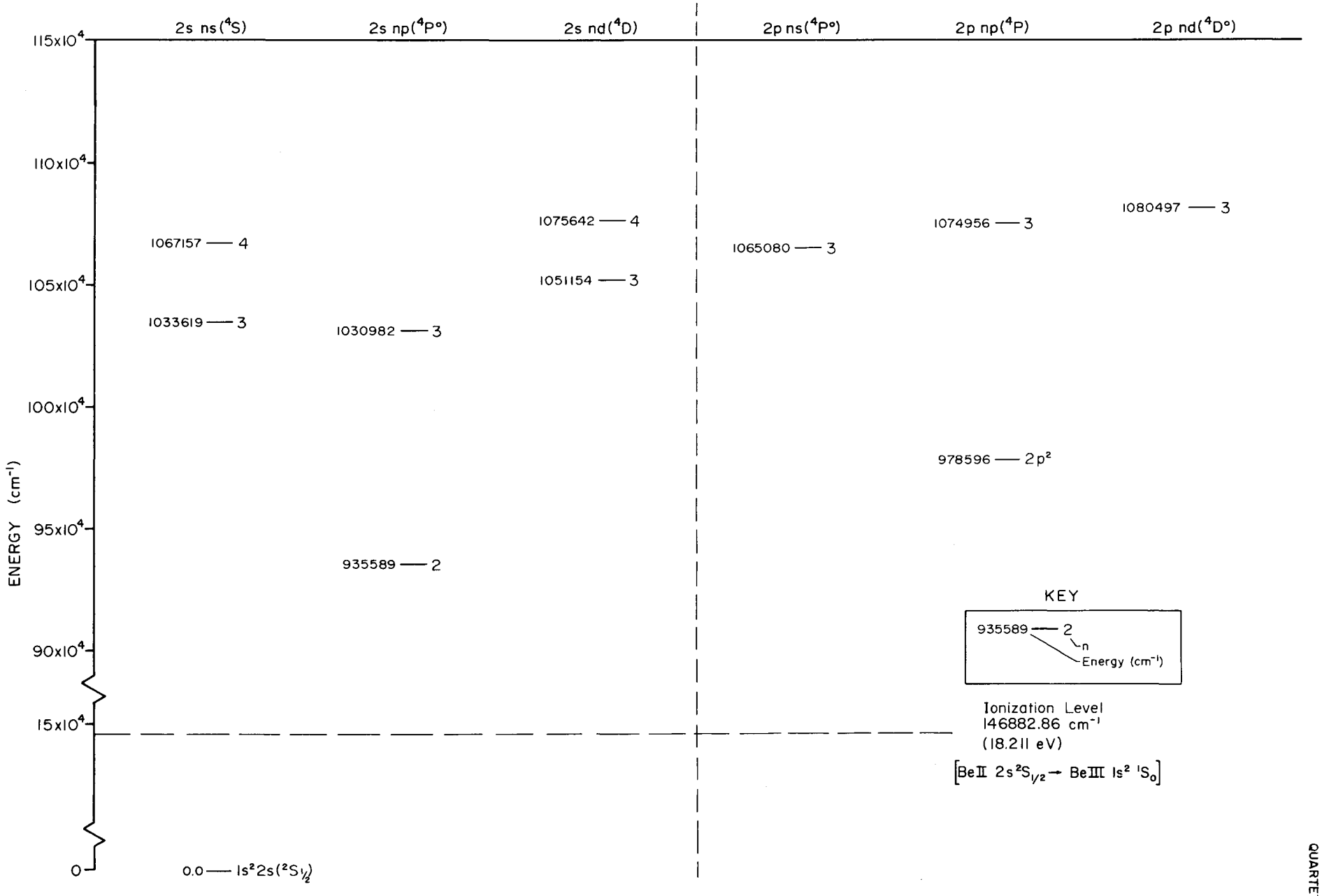
Be II ENERGY LEVELS (3 electrons, Z=3)
(Li I sequence, Configuration: $1s^2$ nl)
Doublet System



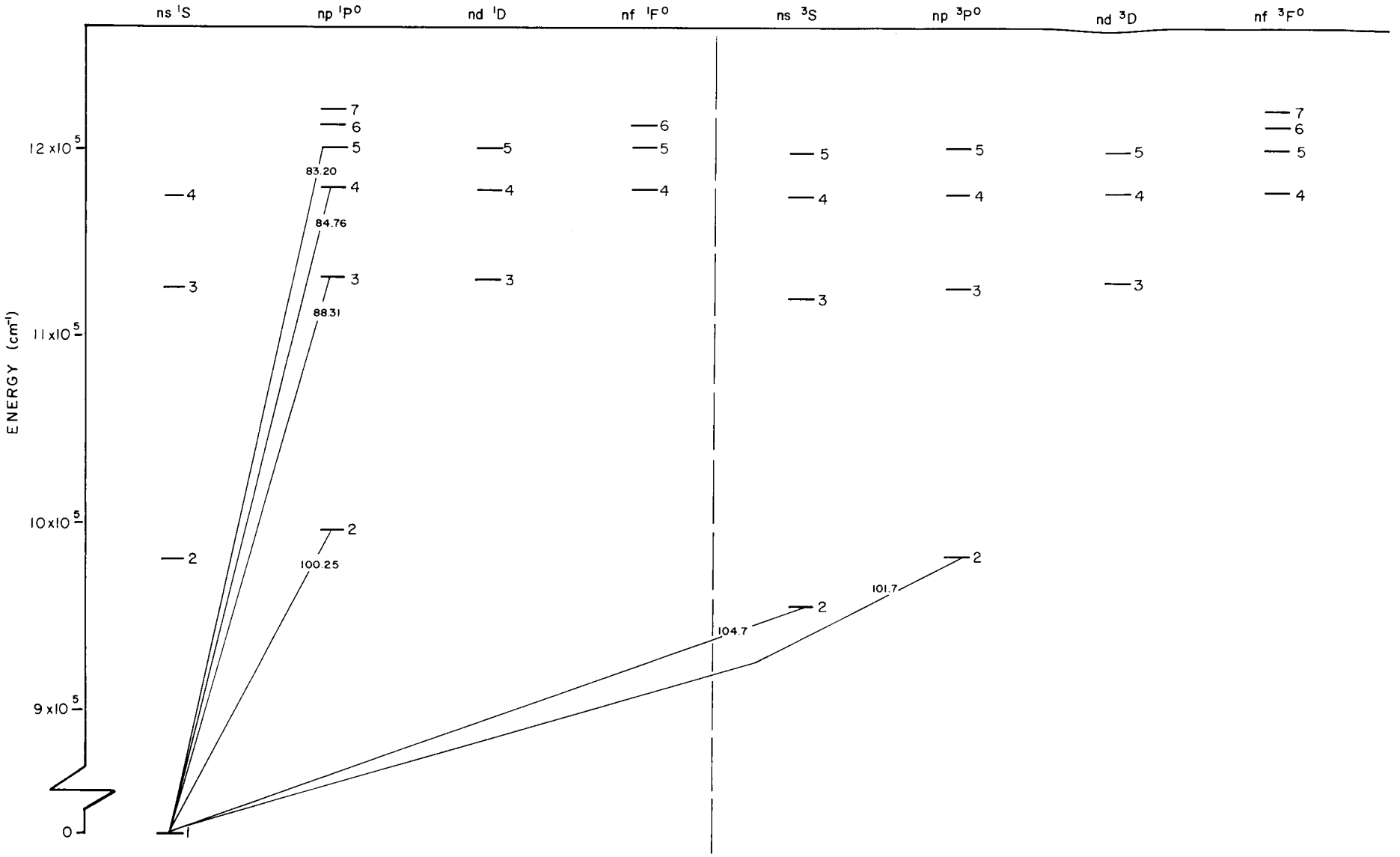
Be II DOUBLY EXCITED GROTRIAN DIAGRAM (3 electrons, Z = 4)
(Li I sequence, Configuration: 1s nl n'l', Quartet System)



Be II DOUBLY EXCITED ENERGY LEVELS (3 electrons, Z=4)
(Li I sequence, Configuration: Is nl n'l', Quartet System)

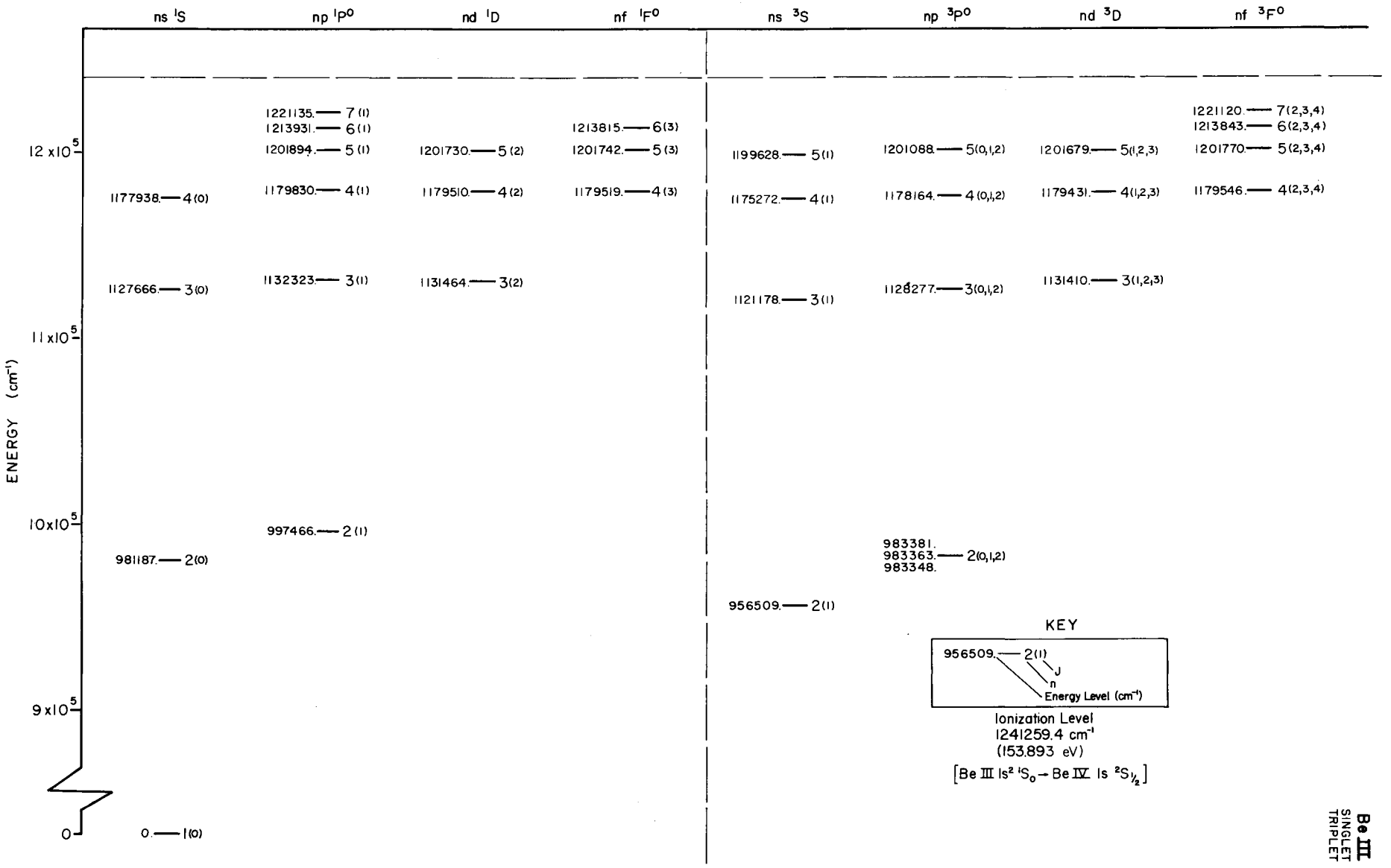


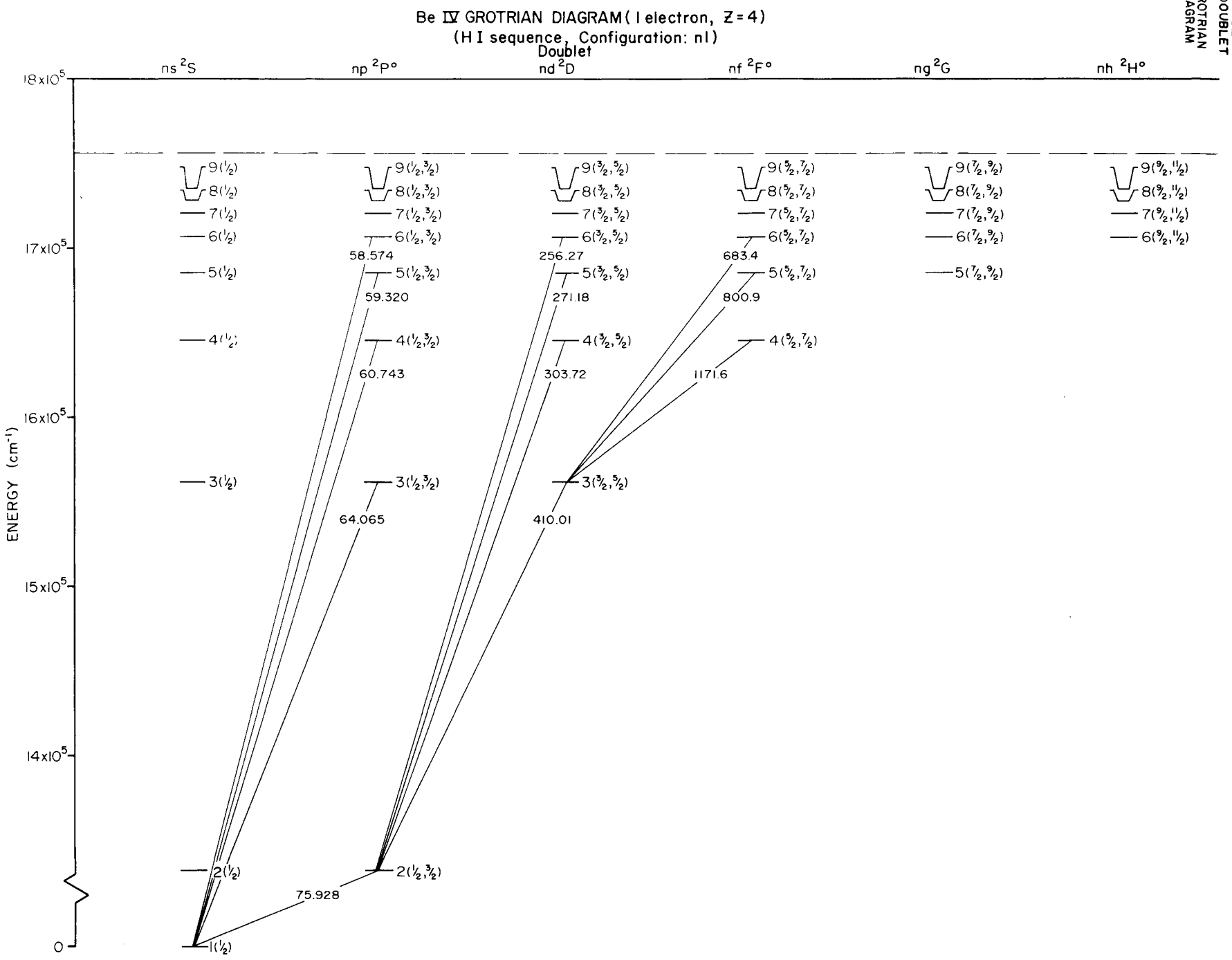
Be III GROTRIAN DIAGRAM (2 electrons, Z=4)
(He I sequence, Configuration: 1s nl, Singlet & Triplet System)



Be III ENERGY LEVELS (2 electrons, Z=4)

(He I sequence, Configuration: 1s nl, Singlet & Triplet System)

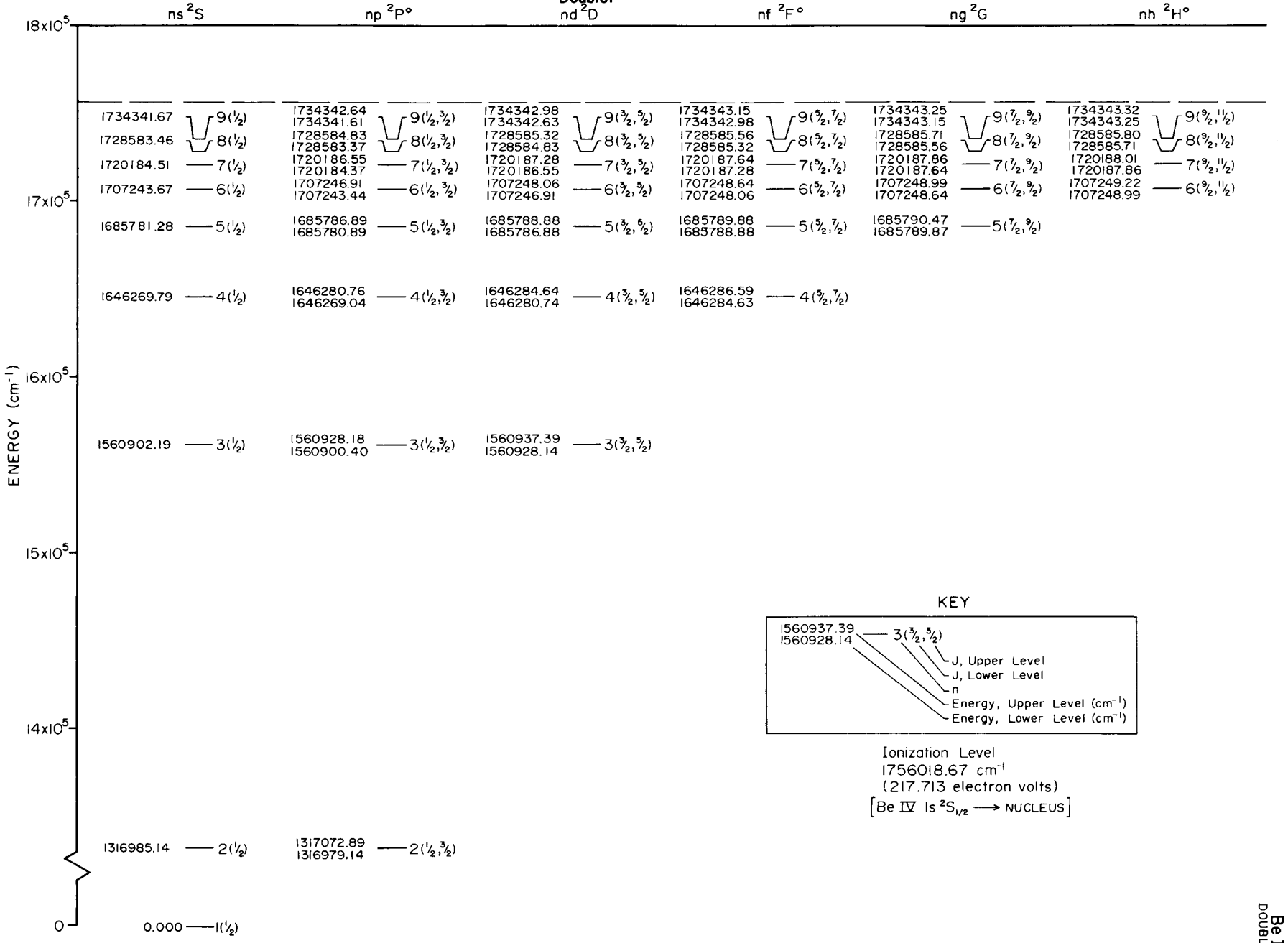



Be IV GROTRIAN DIAGRAM (I electron, Z = 4)
(H I sequence, Configuration: nl)
Doublet
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
ENERGY (cm⁻¹)
18x10⁵
17x10⁵
16x10⁵
15x10⁵
14x10⁵
0
9(½)
8(½)
7(½)
6(½)
5(½)
4(½)
3(½)
2(½)
1(½)
9(½,3/2)
8(½,3/2)
7(½,3/2)
6(½,3/2)
5(½,3/2)
4(½,3/2)
3(½,3/2)
2(½,3/2)
9(3/2,5/2)
8(3/2,5/2)
7(3/2,5/2)
6(3/2,5/2)
5(3/2,5/2)
4(3/2,5/2)
3(3/2,5/2)
9(5/2,7/2)
8(5/2,7/2)
7(5/2,7/2)
6(5/2,7/2)
5(5/2,7/2)
4(5/2,7/2)
9(7/2,9/2)
8(7/2,9/2)
7(7/2,9/2)
6(7/2,9/2)
5(7/2,9/2)
9(9/2,11/2)
8(9/2,11/2)
7(9/2,11/2)
6(9/2,11/2)
58.574
59.320
60.743
64.065
75.928
256.27
271.18
303.72
410.01
683.4
800.9
1171.6

Be IV ENERGY LEVELS (1 electron, Z = 4)

(H I sequence, Configuration: nl)

Doublet



Ionization Level
1756018.67 cm⁻¹
(217.713 electron volts)
[Be IV 1s ²S$_{1/2}$ ⟶ NUCLEUS]

Be I $Z = 4$ 4 electrons

H.G. Berry, J. Bromander, I. Martinson, and R. Buchta, Physica Scripta **3**, 63 (1971).

Authors suggest classifications for spectral lines.

J.-E. Holmström and L. Johansson, Ark. Fys. **40**, 133 (1969).

Authors give line table observed in the range 35 000–3800 Å with Ritz formulae.

E.W.H. Selwyn, Proc. Phys. Soc. **41**, 392 (1929).

Author gives a line table for lines observed in the region 1600–2100 Å.

Note that a few doubly-excited levels not shown on the accompanying diagrams are described in the above reference by Berry *et al.*

Be II $Z = 4$ 3 electrons

H.G. Berry, J. Bromander, I. Martinson, and R. Buchta, Physica Scripta **3**, 63 (1971).

Authors summarize available experimental information on the doubly-excited levels in the Li I isoelectronic sequence.

J.-E. Holmström and L. Johansson, Ark. Fys. **40**, 133 (1969).

Authors give line table and term table for wavelengths observed in range 35 000–3800 Å.

Be III $Z = 4$ 2 electrons

H.G. Berry, J. Désesquelles, and M. Dufay, Phys. Rev. **A6**, 600 (1972).

This paper summarizes experiment and theory for doubly-excited states in the He I isoelectronic sequence.

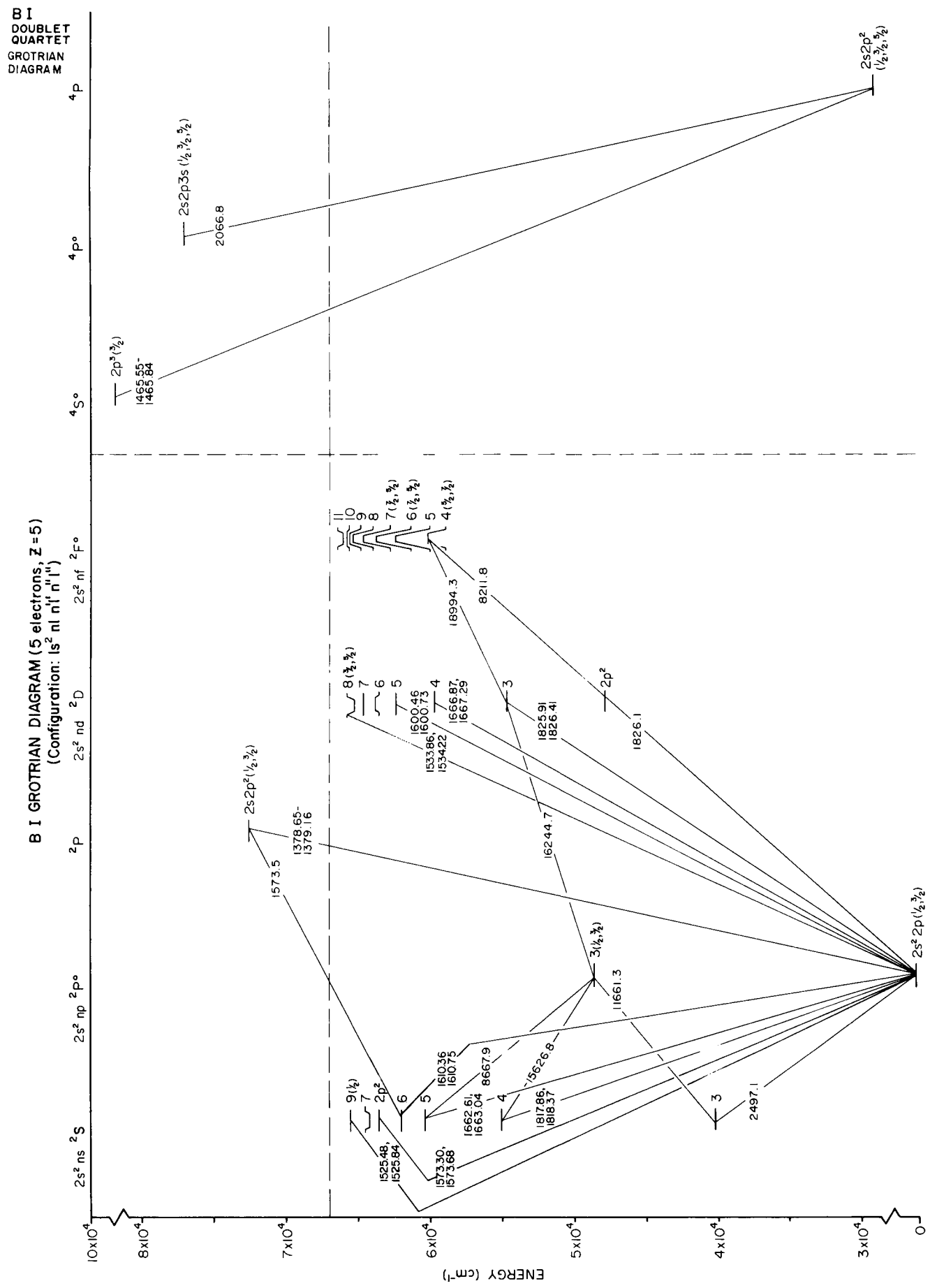
E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculated energy levels nonrelativistically for the He I isoelectronic sequence.

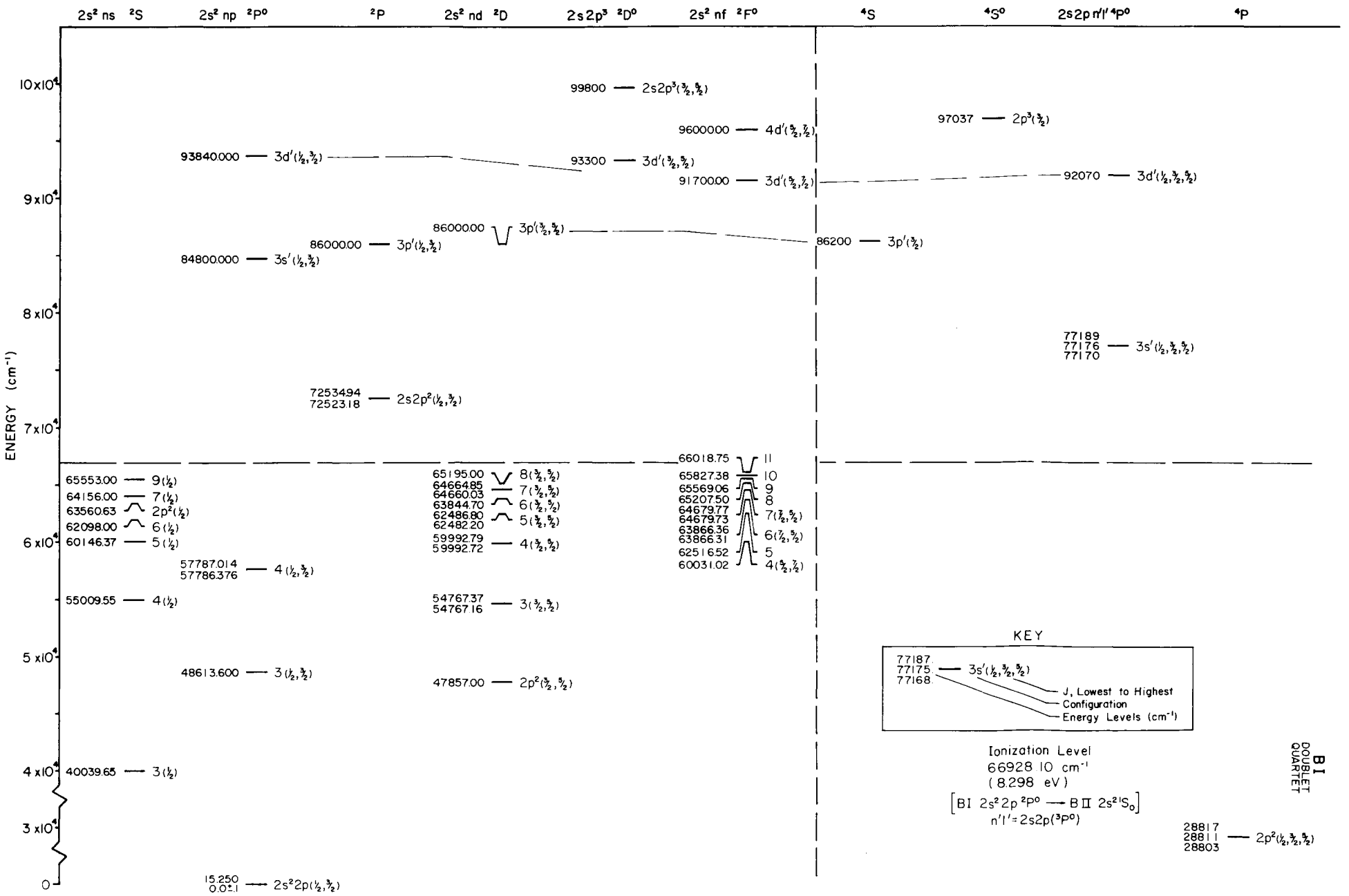
Be IV $Z = 4$ 1 electron

Please see the general references.

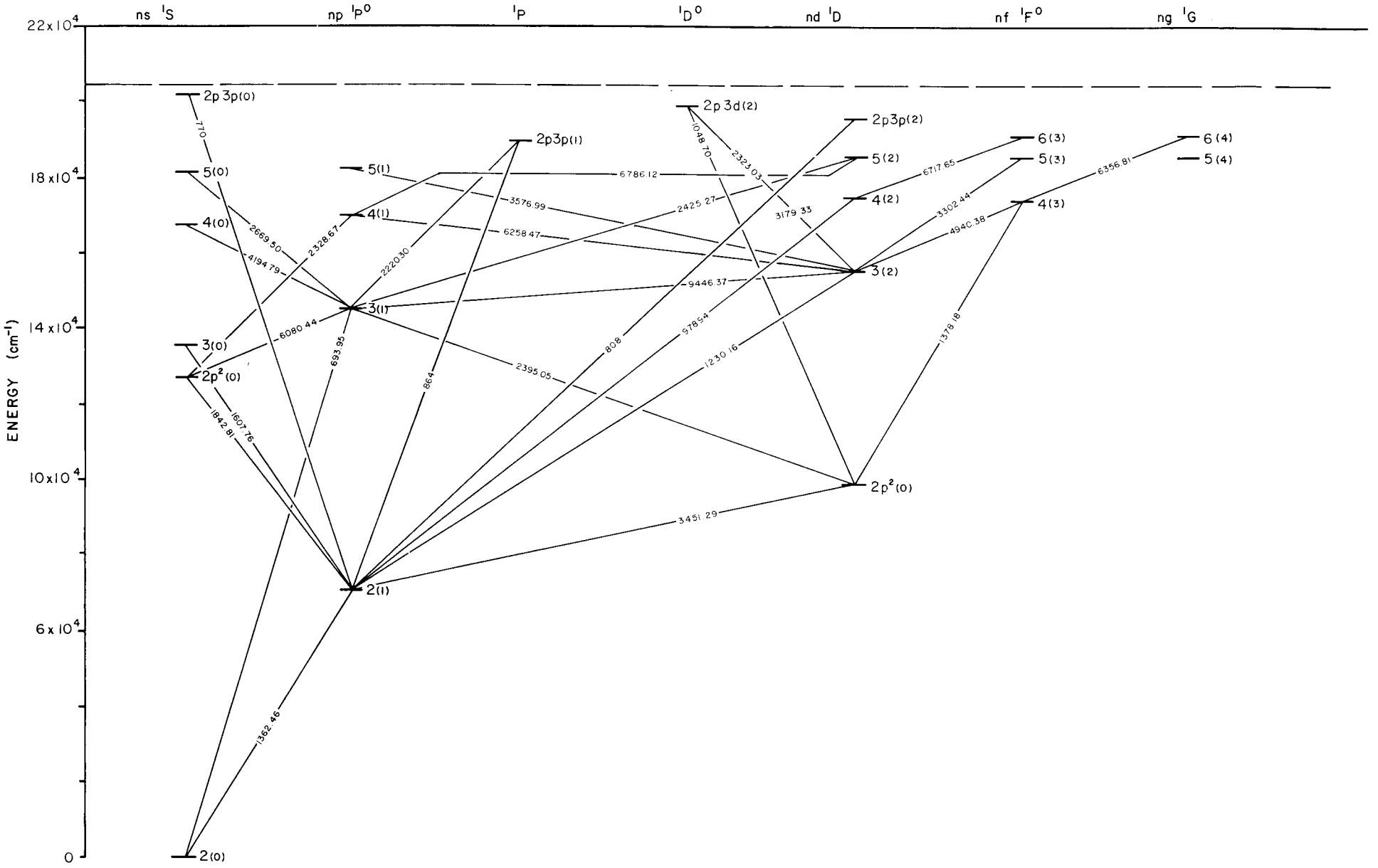
Borium (B)


B I
DOUBLET
QUARTET
GROTRIAN
DIAGRAM
B I GROTRIAN DIAGRAM (5 electrons, Z=5)
(Configuration: 1s² nl n'l' n''l'')
2s² ns ²S
2s² np ²P°
²P
2s² nd ²D
2s² nf ²F°
4S°
4P°
4P
ENERGY (cm⁻¹)
10x10⁴
8x10⁴
7x10⁴
6x10⁴
5x10⁴
4x10⁴
3x10⁴
0
2s2p3s (½,3/2,3/2)
2066.8
2s2p² (½,3/2,5/2)
2p³(3/2)
1465.55-
1465.84
2s2p²(½,3/2)
1378.65-
1379.16
1573.5
2s² 2p(½,3/2)
11
10
9
8
7(7/2,9/2)
6(7/2,7/2)
5
4(9/2,7/2)
18994.3
8211.8
8(9/2,9/2)
7
6
5
4
1600.46
1600.73
1533.86,
1534.22
1666.87,
1667.29
3
1825.91
1826.41
2p²
1826.1
16244.7
3(½,3/2)
11661.3
9(½)
7
2p²
6
5
1610.36
1610.75
8667.9
-15626.8
1662.61,
1663.04
4
1817.86,
1818.37
3
2497.1
1525.48,
1525.84
1573.30,
1573.68

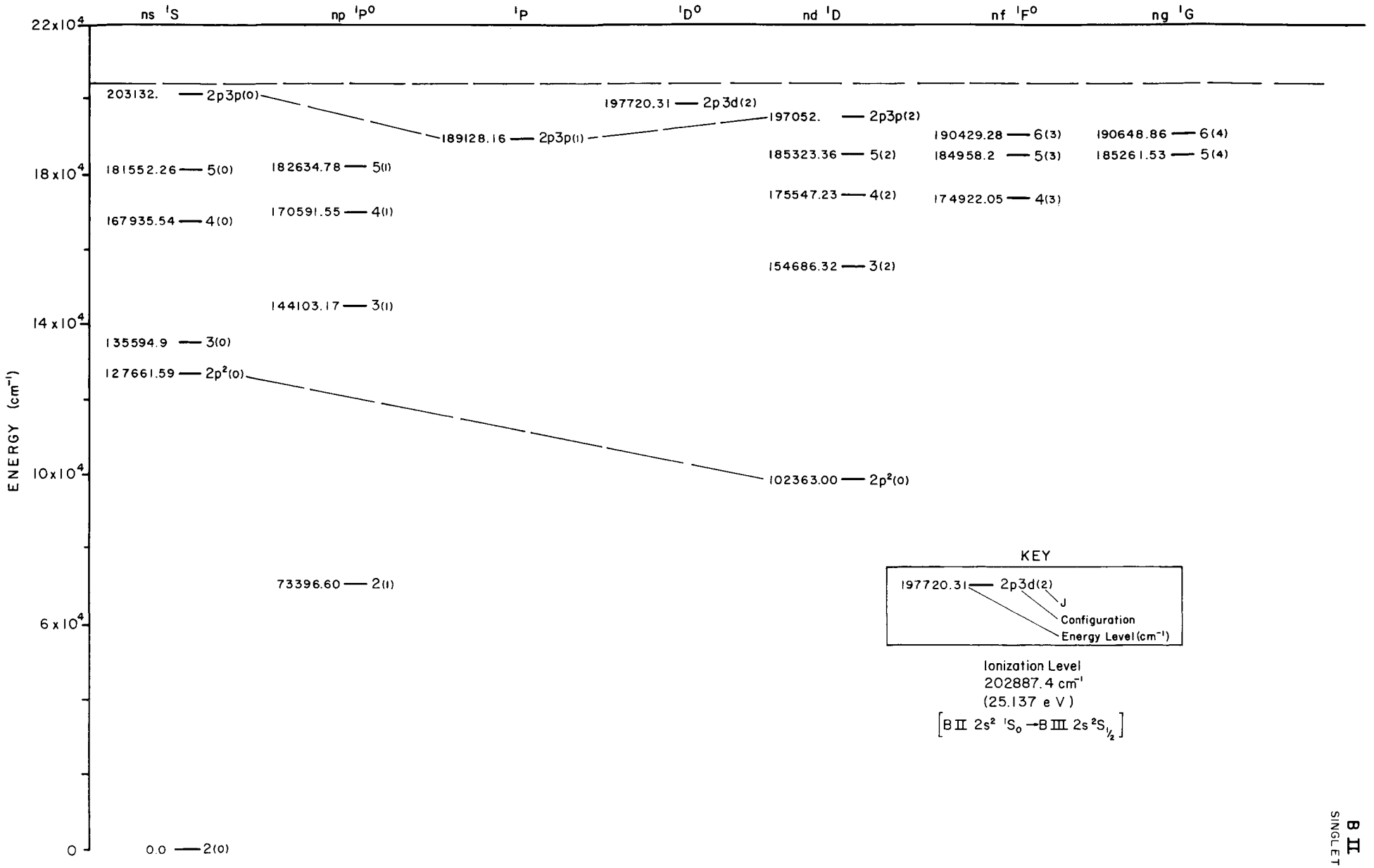
B I ENERGY LEVELS (5 electrons, Z=5)
(Configuration: $1s^2 nl\, n'l'\, n''l''$ Doublet, Quartet)



B II GROTRIAN DIAGRAM(4 electrons, Z= 5)
(Be I sequence, Configuration: $1s^2 2s\,nl$, Singlet System)

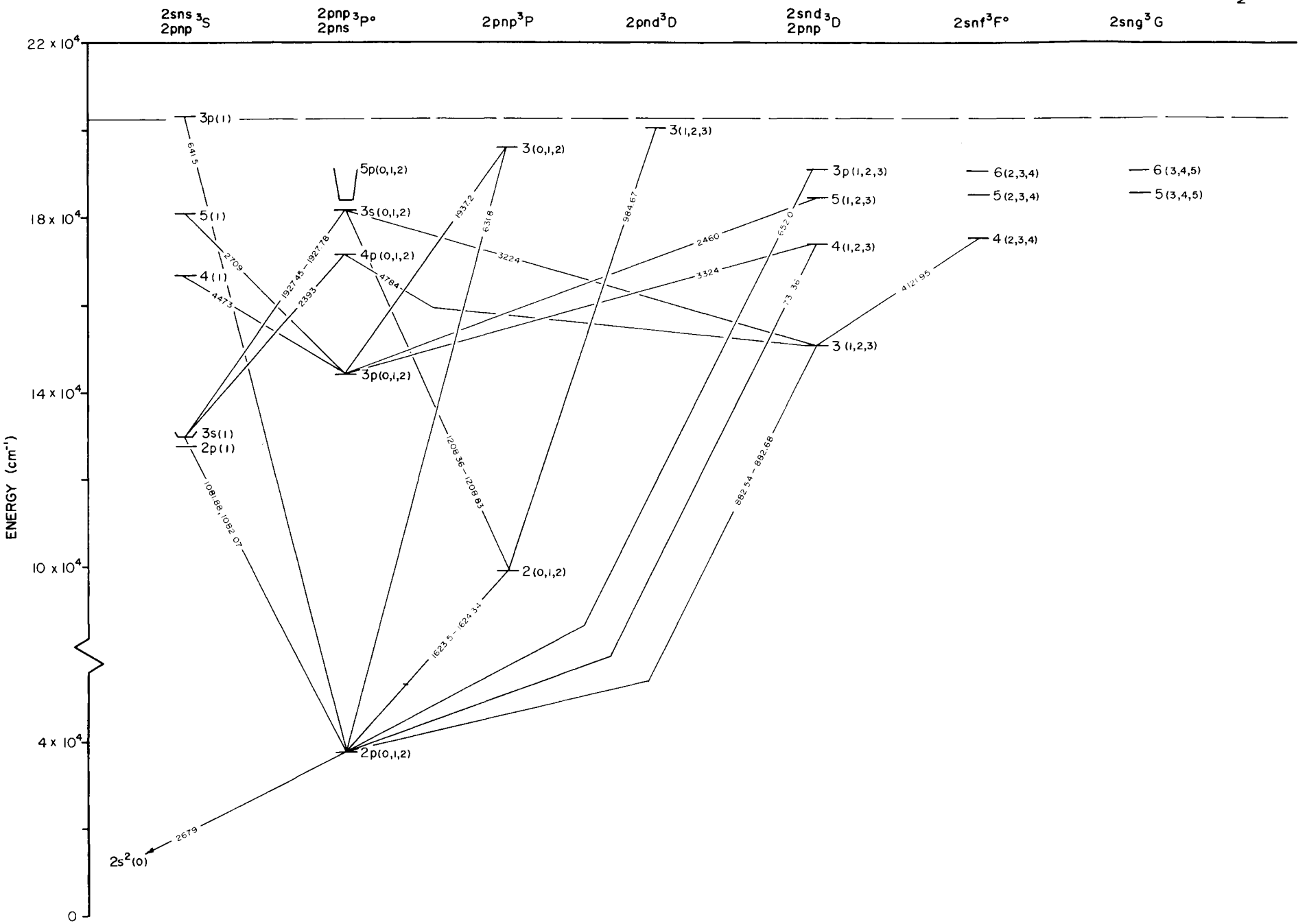


BII ENERGY LEVELS (4 electrons, Z=5)
Be I sequence, Configuration: $1s^2 2s\,nl$, Singlet System)



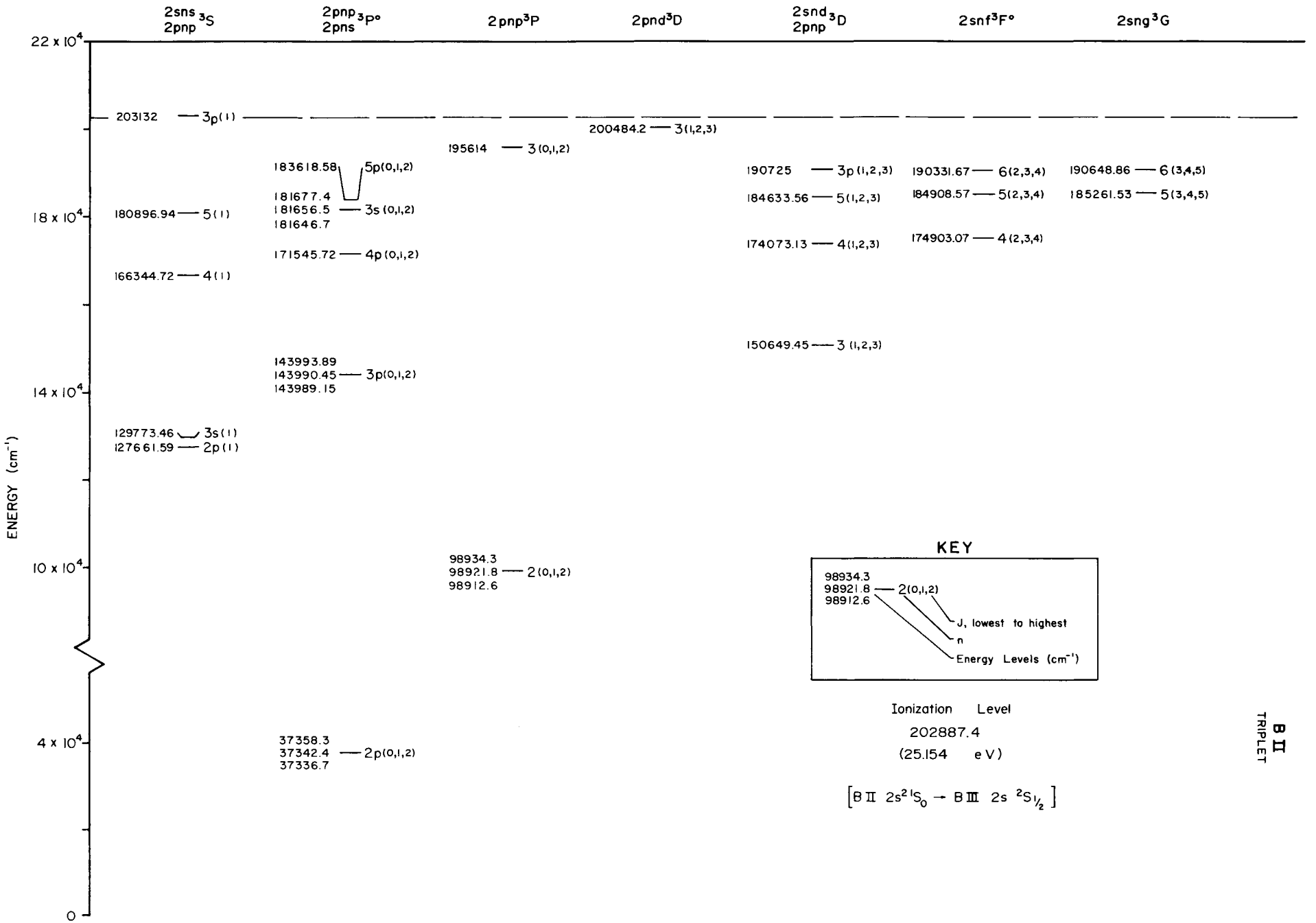
B II GROTRIAN DIAGRAM (4 electrons, Z = 5)

(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Triplet System)



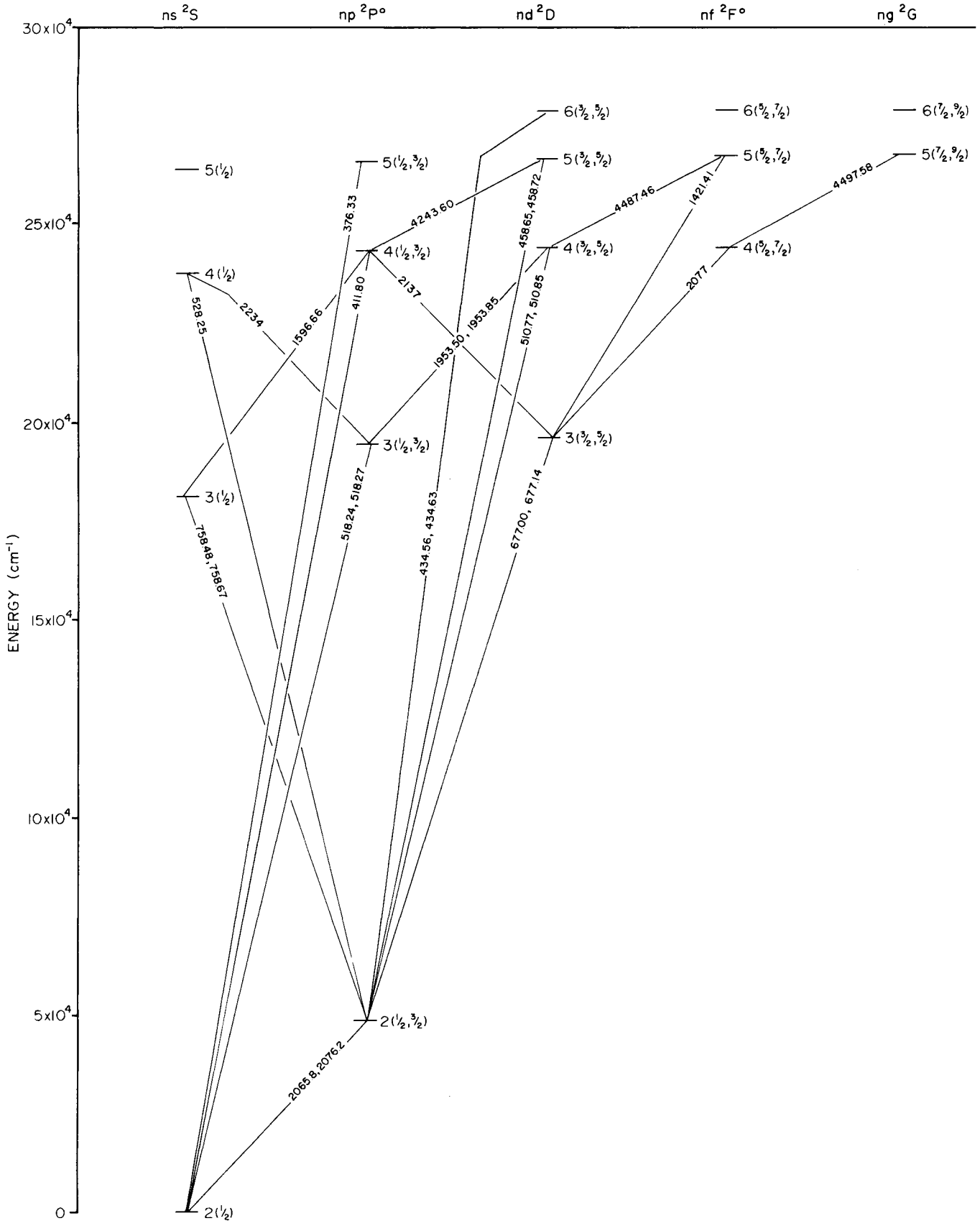
BII ENERGY LEVELS (4 electrons, Z = 5)

(Be I sequence, Configuration: $1s^2 nl\,n'l'$, Triplet System)

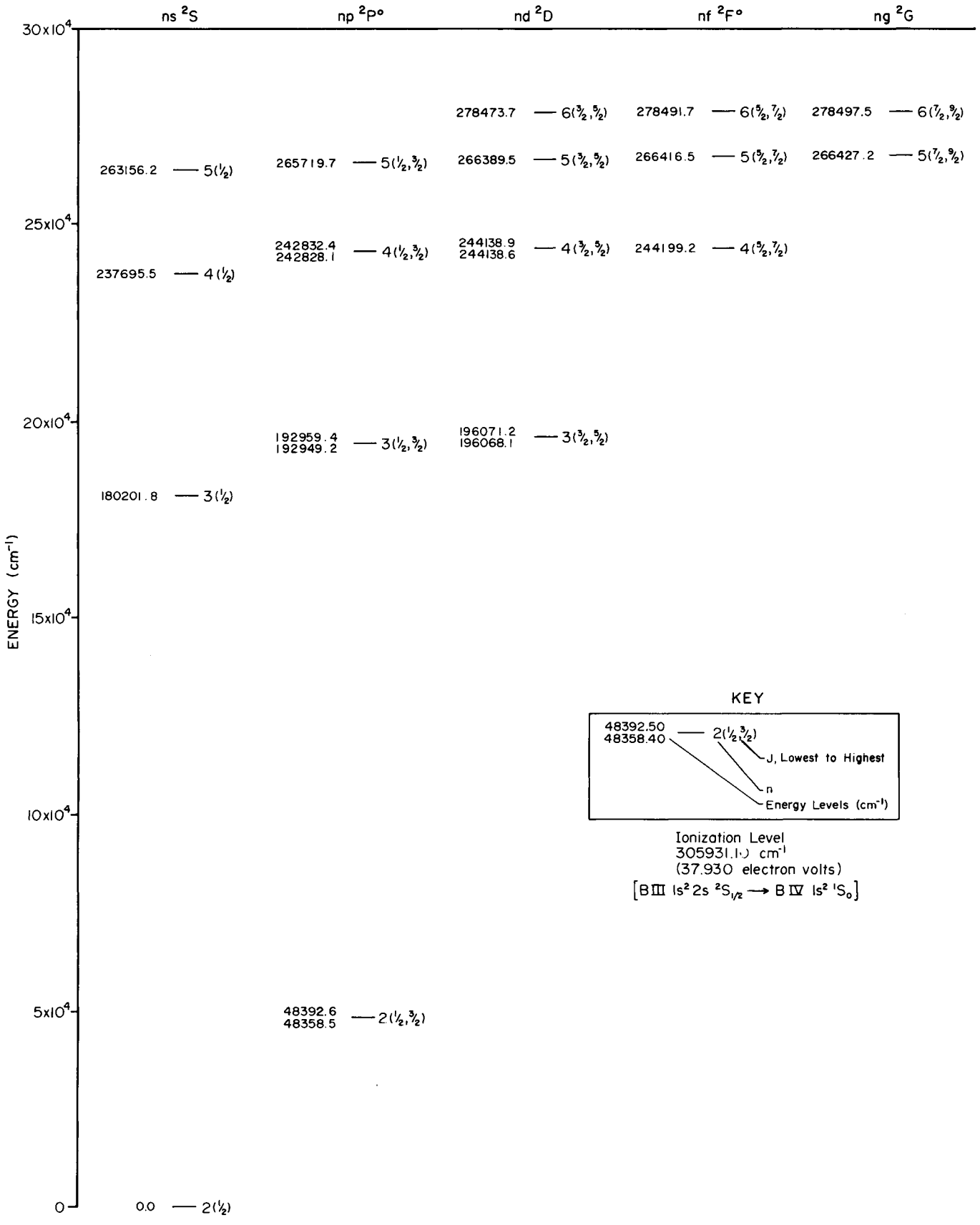


B III
DOUBLET
GROTRIAN
DIAGRAM

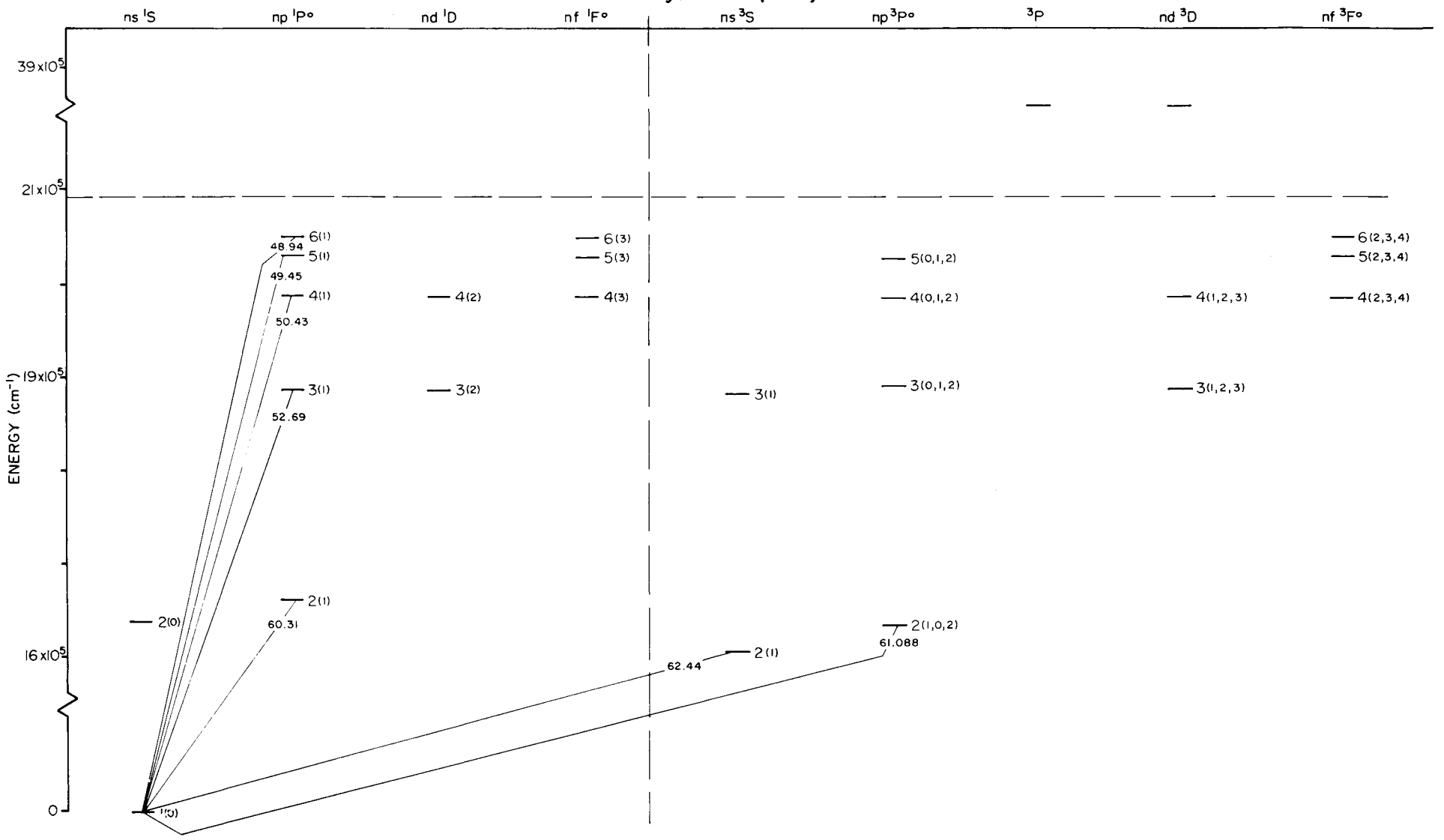
B III GROTRIAN DIAGRAM (3 electrons, Z=5)
(Li I sequence, Configuration: $1s^2\,nl$)



B III ENERGY LEVELS (3 electrons, Z=5)
(Li I sequence, Configuration: $1s^2 nl$)



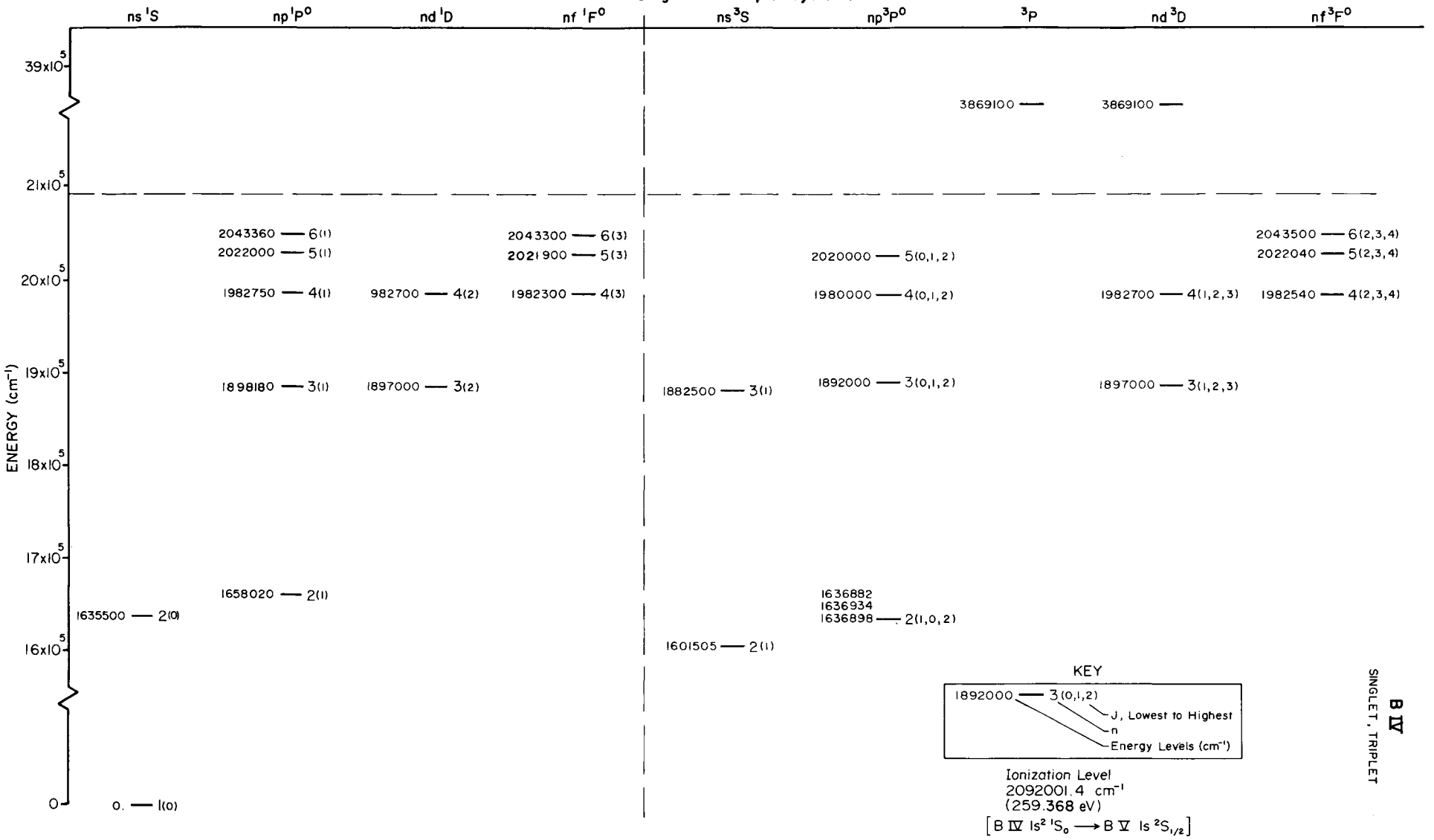
B IV GROTRIAN DIAGRAM (2 electrons, Z=5)
He I sequence, Configuration nl n'l'
Singlet and Triplet Systems



B IV ENERGY LEVELS (2electrons, Z = 5)

He I sequence, Configuration: 1s nl

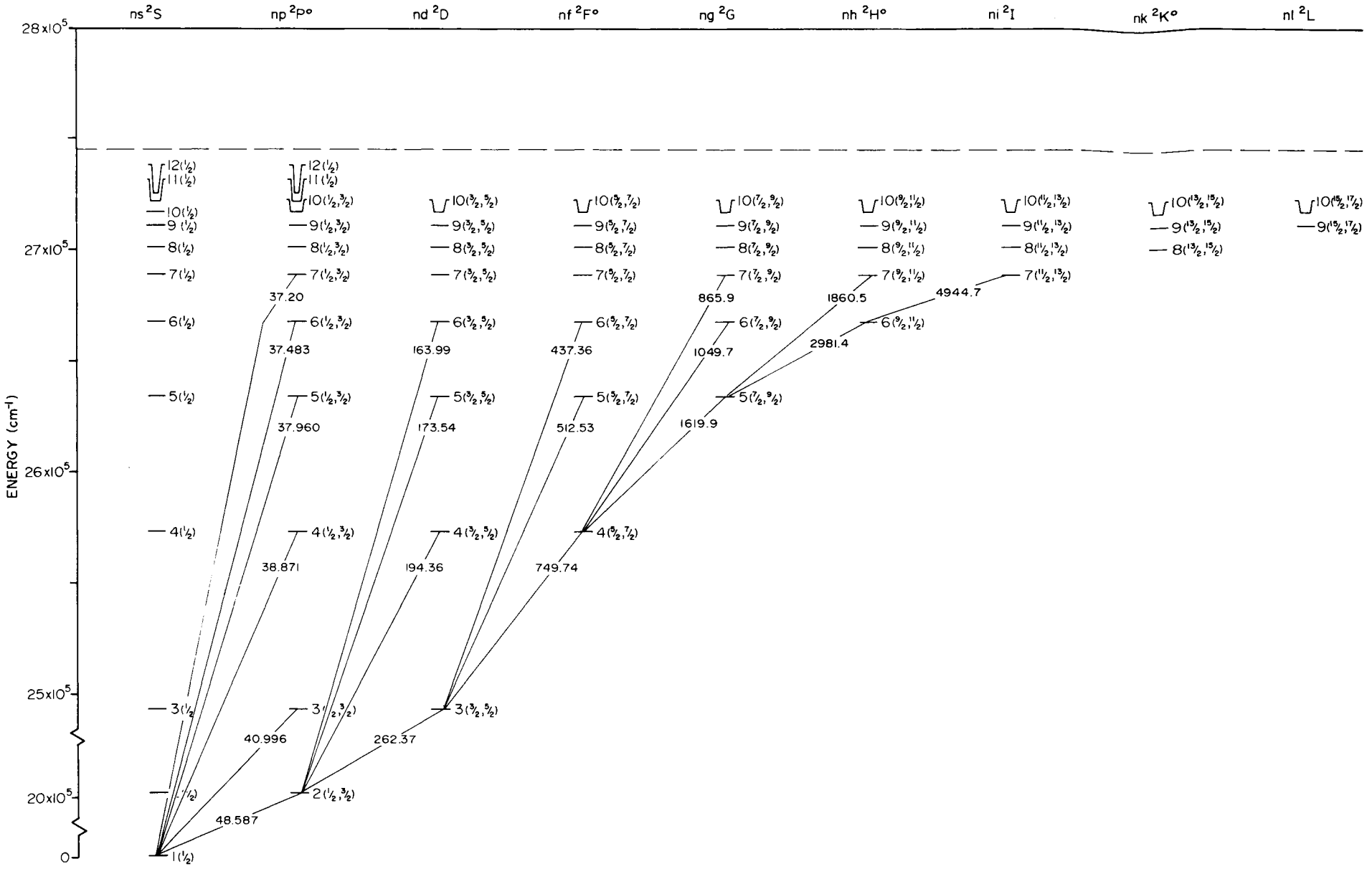
Singlet and Triplet Systems



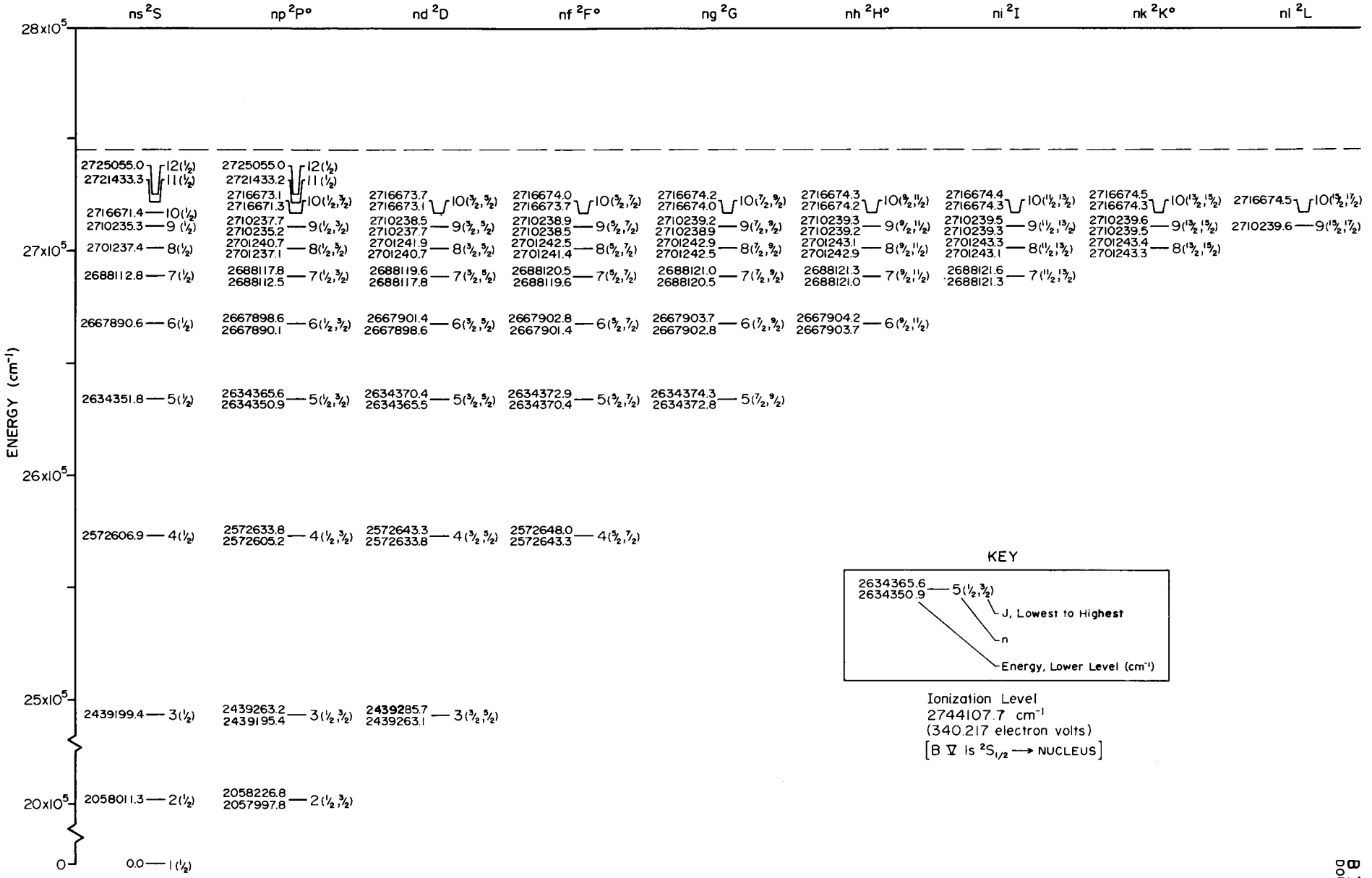
B IV

SINGLET, TRIPLET

B V GROTRIAN DIAGRAM (1 electron, Z=5)
(H I sequence, Configuration: nl) Doublet



B V ENERGY LEVELS (1 electron, Z=5)
(H I sequence, Configuration: nl) Doublet



B I $Z = 5$ 5 electrons

B. Edlén, A. Ölme, G. Herzberg, and J.W.C. Johns, J. Opt. Soc. Amer. **60**, 889 (1970).

Authors give line tables from observed spectra.

P. Gunnvald and L. Minnhagen, Ark. Fys. **22**, 327 (1962).

Authors give line and energy level tables and a Grotrian diagram for the transitions observed.

B II $Z = 5$ 4 electrons

E.W.H. Selwyn, Proc. Phys. Soc. **41**, 392 (1929).

Author gives observed lines of wavelengths in the region 1600–2000 Å.

B III $Z = 5$ 3 electrons

Please see the general references.

B IV $Z = 5$ 2 electrons

E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

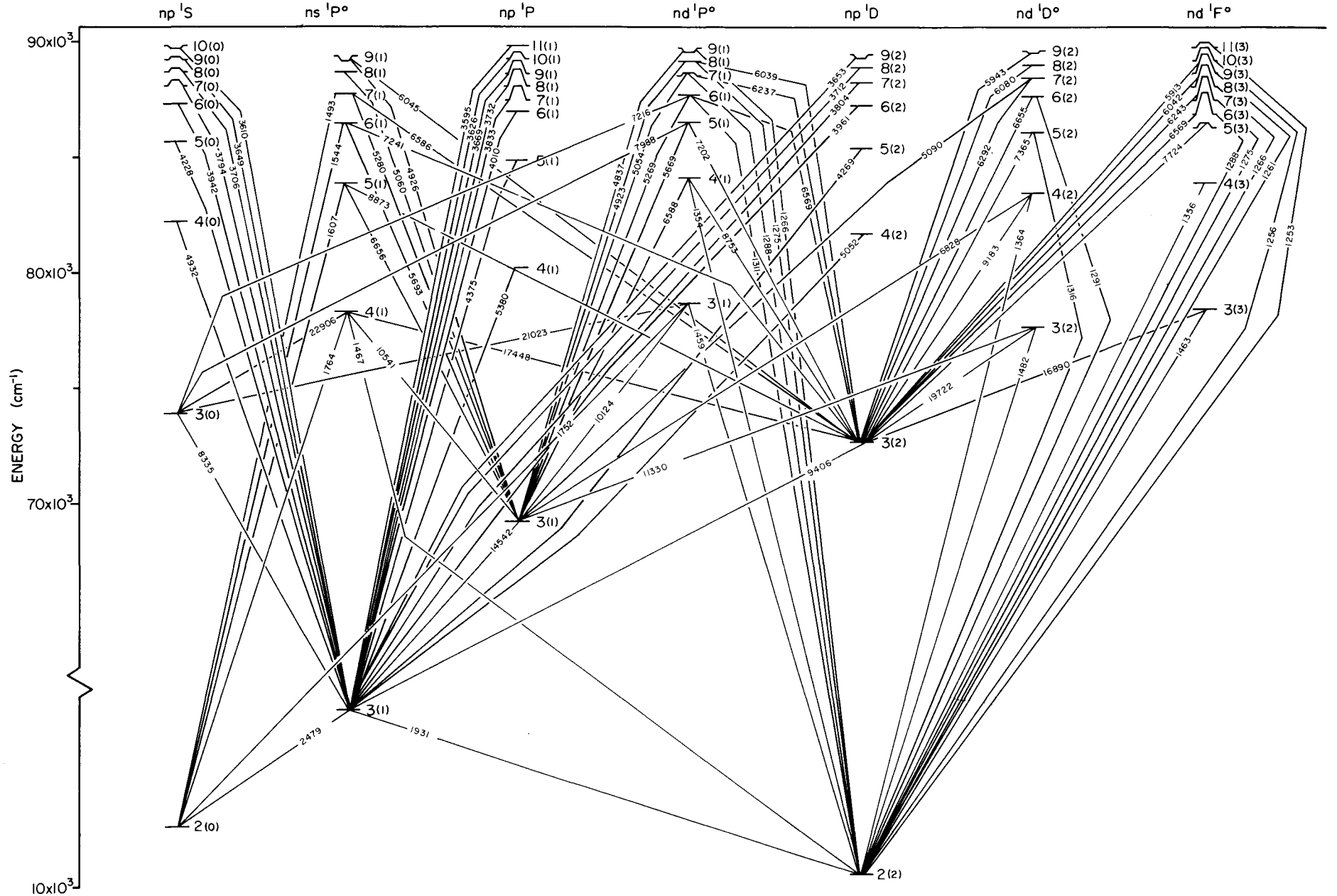
Authors calculate energy levels nonrelativistically for the He I isoelectronic sequence.

B V $Z = 5$ 1 electron

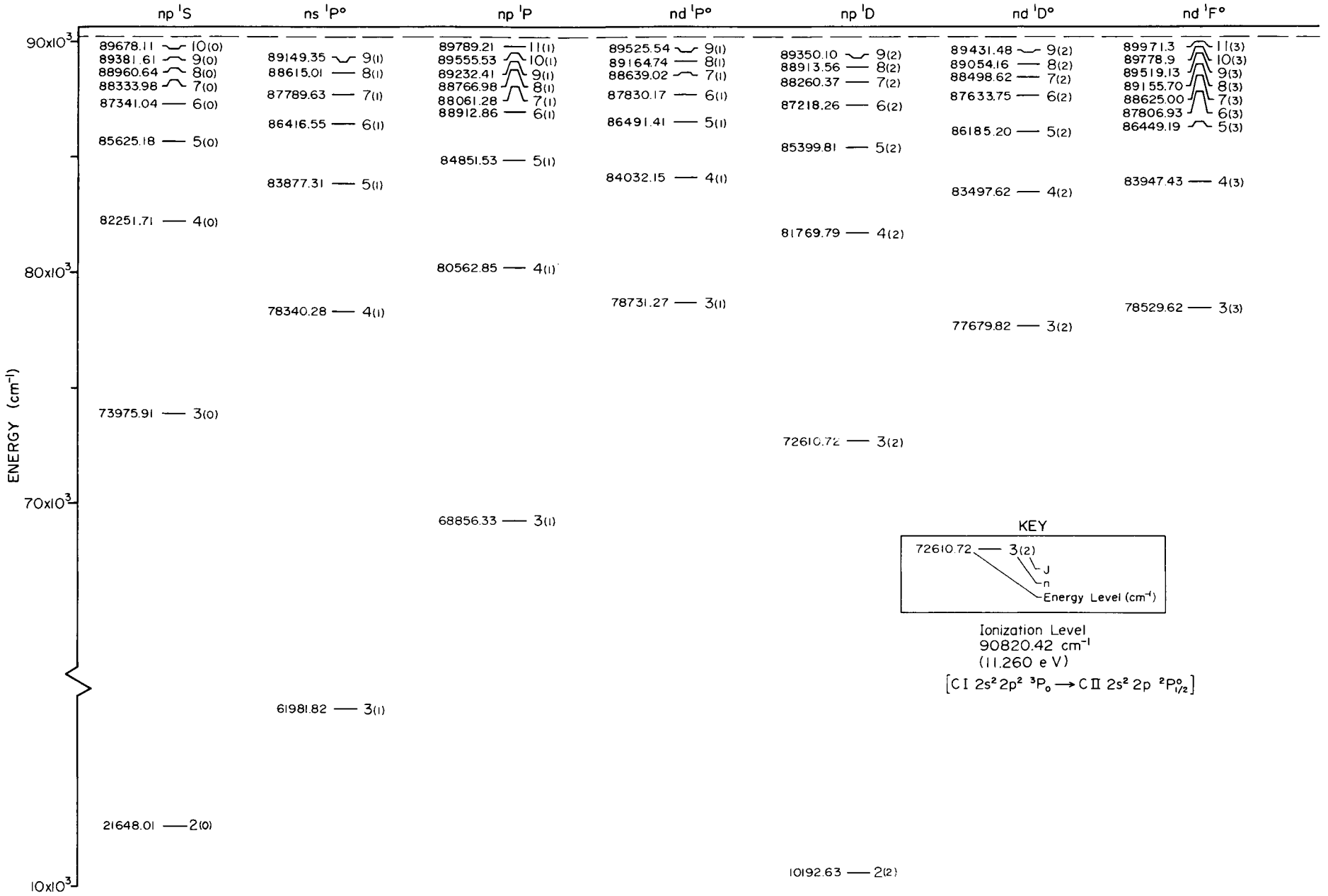
Please see the general references.

Carbon (C)

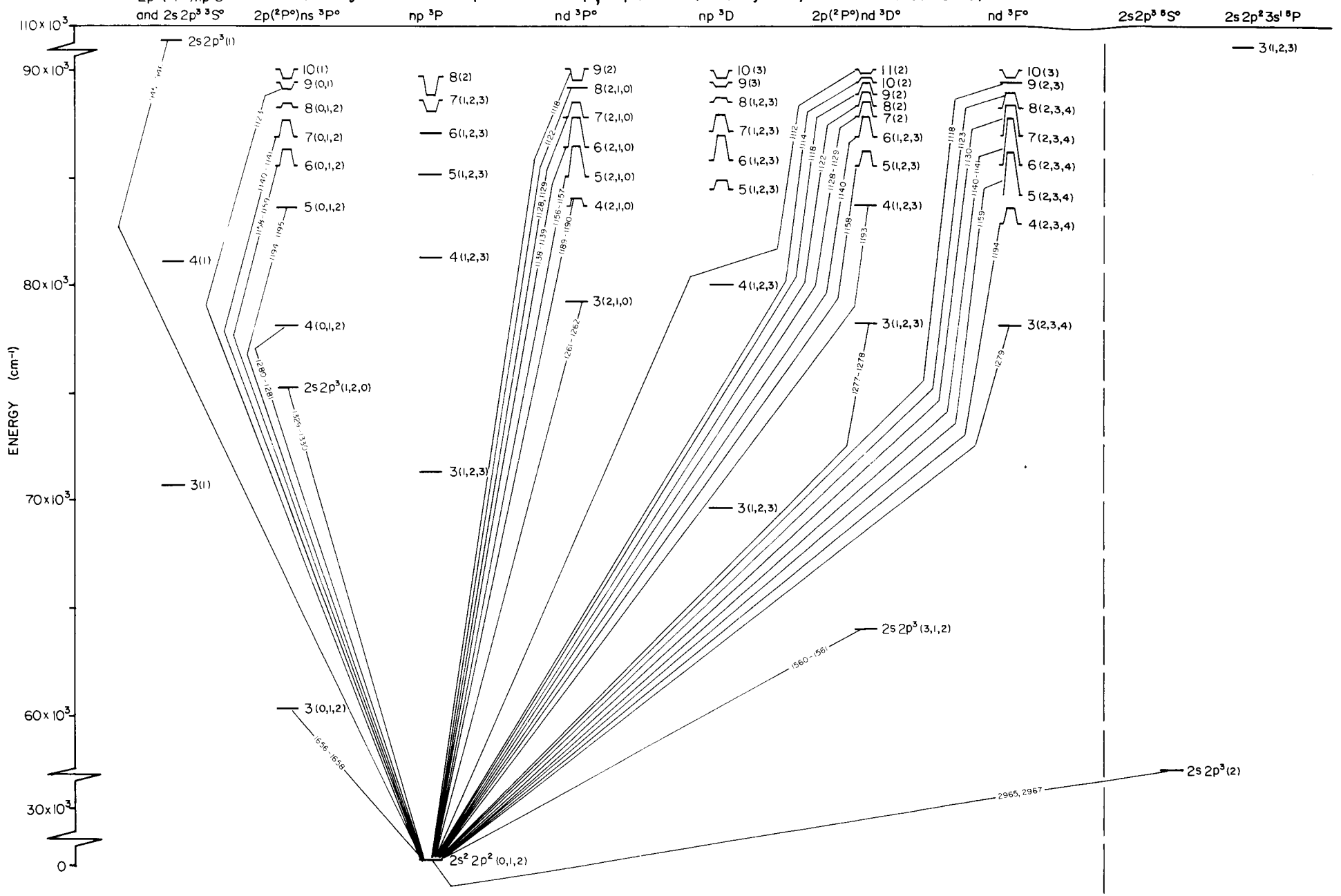
C I GROTRIAN DIAGRAM (6 electrons, Z = 6)
(Configuration: $1s^2 2s^2 2p\,nl$, Singlet System)



CI ENERGY LEVELS (6 electrons, Z = 6)
(Configuration: $1s^2 2s^2 2p\,nl$, Singlet System)

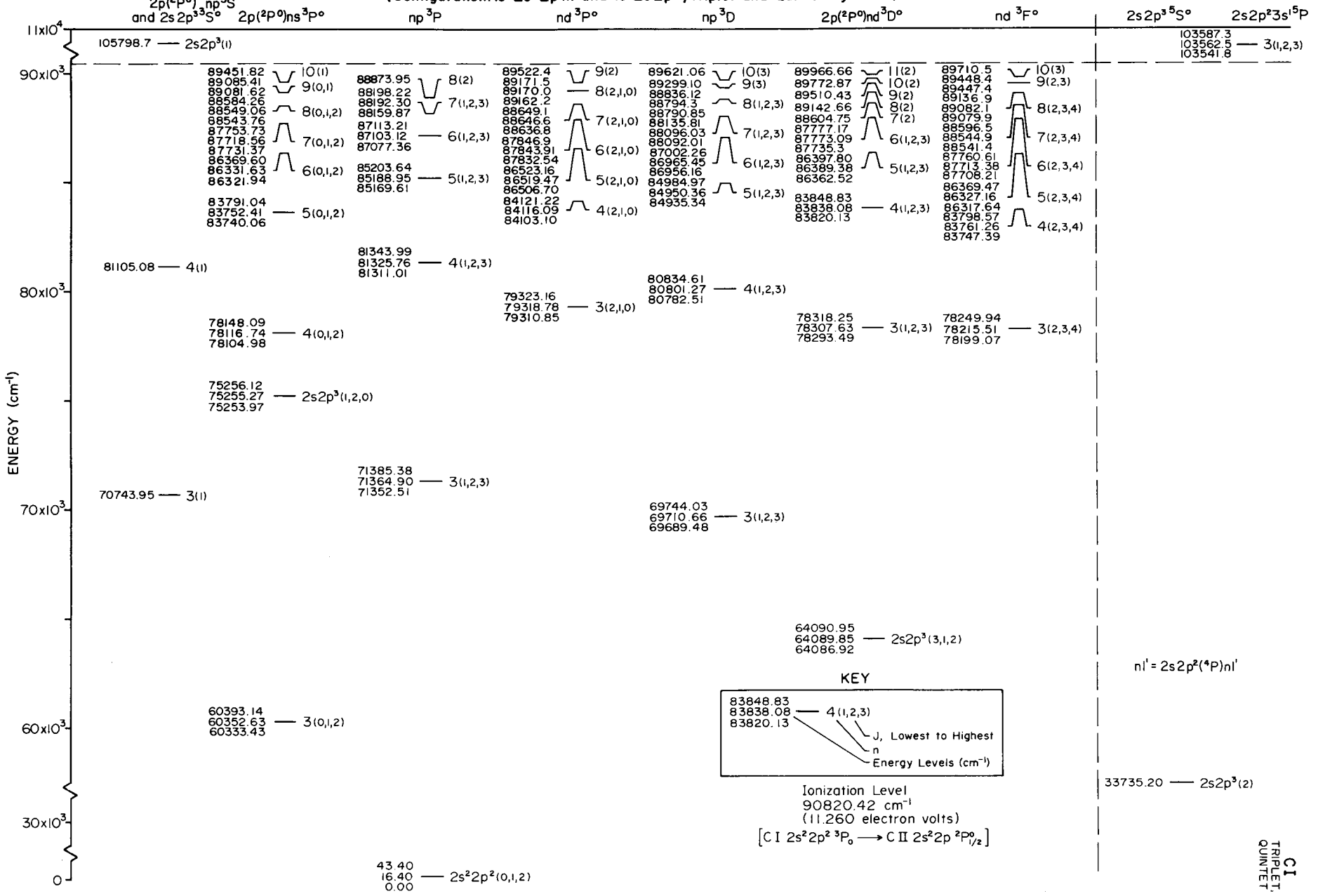


CI GROTRIAN DIAGRAM (6 electrons, Z=6)
(Configuration: $1s^2\,2s^2\,2p\,nl$ & $1s^2\,2s\,2p^3$, Triplet and Quintet Systems, Ground to Excited Terms)



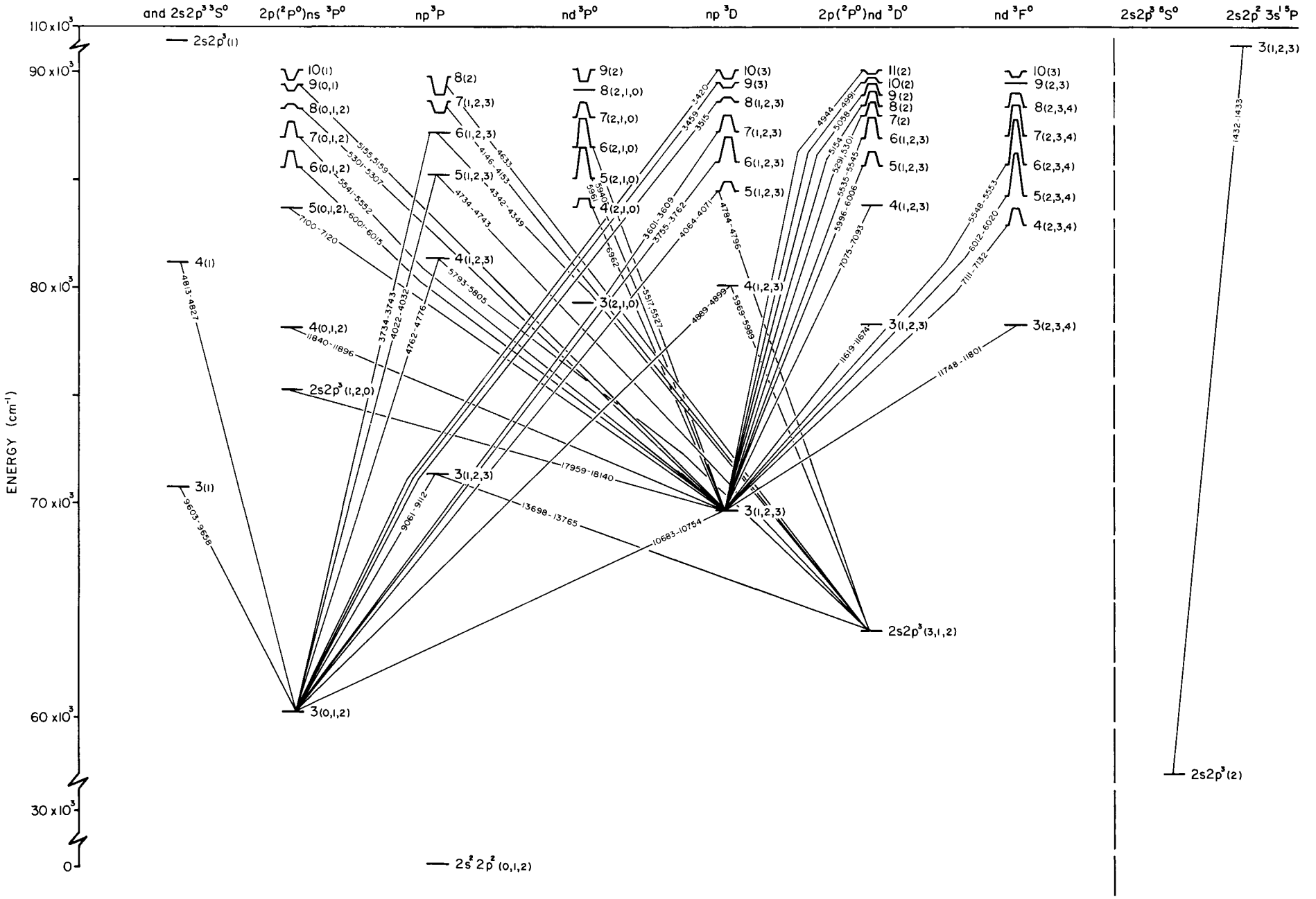
C I ENERGY LEVELS (6 electrons, Z=6)

(Configuration: $1s^2 2s^2 2p\,nl$ and $1s^2 2s 2p^3$, Triplet and Quintet Systems)



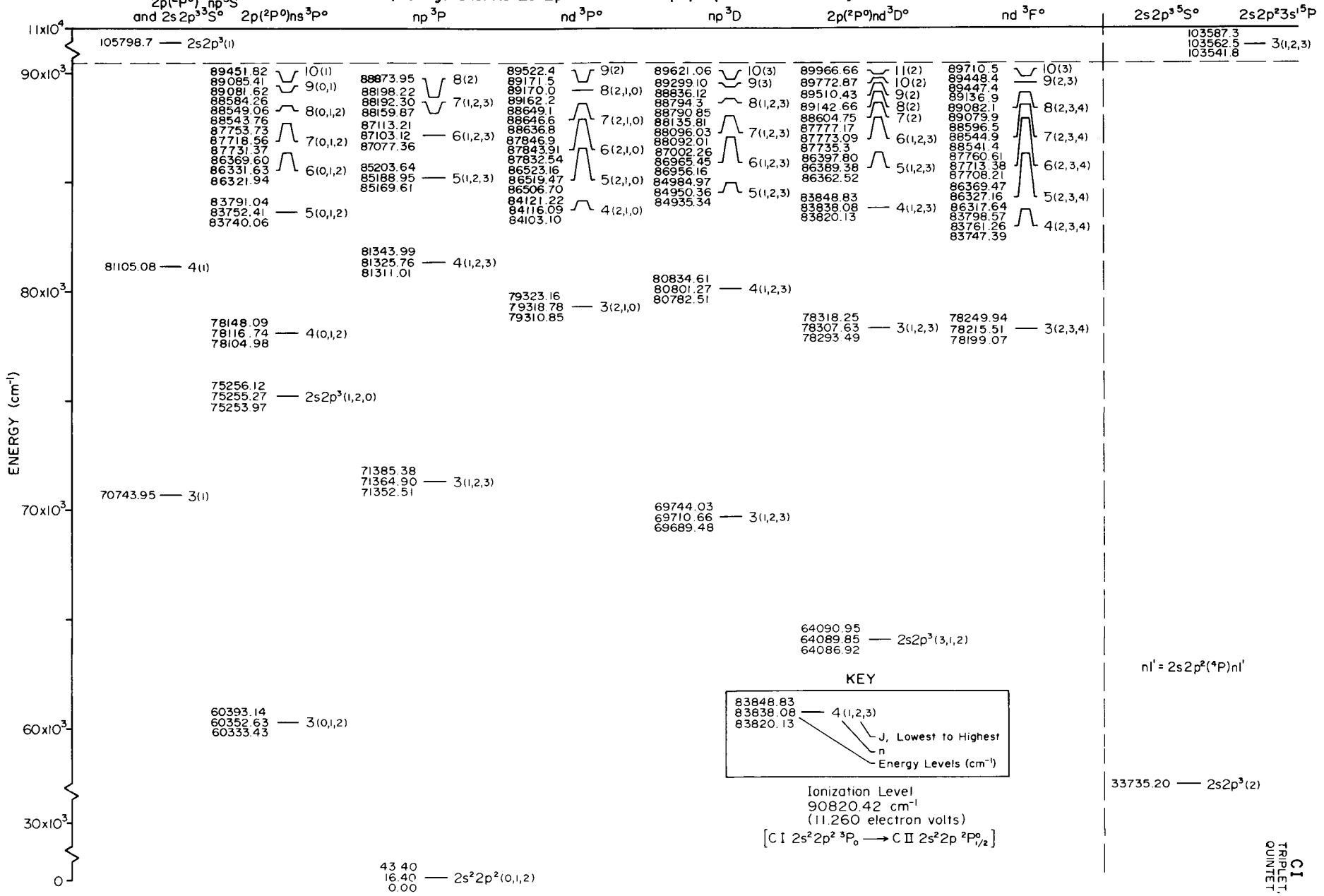
CI GROTRIAN DIAGRAM (6 electrons, Z=6)

(Configuration : $3s\,^3P^0$, $2s2p^3\,^3D^0$, $3p\,^3D$ to higher Triplets, and Quintet to Quintet Terms)

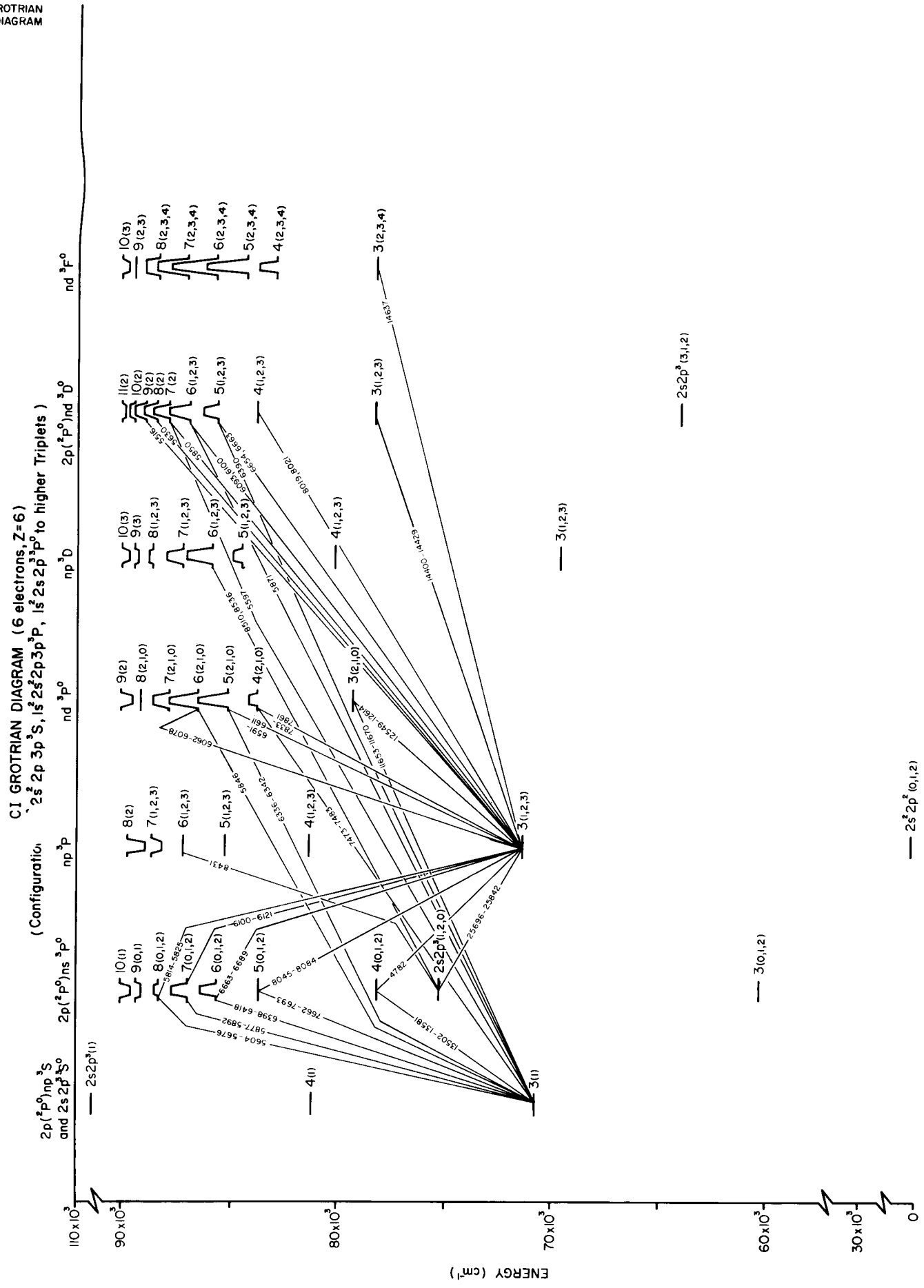


C I ENERGY LEVELS (6 electrons, Z=6)

(Configuration: $1s^2 2s^2 2p\,nl$ and $1s^2 2s 2p^3$, Triplet and Quintet Systems)

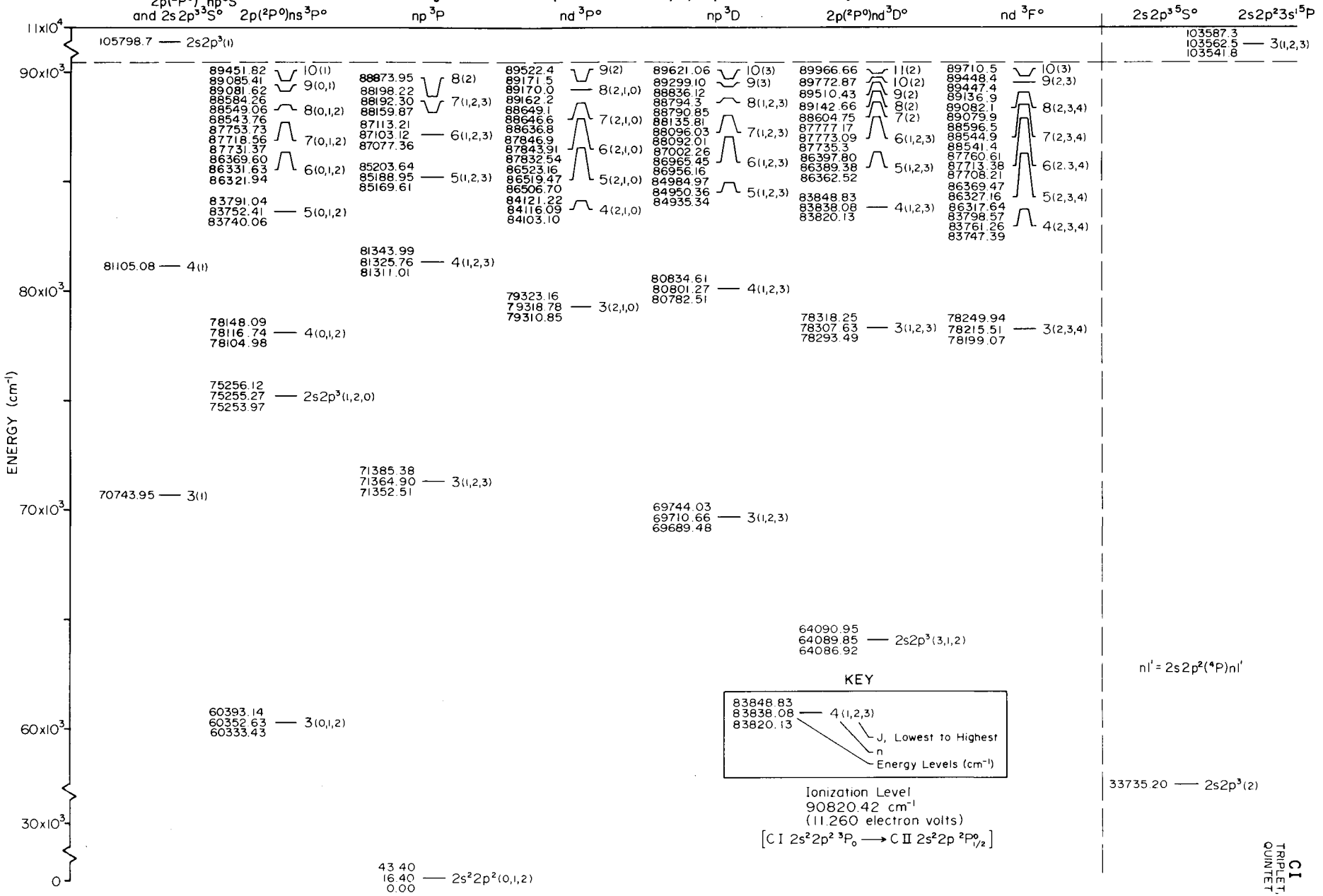


TRIPLET GROTRIAN DIAGRAM



C I ENERGY LEVELS (6 electrons, Z=6)

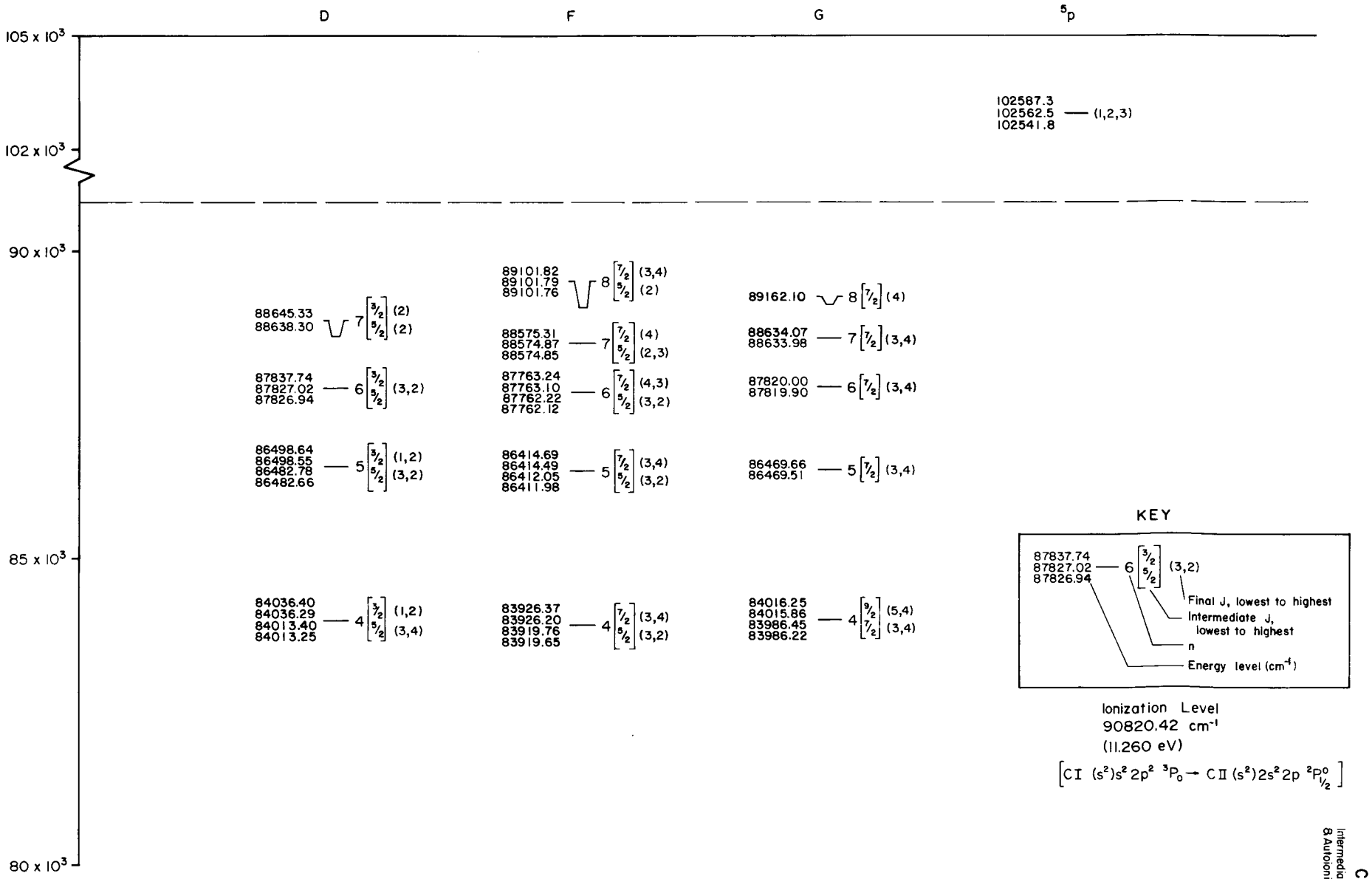
(Configuration: $1s^2 2s^2 2p\,nl$ and $1s^2 2s 2p^3$, Triplet and Quintet Systems)



C I ENERGY LEVELS (6 electrons, Z=6)

(Configurations: $1s^2\,2s^2\,2p\,(^2P^o)\,nf\,L_j(J)$ and $1s^2\,2s2p^2\,(^4P)\,3s\,^5P$)

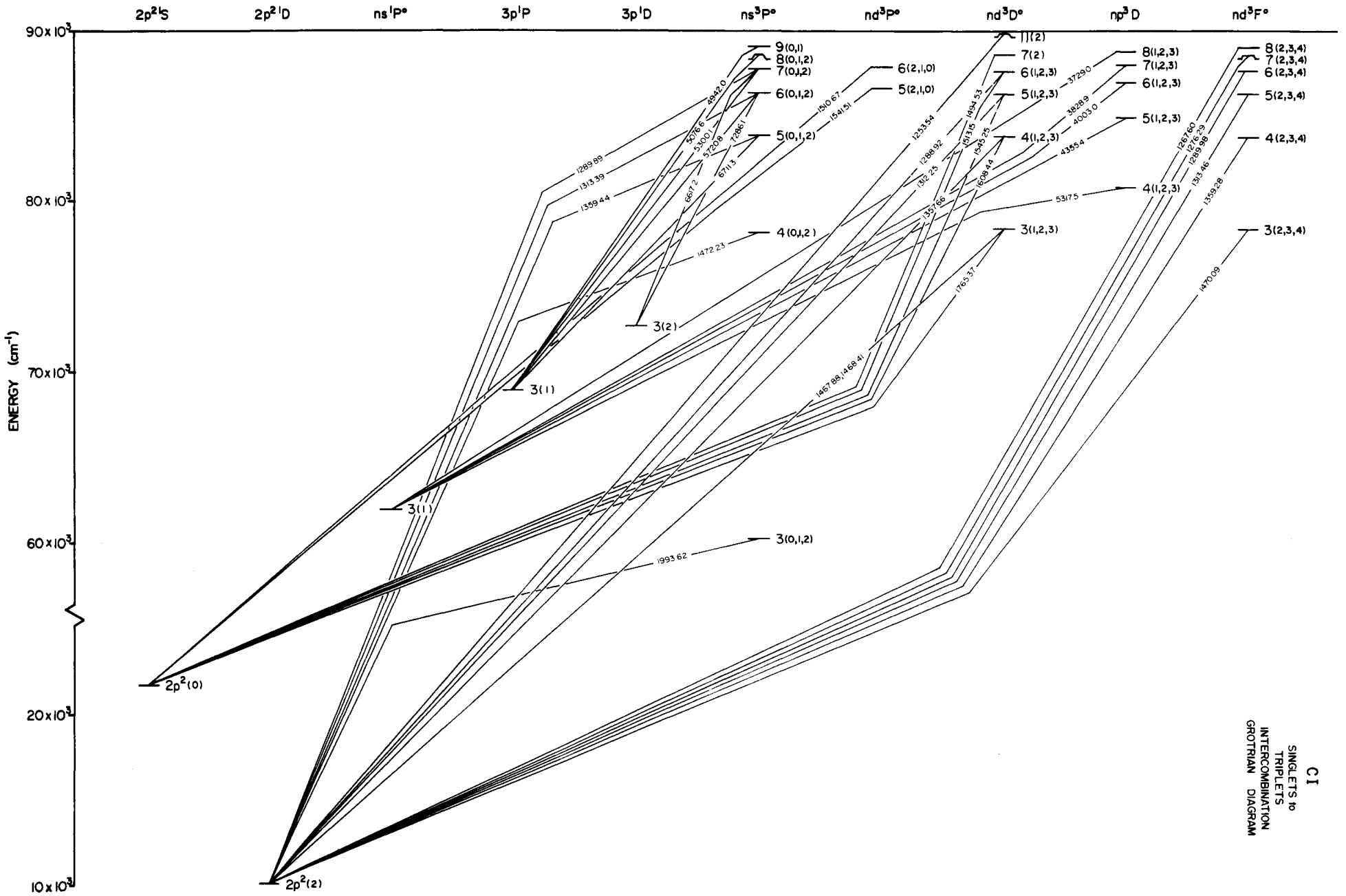
Intermediate Coupling and Autoionizing Terms



Ionization Level
90820.42 cm^{-1}
(11.260 eV)

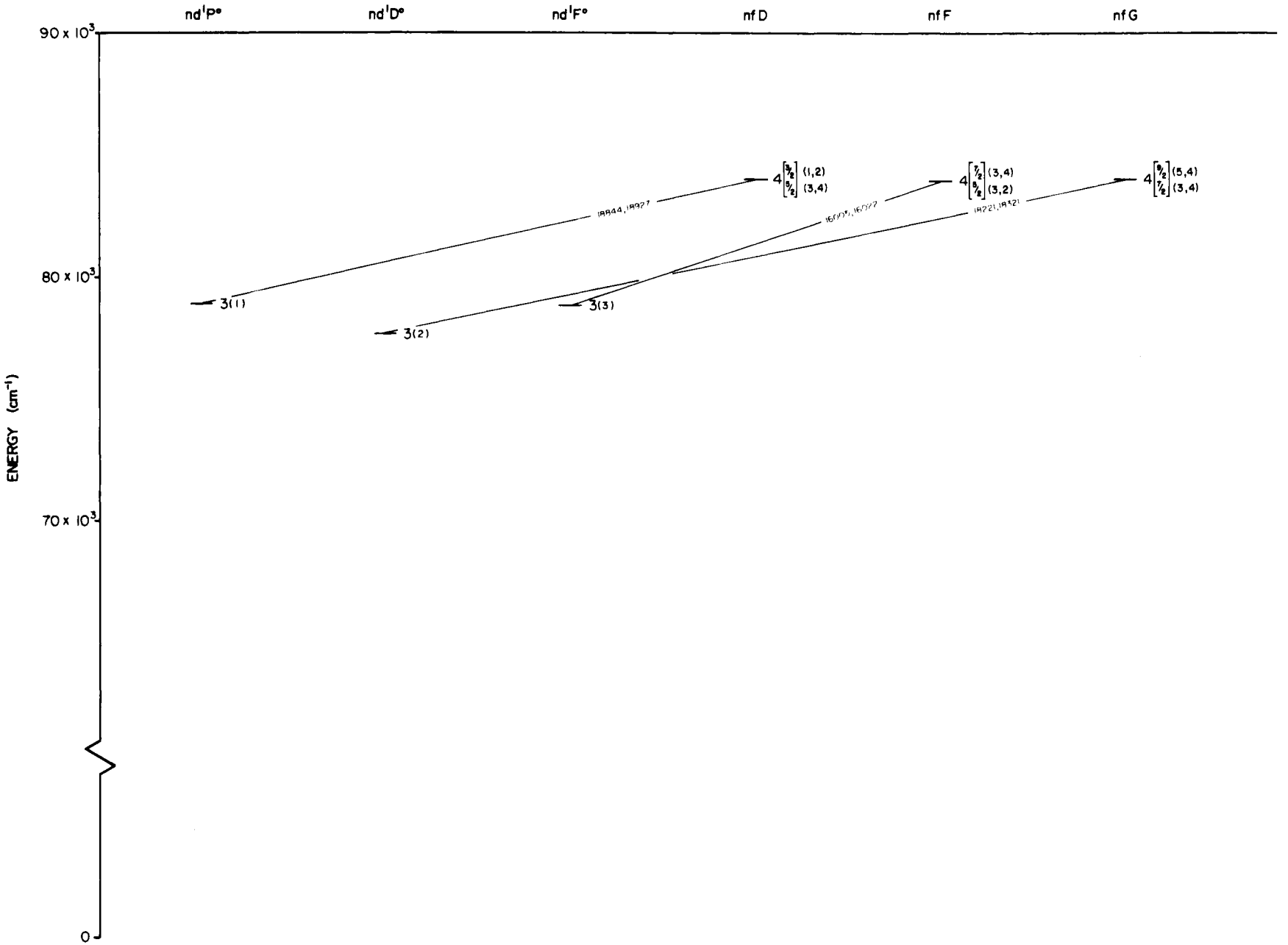
$[C\,I\ (s^2)s^2\,2p^2\ ^3P_0 \rightarrow C\,II\ (s^2)2s^2\,2p\ ^2P^o_{1/2}]$

C I INTERCOMBINATION GROTRIAN DIAGRAM (6 electrons, Z = 6)
(Configuration: $1s^2 2s^2 2pnl$, Singlets to Triplets)



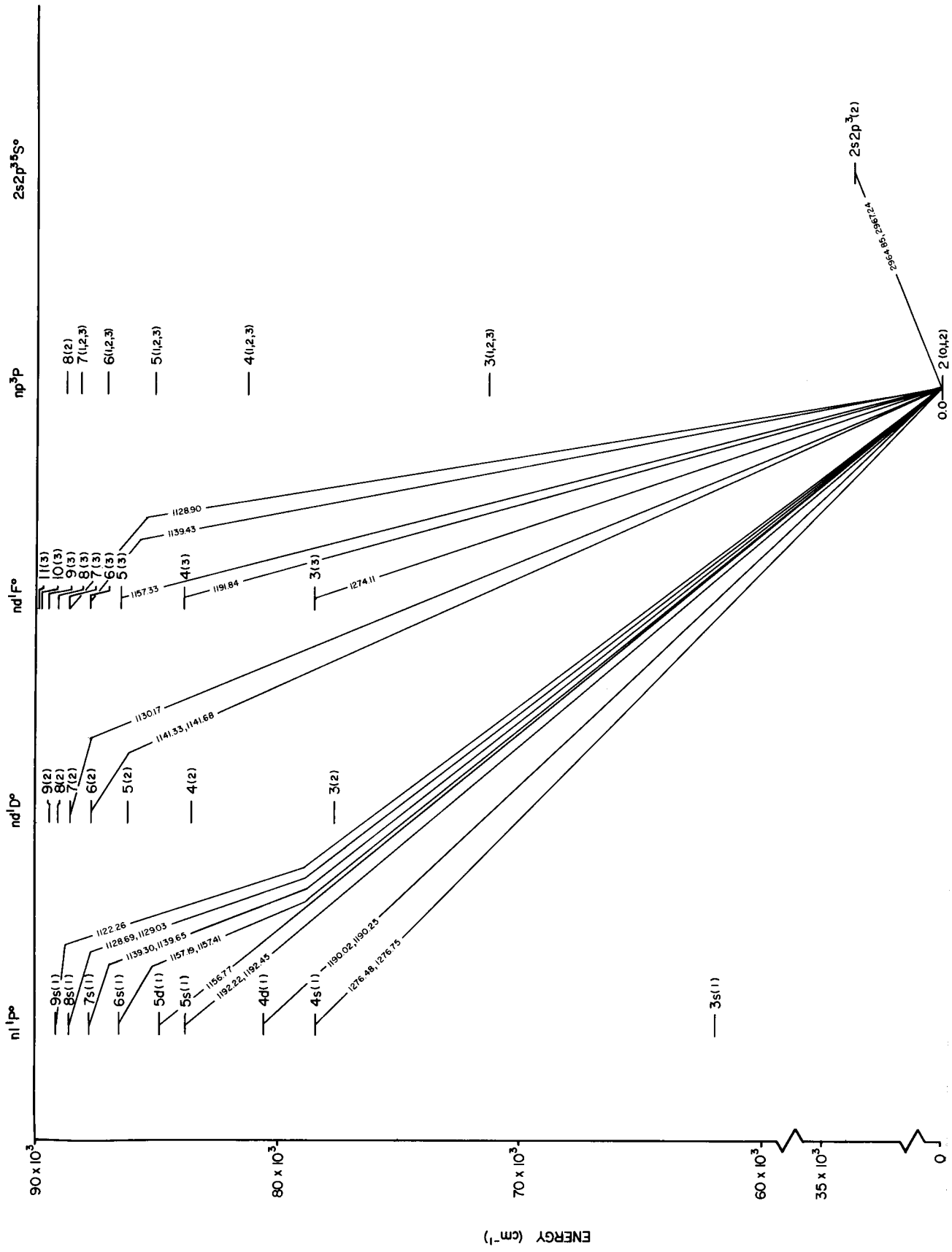
CI
SINGLETS to
TRIPLETS
INTERCOMBINATION
GROTRIAN DIAGRAM

C I INTERCOMBINATION GROTRIAN DIAGRAM (6 electrons, Z = 6)
(Configuration: $1s^2 2s^2 2pnl$, Singlets to Intermediate Coupling)

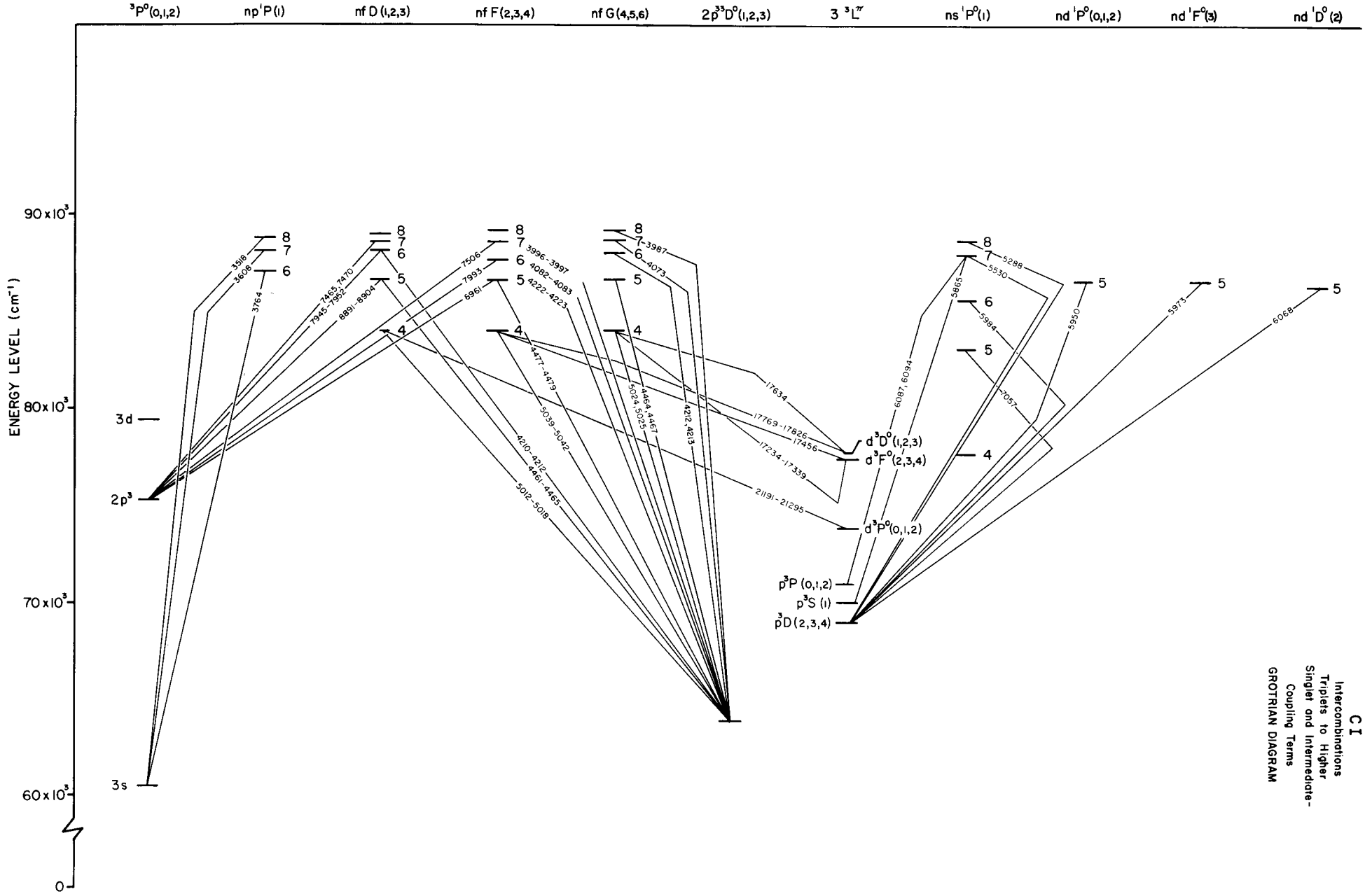


C I
SINGLETS to
INTERMEDIATE COUPLING
INTERCOMBINATION
GROTRIAN DIAGRAM

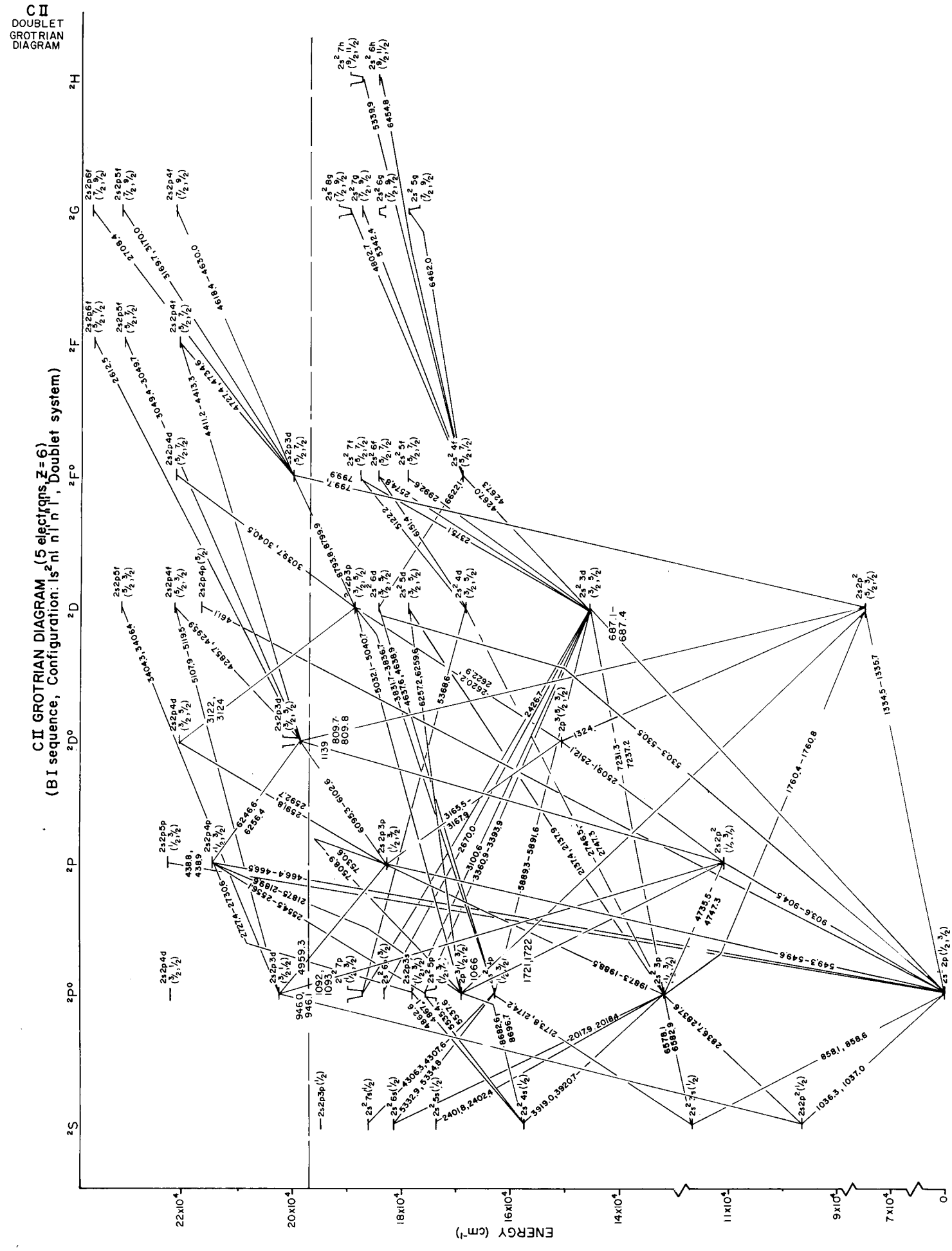
C I
Ground Term ($2p\,^3P$) to
SINGLET, QUINTET
INTERCOMBINATION
GROTRIAN DIAGRAM



GROTRIAN DIAGRAM
C I (6 electrons, Z=6)
Intercombinations Triplets to Higher
Singlet and Intermdiate- Coupling Term

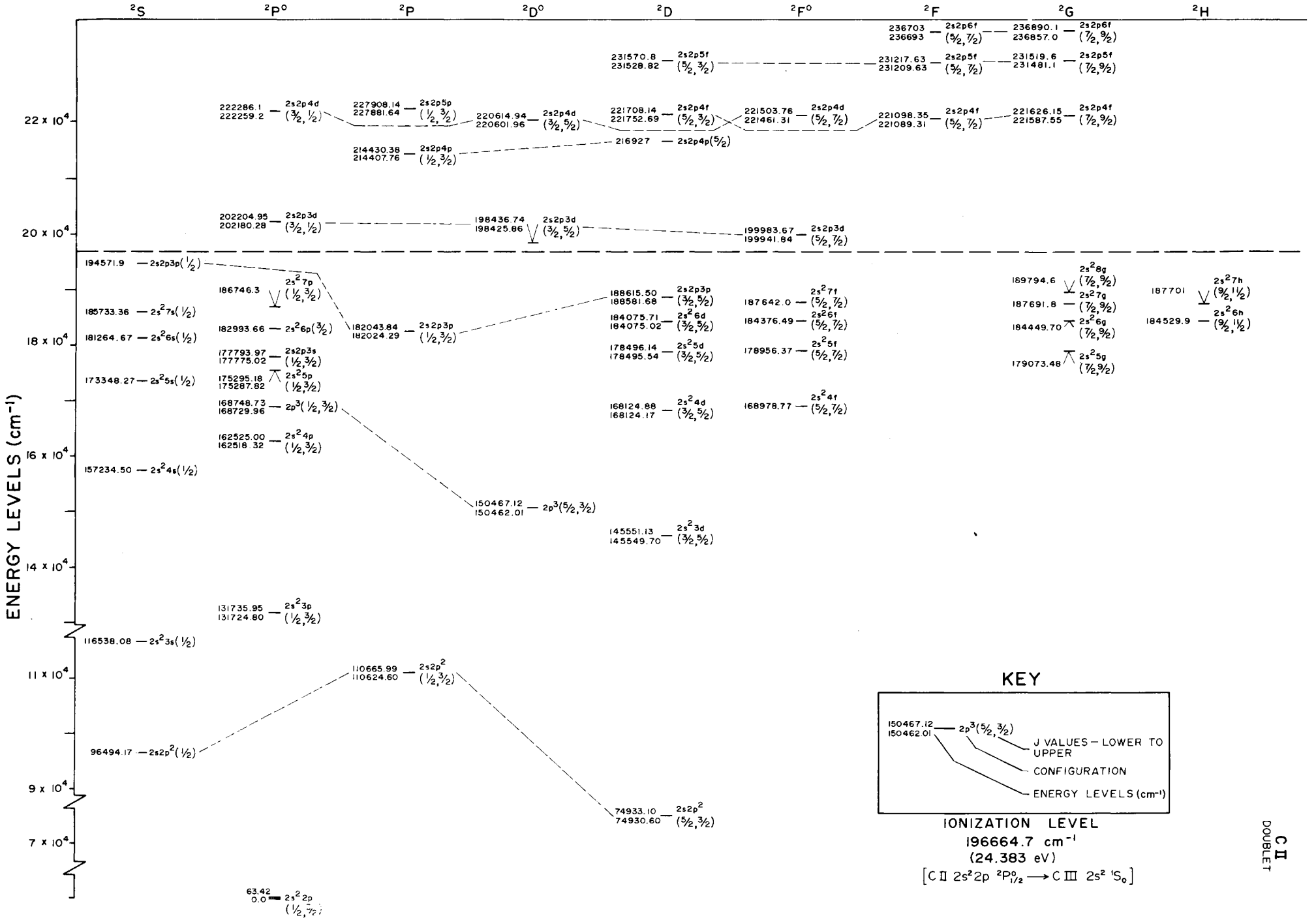


C I
Intercombinations
Triplets to Higher
Singlet and Intermediate-
Coupling Terms
GROTRIAN DIAGRAM

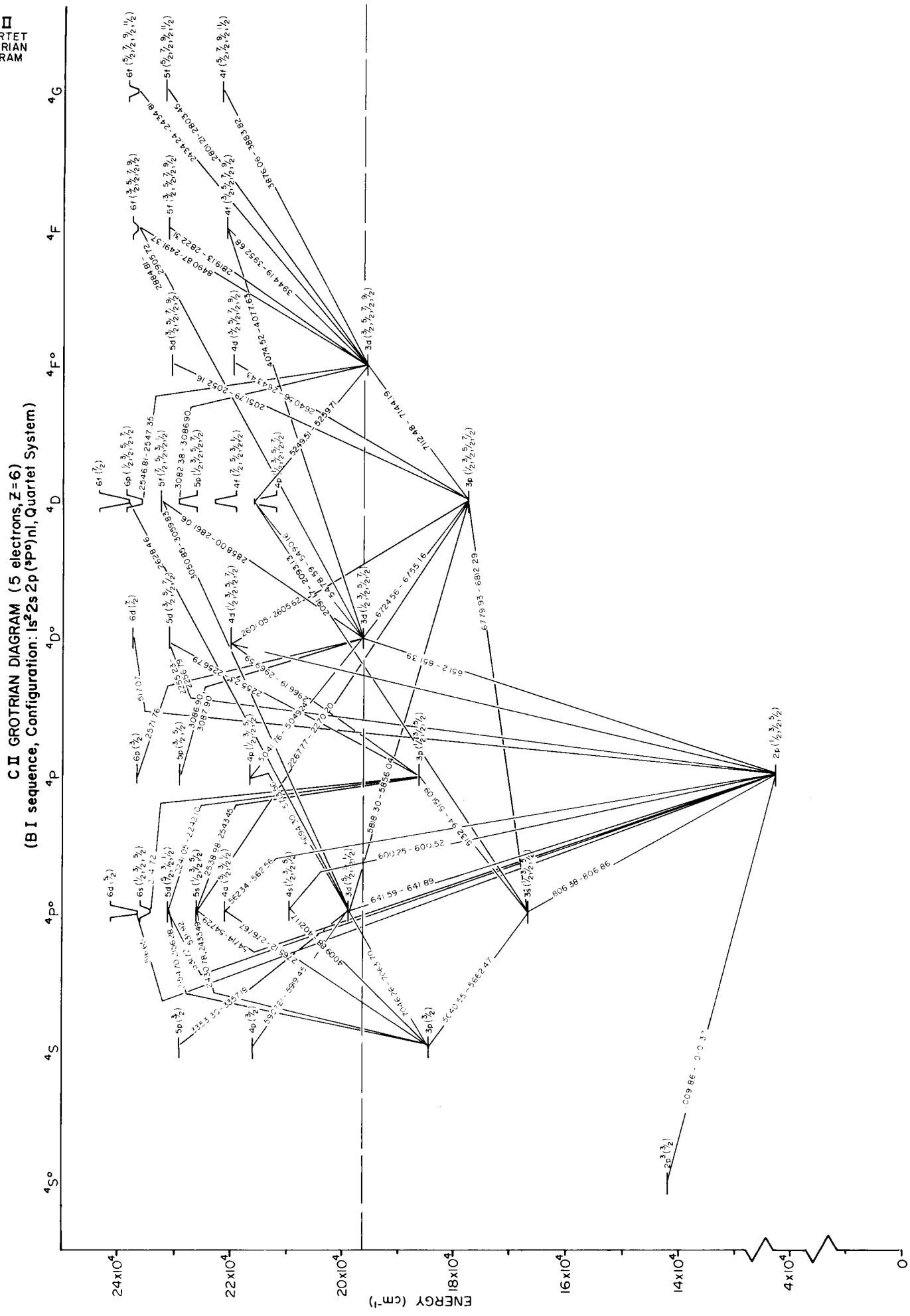

C II
DOUBLET
GROTRIAN
DIAGRAM
C II GROTRIAN DIAGRAM (5 electrons Z=6)
(B I sequence, Configuration: 1s²nl n'l'n''l'', Doublet system)
²S
²P°
²P
²D°
²D
²F°
²F
²G
²H
ENERGY (cm⁻¹)
22x10⁴
20x10⁴
18x10⁴
16x10⁴
14x10⁴
11x10⁴
9x10⁴
7x10⁴
0

C II ENERGY LEVELS (5 electrons, Z = 6)

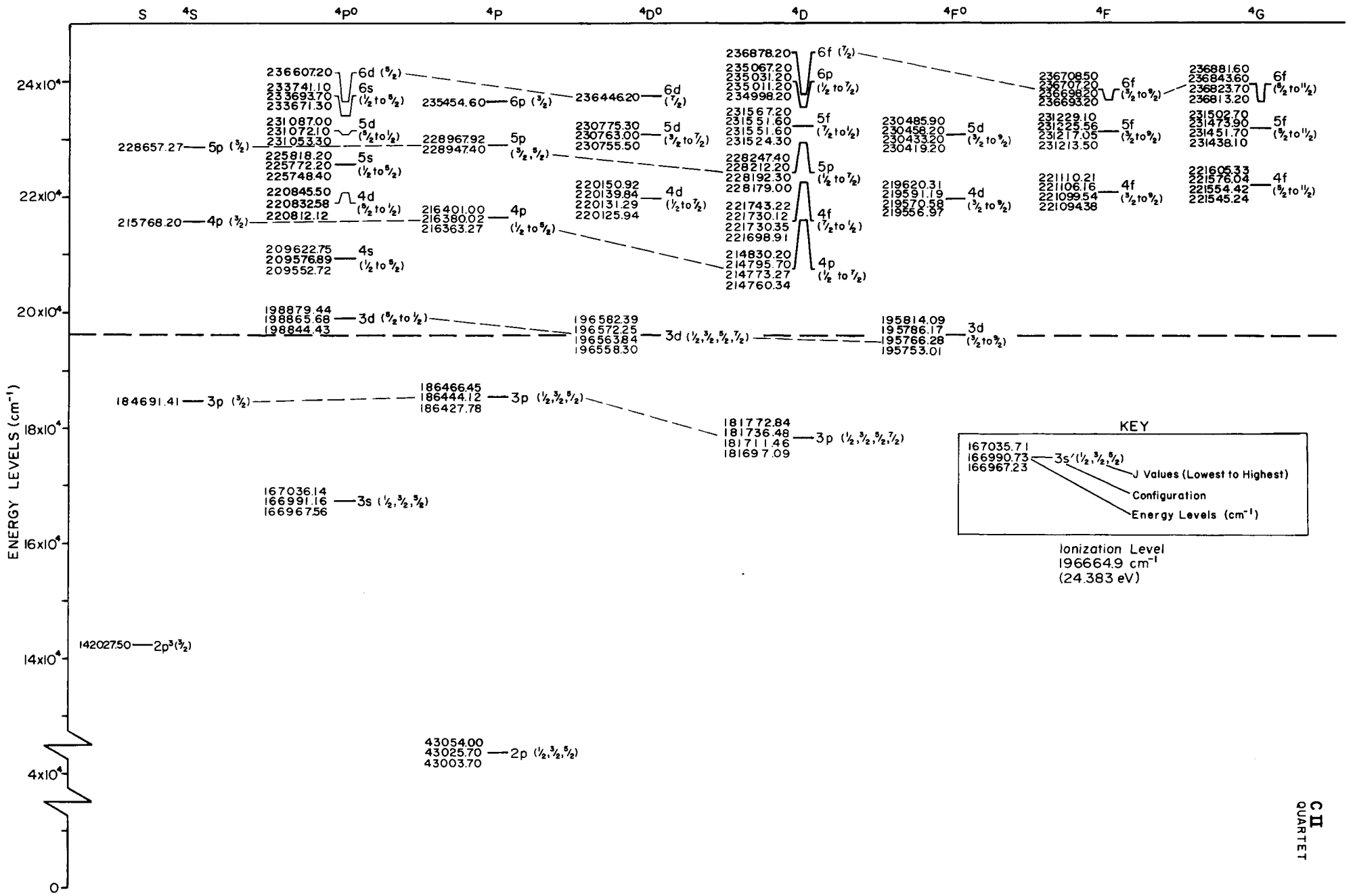
(BI Sequence, Configuration $1s^2nl\ n'l'\ n''l''$, Doublet Term System)



C II
DOUBLET


C II
QUARTET
GROTRIAN
DIAGRAM
C II GROTRIAN DIAGRAM (5 electrons, Z=6)
(B I sequence, Configuration: 1s²2s 2p(³P°)nl, Quartet System)
ENERGY (cm⁻¹)
24x10⁴
22x10⁴
20x10⁴
18x10⁴
16x10⁴
14x10⁴
4x10⁴
0

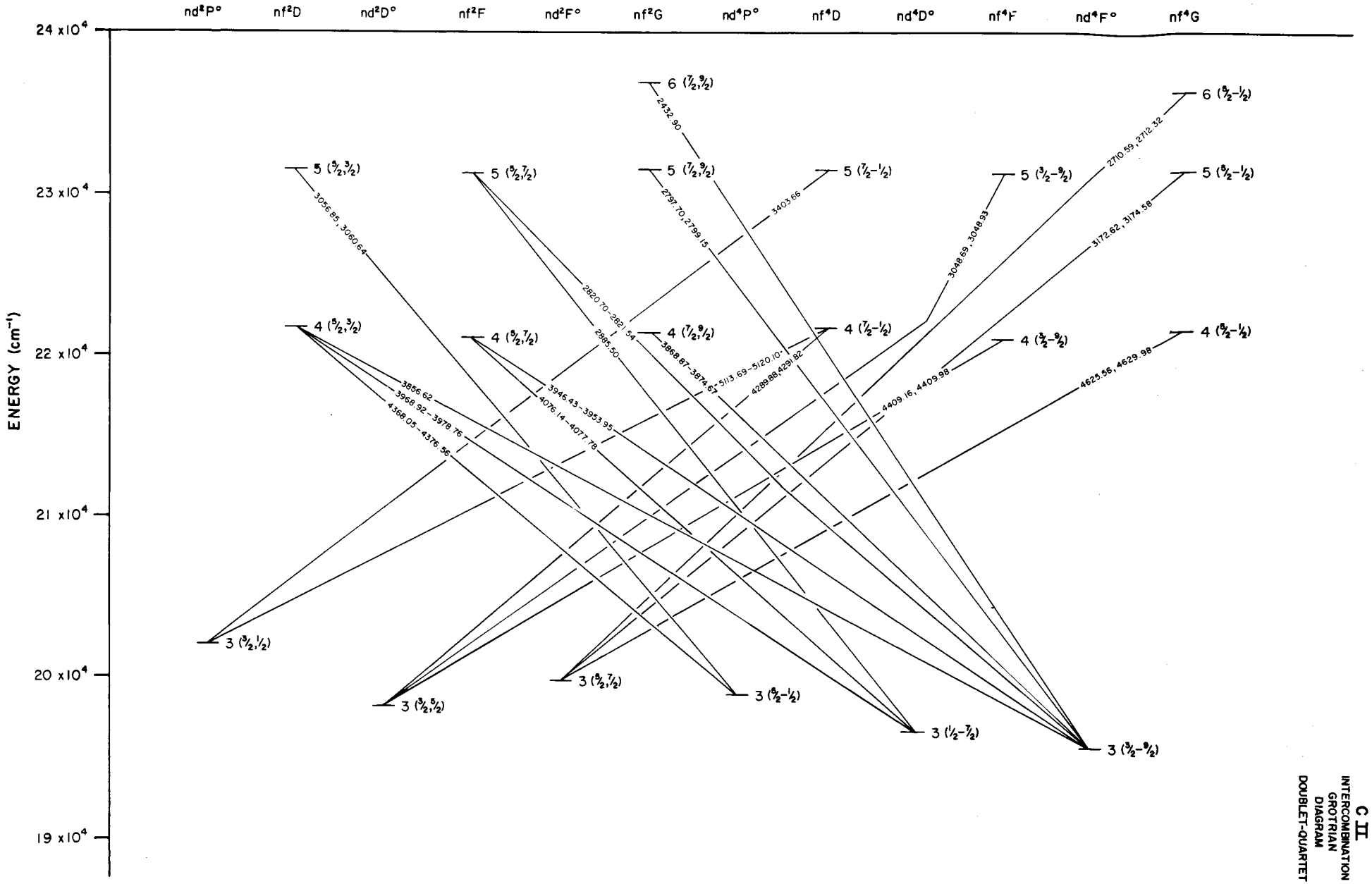
C II ENERGY LEVELS (5 electrons, Z=6)
(BI Sequence, Configuration, $1s^2 2s 2p(^3P^o)nl$, Quartet Term System)



C II
QUARTET

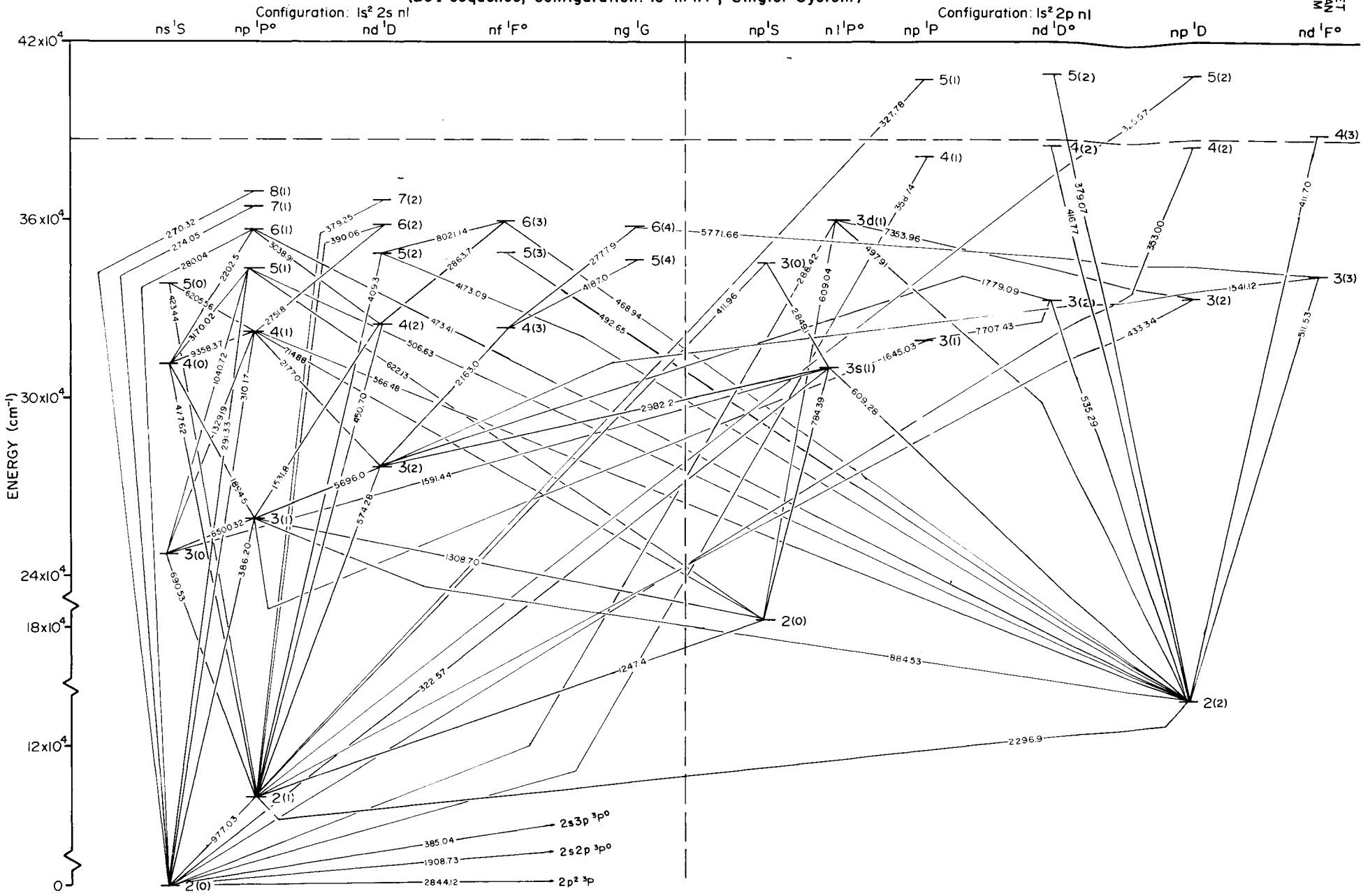
C II GROTRIAN DIAGRAM (5 electrons, Z=6)

(B I sequence, Configuration: $1s^2 2s2p(^3P^o)nl$, Intercombination: Doublets–Quartets)

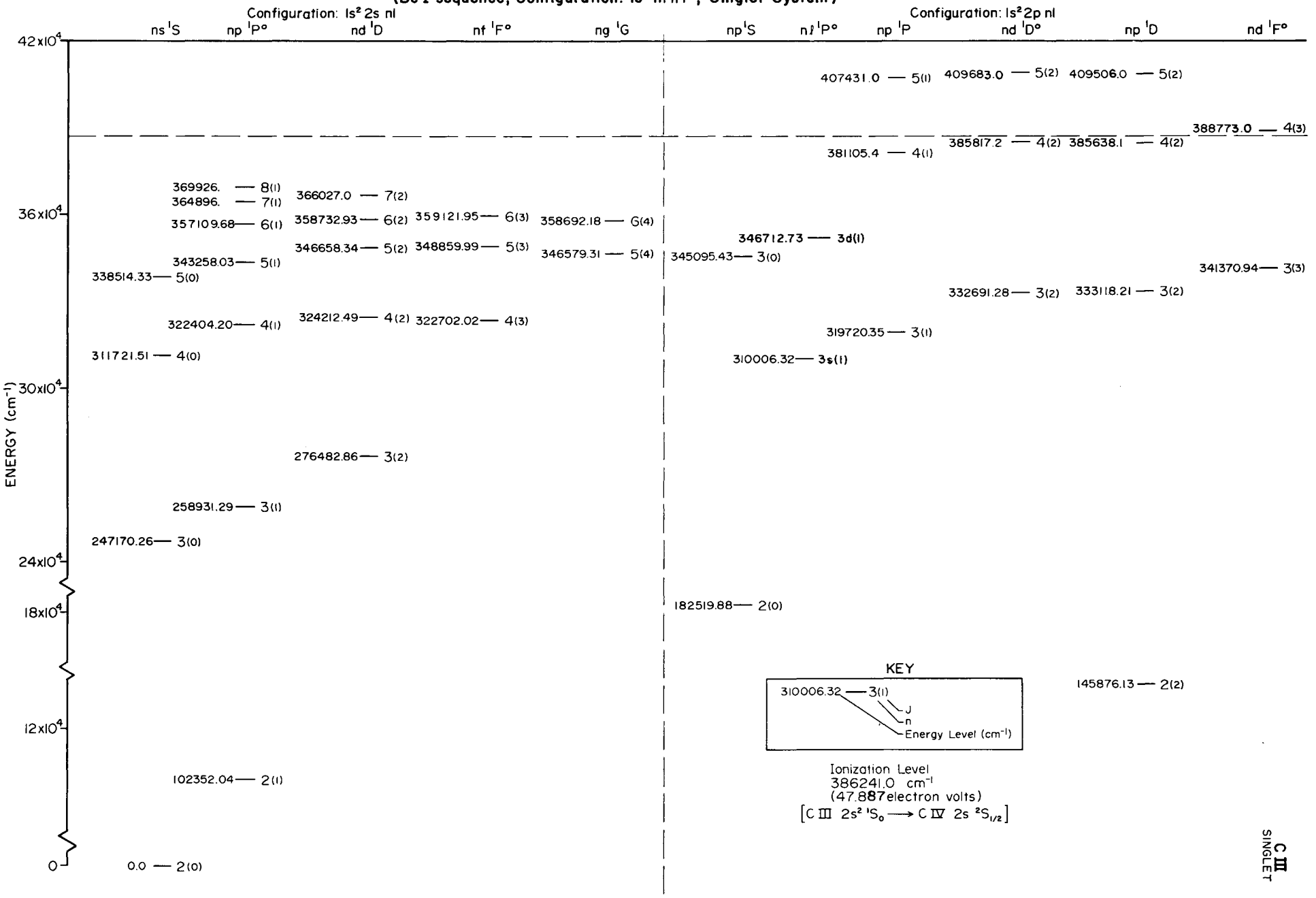


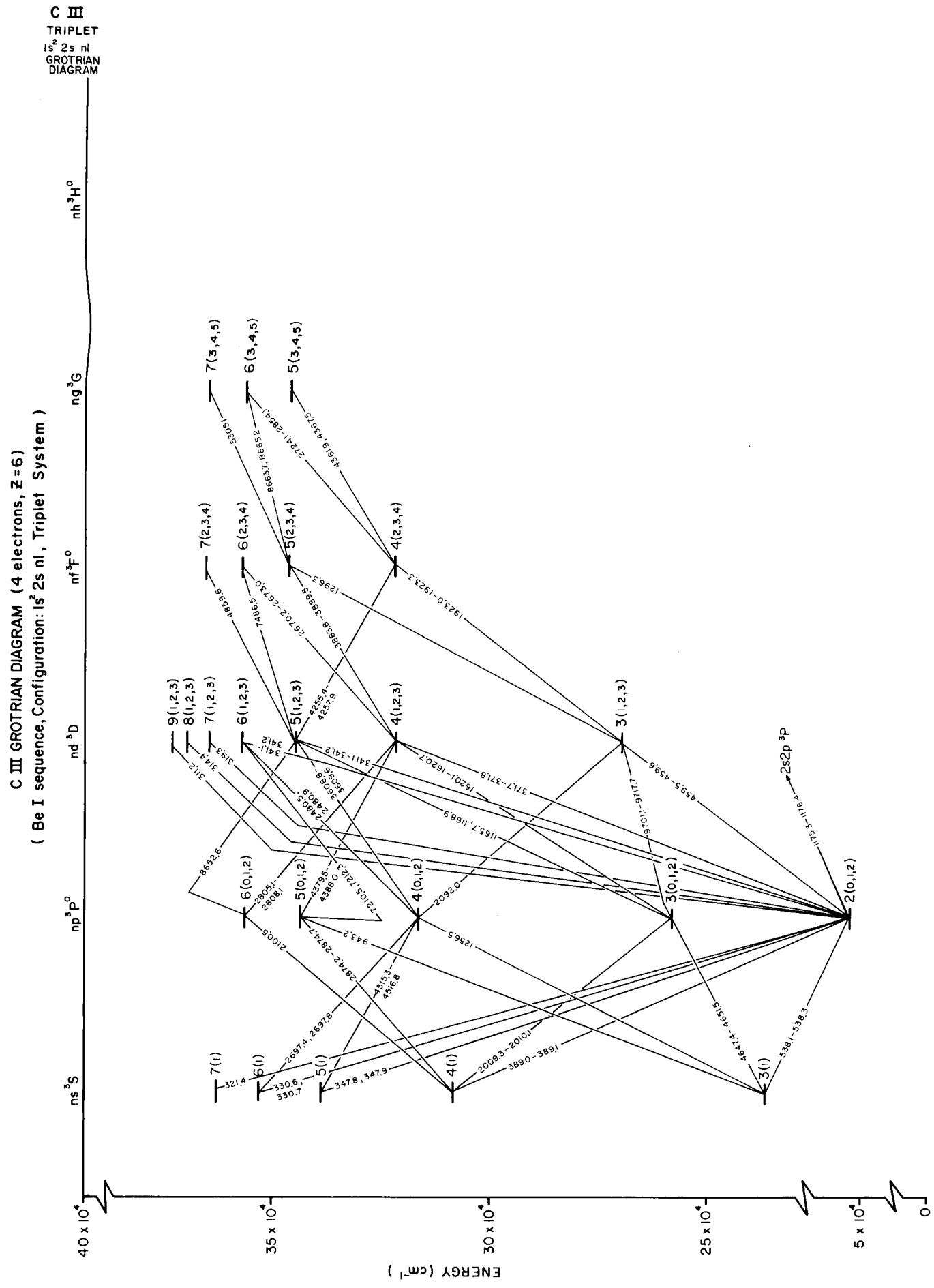
C II
INTERCOMBINATION
GROTRIAN
DIAGRAM
DOUBLET-QUARTET

C III GROTRIAN DIAGRAM (4 electrons, Z=6)
(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Singlet System)



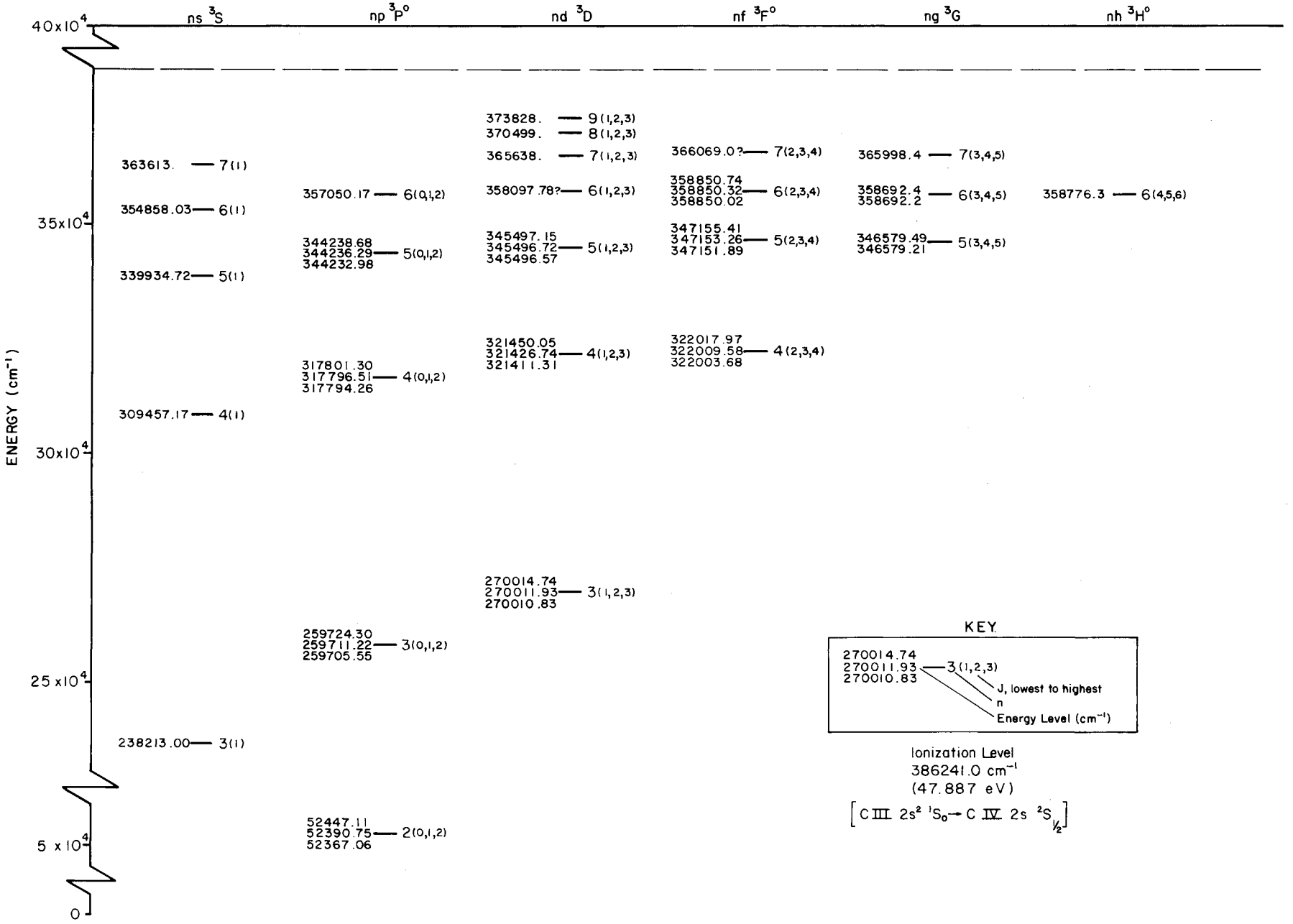
C III ENERGY LEVELS (4 electrons, Z=6)
(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Singlet System)




C III
TRIPLET
1s² 2s nl
GROTRIAN DIAGRAM
C III GROTRIAN DIAGRAM (4 electrons, Z=6)
(Be I sequence, Configuration: 1s² 2s nl, Triplet System)
ns ³S
np ³P°
nd ³D
nf ³F°
ng ³G
nh ³H°
ENERGY (cm⁻¹)
40 x 10⁴
35 x 10⁴
30 x 10⁴
25 x 10⁴
5 x 10⁴
0
2s2p ³P

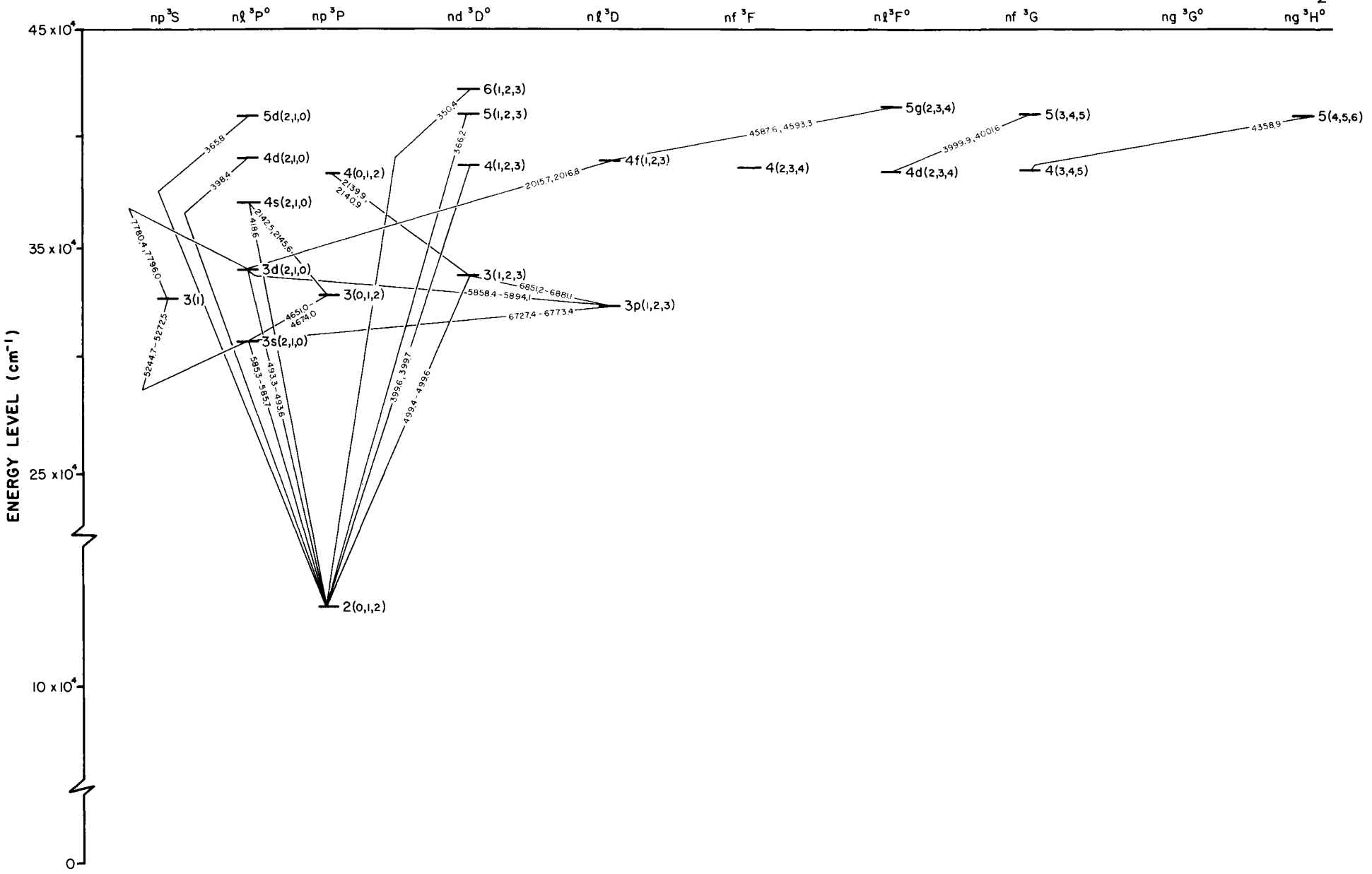
C III ENERGY LEVELS (4 electrons, Z=6)

(Be I sequence, Configuration: $1s^2 2s\,nl$, Triplet System)

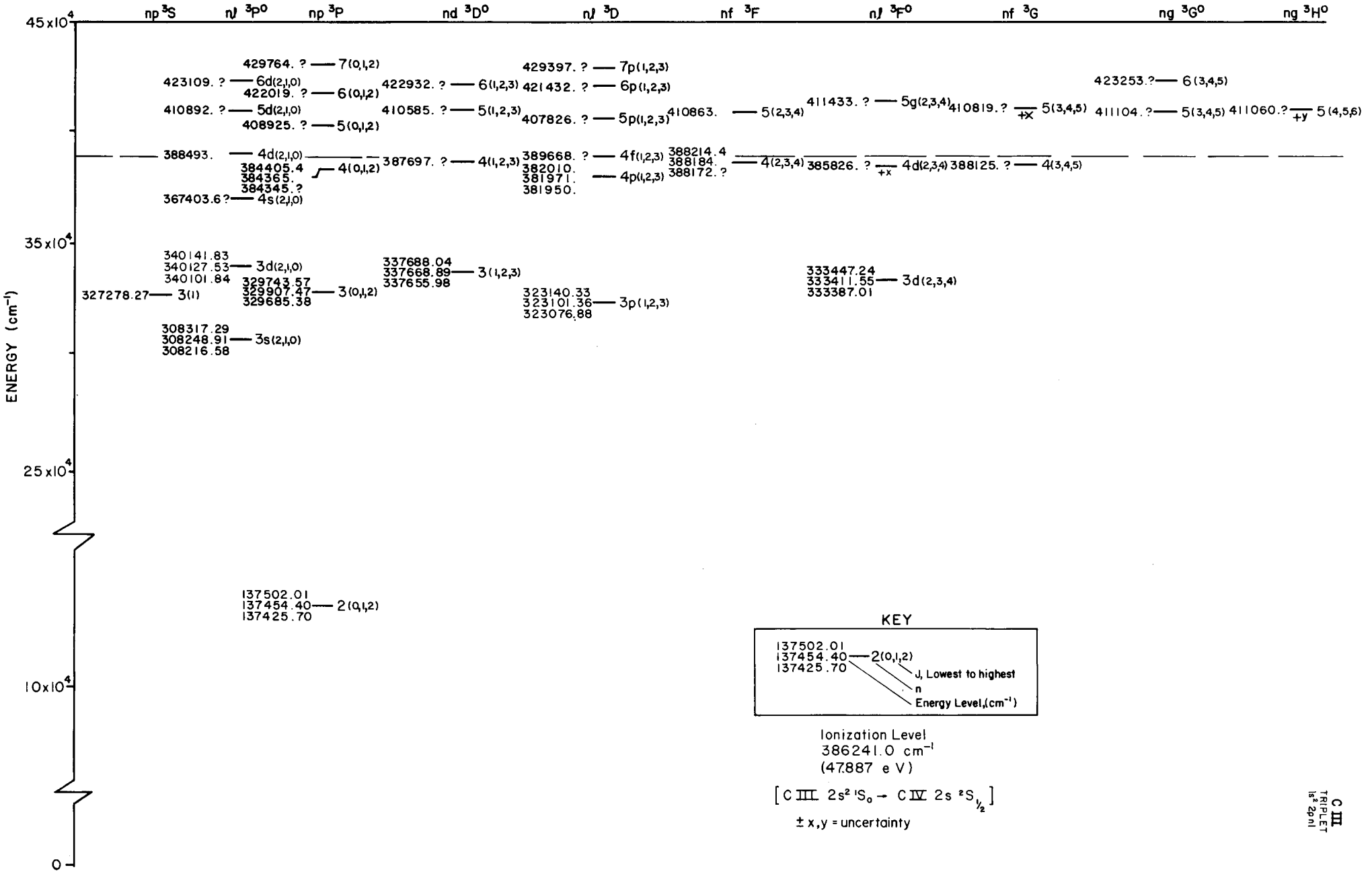


C III
TRIPLET
$1s^2 2s\,nl$

C III GROTRIAN DIAGRAM (4 electrons, Z = 6)
(Be I Sequence, Configuration: 1s 2p nl, Triplet System)



C III ENERGY LEVELS (4 electrons, Z = 6)
(Be I sequence, Configuration: $1s^2 2p\,nl$, Triplet System)



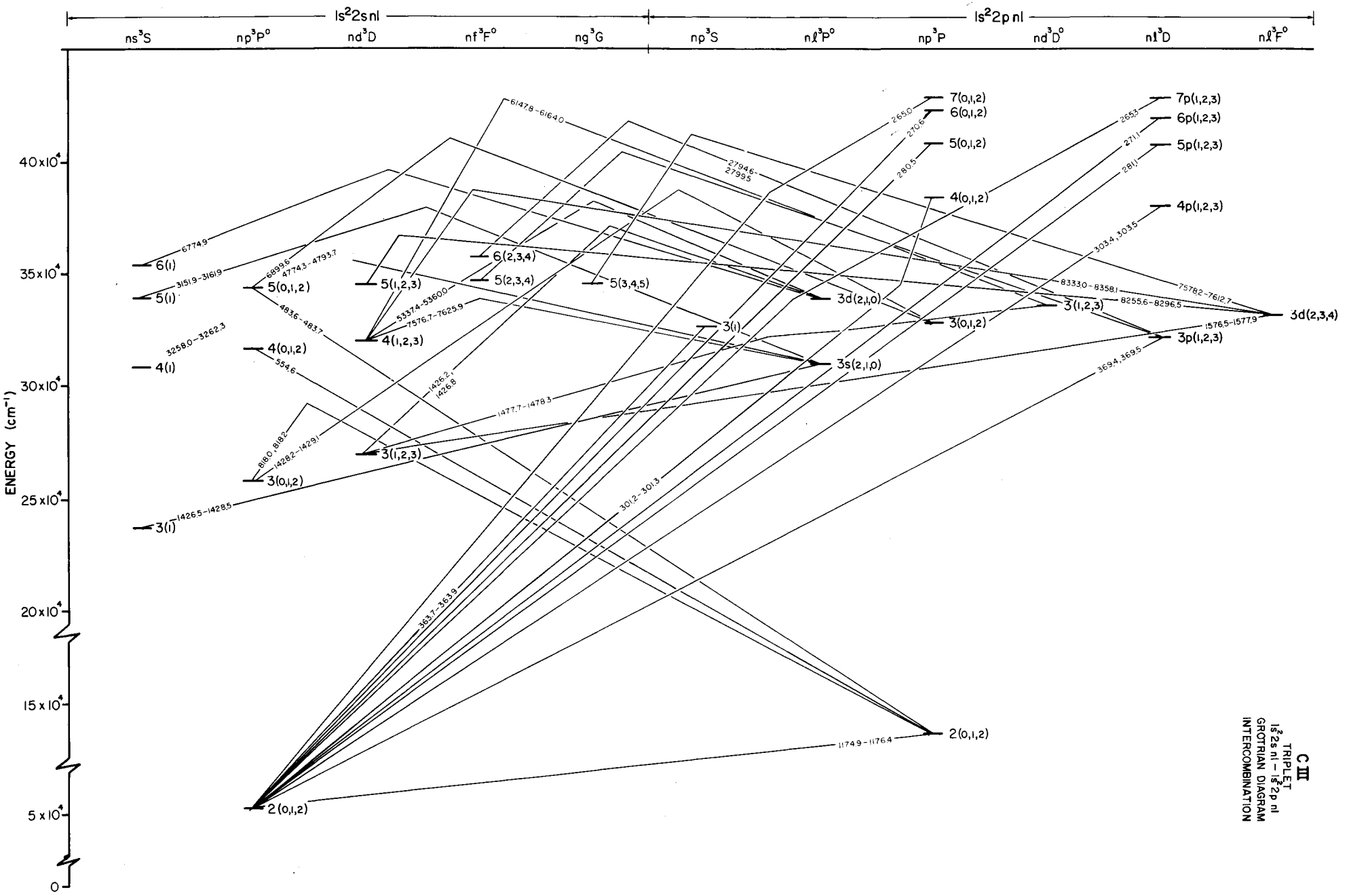
Ionization Level
386241.0 cm⁻¹
(47.887 eV)

[C III $2s^2\,{}^1S_0$ → C IV $2s\,{}^2S_{1/2}$]

± x, y = uncertainty

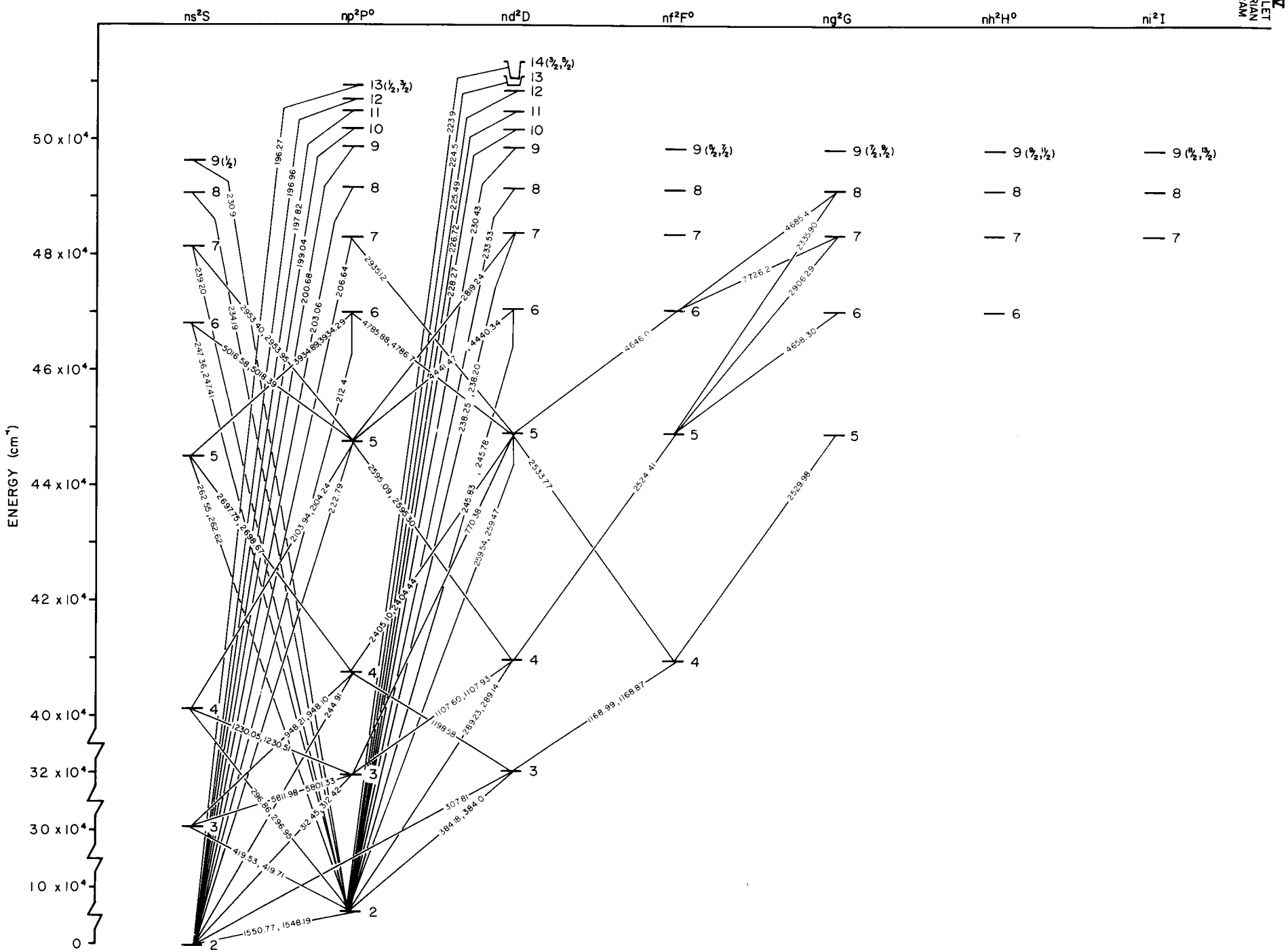
C III
TRIPLET
$1s^2 2p\,nl$

C III GROTRIAN DIAGRAM (4 electrons, Z = 6)
(Intercombination Be I sequence, Configuration: $1s^2 2s\,nl - 1s^2 2p\,nl$, Triplet System)



C III
TRIPLET
$1s^2 2s\,nl - 1s^2 2p\,nl$
GROTRIAN DIAGRAM
INTERCOMBINATION

C IV GROTRIAN DIAGRAM (3 electrons, Z=6)
(Li I sequence, Configuration: $1s^2nl$ Doublet System)



C IV ENERGY LEVELS (3 electrons, Z=6)
(Li I sequence , Configuration: $1s^2nl$ Doublet System)

ENERGY (cm⁻¹)	ns^2S	np^2P^o	nd^2D	nf^2F^o	ng^2G	nh^2H^o	ni^2I
			511254.0 — 14(3/2,5/2)				
			509821.0 — 13(3/2,5/2)				
		509728.0 — 13(1/2,3/2)	508018.0 — 12(3/2,5/2)				
		507906.0 — 12(1/2,3/2)					
		505510.0 — 11(1/2,3/2)	505696.0 — 11(3/2,5/2)				
		502412.0 — 10(1/2,3/2)	502398.0 — 10(3/2,5/2)				
50 x 10⁴		498315.7					
	497736.7 — 9(1/2)	498314.6 — 9(1/2,3/2)	498490.6 — 9(3/2,5/2)	498500.3 — 9(5/2,7/2)	498501.17 — 9(7/2,9/2)	498501.37 — 9(9/2,11/2)	498501.44 — 9(11/2,13/2)
	491650.8 — 8(1/2)	492479.3 / 492477.7 — 8(1/2,3/2)	492728.5 — 8(3/2,5/2)	492742.2 — 8(5/2,7/2)	492743.49 — 8(7/2,9/2)	492743.78 — 8(9/2,11/2)	492743.86 — 8(11/2,13/2)
48 x 10⁴	482706.0 — 7(1/2)	483950.8 / 483948.4 — 7(1/2,3/2)	484320.6 / 484300.0 — 7(3/2,5/2)	484343.5 — 7(5/2,7/2)	484345.42 — 7(7/2,9/2)	484345.84 — 7(9/2,11/2)	484345.96 — 7(11/2,13/2)
46 x 10⁴	468784.0 — 6(1/2)	470778.9 / 470775.0 — 6(1/2,3/2)	471371.5 / 471370.3 — 6(3/2,5/2)	471403.2 — 6(5/2,7/2)	471406.16 — 6(7/2,9/2)	471406.80 — 6(9/2,11/2)	
44 x 10⁴	445368.5 — 5(1/2)	448862.9 / 448855.8 — 5(1/2,3/2)	449889.9 / 449888.2 — 5(3/2,5/2)	449939.8 — 5(5/2,7/2)	449948.40 — 5(7/2,9/2)		
42 x 10⁴							
40 x 10⁴	401348.1 — 4(1/2)	408324.2 / 408311.1 — 4(1/2,3/2)	410340.1 / 410336.1 — 4(3/2,5/2)	410434.2 — 4(5/2,7/2)			
32 x 10⁴		320081.7 / 320050.1 — 3(1/2,3/2)	324890.3 / 324879.8 — 3(3/2,5/2)				
30 x 10⁴	302849.0 — 3(1/2)						
10 x 10⁴		64591.7 / 64484.0 — 2(1/2,3/2)					
0	0.0 — 2(1/2)						

KEY

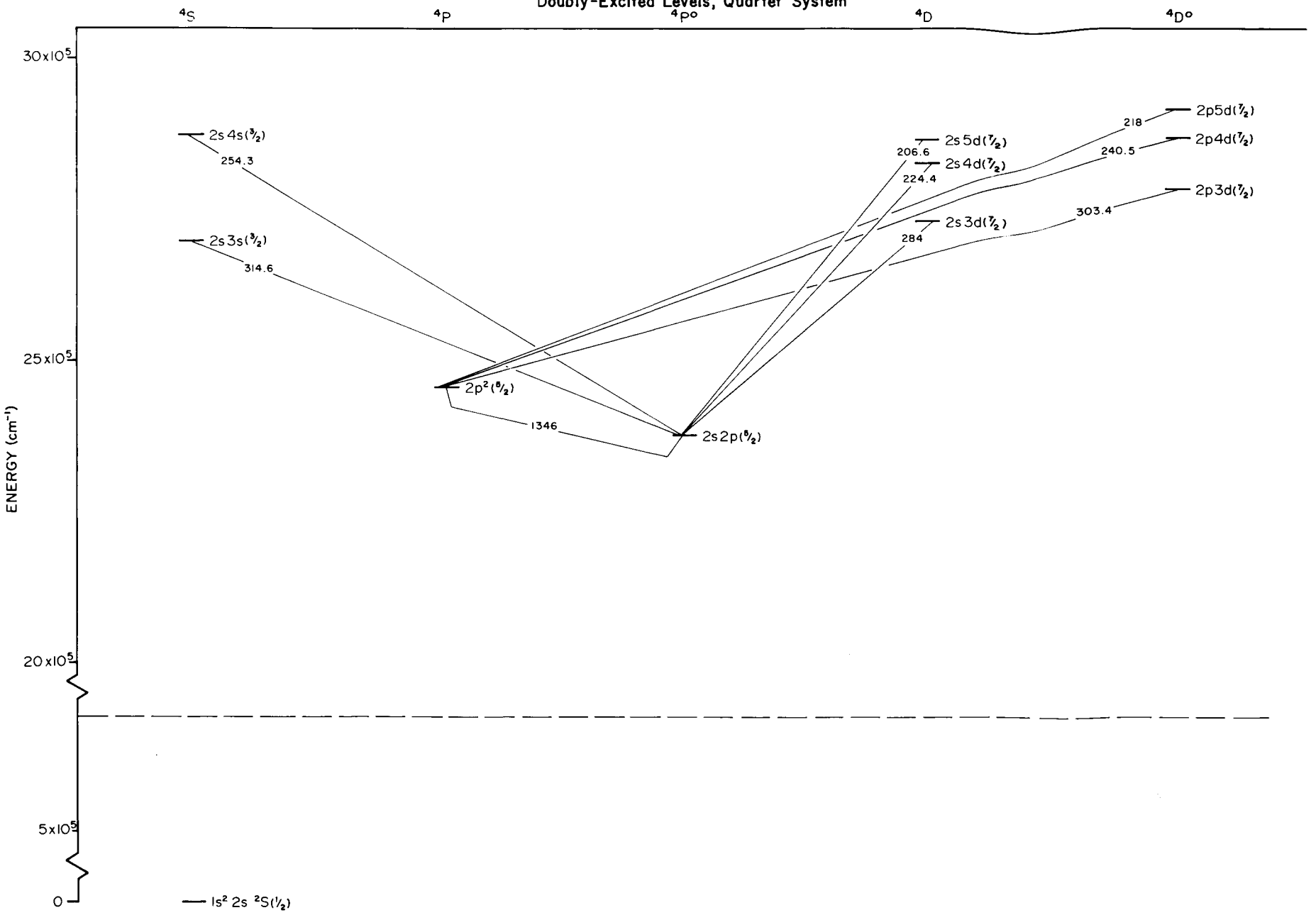
449948.40 — 5(7/2,9/2)

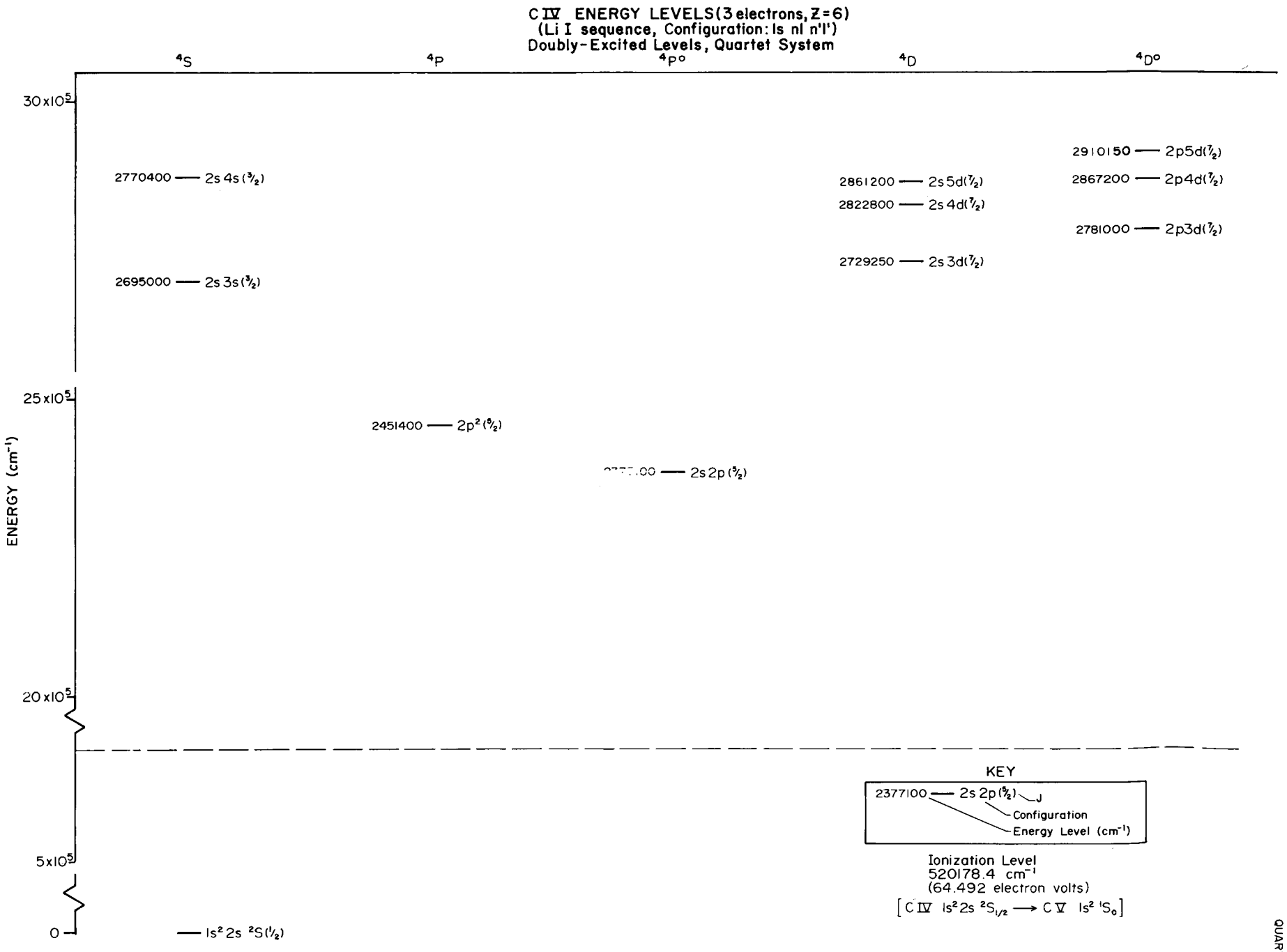
- J, Lowest to Highest
- Configuration
- Energy Level (cm⁻¹)

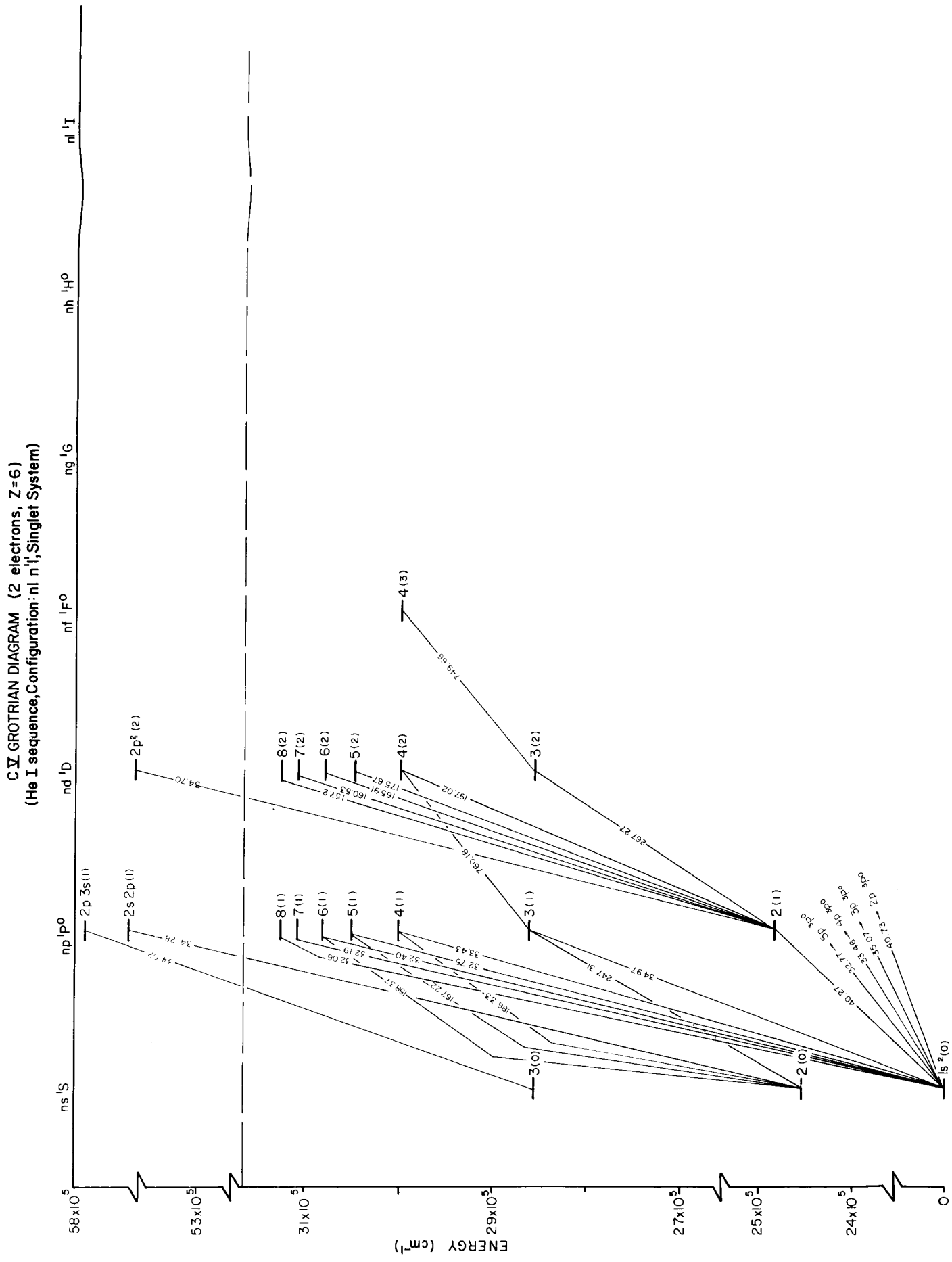
Ionization Level
520178.4 cm⁻¹
(64.492 eV)
[C IV $1s^22s\,^2S_{1/2}$ → C V $1s^2\,^1S_0$]

C IV DOUBLET

C IV GROTRIAN DIAGRAM (3 electrons, Z=6)
(Li I sequence, Configuration: 1s nl n'l')
Doubly-Excited Levels, Quartet System

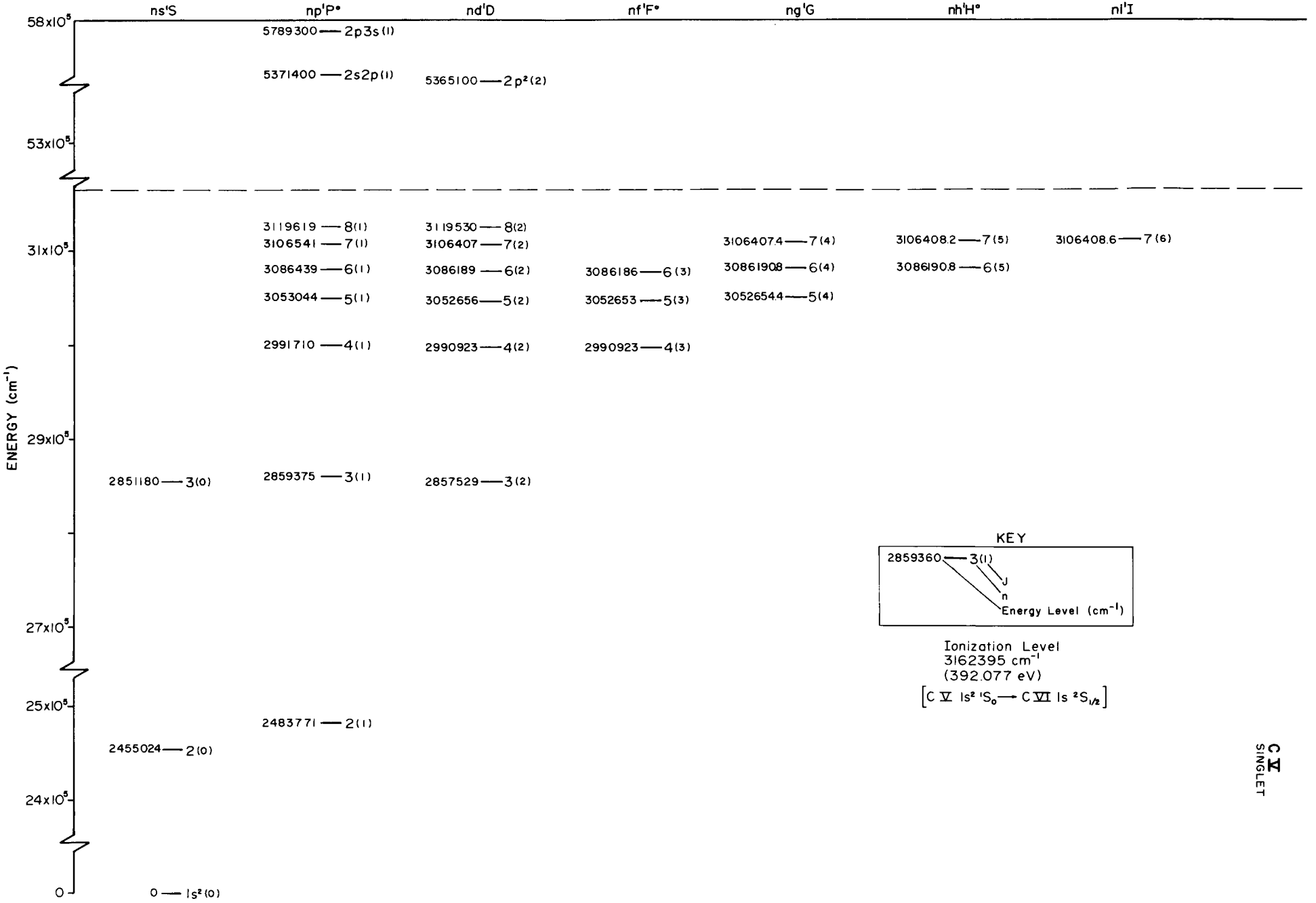



C IV ENERGY LEVELS (3 electrons, Z=6)
(Li I sequence, Configuration: 1s nl n'l')
Doubly-Excited Levels, Quartet System
4S
4P
4P°
4D
4D°
ENERGY (cm⁻¹)
30x10⁵
25x10⁵
20x10⁵
5x10⁵
0
2770400 — 2s 4s (3/2)
2695000 — 2s 3s (3/2)
2451400 — 2p² (5/2)
2377100 — 2s 2p (5/2)
2861200 — 2s 5d (7/2)
2822800 — 2s 4d (7/2)
2729250 — 2s 3d (7/2)
2910150 — 2p5d (7/2)
2867200 — 2p4d (7/2)
2781000 — 2p3d (7/2)
— 1s² 2s ²S (1/2)
KEY
2377100 — 2s 2p (5/2)
J
Configuration
Energy Level (cm⁻¹)
Ionization Level
520178.4 cm⁻¹
(64.492 electron volts)
[C IV 1s² 2s ²S1/2 → C V 1s² ¹S0]


C VI GROTRIAN DIAGRAM (2 electrons, Z=6)
(He I sequence, Configuration: nl n'l', Singlet System)
ns ¹S
np ¹P°
nd ¹D
nf ¹F°
ng ¹G
nh ¹H°
nl ¹I
ENERGY (cm⁻¹)
58x10⁵
53x10⁵
31x10⁵
29x10⁵
27x10⁵
25x10⁵
24x10⁵
0
2p 3s(1)
2s 2p(1)
2p²(2)
1s²(0)
2(0)
3(0)
2(1)
3(1)
4(1)
5(1)
6(1)
7(1)
8(1)
3(2)
4(2)
5(2)
6(2)
7(2)
8(2)
4(3)
34.70
34.29
34.01
267.27
247.31
34.97
760.18
197.02
165.91
160.53
157.2
175.67
743.66
186.33
187.22
188.37
32.06
32.19
32.40
32.75
33.43
40.27
32.77 — 5p 3p°
33.46 — 4p 3p°
35.07 — 3p 3p°
40.73 — 2p 3p°

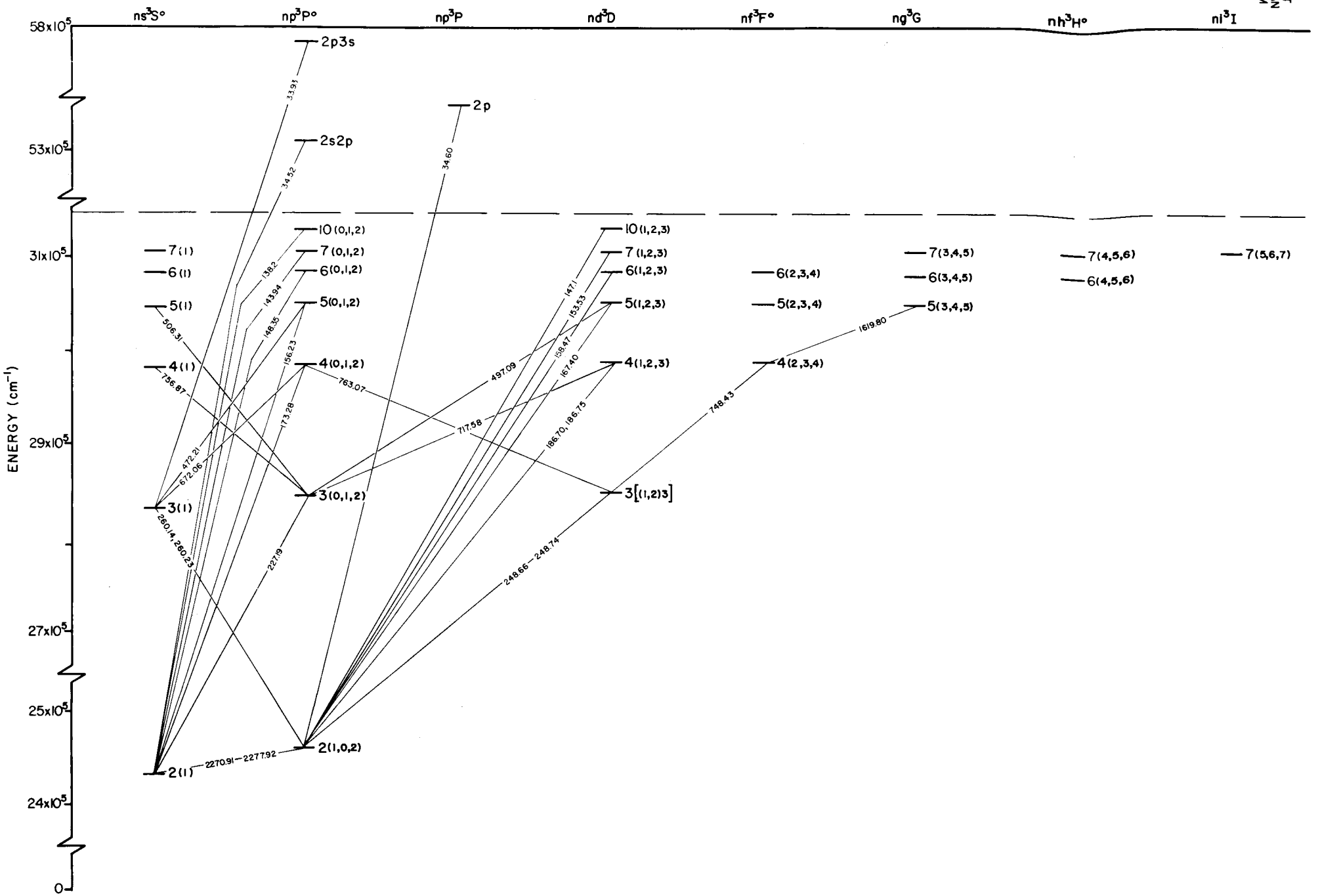
C V ENERGY LEVELS (2 electrons, Z = 6)

(He I Sequence, Configuration; nl n'l', Singlet System)

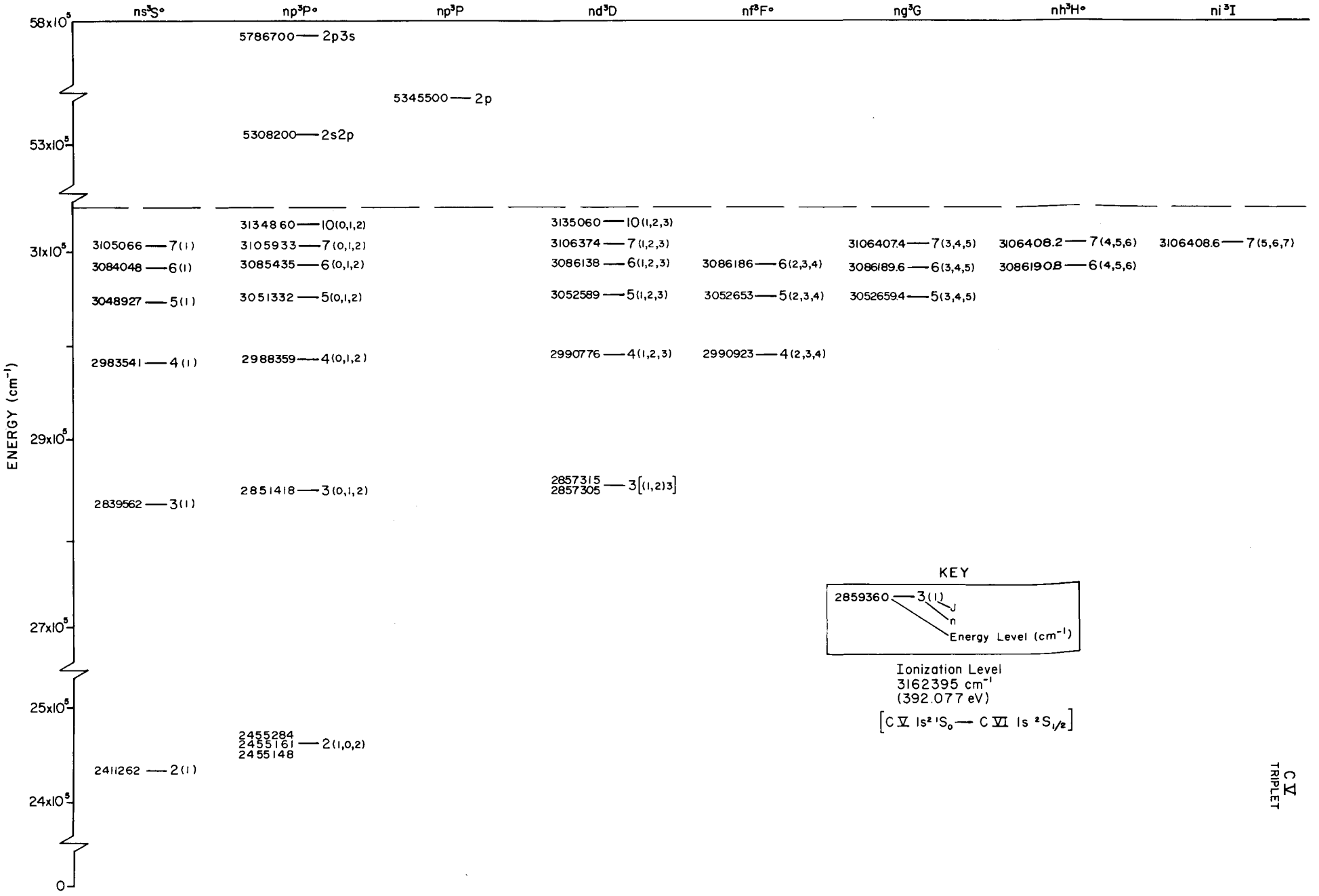


C V
SINGLET

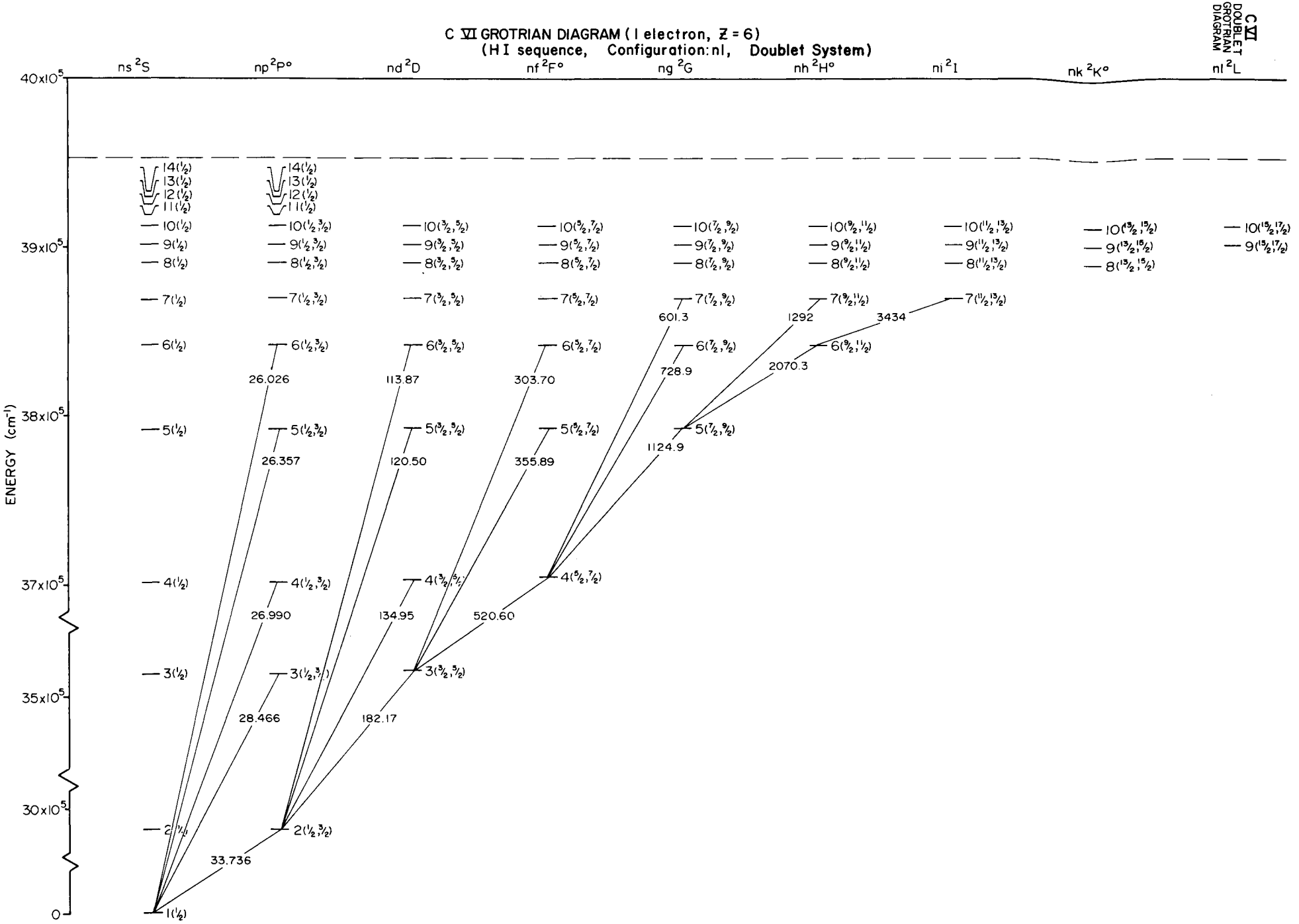
C V GROTRIAN DIAGRAM (2 electrons, Z = 6)
(He I sequence, Configuration: nl n'l', Triplet System)



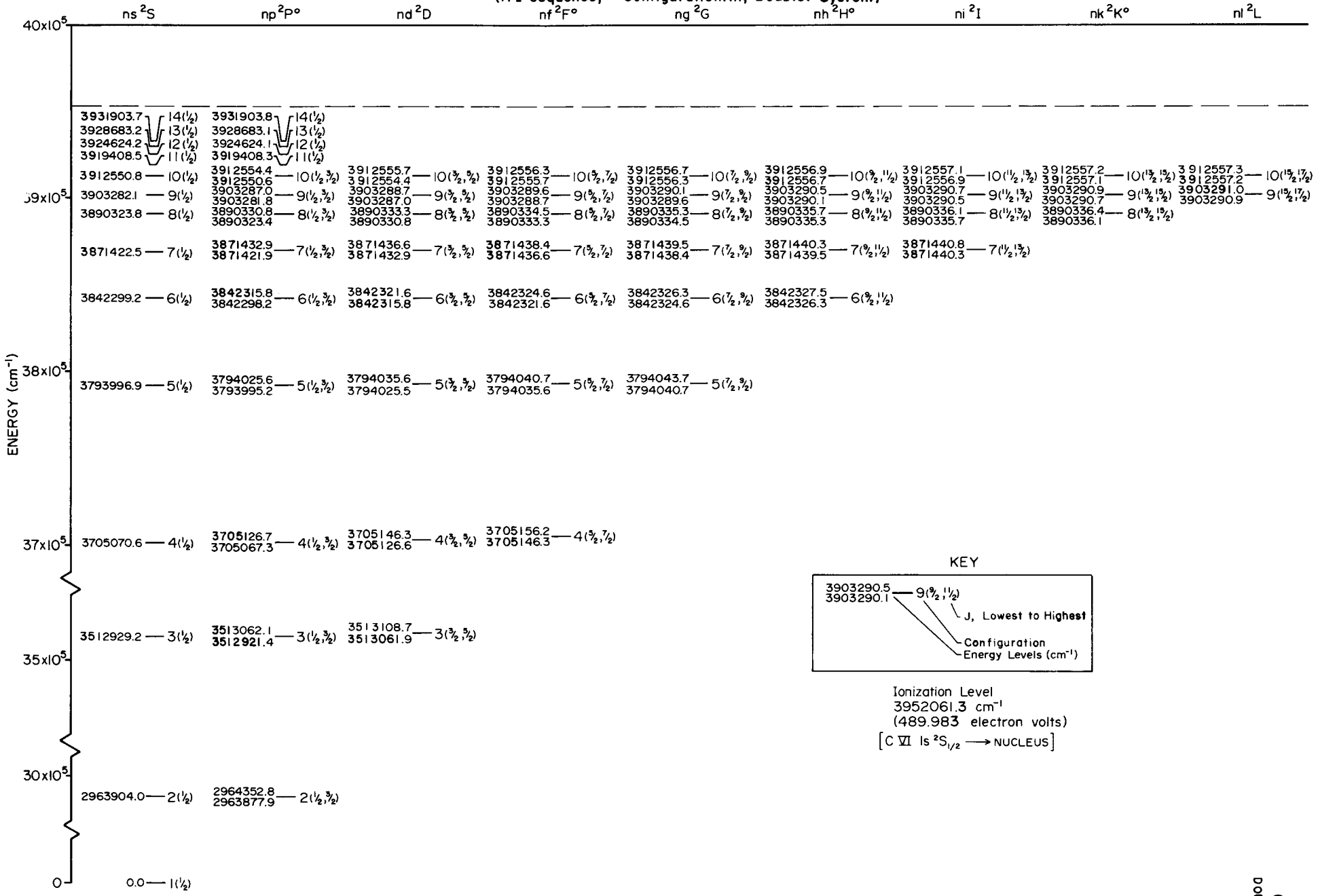
C V ENERGY LEVELS (2 electrons, Z = 6)
(He I sequence, Configuration; nl n'l', Triplet System)



C V
TRIPLET


C VI GROTRIAN DIAGRAM (I electron, Z = 6)
(H I sequence, Configuration: nl, Doublet System)
C VI DOUBLET GROTRIAN DIAGRAM
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
ni ²I
nk ²K°
nl ²L
ENERGY (cm⁻¹)
40x10⁵
39x10⁵
38x10⁵
37x10⁵
35x10⁵
30x10⁵
0
26.026
26.357
26.990
28.466
33.736
113.87
120.50
134.95
182.17
303.70
355.89
520.60
601.3
728.9
1124.9
1292
2070.3
3434

C VI ENERGY LEVELS (1 electron, Z = 6)
(H I sequence, Configuration: nl, Doublet System)



C I $Z = 6$ 6 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives a line table from empirical data of forbidden transitions.

L. Johansson, Ark. Fys. **25**, 425 (1963).

Author gives line tables for spectral lines observed in the range 3420–9659 Å.

Comment on intermediate coupling: According to L. Johansson, Ark. Fys. **31**, 201 (1966), the pair coupling with f electrons lies between

$[\{(l_1,s_1)j_1,l_2\}K_1s_2]J$ and $[\{(l_1,l_2)L,s_1\}K_1s_2]J$.

In our key, we have called Johansson's "K", "intermediate J", and we have not used the symbol, "K", at all.

C II $Z = 6$ 5 electrons

Please see the general references.

C III $Z = 6$ 4 electrons

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to energy-level values by K. Bockasten, Ark. Fys. **9**, 457 (1955).

C IV $Z = 6$ 3 electrons

H.G. Berry, M.C. Buchet-Poulizac, and J.P. Buchet, J. Opt. Soc. Amer. **63**, 240 (1973).

Lines arising from transitions within the quartet system are given.

C V $Z = 6$ 2 electrons

H.G. Berry, J. Désesquelles, and M. Dufay, Phys. Rev. **A6**, 600 (1972).

These authors summarize information on doubly-excited states in the He I isoelectronic sequence.

B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

Authors identify wavelengths observed in zeta spectrum in range 16–400 Å.

E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors give nonrelativistic calculations of energies in treatment of the helium isoelectronic sequence.

C VI $Z = 6$ 1 electron

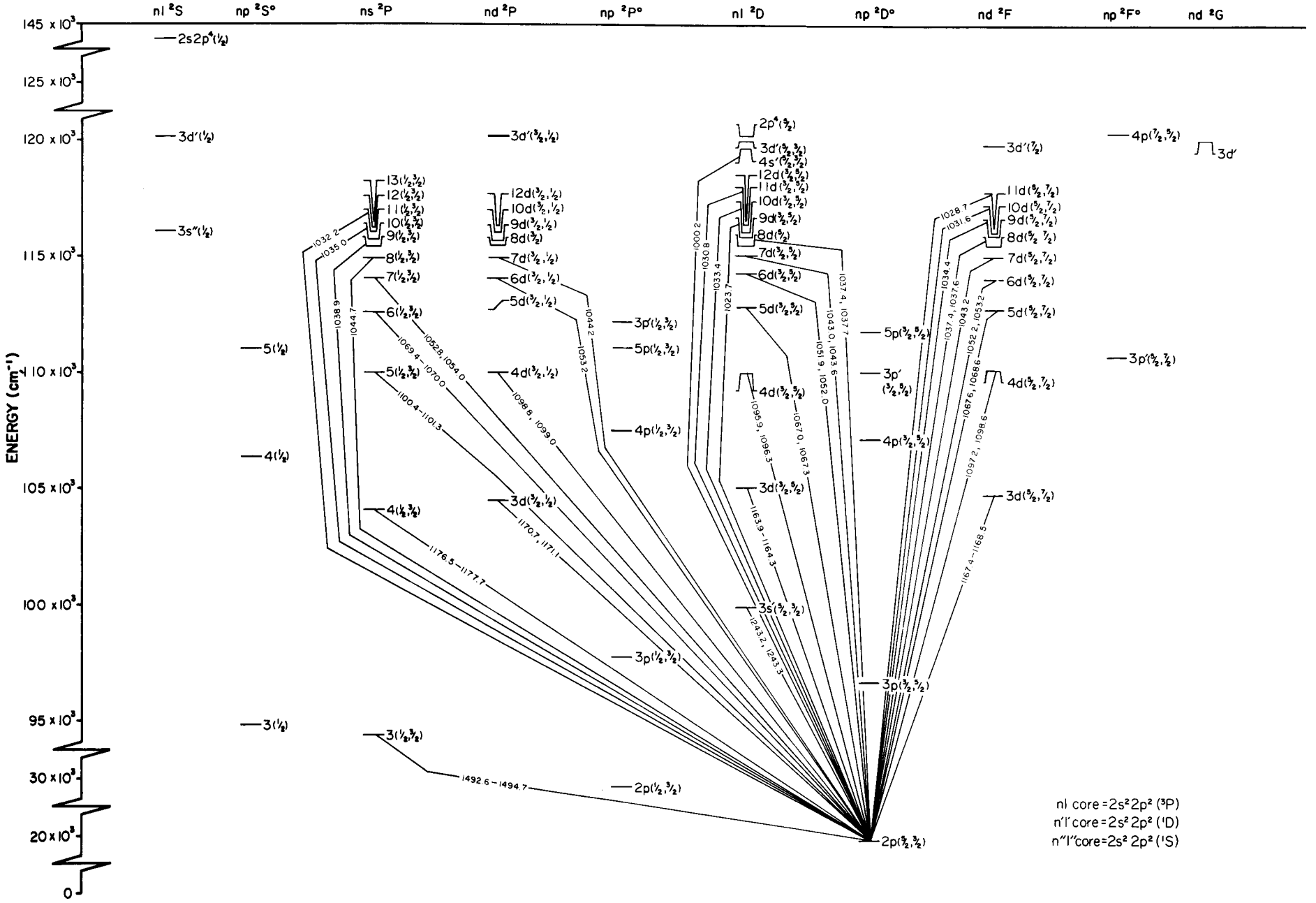
B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

Authors give observed spectrum in range 16–400 Å.

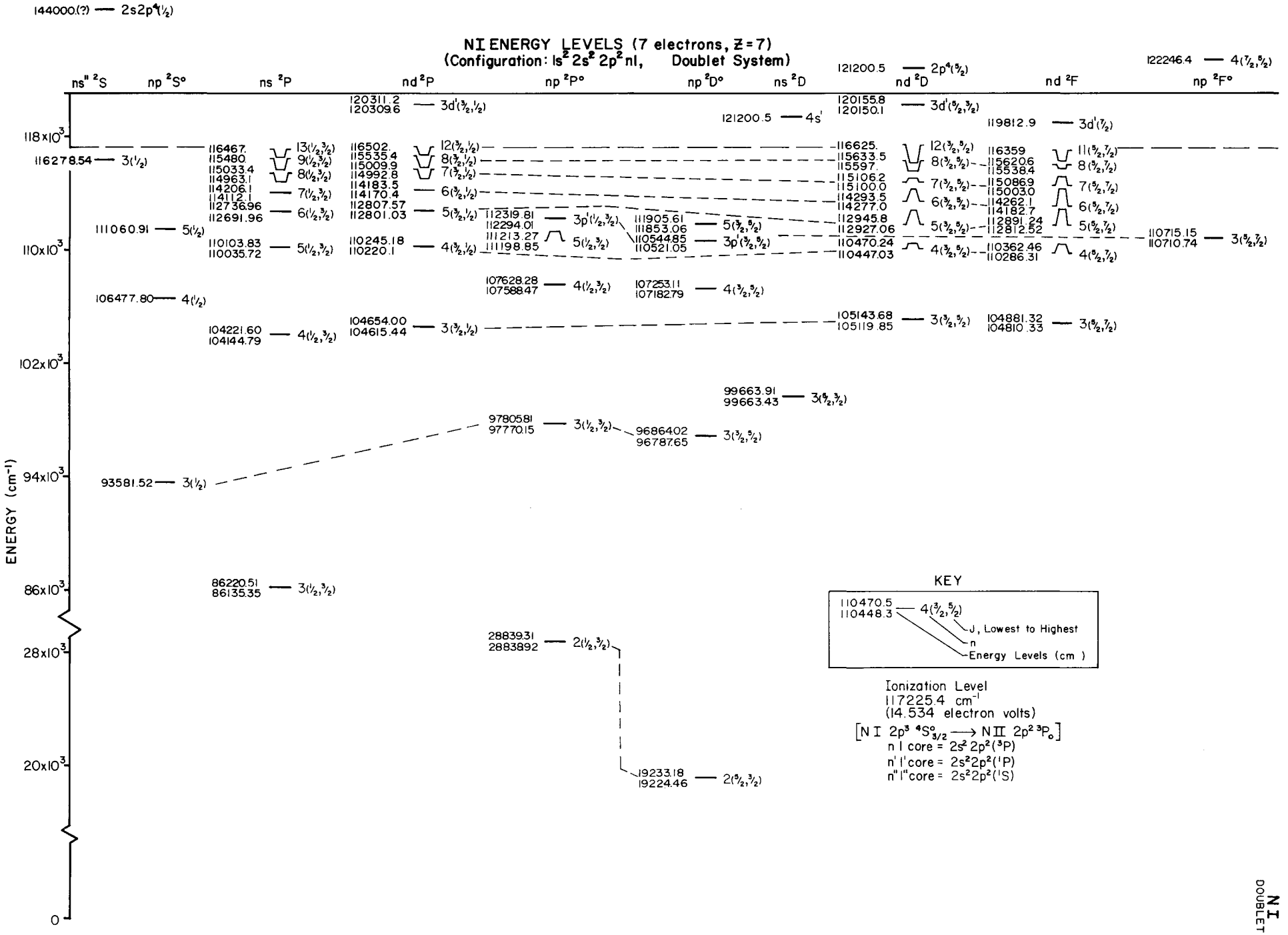
Nitrogen (N)

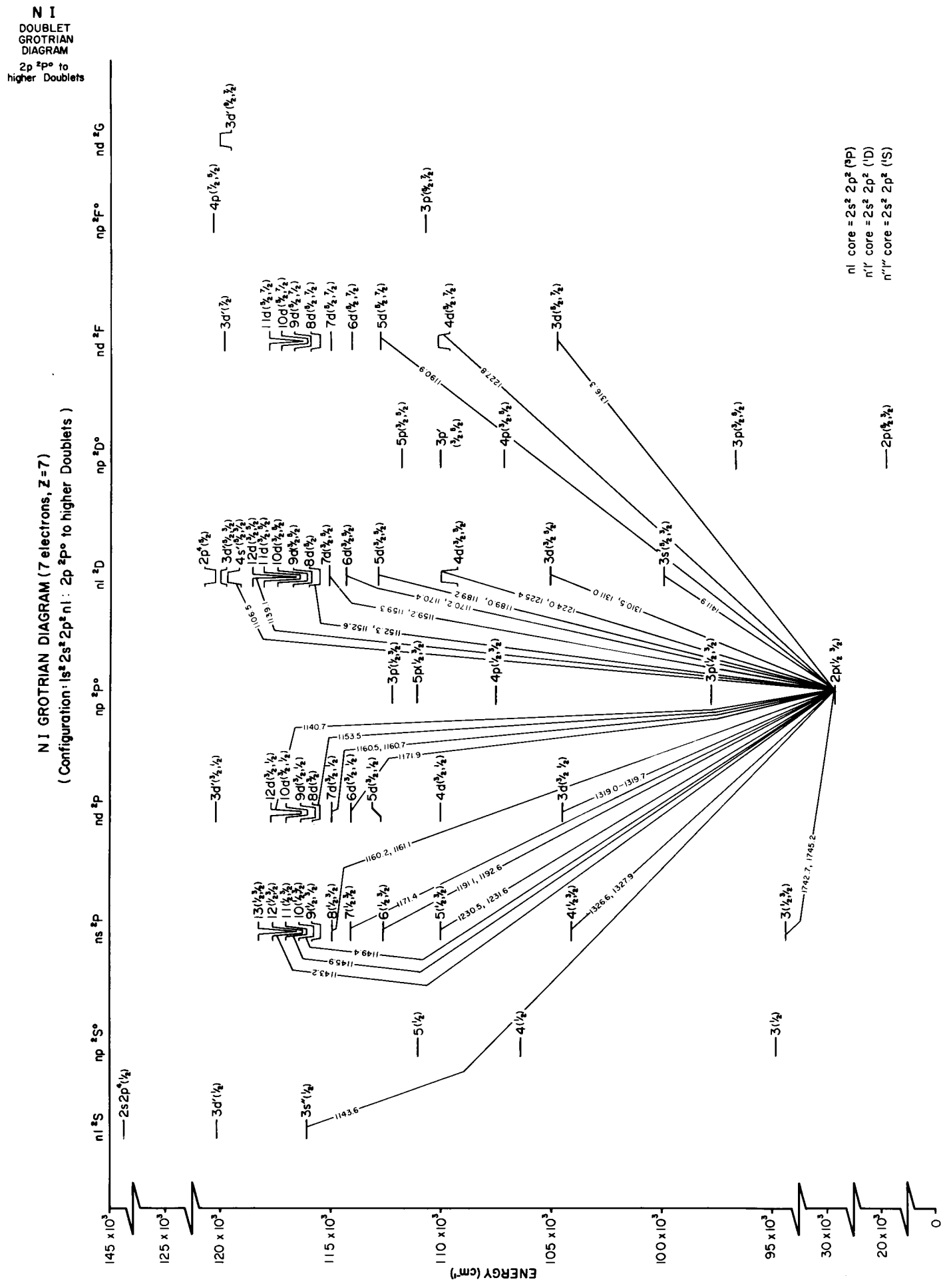
N I GROTRIAN DIAGRAM (7 electrons, Z = 7)

(Configuration: $1s^2\,2s^2\,2p^2\,nl$: $2p\,^2D^\circ$ to higher Doublets)

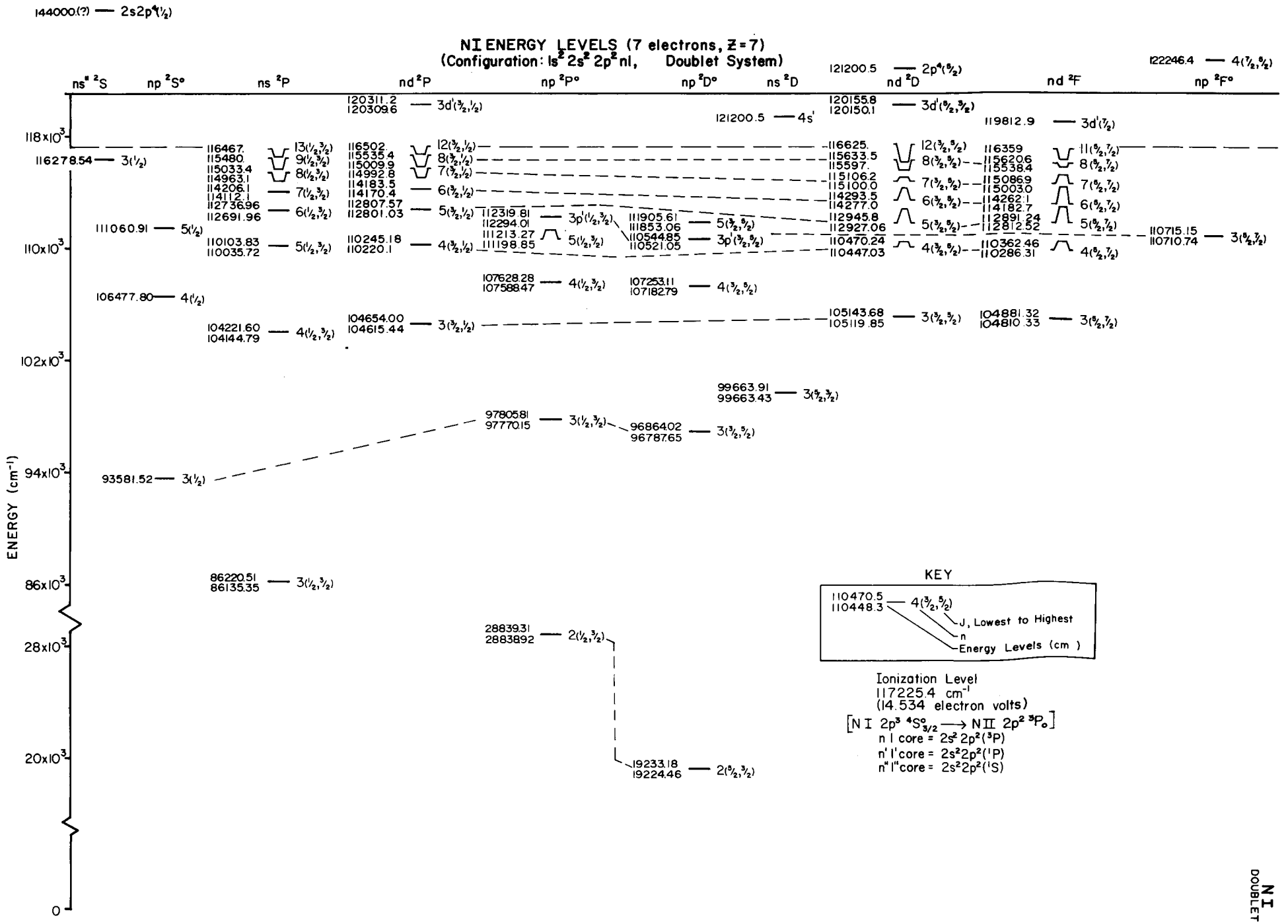


N I ENERGY LEVELS (7 electrons, Z = 7)
(Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



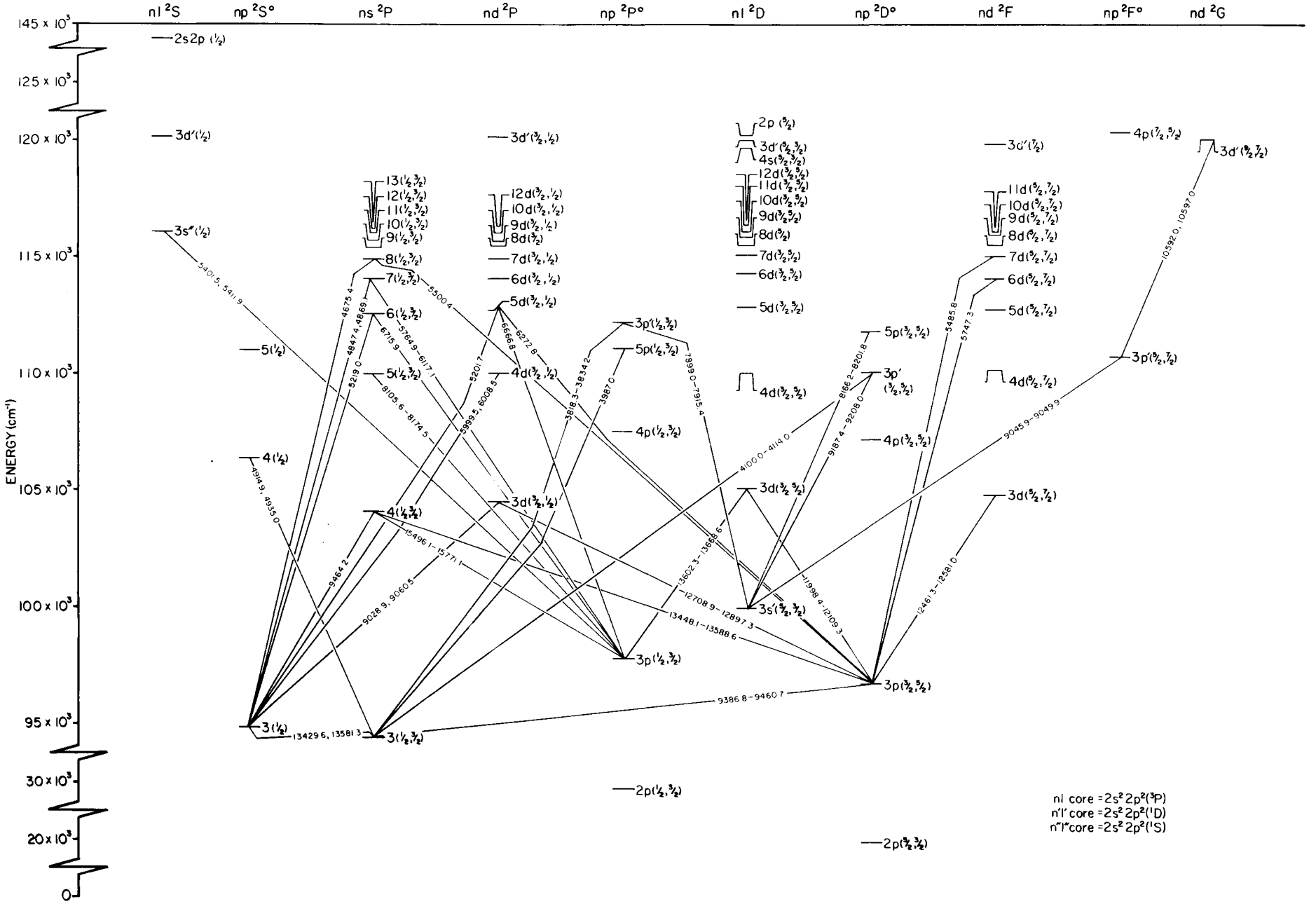

N I
DOUBLET
GROTRIAN
DIAGRAM
2p ²P° to
higher Doublets
N I GROTRIAN DIAGRAM (7 electrons, Z=7)
(Configuration: 1s² 2s² 2p² nl : 2p ²P° to higher Doublets)
nl ²S
np ²S°
ns ²P
nd ²P
nl ²D
np ²P°
np ²D°
nd ²F
np ²F°
nd ²G
ENERGY (cm⁻¹)
145 x10³
125 x10³
120 x10³
115 x10³
110 x10³
105 x10³
100 x10³
95 x10³
30 x10³
20 x10³
0
nl core = 2s² 2p² (³P)
n'l' core = 2s² 2p² (¹D)
n''l'' core = 2s² 2p² (¹S)

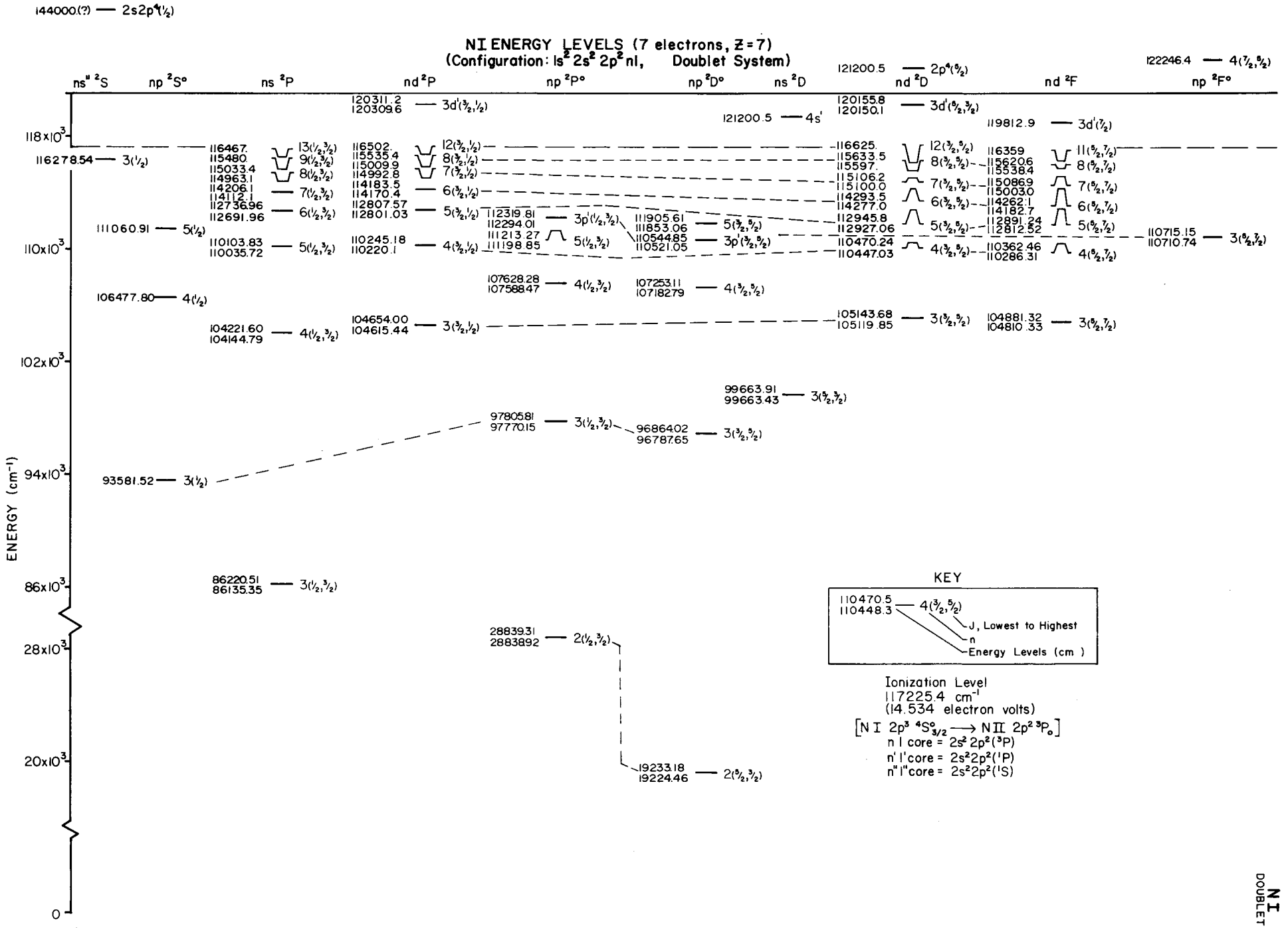
NI ENERGY LEVELS (7 electrons, Z = 7)
(Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)

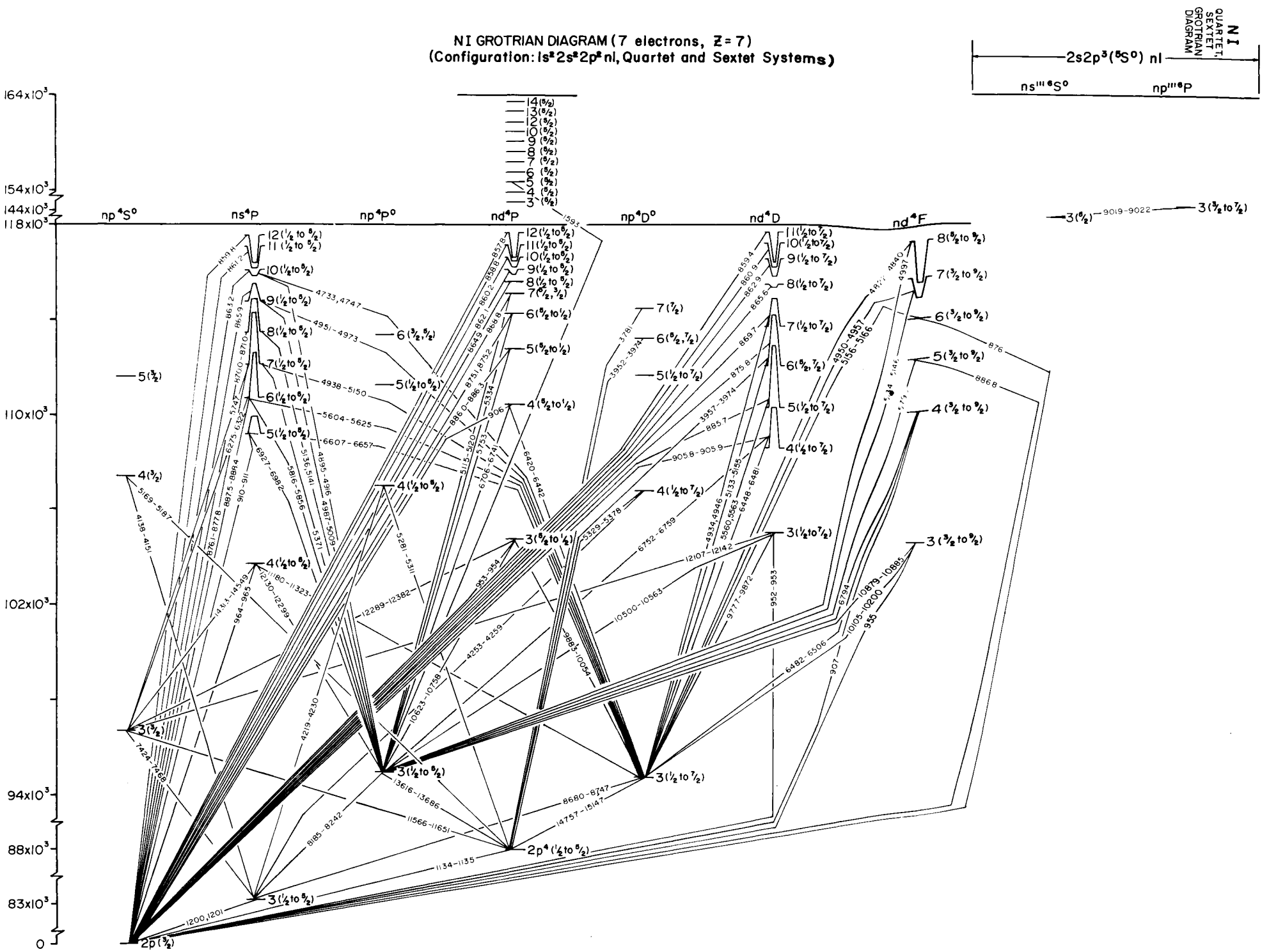


N I GROTRIAN DIAGRAM (7 electrons, Z=7)

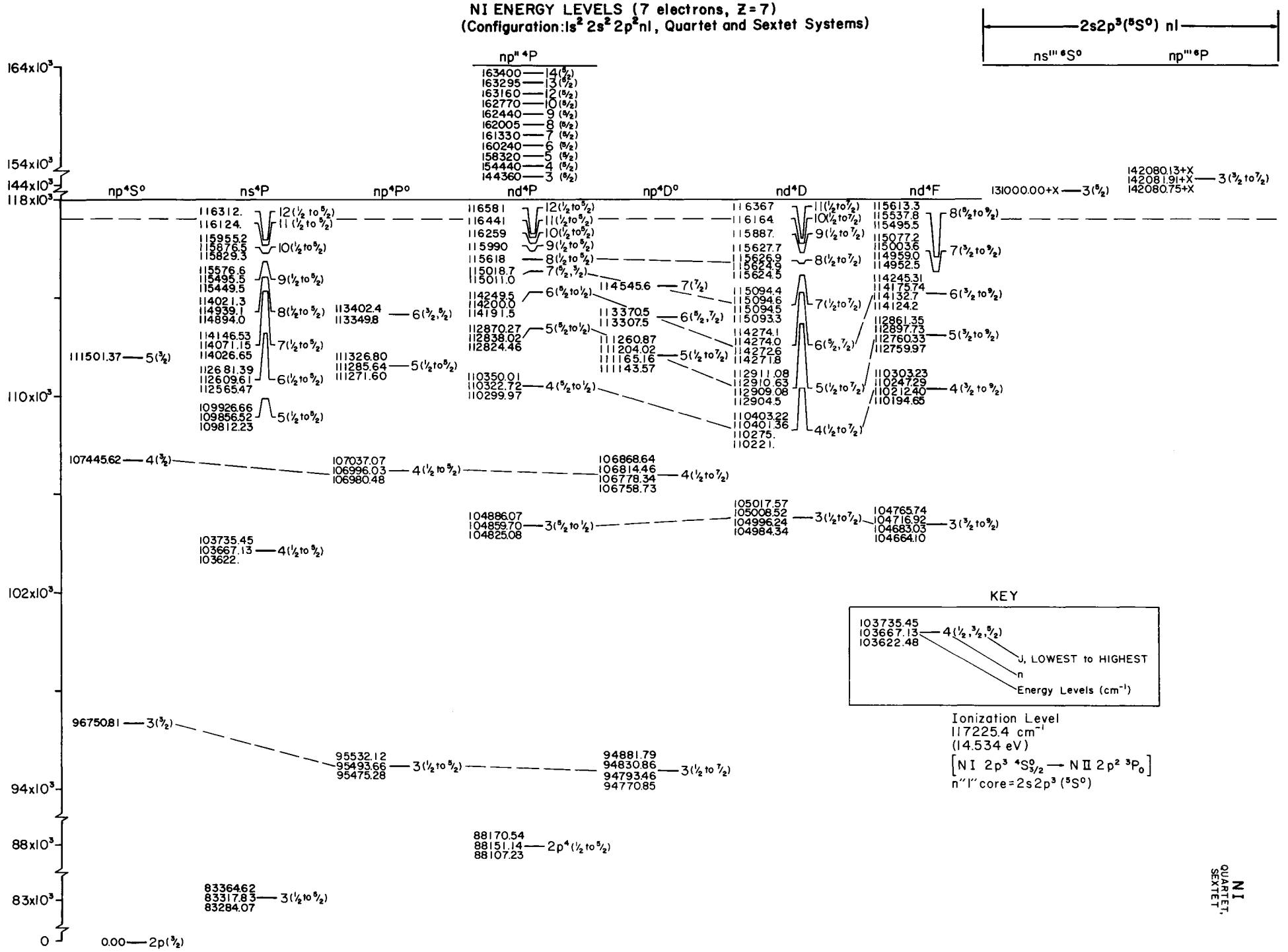
(Configuration: $1s^2\,2s^2\,2p^2\,nl$, n=3 Doublets to higher Doublets)



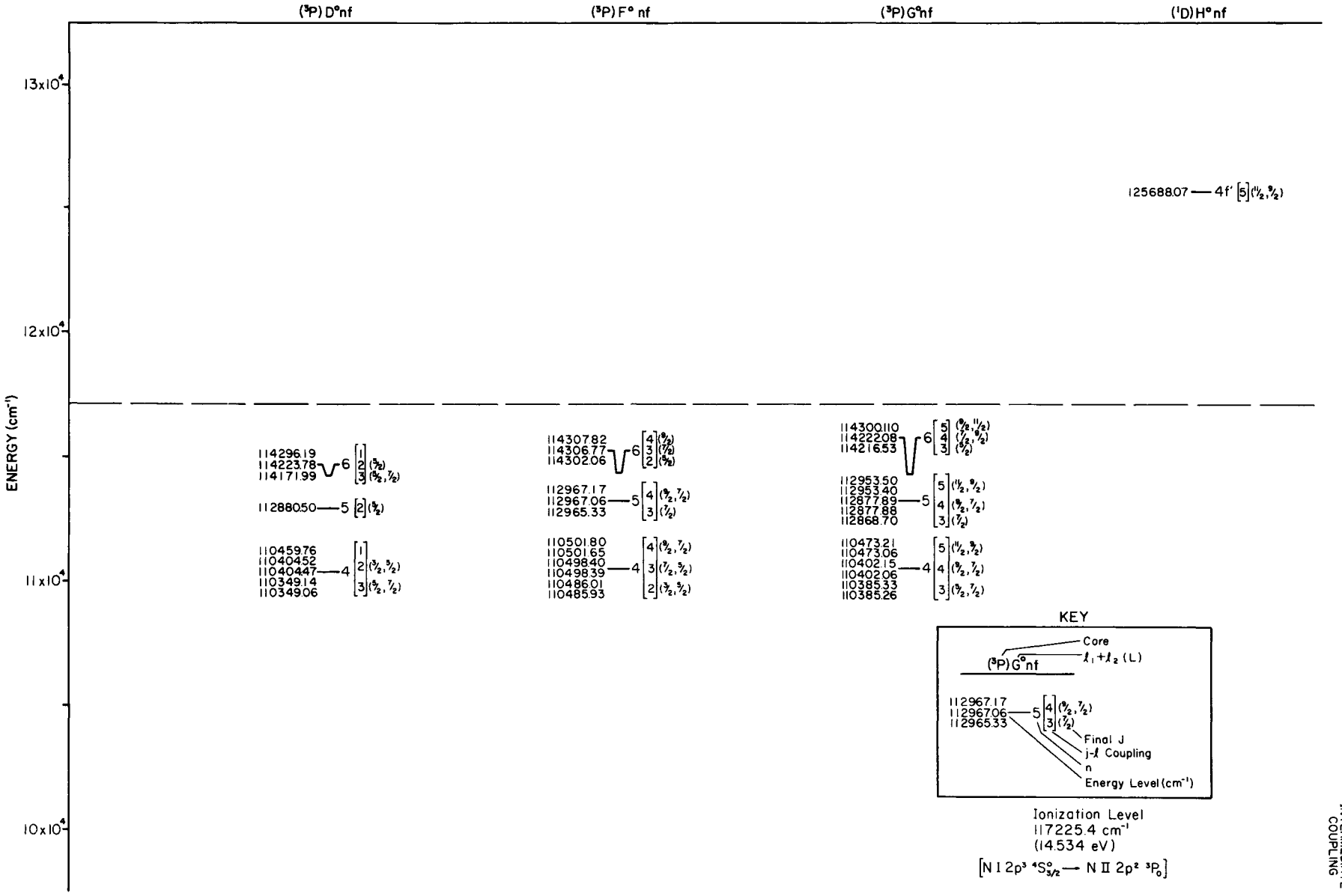

NI ENERGY LEVELS (7 electrons, Z=7)
(Configuration: 1s² 2s² 2p² nl, Doublet System)
ns'' ²S
np ²S°
ns ²P
nd ²P
np ²P°
np ²D°
ns ²D
nd ²D
nd ²F
np ²F°
ENERGY (cm⁻¹)
118x10³
110x10³
102x10³
94x10³
86x10³
28x10³
20x10³
0
144000(?) — 2s2p⁴(½)
116278.54 — 3(½)
111060.91 — 5(½)
106477.80 — 4(½)
93581.52 — 3(½)
116467.
115480.
115033.4
114963.1
114206.1
114112.1
112736.96
112691.96
110103.83
110035.72
104221.60
104144.79
86220.51
86135.35
13(½,3/2)
9(½,3/2)
8(½,3/2)
7(½,3/2)
6(½,3/2)
5(½,3/2)
4(½,3/2)
3(½,3/2)
120311.2
120309.6
3d'(3/2,½)
116502.
115535.4
115009.9
114992.8
114183.5
114170.4
112807.57
112801.03
110245.18
110220.1
104654.00
104615.44
12(3/2,½)
8(3/2,½)
7(3/2,½)
6(3/2,½)
5(3/2,½)
4(3/2,½)
3(3/2,½)
112319.81
112294.01
111213.27
111198.85
3p'(½,3/2)
5(½,3/2)
107628.28
107588.47
4(½,3/2)
97805.81
97770.15
3(½,3/2)
28839.31
28838.92
2(½,3/2)
111905.61
111853.06
110544.85
110521.05
5(3/2,5/2)
3p'(3/2,5/2)
107253.11
107182.79
4(3/2,5/2)
96864.02
96787.65
3(3/2,5/2)
19233.18
19224.46
2(5/2,3/2)
121200.5 — 4s'
99663.91
99663.43
3(5/2,3/2)
121200.5 — 2p⁴(5/2)
120155.8
120150.1
3d'(5/2,3/2)
116625.
115633.5
115597.
115106.2
115100.0
114293.5
114277.0
112945.8
112927.06
110470.24
110447.03
12(3/2,5/2)
8(3/2,5/2)
7(3/2,5/2)
6(3/2,5/2)
5(3/2,5/2)
4(3/2,5/2)
105143.68
105119.85
3(3/2,5/2)
119812.9 — 3d'(7/2)
116359
115620.6
115538.4
115086.9
115003.0
114262.1
114182.7
112891.24
112812.52
110362.46
110286.31
11(5/2,7/2)
8(5/2,7/2)
7(5/2,7/2)
6(5/2,7/2)
5(5/2,7/2)
4(5/2,7/2)
104881.32
104810.33
3(5/2,7/2)
122246.4 — 4(7/2,5/2)
110715.15
110710.74
3(5/2,7/2)
KEY
110470.5
110448.3
4(3/2,5/2)
J, Lowest to Highest
n
Energy Levels (cm)
Ionization Level
117225.4 cm⁻¹
(14.534 electron volts)
[N I 2p³ ⁴S°3/2 ⟶ N II 2p² ³P₀]
n l core = 2s² 2p² (³P)
n' l' core = 2s² 2p² (¹P)
n'' l'' core = 2s² 2p² (¹S)


NI GROTRIAN DIAGRAM (7 electrons, Z = 7)
(Configuration: 1s²2s²2p²nl, Quartet and Sextet Systems)
NI QUARTET, SEXTET GROTRIAN DIAGRAM
2s2p³(⁵S°) nl
ns'''⁶S°
np'''⁶P
164x10³
154x10³
144x10³
118x10³
110x10³
102x10³
94x10³
88x10³
83x10³
0
np⁴S°
ns⁴P
np⁴P°
nd⁴P
np⁴D°
nd⁴D
nd⁴F
2p(3/2)
3(1/2 to 5/2)
3(1/2 to 7/2)
2p⁴(1/2 to 5/2)
3(5/2)-9019-9022-3(3/2 to 7/2)

NI ENERGY LEVELS (7 electrons, Z = 7)
(Configuration: $1s^2\,2s^2\,2p^2\,nl$, Quartet and Sextet Systems)

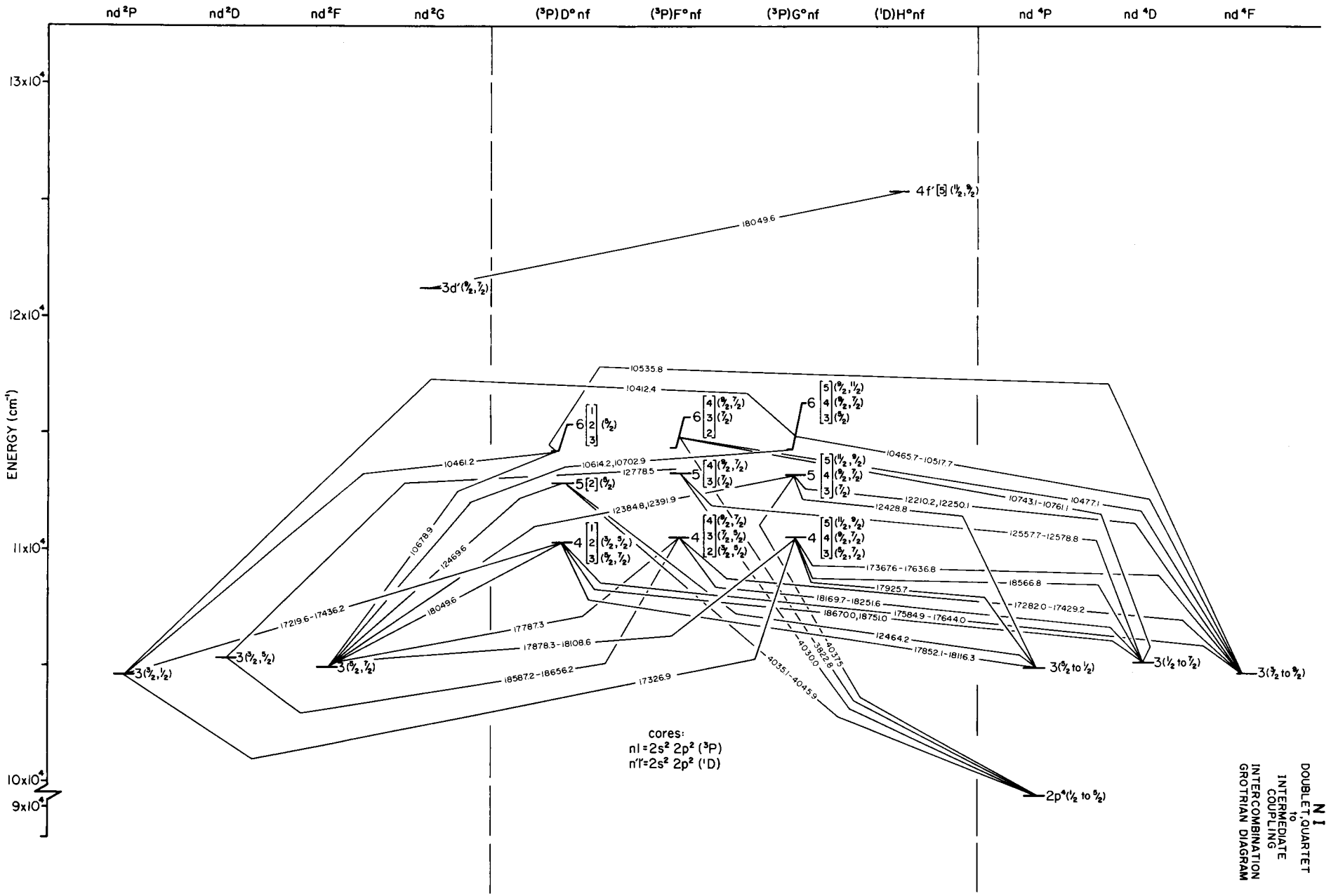


N I ENERGY LEVELS (7 electrons, Z = 7)
(Configuration: $1s^2\,2s^2\,2p^2\,(^{m}L)\,nf$, Intermediate Coupling)



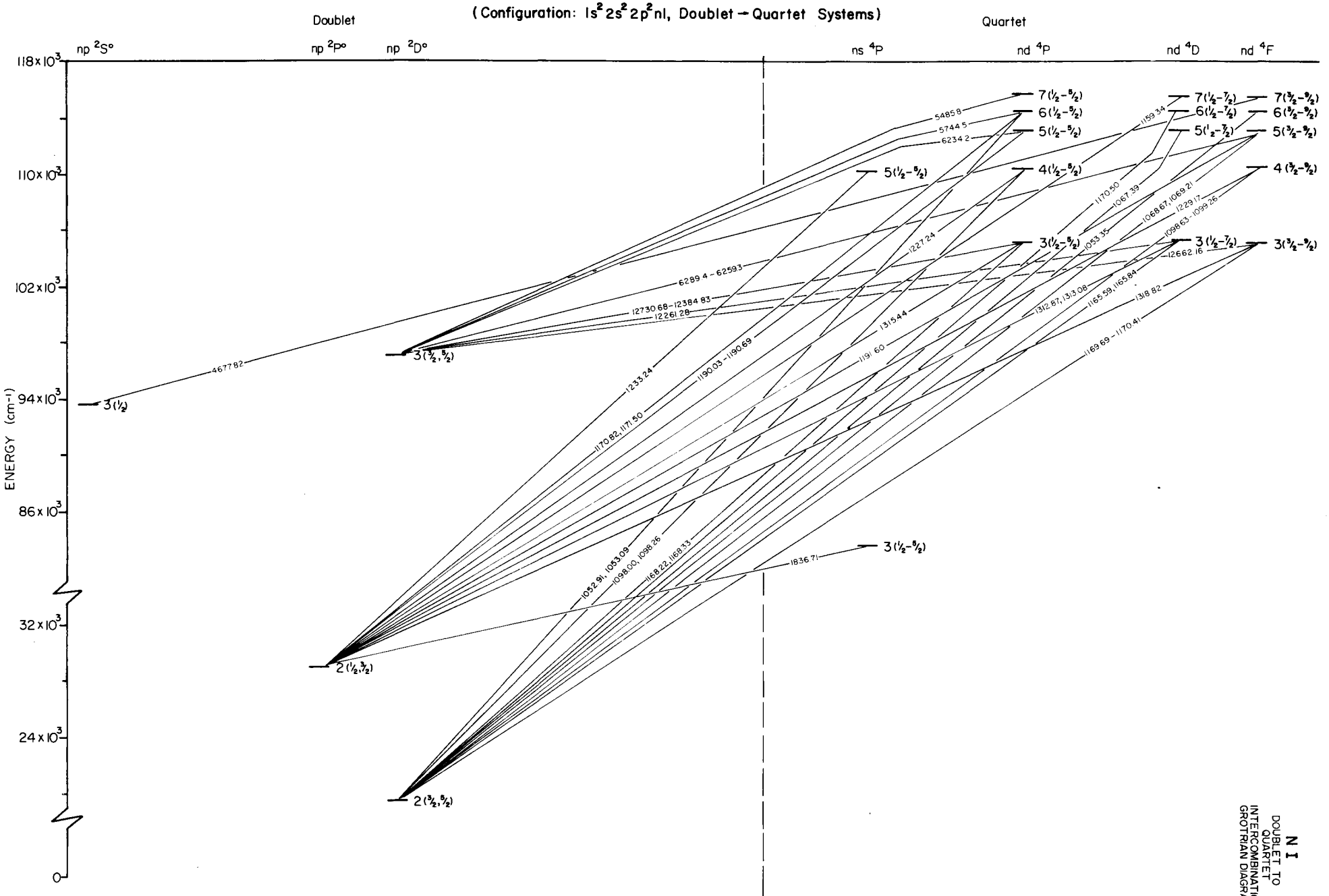
N I
INTERMEDIATE COUPLING

NI INTERCOMBINATION GROTRIAN DIAGRAM (7 electrons, Z=7)
(Configuration: $1s^2\,2s^2\,2p^2\,nl$, Doublets, Quartets to j-l Coupling)

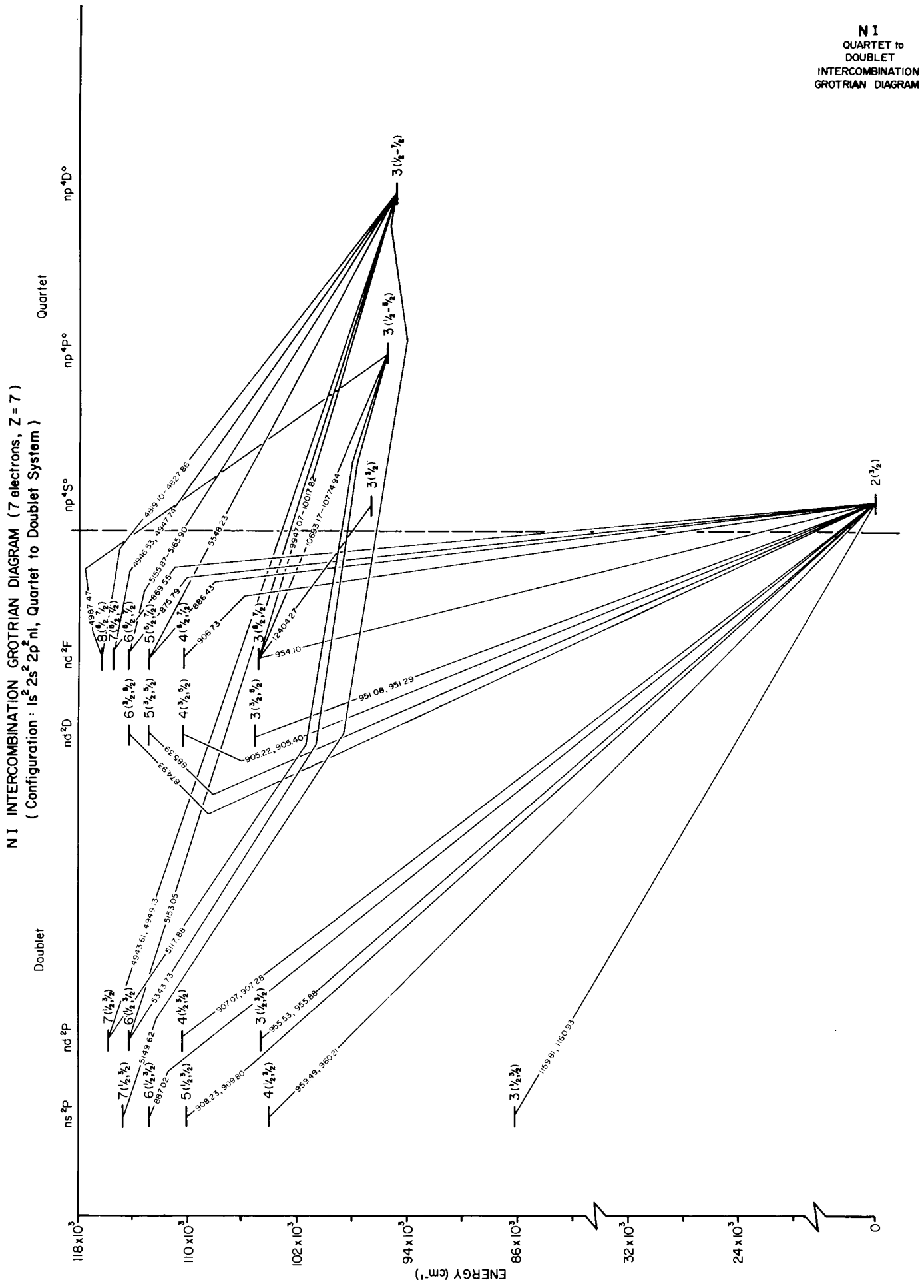


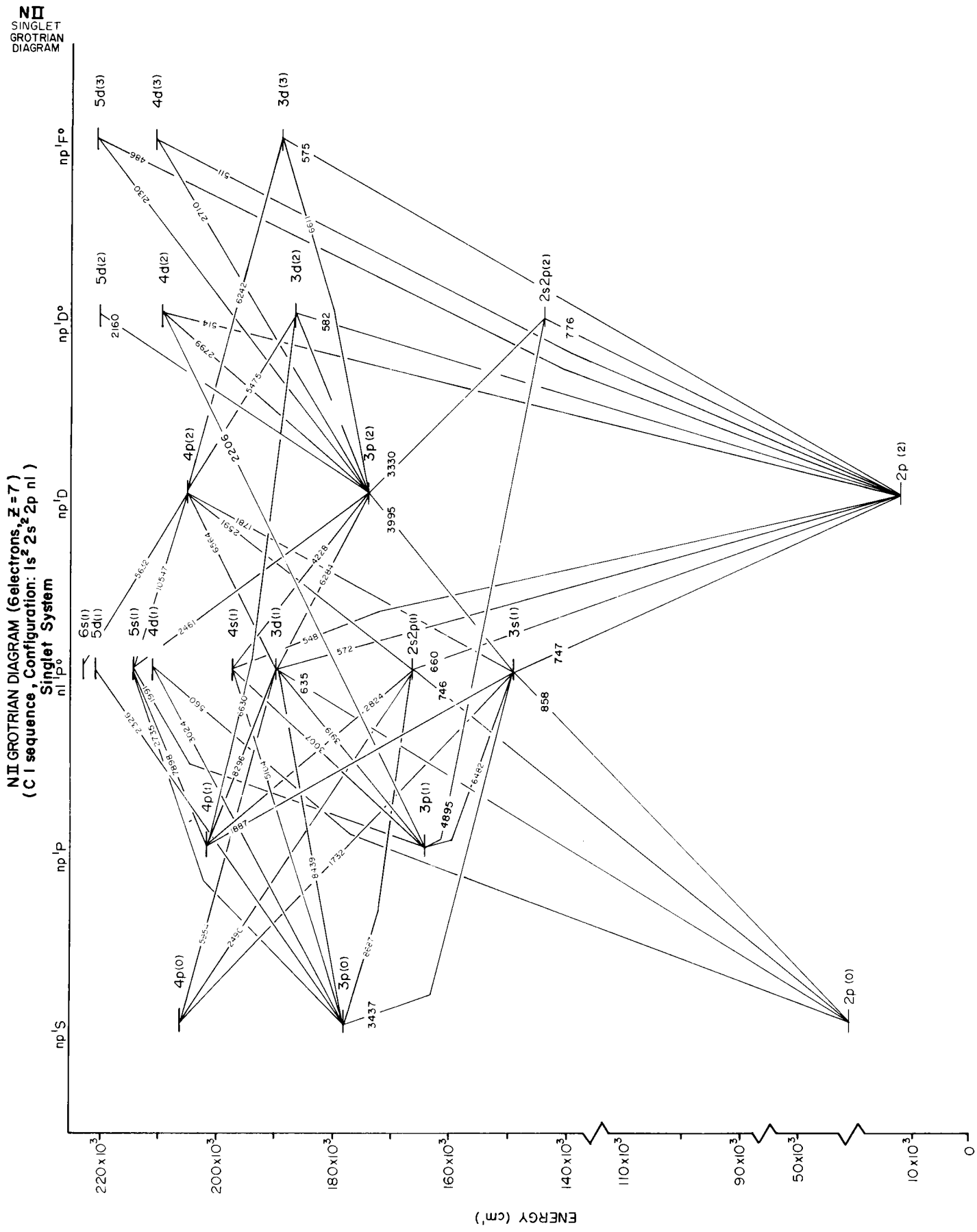
NI
DOUBLET, QUARTET
to
INTERMEDIATE
COUPLING
INTERCOMBINATION
GROTRIAN DIAGRAM

N I INTERCOMBINATION GROTRIAN DIAGRAM (7 electrons, Z = 7)
(Configuration: $1s^2 2s^2 2p^2 nl$, Doublet → Quartet Systems)



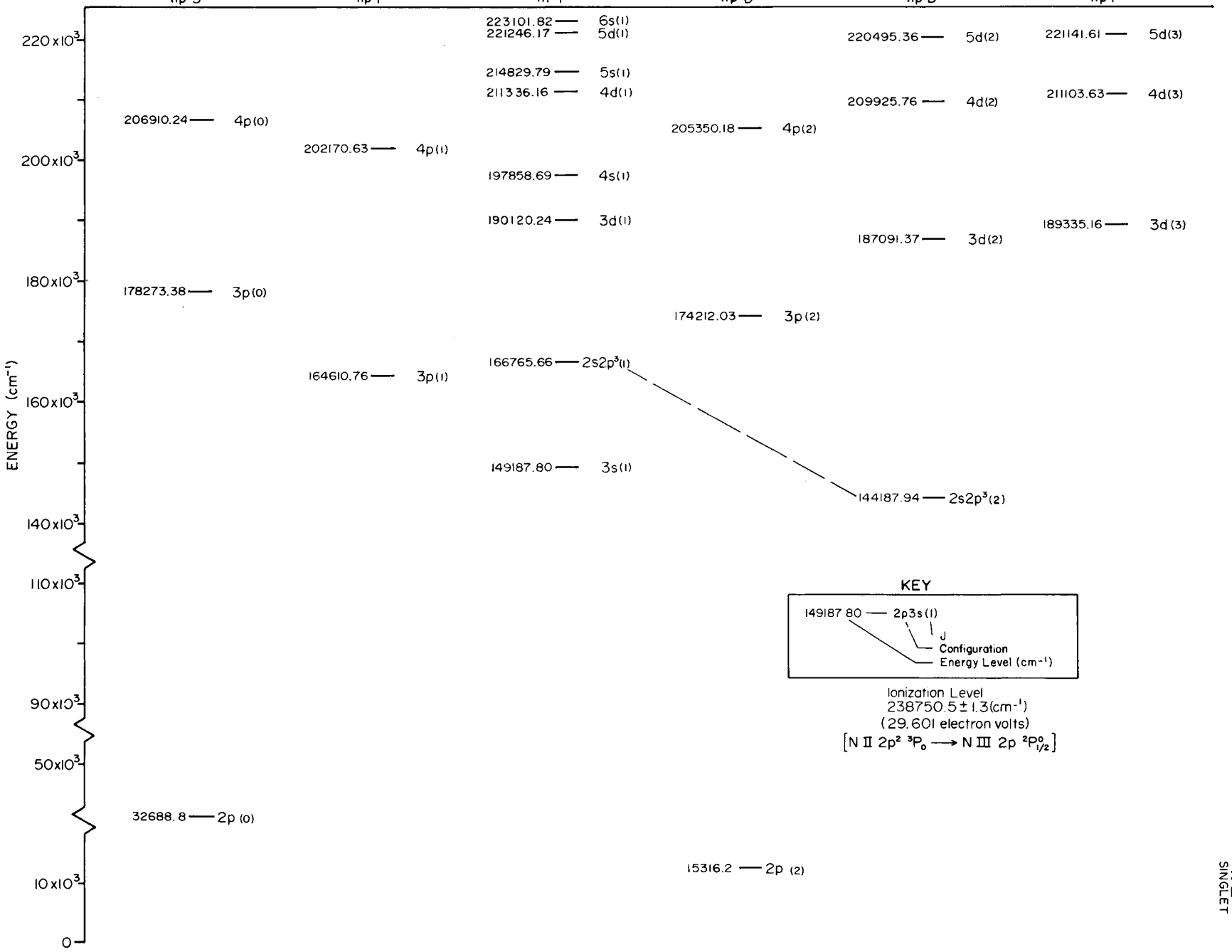
N I
DOUBLET TO
QUARTET
INTERCOMBINATION
GROTRIAN DIAGRAM


N I
QUARTET to
DOUBLET
INTERCOMBINATION
GROTRIAN DIAGRAM
N I INTERCOMBINATION GROTRIAN DIAGRAM (7 electrons, Z = 7)
(Configuration : $1s^2 2s^2 2p^2 nl$, Quartet to Doublet System)
Quartet
Doublet
$np\,^4D^o$
$np\,^4P^o$
$np\,^4S^o$
$nd\,^2F$
$nd\,^2D$
$nd\,^2P$
$ns\,^2P$
ENERGY (cm^{-1})
118x10³
110x10³
102x10³
94x10³
86x10³
32x10³
24x10³
0

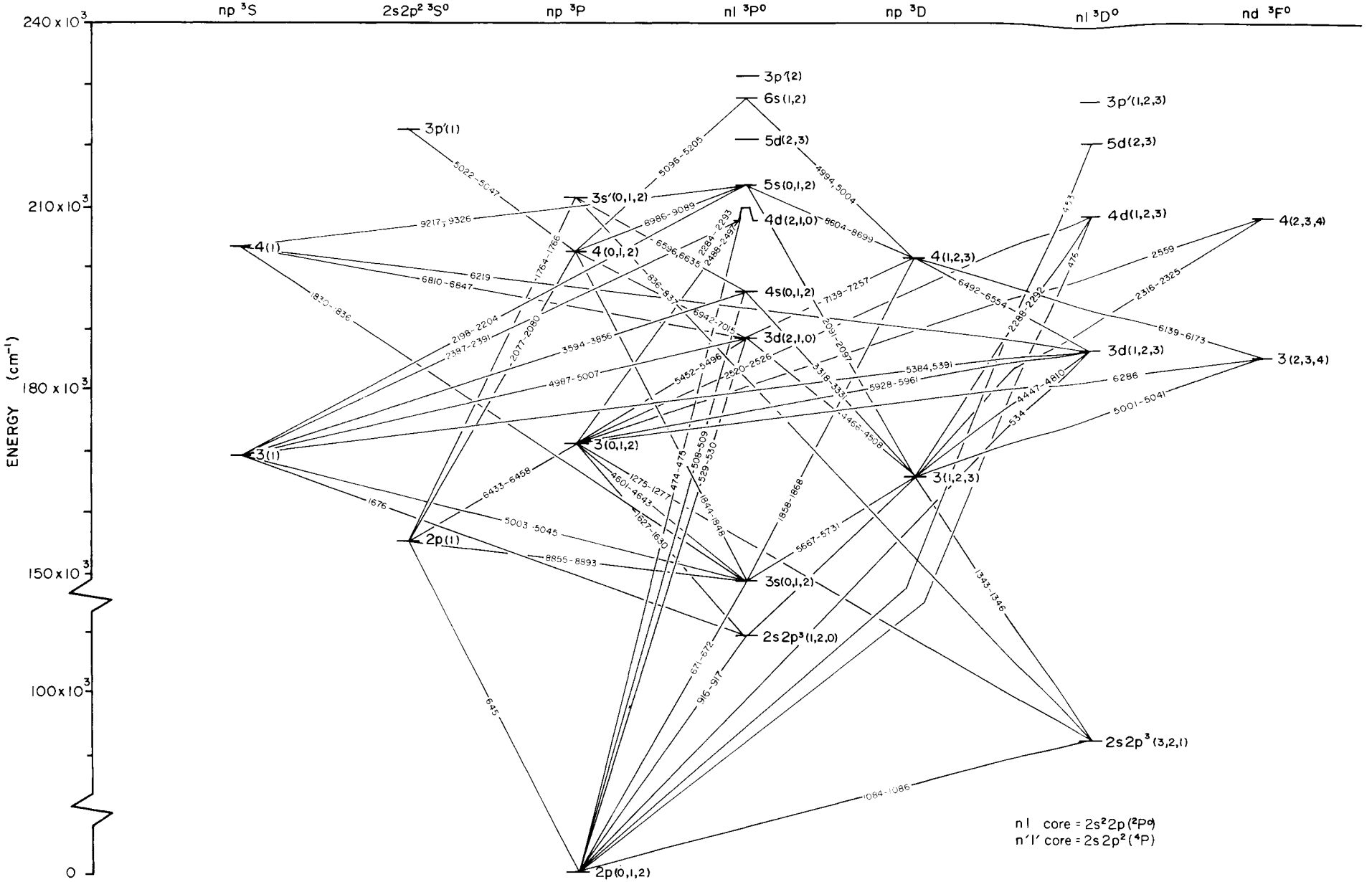

NII
SINGLET
GROTRIAN
DIAGRAM
NII GROTRIAN DIAGRAM (6electrons, Z=7)
(C I sequence, Configuration: 1s² 2s² 2p nl)
Singlet System
nl ¹P°
np ¹S
np ¹P
np ¹D
np ¹D°
np ¹F°
ENERGY (cm⁻¹)
220x10³
200x10³
180x10³
160x10³
140x10³
110x10³
90x10³
50x10³
10x10³
0
2p (0)
2p (2)
2s2p(1)
2s2p(2)
3s(1)
3p(0)
3p(1)
3p(2)
3d(1)
3d(2)
3d(3)
4s(1)
4p(0)
4p(1)
4p(2)
4d(1)
4d(2)
4d(3)
5s(1)
5d(1)
5d(2)
5d(3)
6s(1)
3437
4895
3995
3330
2160
747
858
746
660
635
582
575
776
887
1732
2824
2206
2461
2591
2799
2326
2735
1898
1781
1991
1514
1732
1439
1298
1347
1542
1547
1542
1547
1542
1547

N II ENERGY LEVELS (6 electrons, Z = 7)

(C I sequence, Configuration: $1s^2 2s^2 2p\,nl$, Singlet System)

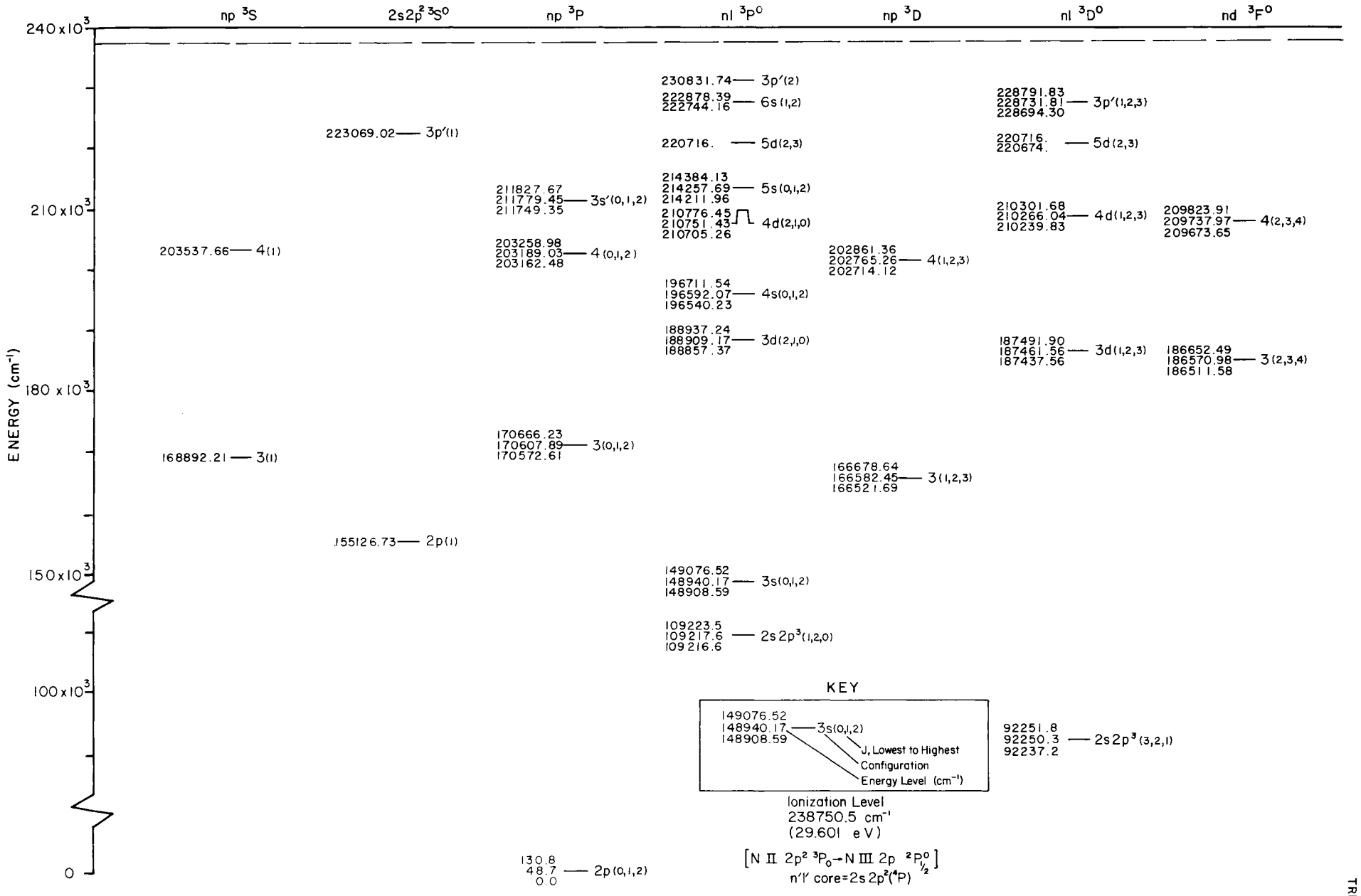


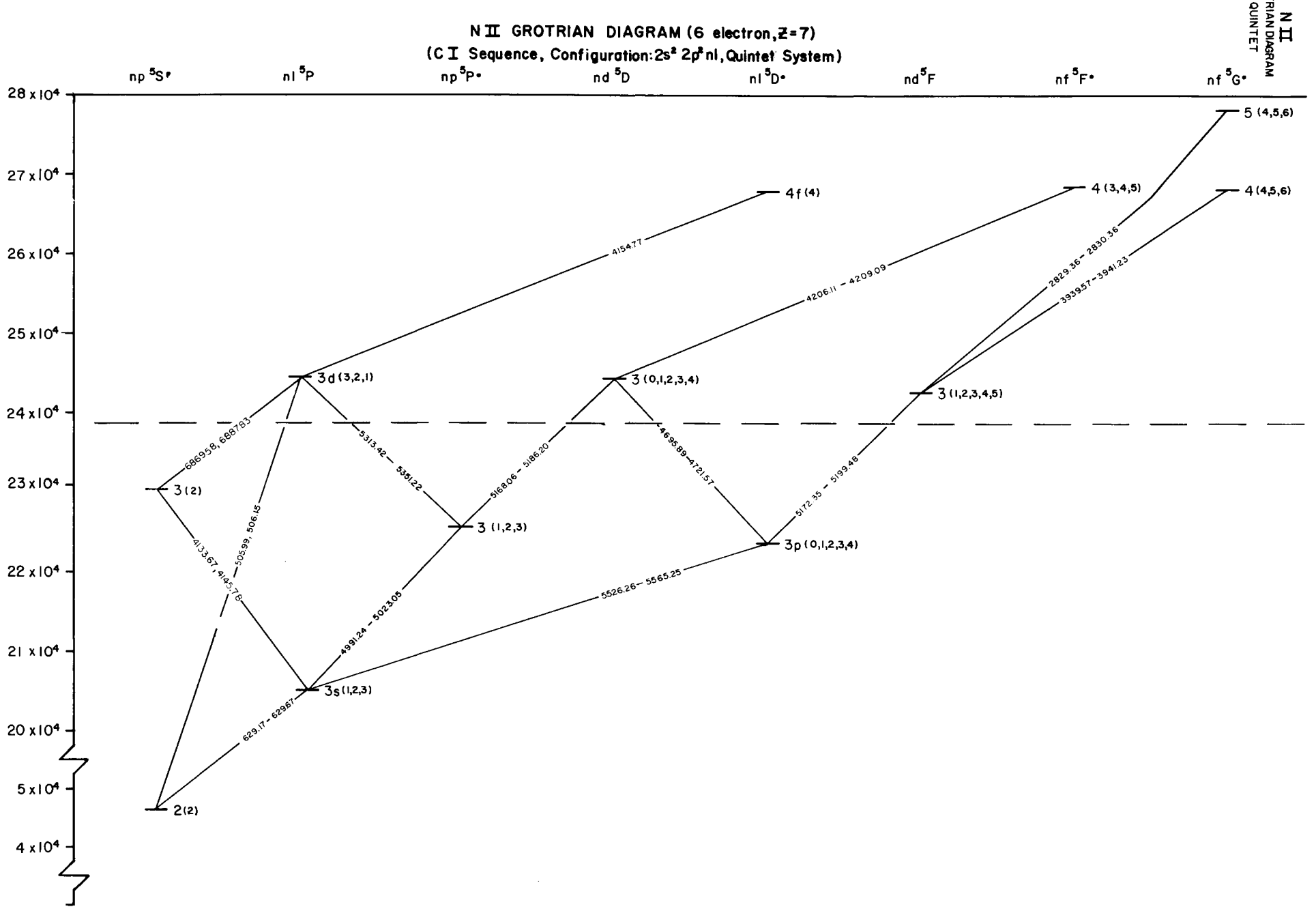
N II GROTRIAN DIAGRAM (6 electrons, Z = 7)
(C I sequence, Configuration: $1s^2 2s^2 2p\,nl$, Triplet System)



N II ENERGY LEVELS (6 electrons, Z = 7)

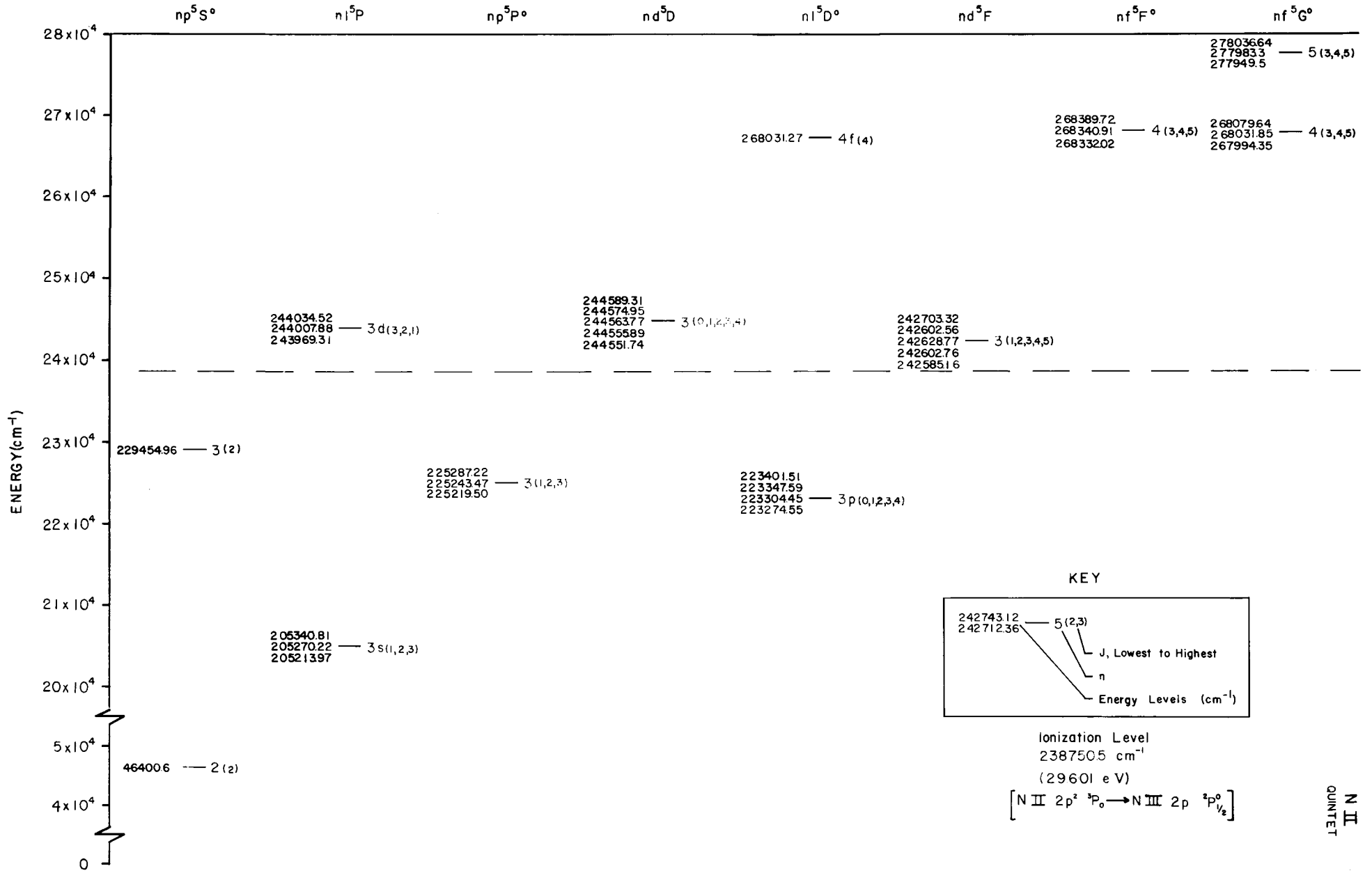
(C I sequence, Configuration: $1s^2 2s^2 2p\ nl$, Triplet System)

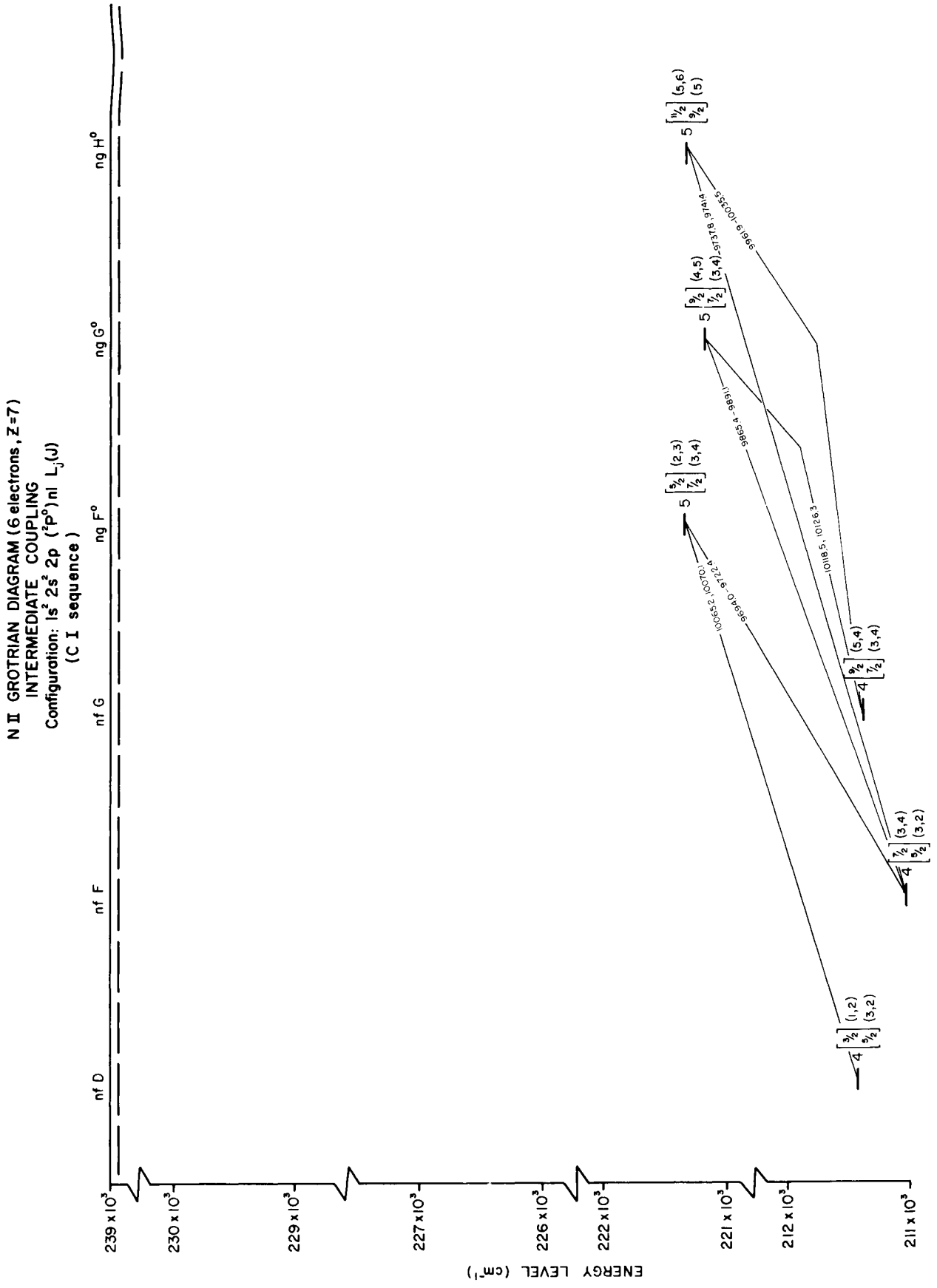



N II GROTRIAN DIAGRAM (6 electron, Z=7)
(C I Sequence, Configuration: 2s² 2p² nl, Quintet System)
np ⁵S°
nl ⁵P
np ⁵P°
nd ⁵D
nl ⁵D°
nd ⁵F
nf ⁵F°
nf ⁵G°
28 x 10⁴
27 x 10⁴
26 x 10⁴
25 x 10⁴
24 x 10⁴
23 x 10⁴
22 x 10⁴
21 x 10⁴
20 x 10⁴
5 x 10⁴
4 x 10⁴
5 (4,5,6)
4f (4)
4 (3,4,5)
4 (4,5,6)
3d (3,2,1)
3 (0,1,2,3,4)
3 (1,2,3,4,5)
3 (2)
3 (1,2,3)
3p (0,1,2,3,4)
3s (1,2,3)
2(2)
415.477
4206.11 - 4209.09
2829.36 - 2830.36
3939.57 - 3941.23
6869.58, 6887.83
5313.42 - 5351.22
5168.06 - 5186.20
4695.89 - 4721.57
5172.35 - 5199.48
4133.67, 4145.78
505.99, 506.15
4991.24 - 5023.05
5526.26 - 5565.25
629.17 - 629.67

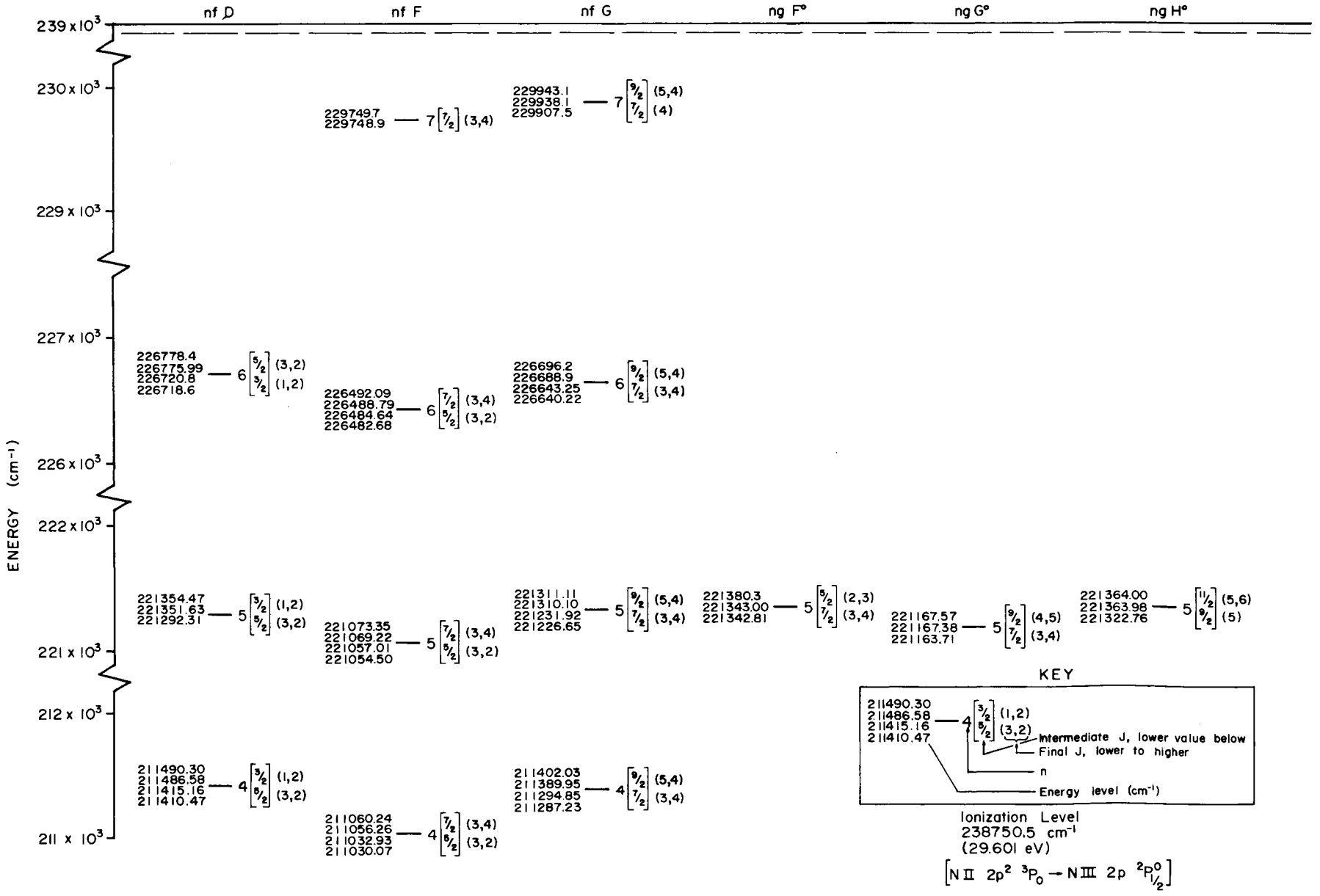
N II ENERGY LEVELS (6 electron, Z=7)

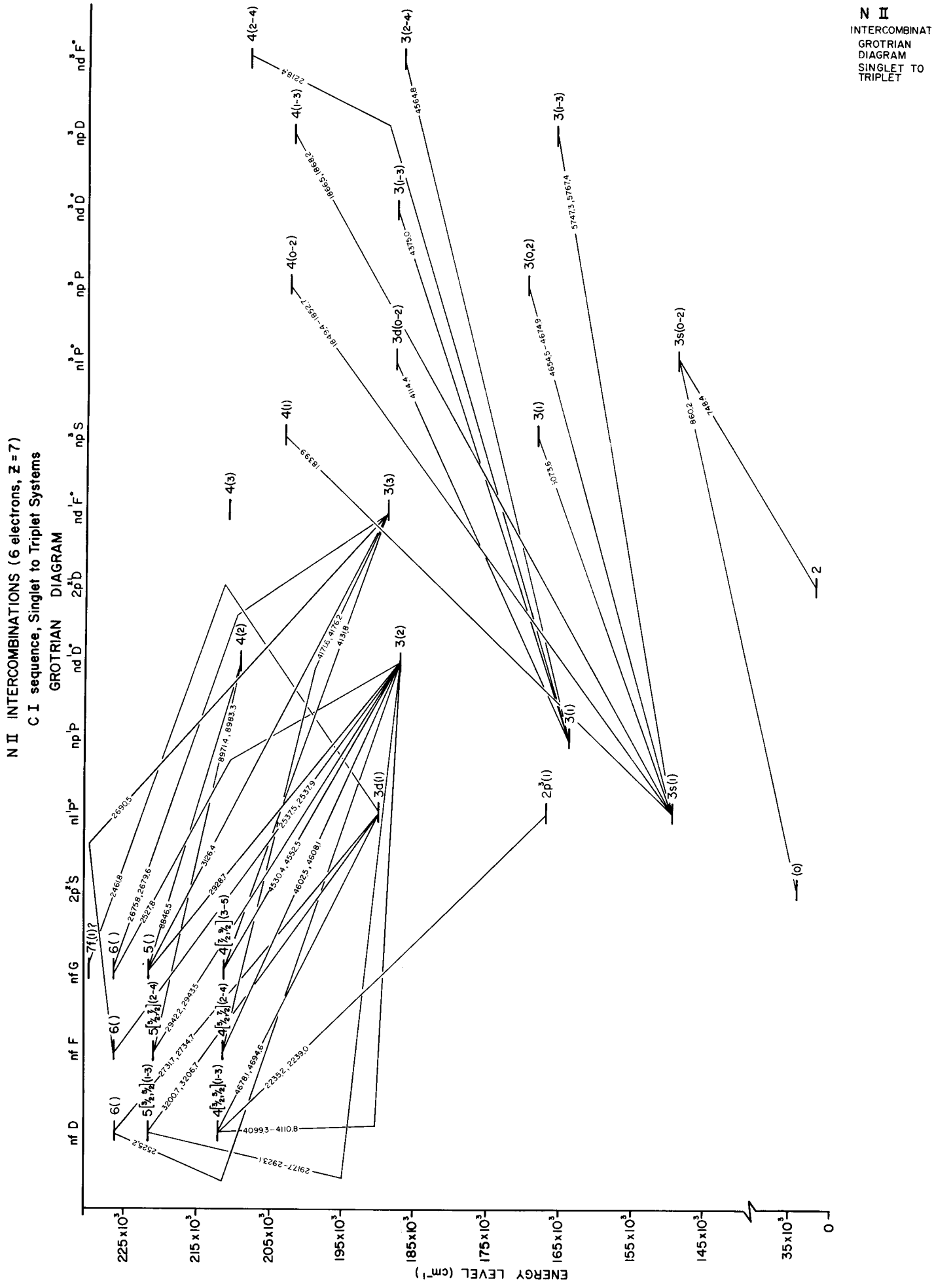
(C I Sequence, Configuration: $2s^2\,2p^2\,nl$, Quintet System)



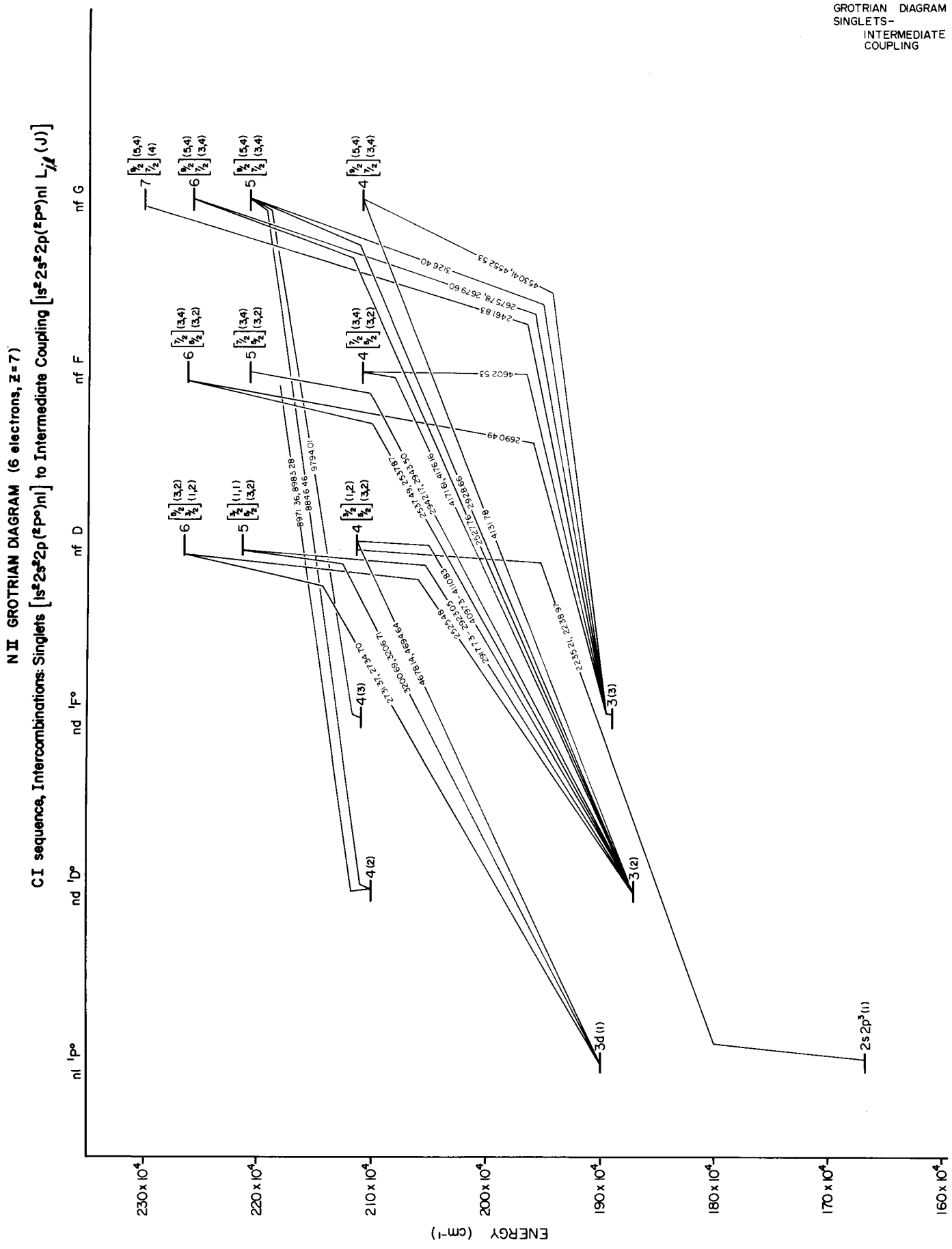

N II GROTRIAN DIAGRAM (6 electrons, Z=7)
INTERMEDIATE COUPLING
Configuration: 1s² 2s² 2p (²P°)nl L_j(J)
(C I sequence)
nf D
nf F
nf G
ng F°
ng G°
ng H°
239 x 10³
230 x 10³
229 x 10³
227 x 10³
226 x 10³
222 x 10³
221 x 10³
212 x 10³
211 x 10³
ENERGY LEVEL (cm⁻¹)
5 [11/2 9/2] (5,6) (5)
5 [9/2 7/2] (4,5) (3,4)
5 [5/2 7/2] (2,3) (3,4)
4 [9/2 7/2] (5,4) (3,4)
4 [7/2 5/2] (3,4) (3,2)
4 [3/2 5/2] (1,2) (3,2)
99619-100355
99654-99891
99640-97218, 97414
10118.5, 10126.3
100652-100701
97224

N II ENERGY LEVELS (6 electrons, Z=7)
INTERMEDIATE COUPLING
(C I sequence, Configuration: $1s^2\,2s^2\,2p\,(^2P^o)nl\;L_j(J)$

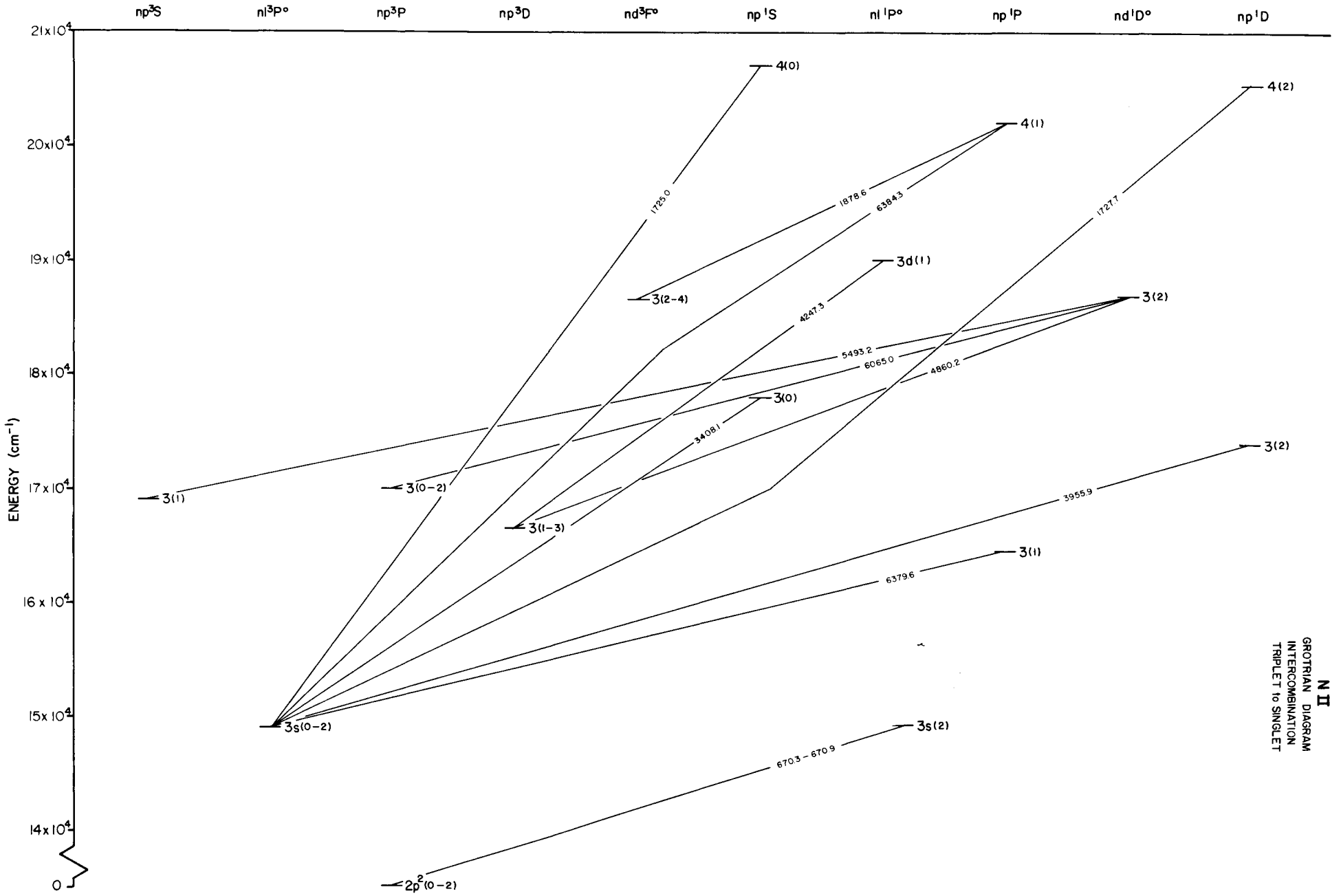



N II INTERCOMBINATIONS (6 electrons, Z = 7)
C I sequence, Singlet to Triplet Systems
GROTRIAN DIAGRAM
N II
INTERCOMBINAT
GROTRIAN
DIAGRAM
SINGLET TO
TRIPLET
ENERGY LEVEL (cm⁻¹)
225x10³
215x10³
205x10³
195x10³
185x10³
175x10³
165x10³
155x10³
145x10³
35x10³
0

N II
INTERCOMBINATIONS
GROTRIAN DIAGRAM
SINGLETS-
INTERMEDIATE
COUPLING

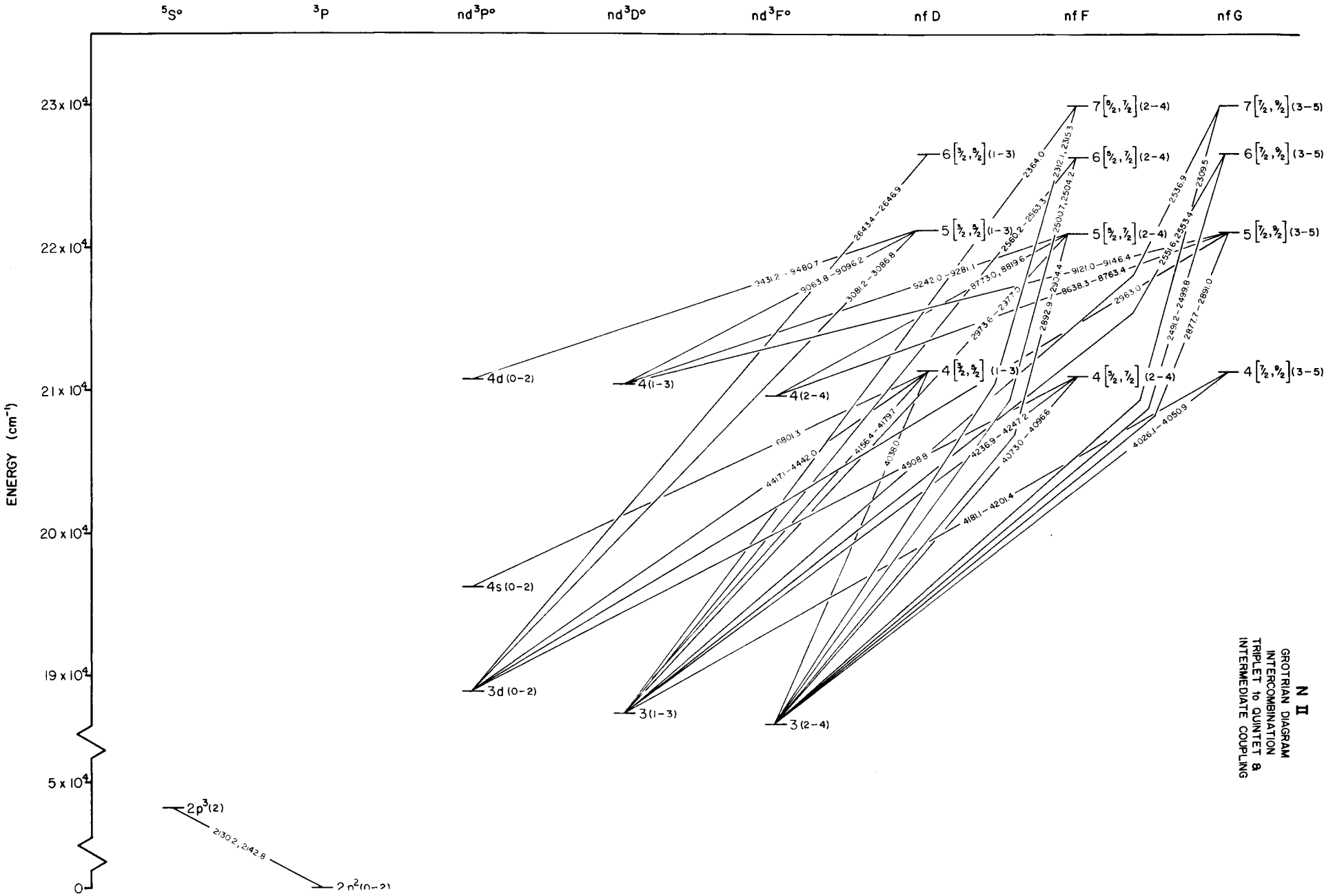


N II GROTRIAN DIAGRAM (6 electrons, Z = 7)
(C I sequence, Intercombinations: Triplets to Singlets)



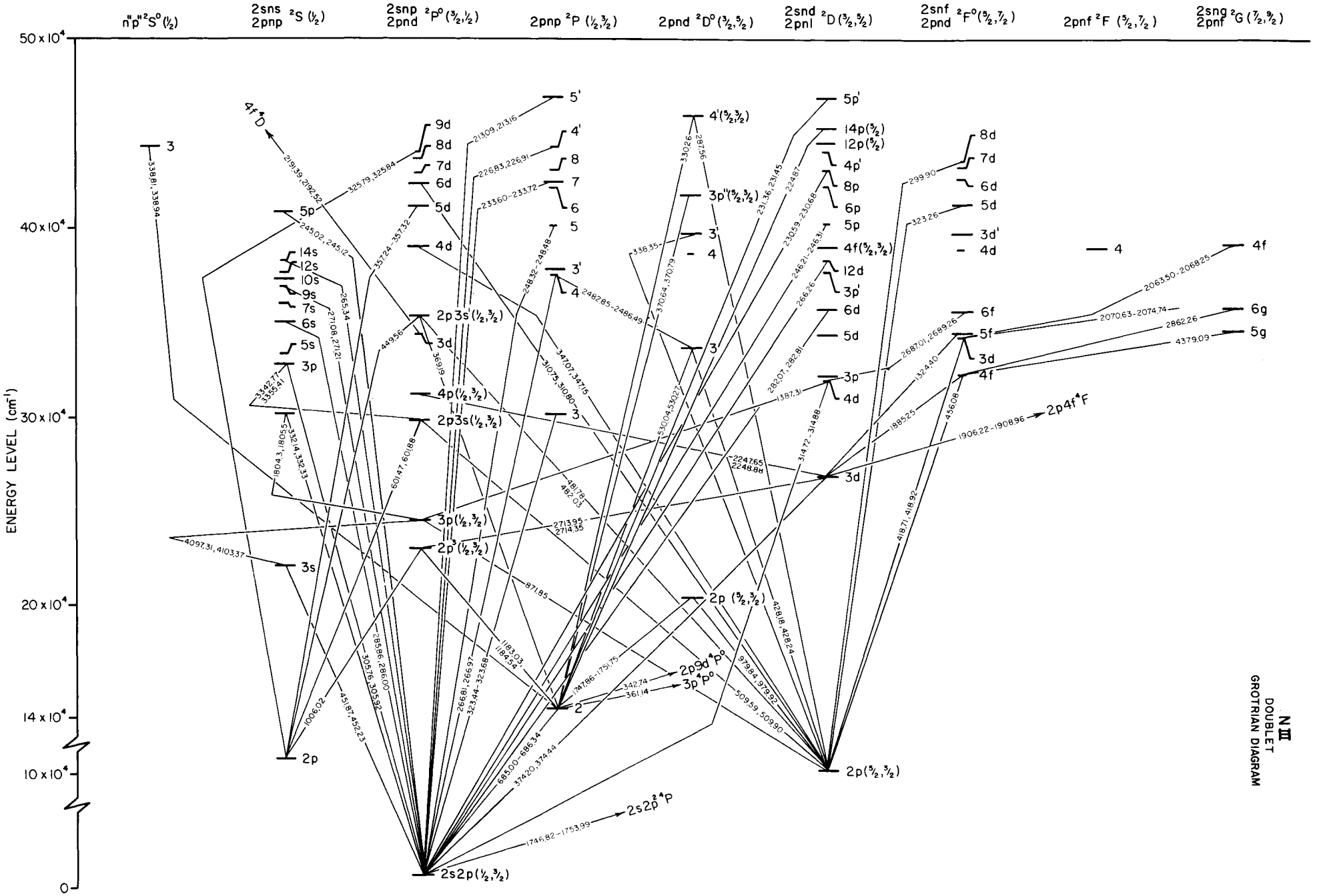
N II
GROTRIAN DIAGRAM
INTERCOMBINATION
TRIPLET to SINGLET

N II GROTRIAN DIAGRAM (6 electrons, Z = 7)
(Intercombination Triplets to Quintets & Intermediate Coupling Terms)
(C I sequence)



N III GROTRIAN DIAGRAM (5 electrons, Z=7)

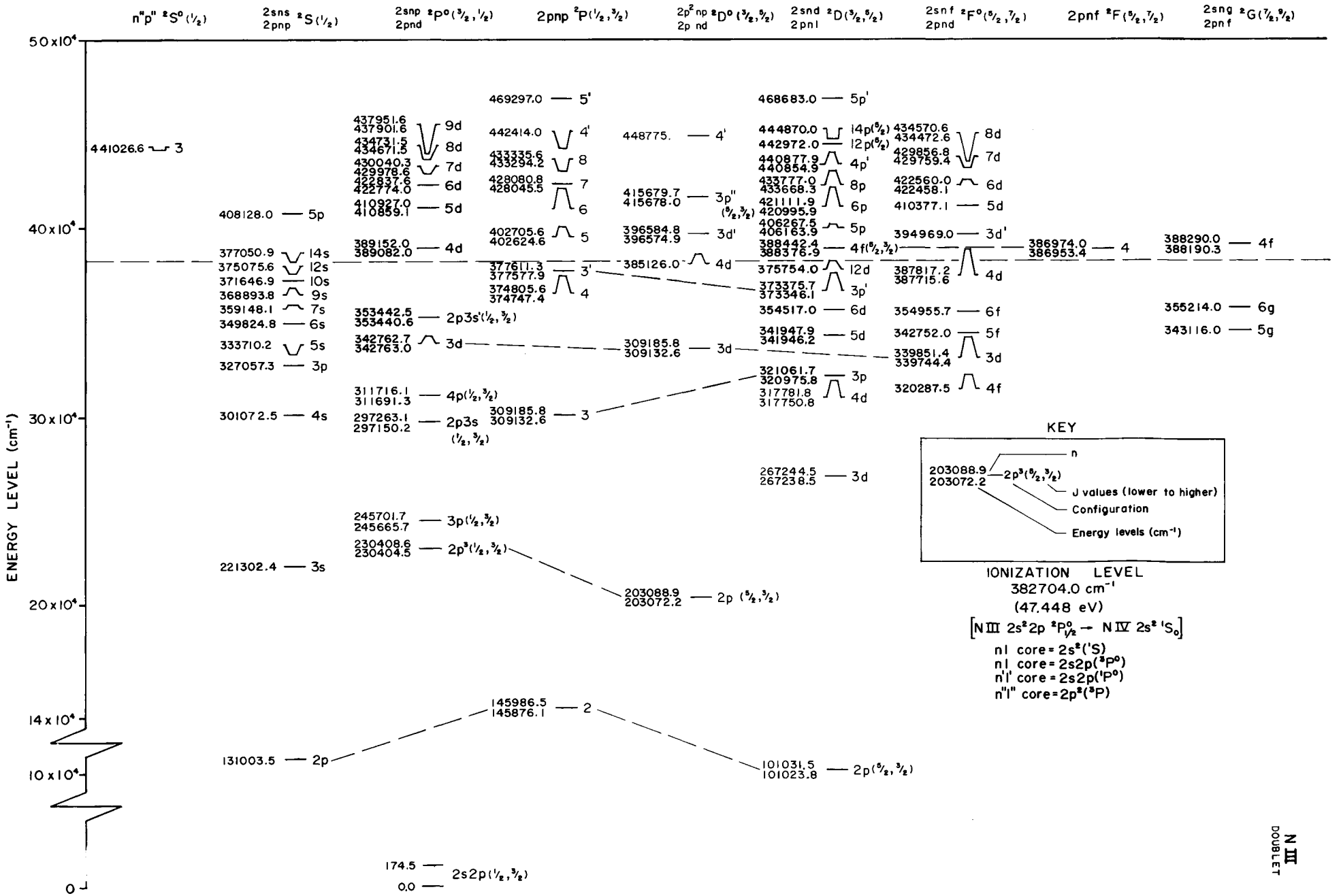
(BI Sequence, Configuration $1s^2 2s\, nl\, n'l'$ Doublet Term System)

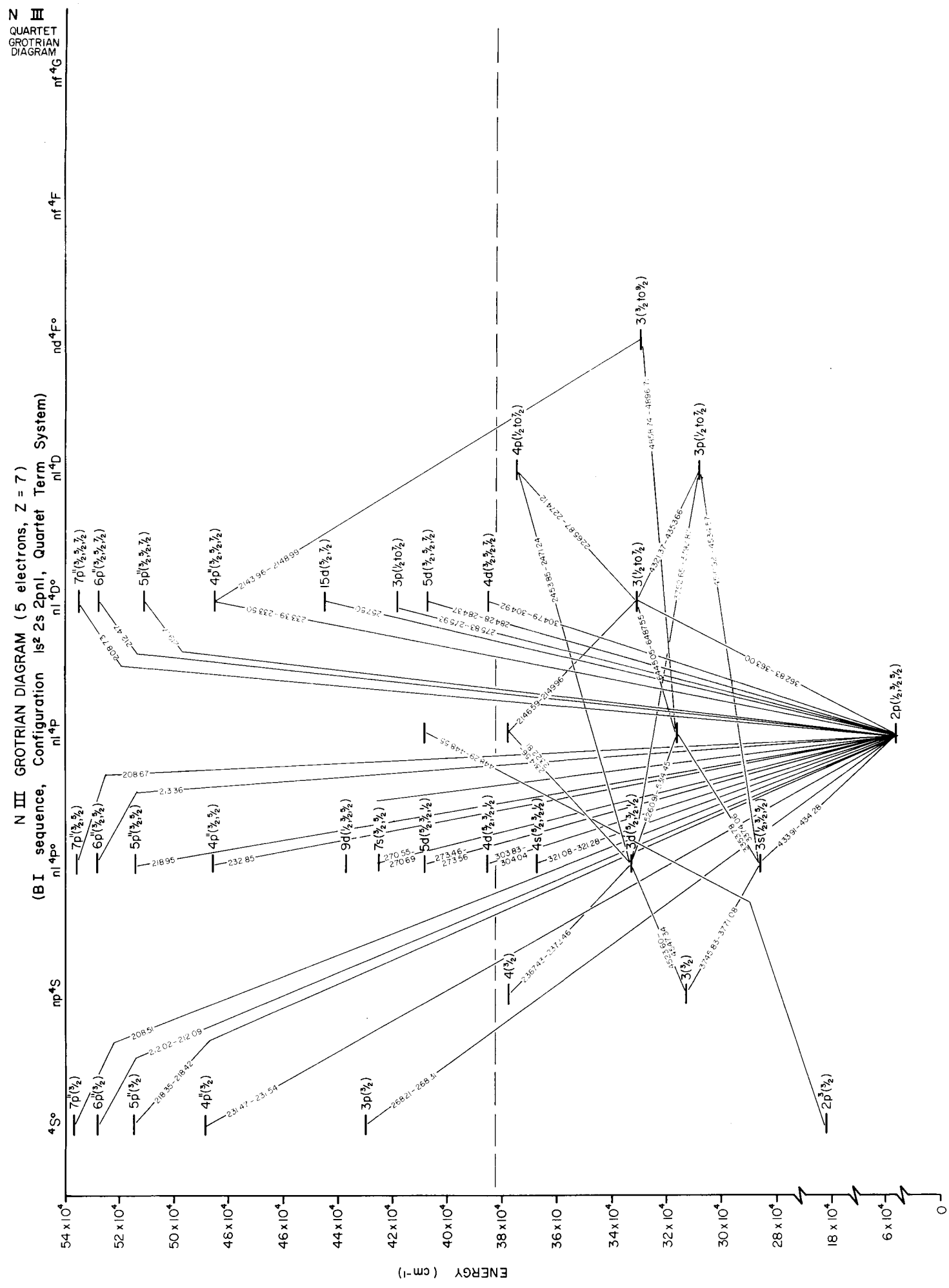


N III DOUBLET GROTRIAN DIAGRAM

N III ENERGY LEVELS (5 electrons, Z=7)

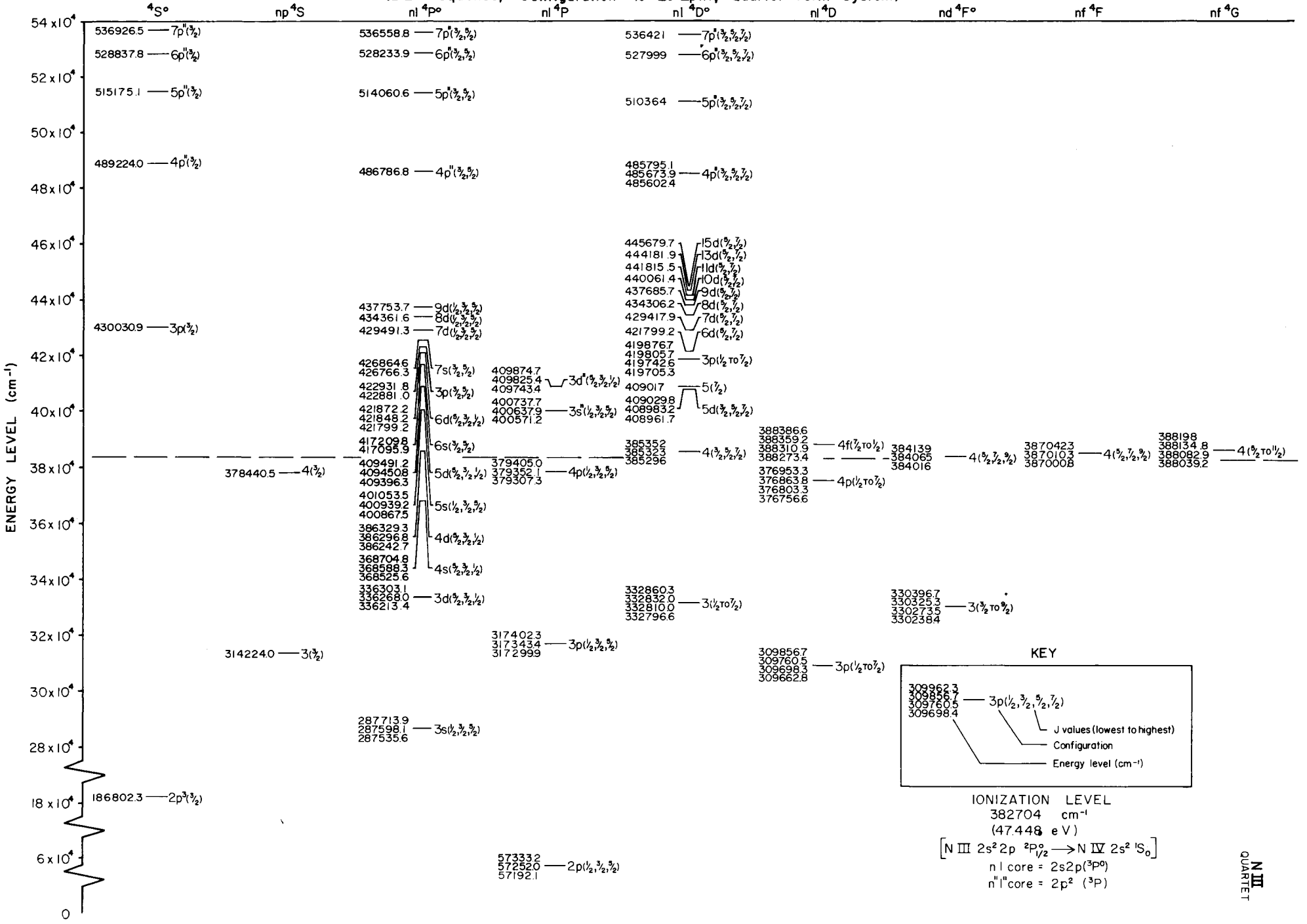
(BI Sequence, Configuration $1s^2\,2s\,nl\,n'l'$ Doublet Term System)




N III
QUARTET
GROTRIAN
DIAGRAM
N III GROTRIAN DIAGRAM (5 electrons, Z = 7)
(B I sequence, Configuration 1s² 2s 2pnl, Quartet Term System)
4S°
np⁴S
nl⁴P°
nl⁴D°
nl⁴P
nd⁴P°
nl⁴D
nf⁴F
nf⁴G
ENERGY (cm⁻¹)
54 x 10⁴
52 x 10⁴
50 x 10⁴
48 x 10⁴
46 x 10⁴
44 x 10⁴
42 x 10⁴
40 x 10⁴
38 x 10⁴
36 x 10
34 x 10⁴
32 x 10⁴
30 x 10⁴
28 x 10⁴
18 x 10⁴
6 x 10⁴
0
2p(½,3/2,3/2)
2p³(3/2)
3s(3/2,3/2,3/2)
3(3/2)
3d(3/2,1/2,1/2)
4(3/2)
4s(3/2,3/2,1/2)
4d(3/2,3/2,1/2)
5d(3/2,3/2,1/2)
7s(3/2,1/2)
9d(1/2,3/2,3/2)
4p''(3/2,5/2)
5p''(3/2,5/2,1/2)
6p''(3/2,5/2,1/2)
7p''(3/2,5/2)
4p''(3/2,5/2,1/2)
5p''(3/2,5/2,1/2)
6p''(3/2,5/2,7/2)
7p''(3/2,5/2,7/2)
4d(3/2,3/2,1/2)
5d(3/2,3/2,1/2)
3p(1/2 to 7/2)
15d(3/2,7/2)
4p''(3/2,5/2,7/2)
5p''(3/2,5/2,7/2)
6p''(3/2,5/2,7/2)
7p''(3/2,5/2,7/2)
3(1/2 to 7/2)
4p(1/2 to 7/2)
3p(1/2 to 7/2)
3(3/2 to 9/2)
7p''(3/2)
6p''(3/2)
5p''(3/2)
4p''(3/2)
3p(3/2)
208.51
212.02-212.09
218.35-218.42
231.47-231.54
268.21-268.51
208.67
213.36
218.95
232.85
270.55-270.69
273.46-273.56
303.83-304.04
321.08-321.28
2367.47-2367.46
2145.99-2148.99
2143.96-2148.99
2146.39-2149.96
2448.29-2448.55
2471.24
2538.58-2538.58
2260.91-2309.45
2245.00-2246.55
2268.87-2274.12
4454.74-4896.71
4321.37-4356.66
2733.68-2742.92
4634.67
3745.85-3771.08
362.83-363.00
275.83-279.92
284.28-287.37
304.79-304.92
233.39-233.50
257.50
212.47
208.73

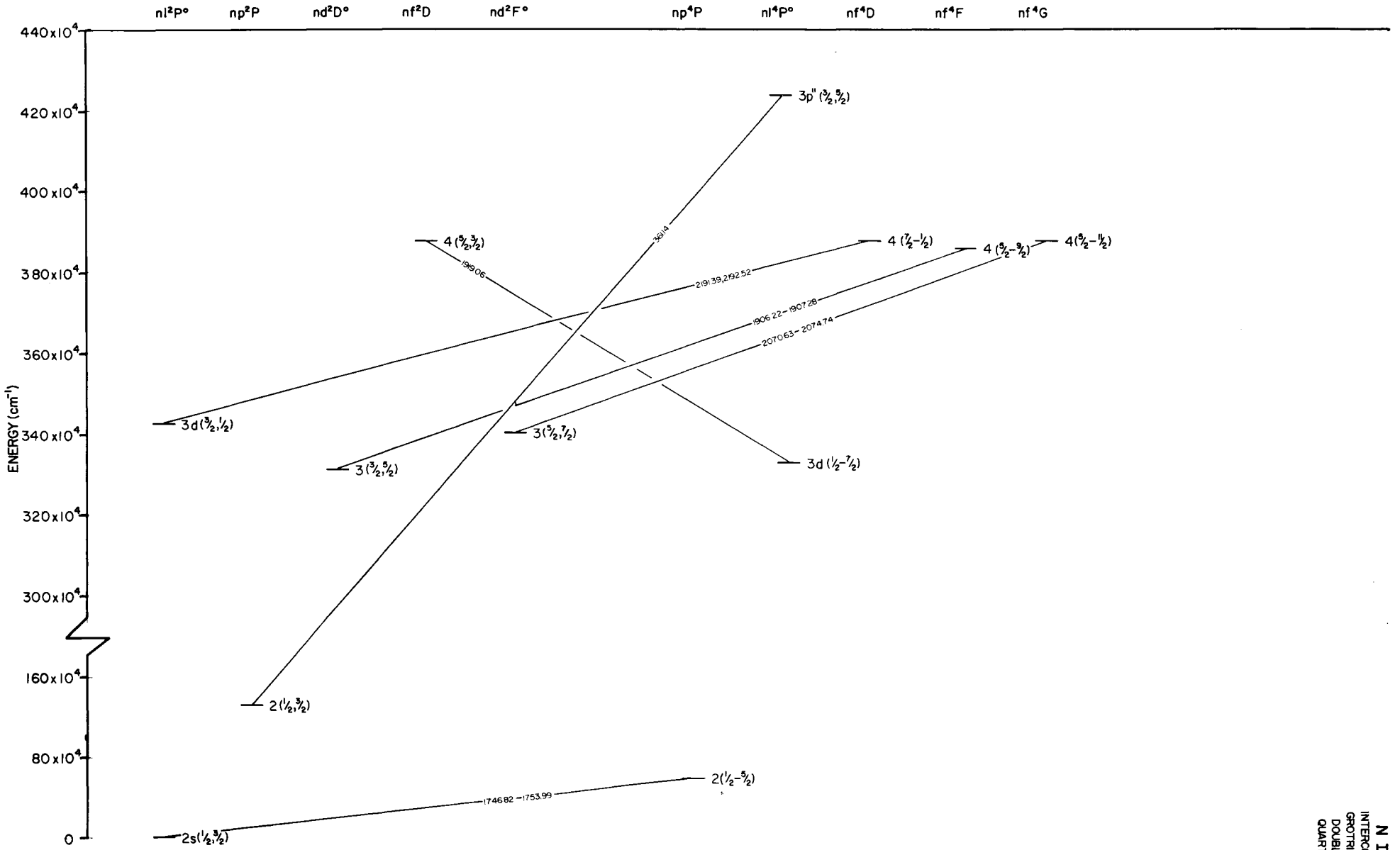
N III ENERGY LEVELS (5 electrons, Z = 7)

(B I Sequence, Configuration $1s^2\,2s\,2pnl$, Quartet Term System)

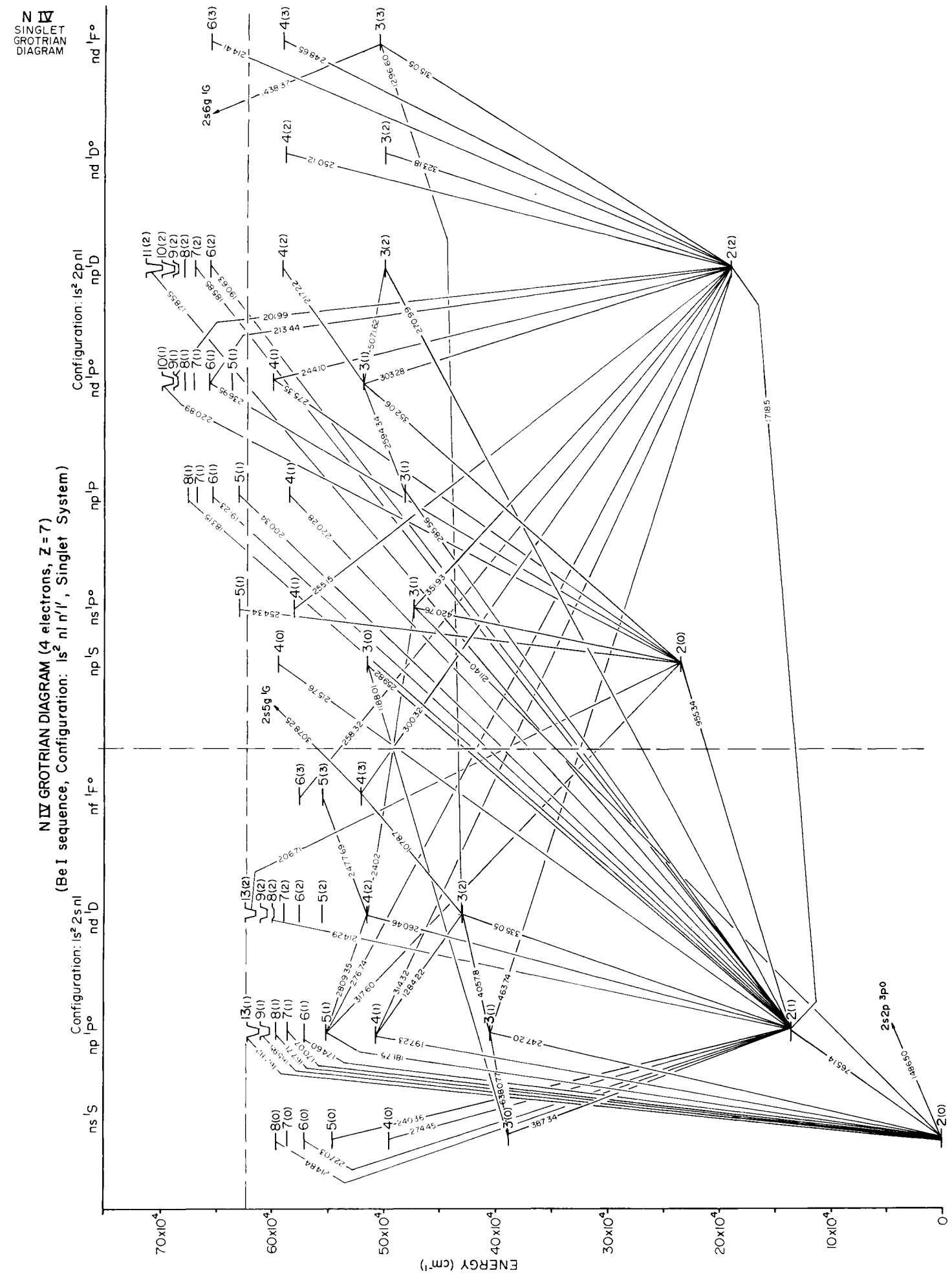


N III GROTRIAN DIAGRAM (5 electrons, Z=7)

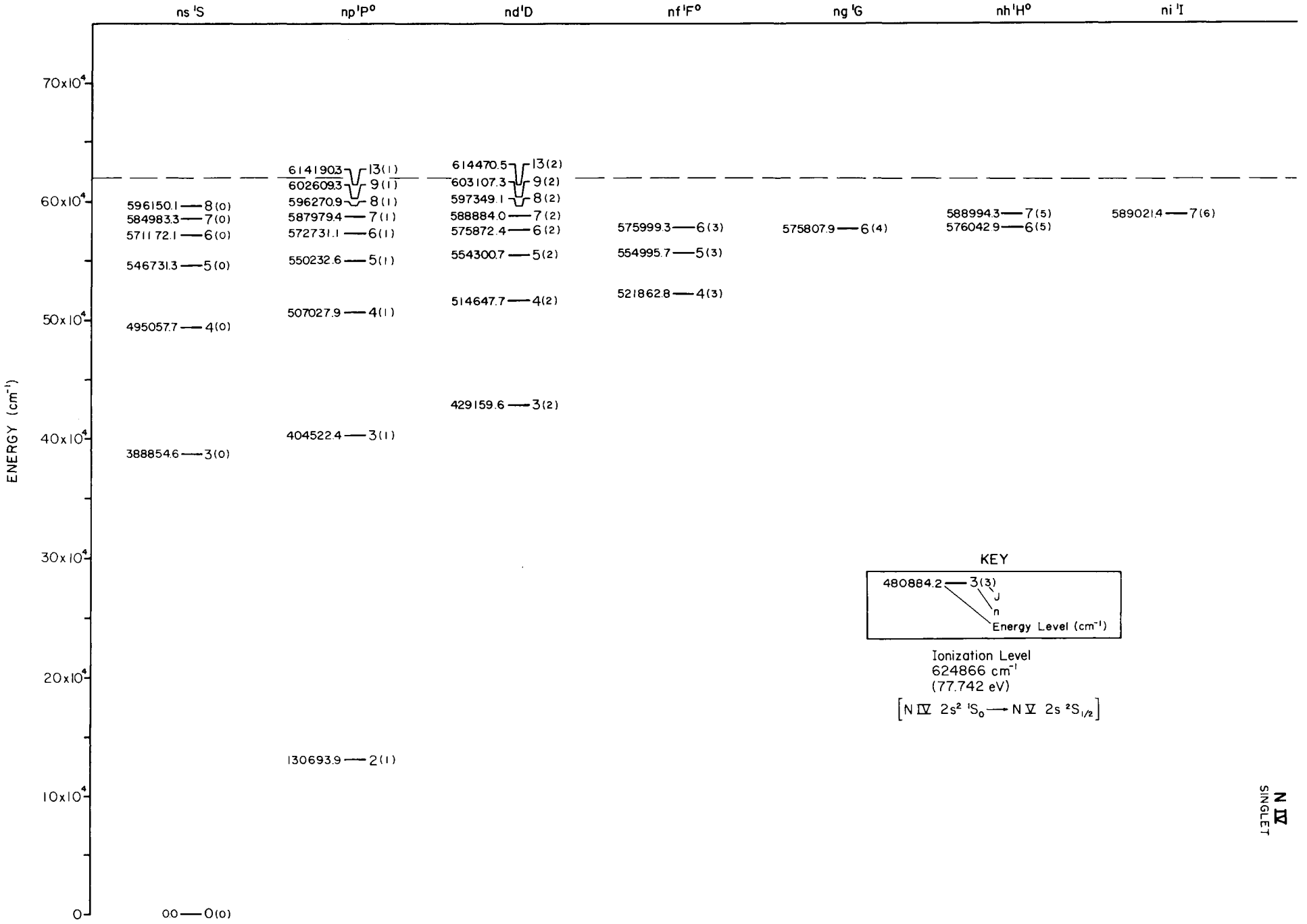
B I Sequence, Intercombination: Doublets [$1s^2 2s2pnl$] – Quartets [$1s^2 2s2p(^3P^o)nl$, $1s^2 2p^2(^3P)n''l''$]



N III
INTERCOMBINATION
GROTRIAN DIAGRAM
DOUBLETS-
QUARTETS

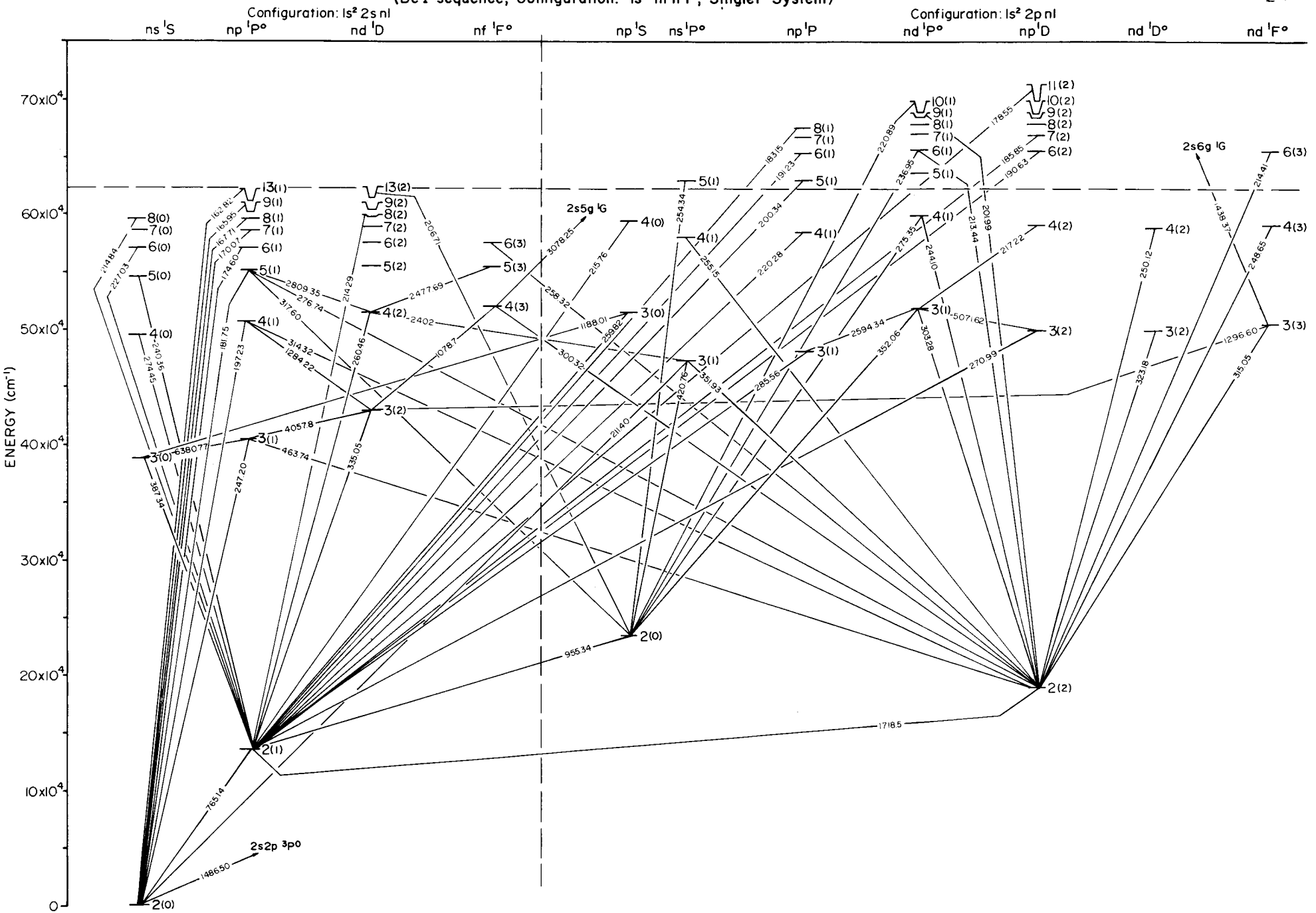

N IV
SINGLET
GROTRIAN
DIAGRAM
N IV GROTRIAN DIAGRAM (4 electrons, Z = 7)
(Be I sequence, Configuration: 1s² nl n'l', Singlet System)
Configuration: 1s² 2s nl
Configuration: 1s² 2p nl
ns ¹S
np ¹P°
nd ¹D
nf ¹F°
np ¹S
ns ¹P°
nd ¹P°
np ¹P
np ¹D
nd ¹D°
nd ¹F°
2s5g ¹G
2s6g ¹G
2s2p 3p°
ENERGY (cm⁻¹)
70x10⁴
60x10⁴
50x10⁴
40x10⁴
30x10⁴
20x10⁴
10x10⁴
0

N IV ENERGY LEVELS (4 electrons, Z = 7)
(Be I sequence, Configuration: $1s^2\ 2s\ nl$, Singlet System)



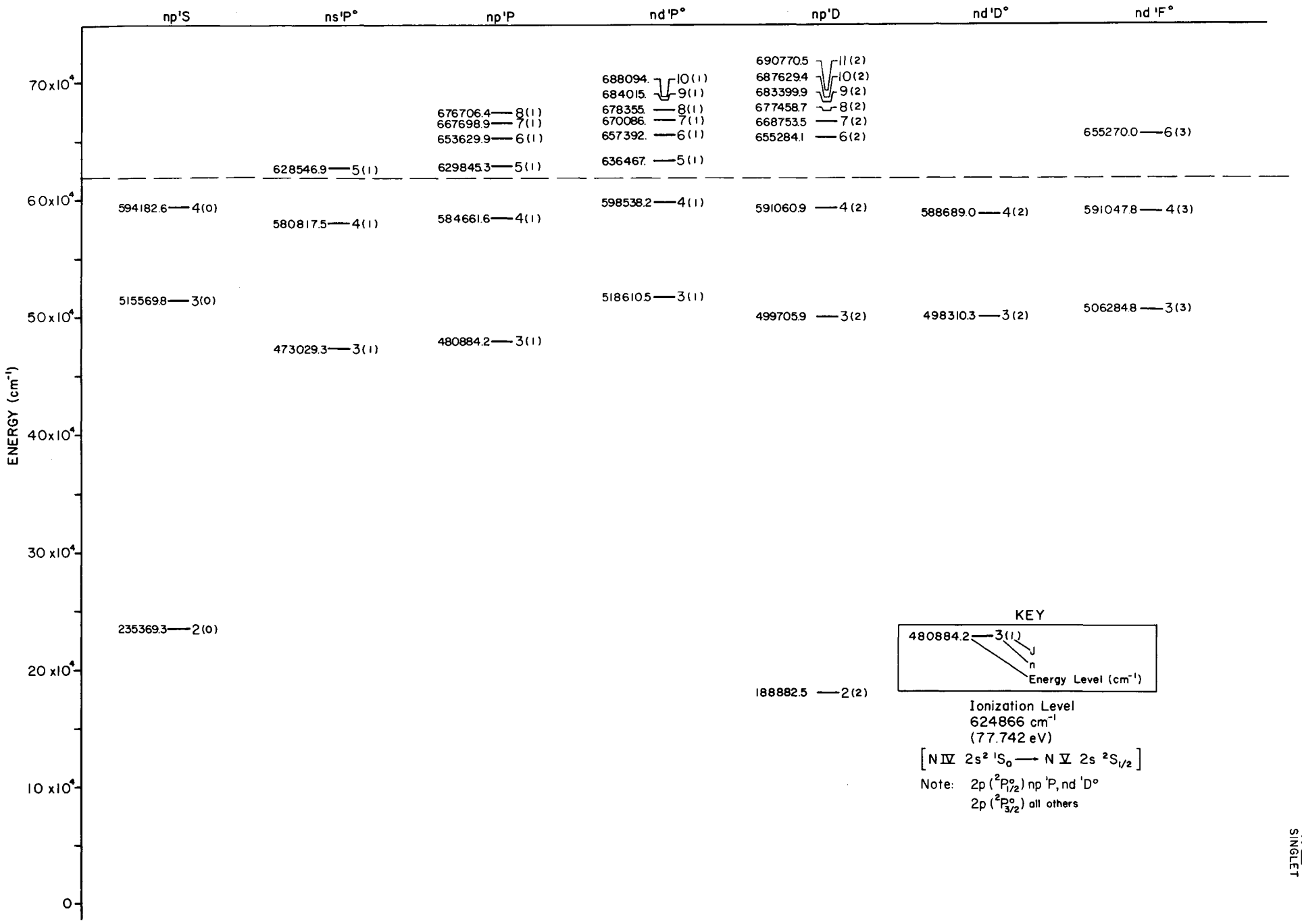
N IV
SINGLET

N IV GROTRIAN DIAGRAM (4 electrons, Z = 7)
(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Singlet System)



N IV ENERGY LEVELS (4 electrons, Z=7)

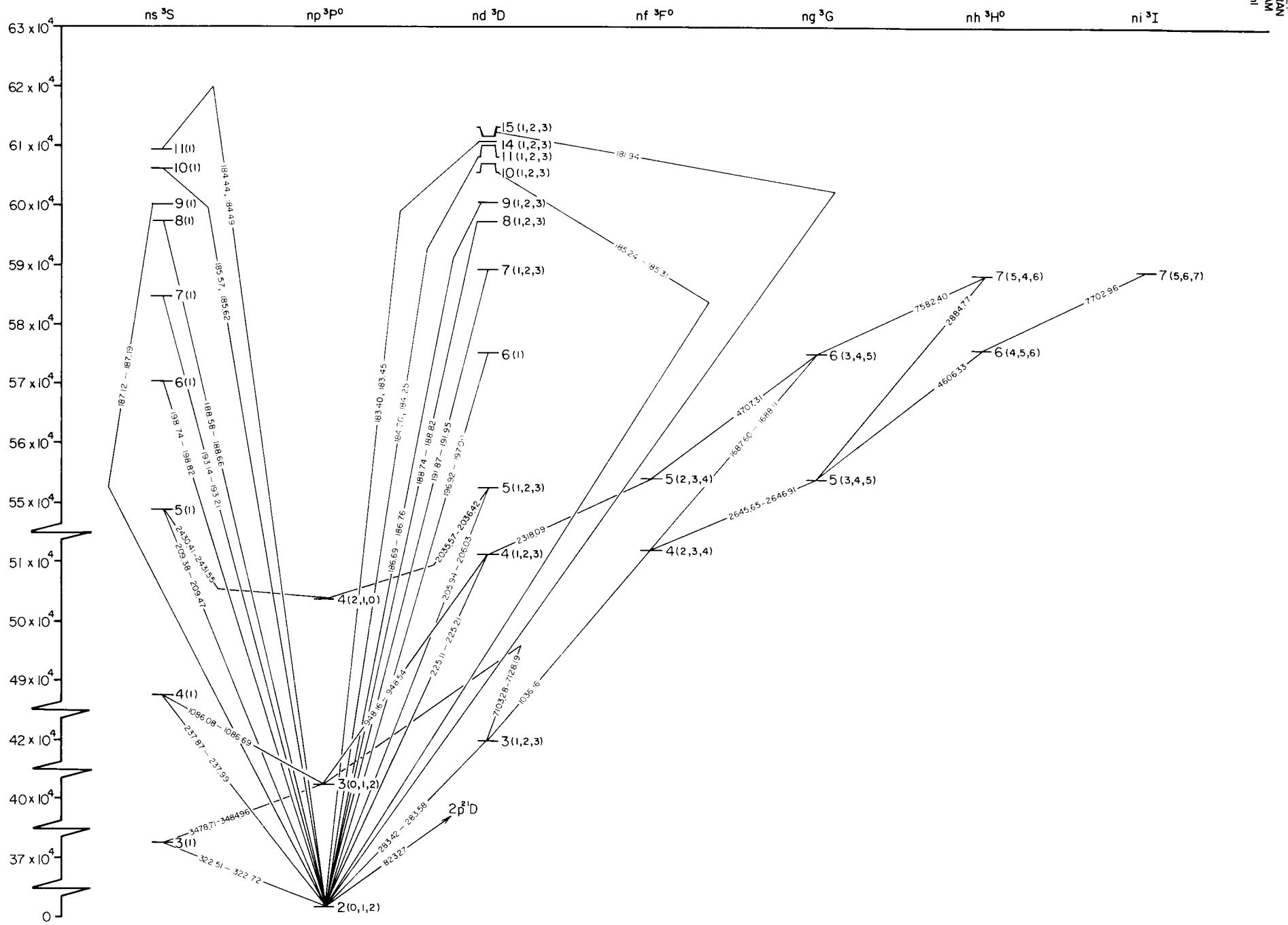
(Be I sequence, Configuration: $1s^2\,2p\,nl$, Singlet System)



N IV
SINGLET

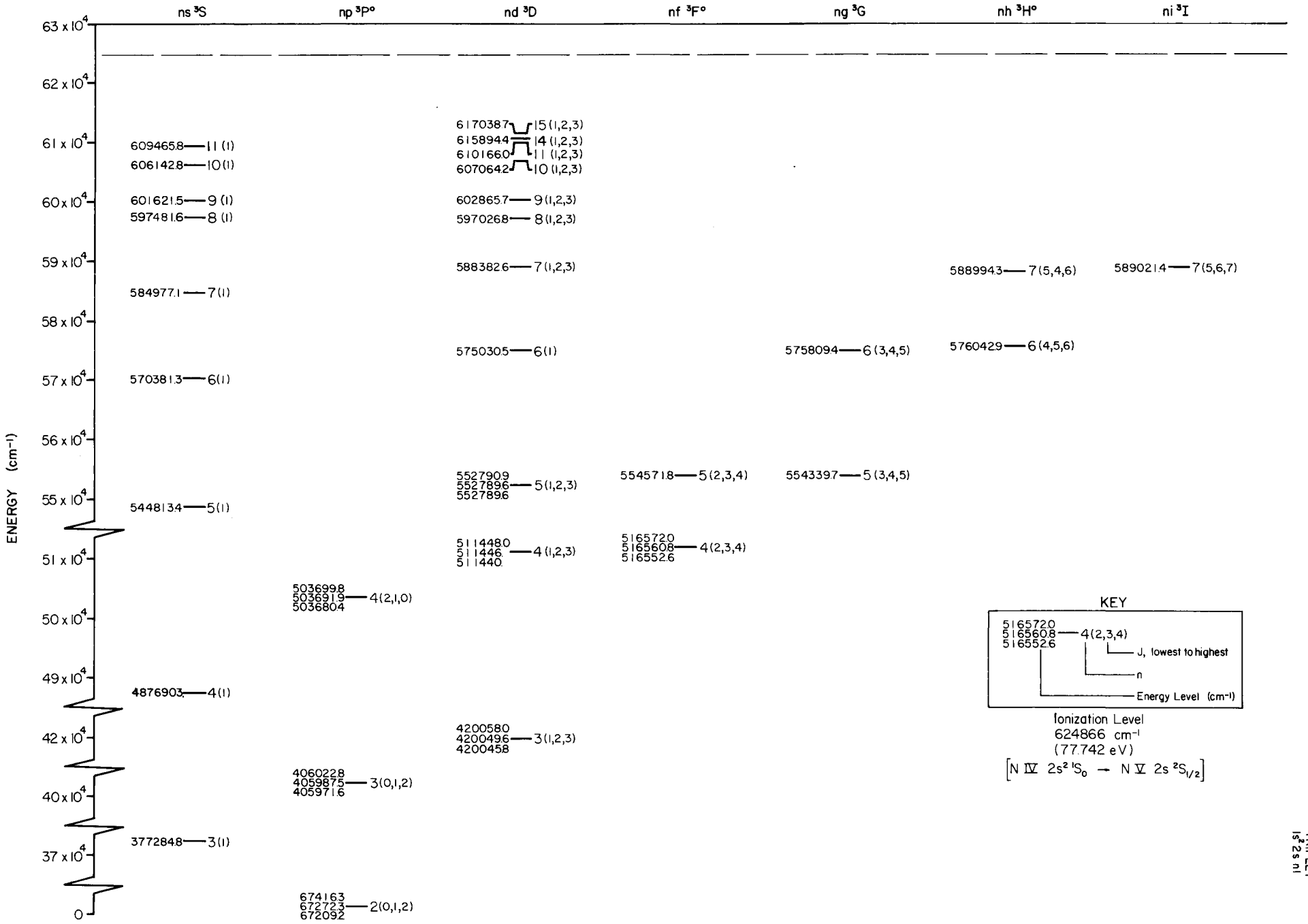
N IV GROTRIAN DIAGRAM (4 electrons, Z = 7)

(Be I sequence, Configuration: $1s^2$ 2s nl, Triplet System)



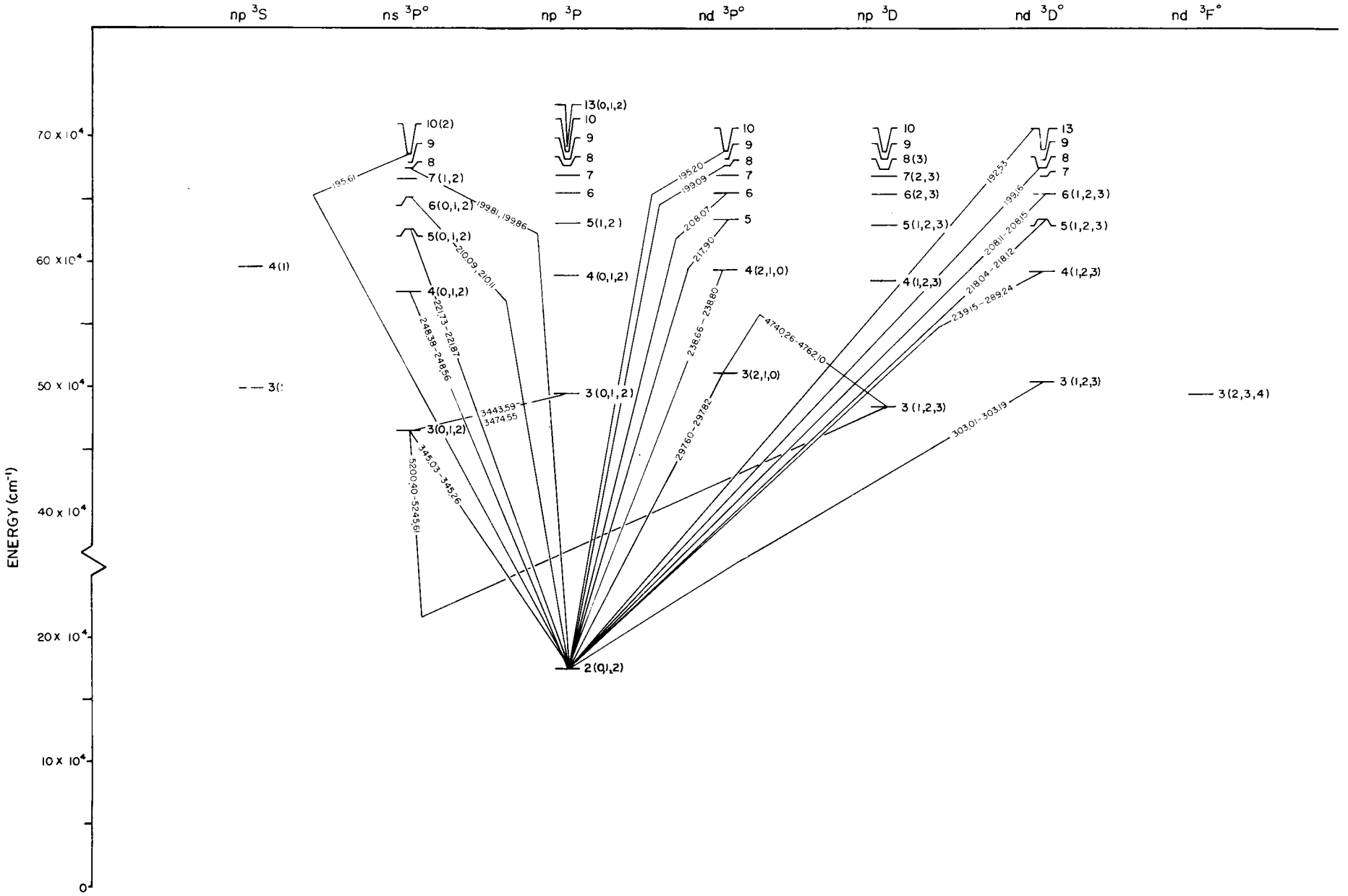
N IV ENERGY LEVELS (4 electrons, Z=7)

(Be I sequence, Configuration: $1s^2\ 2s\ nl$, Triplet System)



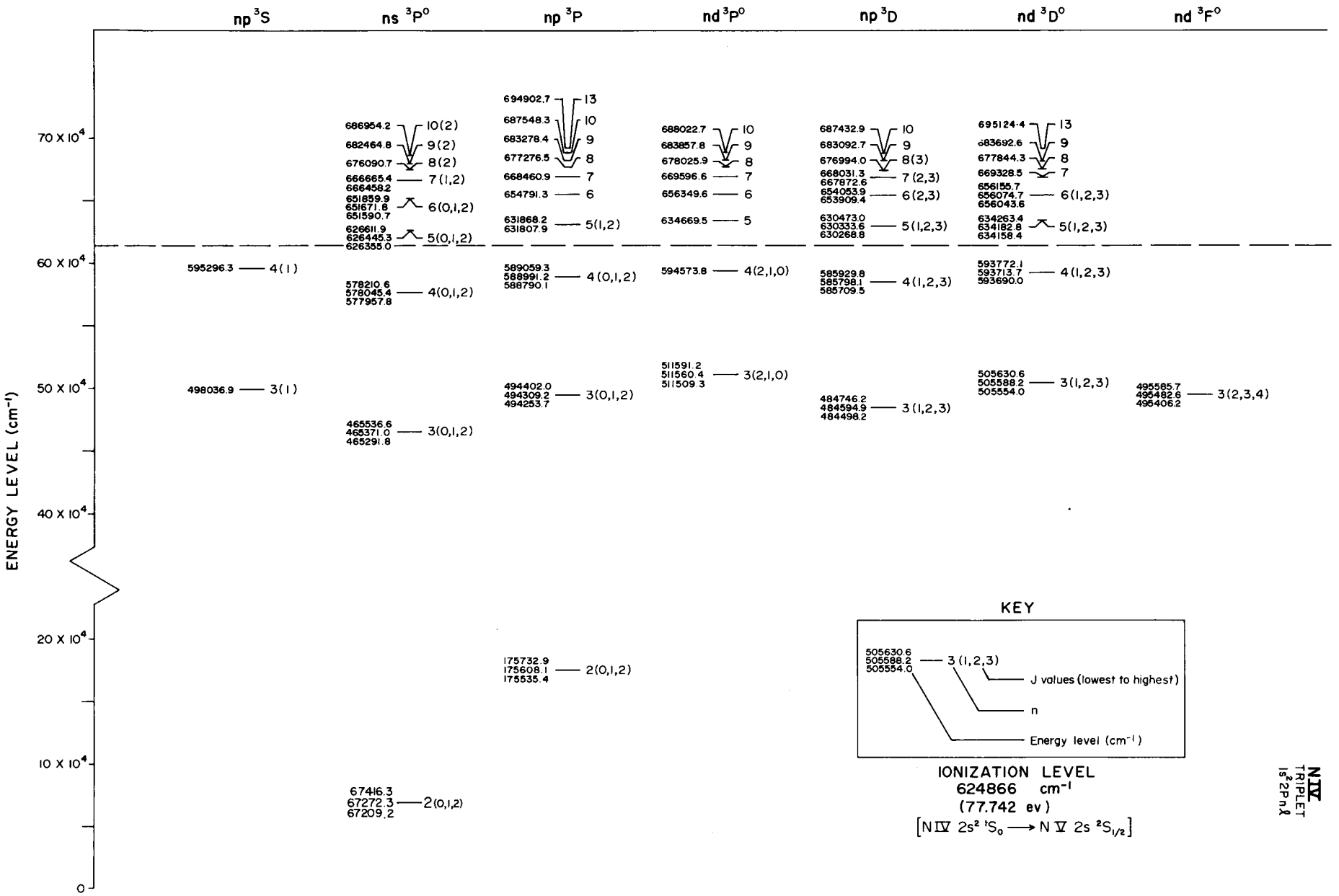
N IV
TRIPLET
$1s^2\ 2s\ nl$

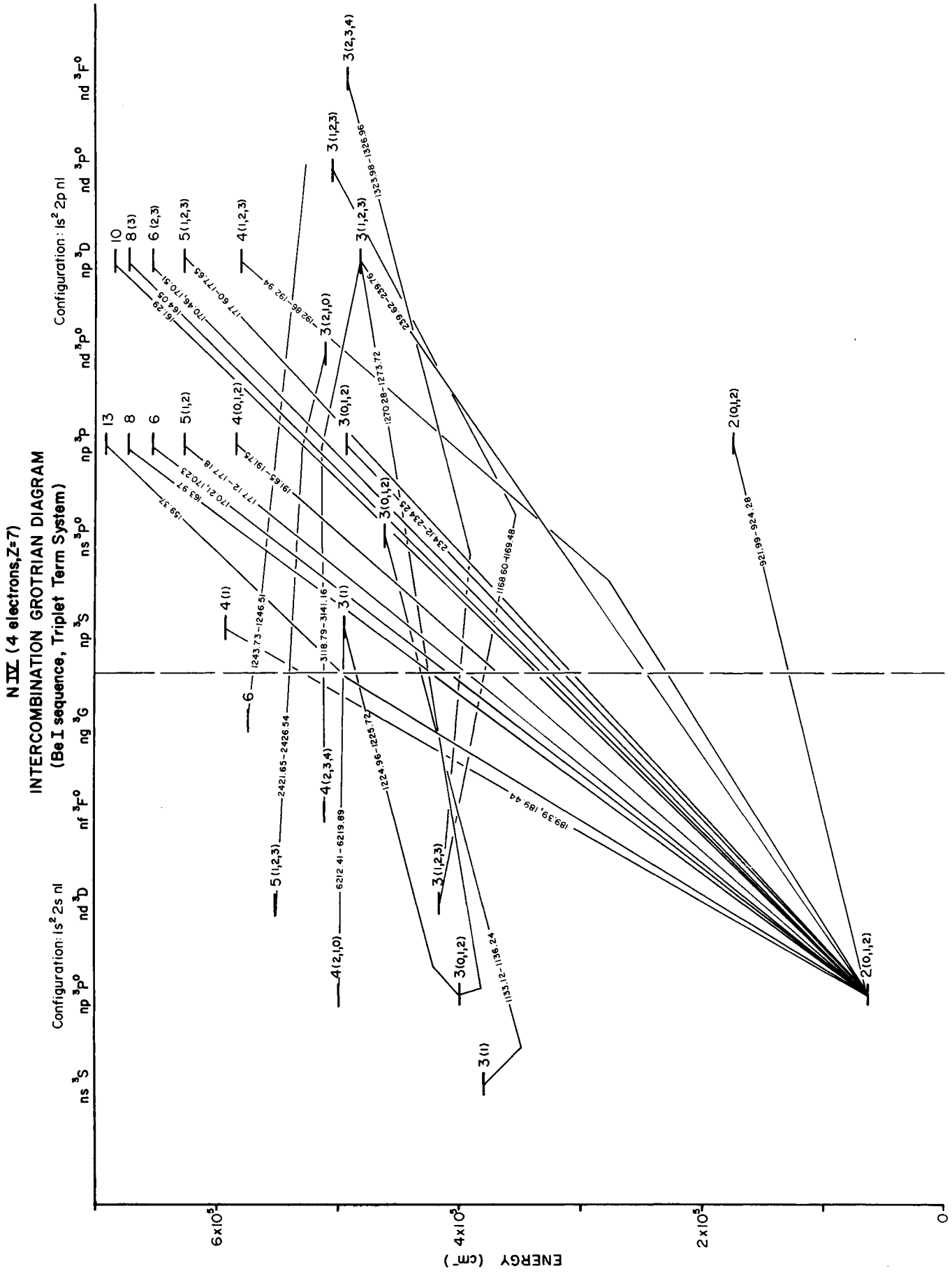
N IV GROTRIAN DIAGRAM (4 electrons, Z=7)
(Configuration $1s^2 2p\,nl$, Triplet System)



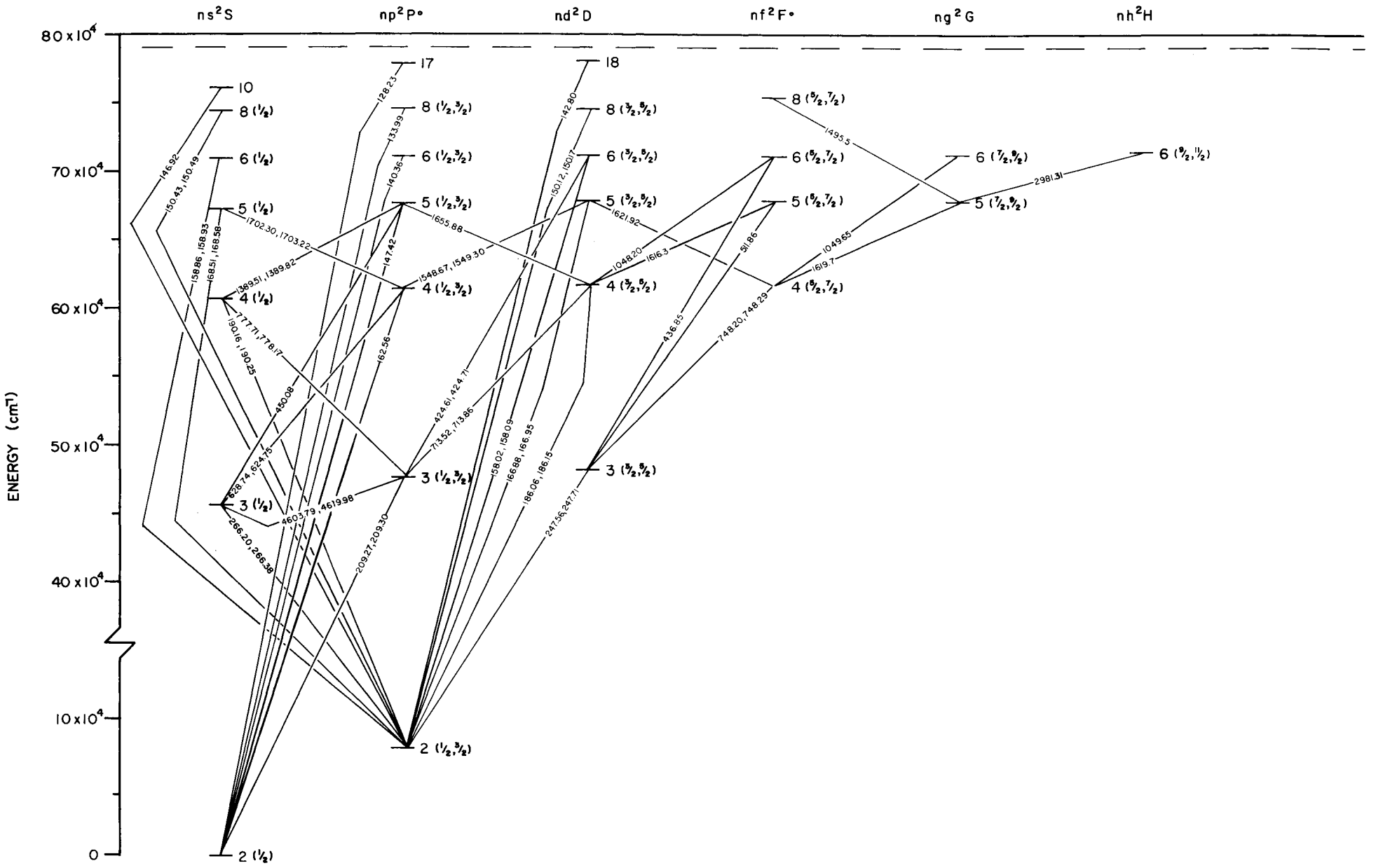
N IV ENERGY LEVELS (4 electrons, Z = 7)

(Configuration $1s^2 2pnl$, Triplet Term System)



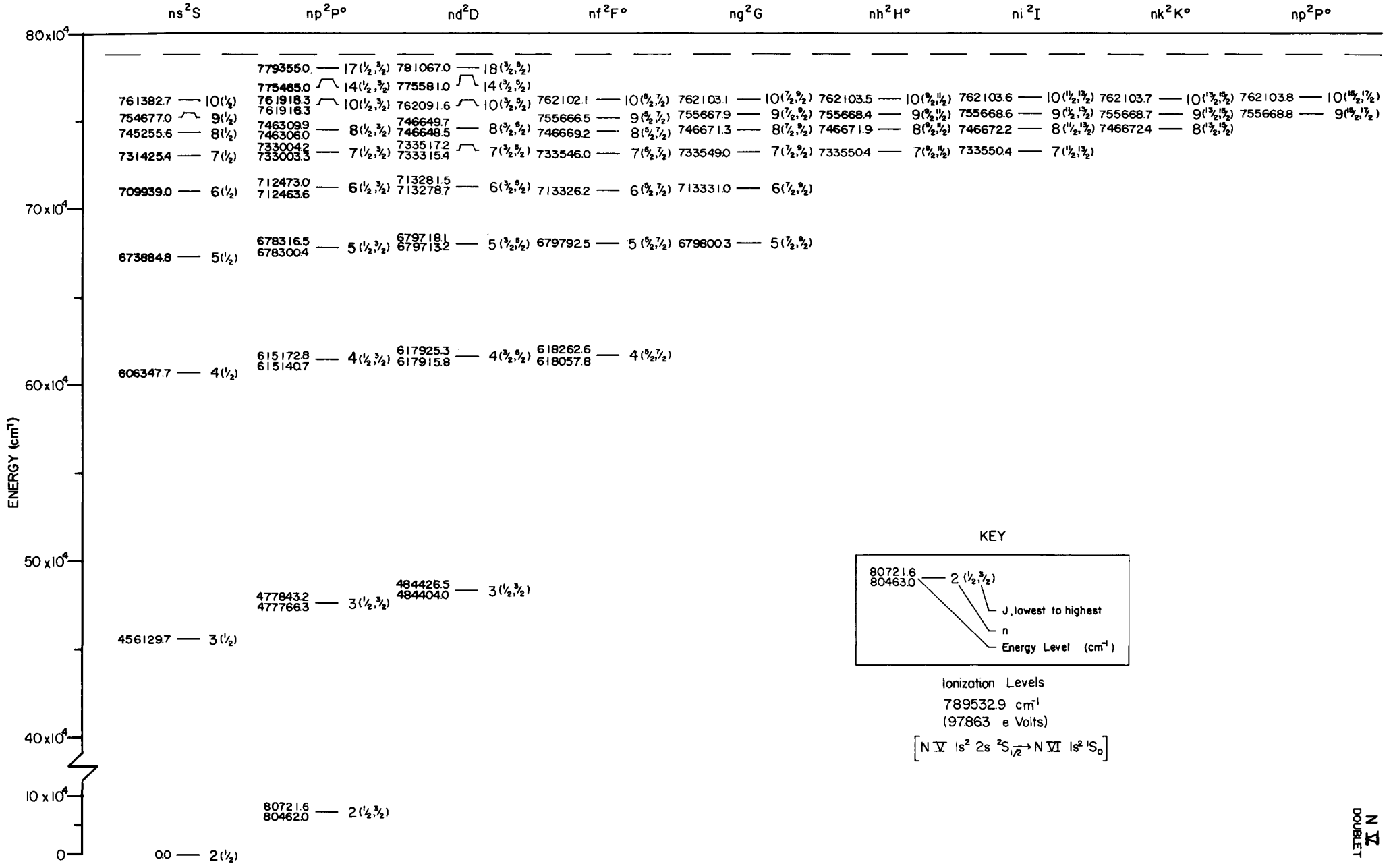

N IV (4 electrons, Z=7)
INTERCOMBINATION GROTRIAN DIAGRAM
(Be I sequence, Triplet Term System)
Configuration: 1s² 2s nl
Configuration: 1s² 2p nl
ns ³S
np ³P°
nd ³D
nf ³F°
ng ³G
np ³S
ns ³P°
np ³P
nd ³P°
np ³D
nd ³F°
ENERGY (cm⁻¹)
6x10⁵
4x10⁵
2x10⁵
0

N V GROTRIAN DIAGRAM (3 electrons, Z=7)
(Li I sequence, Configuration: $1s^2nl$, Doublet System)



N V ENERGY LEVELS (3electrons, Z=7)

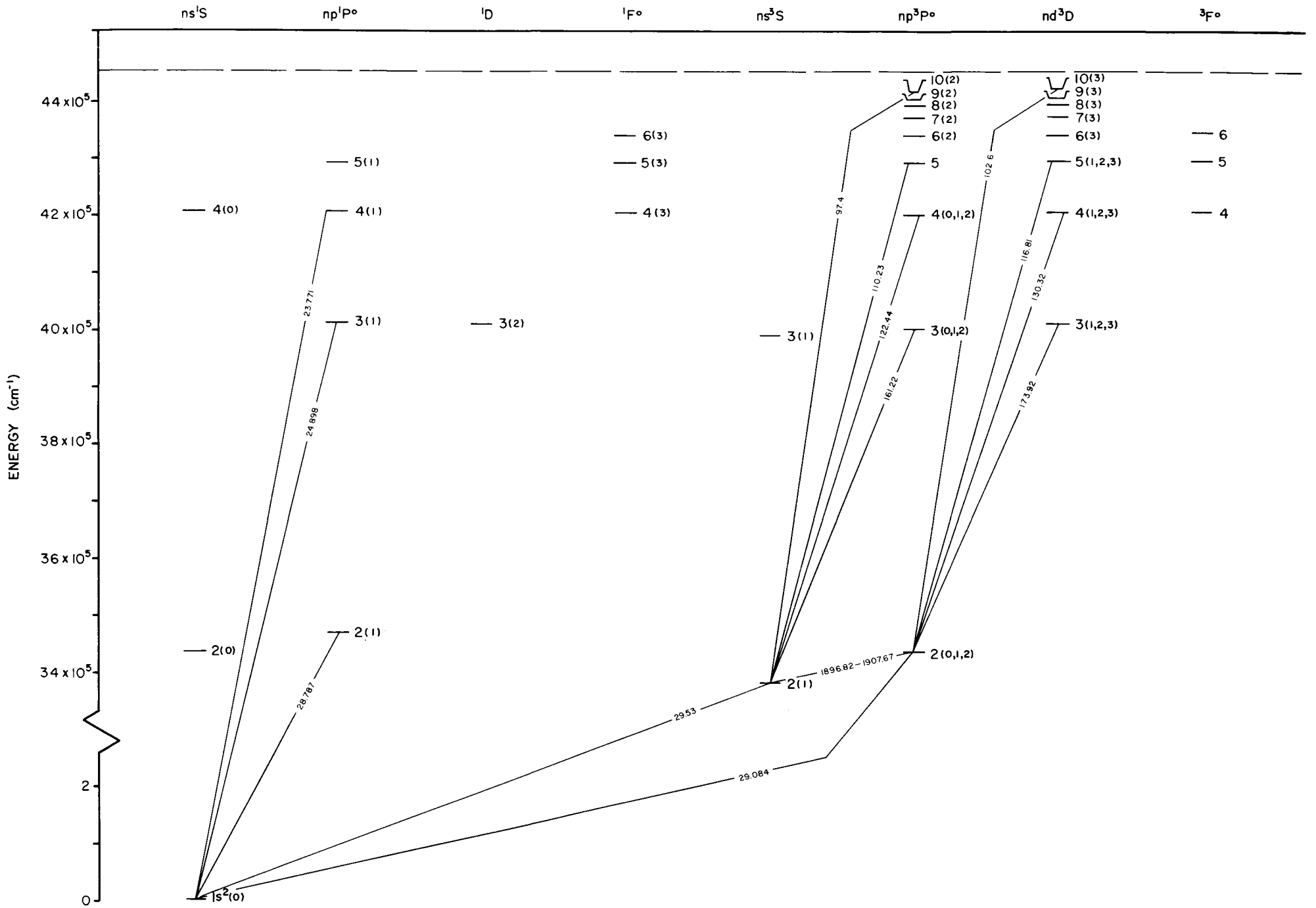
(Li I sequence, Configuration: $1s^2nl$, Doublet System)



N V DOUBLET

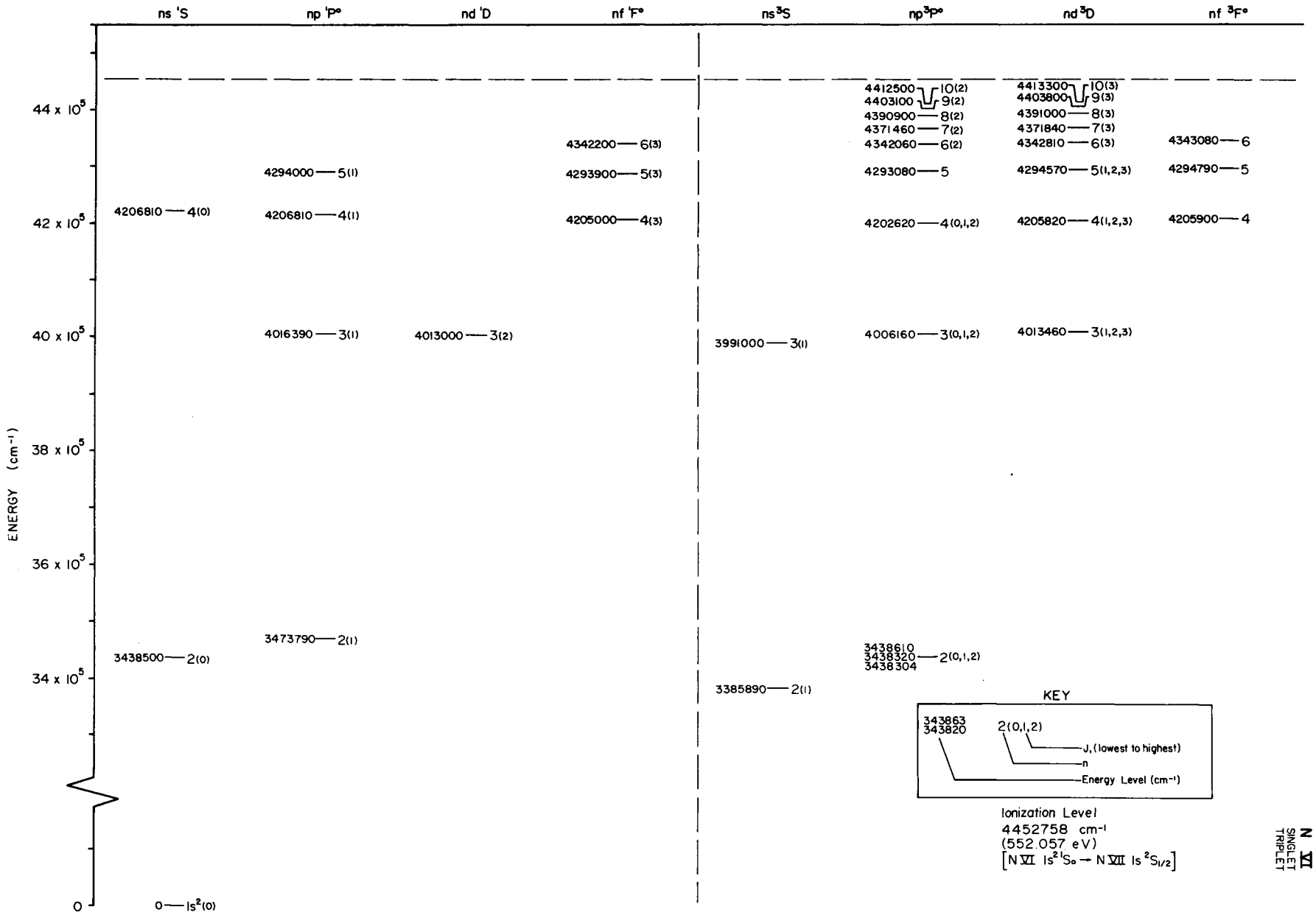
N VI GROTRIAN DIAGRAM (2 electrons, Z=7)

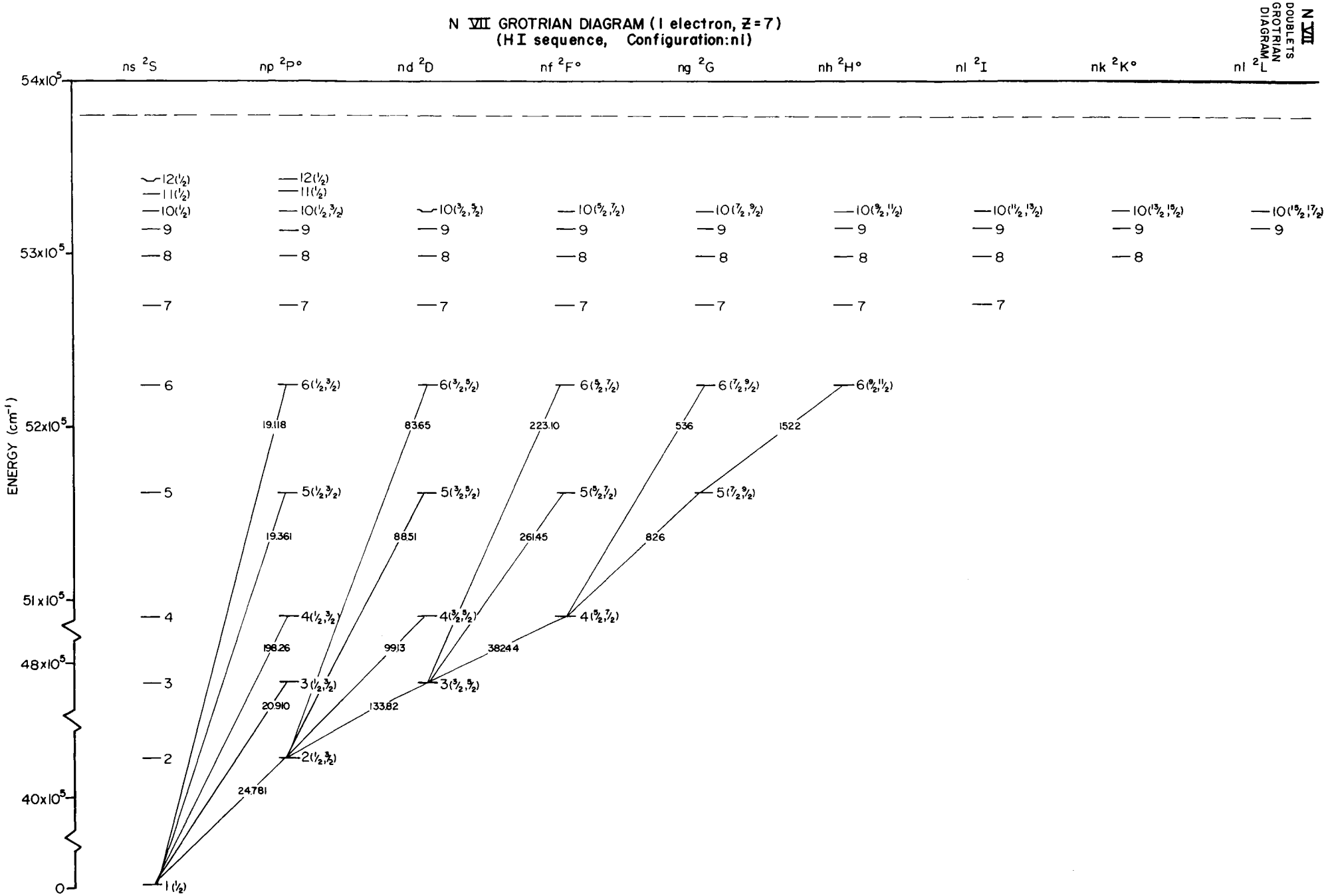
(He I sequence, Configuration: 1s nl, Singlet & Triplet Term System)



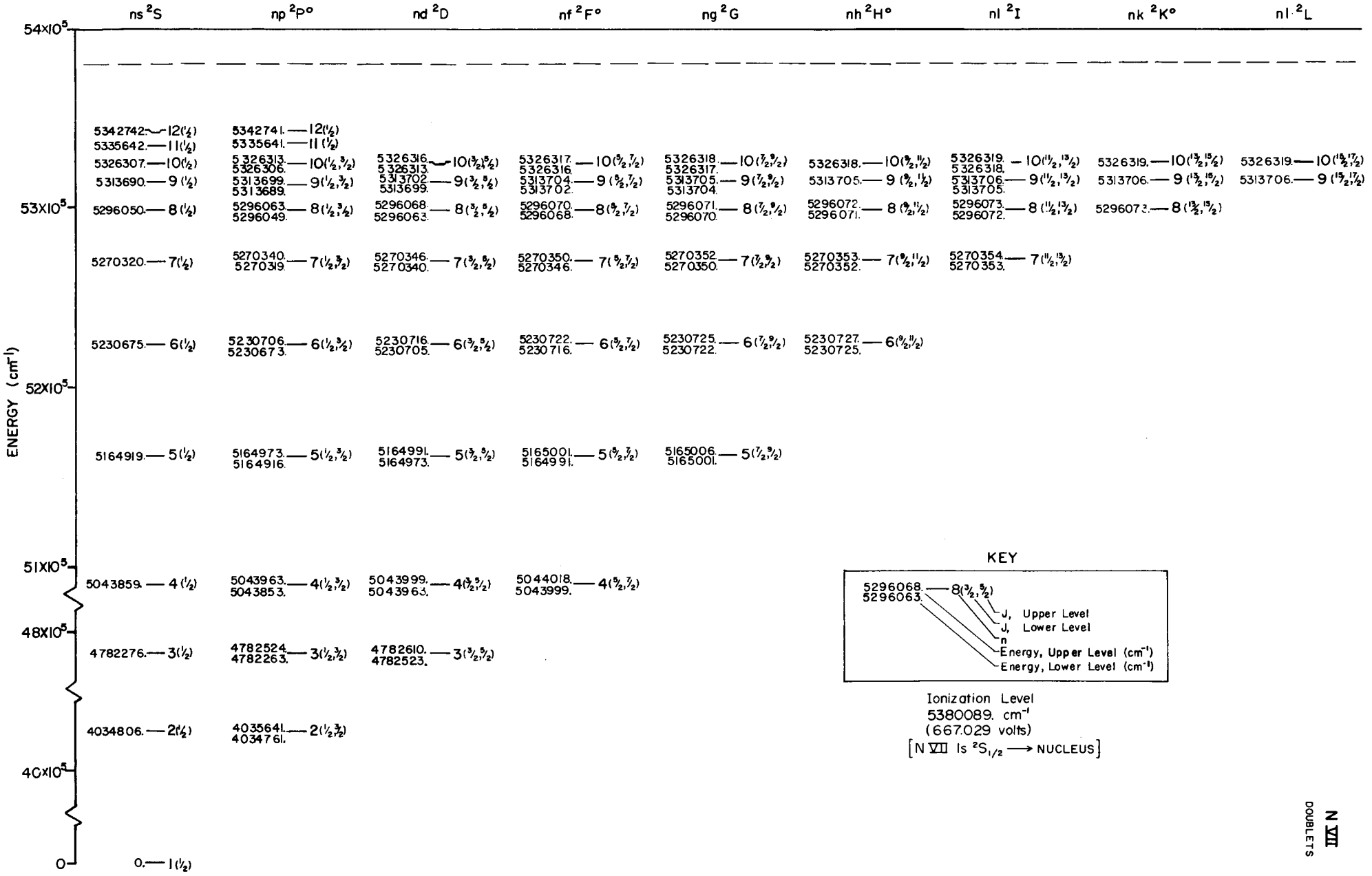
N VI ENERGY LEVELS (2 electrons, Z = 7)

(He I sequence, Configuration: 1s nl, Singlet & Triplet System)




N VII GROTRIAN DIAGRAM (1 electron, Z=7)
(H I sequence, Configuration:nl)
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
nl ²I
nk ²K°
nl ²L
ENERGY (cm⁻¹)
54x10⁵
53x10⁵
52x10⁵
51x10⁵
48x10⁵
40x10⁵
0
19.118
19.361
198.26
20.910
24.781
83.65
88.51
99.13
133.82
223.10
261.45
382.44
536
826
1522

N VII ENERGY LEVELS (1 electron, Z=7)
(H I sequence, Configuration: nl)



N VII
DOUBLETS

N I $Z = 7$ 7 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular observations.

K.B.S. Eriksson, Physica Scripta **9**, 151 (1974).

Line and energy-level tables based on wavelengths from 860–9100 Å.

J.W. McConkey, D.J. Burns, and J.A. Kernahan, J. Quant. Spectrosc. Radiat. Transfer **8**, 823 (1968).

Authors give a spectrogram and a line table for lines observed in the region 10 105–10 775 Å.

Comment on intermediate coupling: Here an f-electron ($l = 3$) is coupled to a ^{3}P core ($l = 1$), whence a total orbital L-value of 2, 3, or 4 can be made. Terms with these values are represented by the symbols D, F, and G, respectively.

Following the symbol for L is a bracketed number formed from a core j-value and the l-value of the f-electron. The spin of the f-electron is then coupled to the bracketed number to yield the final J-value of the level.

See Eriksson and Johansson, Ark. Fys. **19**, 235 (1961).

Note: New Tables of Energy Levels and Multiplets for N I, N II, and N III have recently appeared.
The reference is: C.E. Moore, Selected Tables of Atomic Spectra, N I, N II, N III, NSRDS-NBS 3, Sec. 5 (U.S. Govt. Printing Office, 1975).
The difference between the new compilation and our own is small

N II $Z = 7$ 6 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular observations.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give a line table for transitions calculated and observed in ion lasers.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to Eriksson's energy level values.

K.B.S. Eriksson, Phys. Rev. **102**, 102 (1956).

Theory of coupling of ^{2}P core with f and g electrons, applied to N II.

T. Sasaki, N. Kaifu, N. Itoh, K. Sakai, and I. Shimada, Sci. of Light **14**, 142 (1965).

Authors give Grotrian diagrams.

J.B. Tatus, Mon. Not. R. Astr. Soc. **140**, 87 (1968).

Author gives a line table of calculated and observed wavelengths.

Comment on intermediate coupling: We have to deal with the coupling of f- and g-electrons to a core. Following Eriksson, Phys. Rev. **102**, 102 (1956), the pair-coupling approximation is used to link a p-electron with f or g, as required. A total L-value appears, represented by D, F, G, or H, along with an intermediate-coupling angular momentum formed from L and j_l. We call this value, $[j,l]$ in our key; Eriksson calls it K. There is then a total angular momentum formed from $[j,l]$ and the spin of the f- or g-electron.

The table below, adapted from Eriksson's paper, summarizes the coupling assigned to a ^2P core with an f- or g-electron.

	J_P	L	$J_P, l_2 = 3$:	J_{final}
$^2P + f$	3/2	G	9/2	5,4
			7/2	4,3
	1/2	F	7/2	4,3
			5/2	3,2
	3/2	D	5/2	3,2
			3/2	2,1
			$J_P, l_2 = 4$:	
$^2P + g$	3/2	H	11/2	6,5
			9/2	5,4
	1/2	G	9/2	5,4
			7/2	4,3
	3/2	F	7/2	4,3
			5/2	3,2

See Note in bibliography of N I

N III $Z = 7$ 5 electrons

H.G. Berry, W.S. Bickel, S. Bashkin, J. Désesquelles, and R.M. Schectman, J. Opt. Soc. Amer. **61**, 947 (1971).

Authors give transition wavelengths and Grotrian diagrams.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give wavelengths calculated and observed in ion gas lasers.

See Note in bibliography of N I

N IV $Z = 7$ 4 electrons

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give wavelengths calculated and observed in ion gas lasers.

T. Sasaki, N. Kaifu, N. Itoh, K. Sakai, and I. Shimada, Sci. of Light **14**, 142 (1965).

Authors give Grotrian diagrams.

N V $Z = 7$ 3 electrons

Please see the general references.

N VI $Z = 7$ 2 electrons

B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

Authors identify lines attributed to N VI in the range 16–400 Å.

E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculate energies nonrelativistically in a treatment of the He I isoelectronic sequence.

N VII $Z = 7$ 1 electron

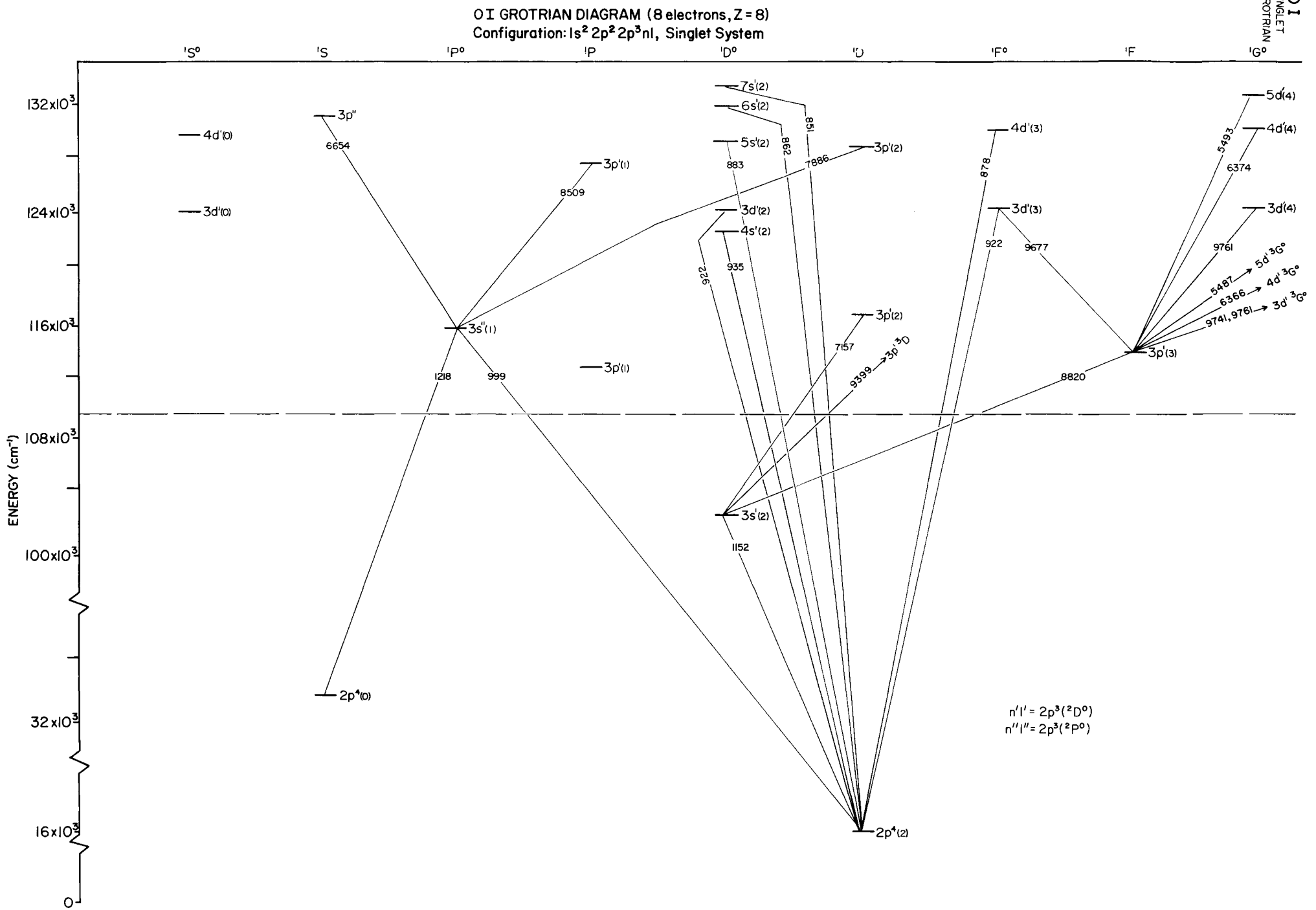
R.L. Blake, T.A. Chubb, H. Friedman, and A.E. Unzicker, Science **146**, 1037 (1964).

Authors give a line table of lines observed in the solar spectrum below 25 Å.

B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

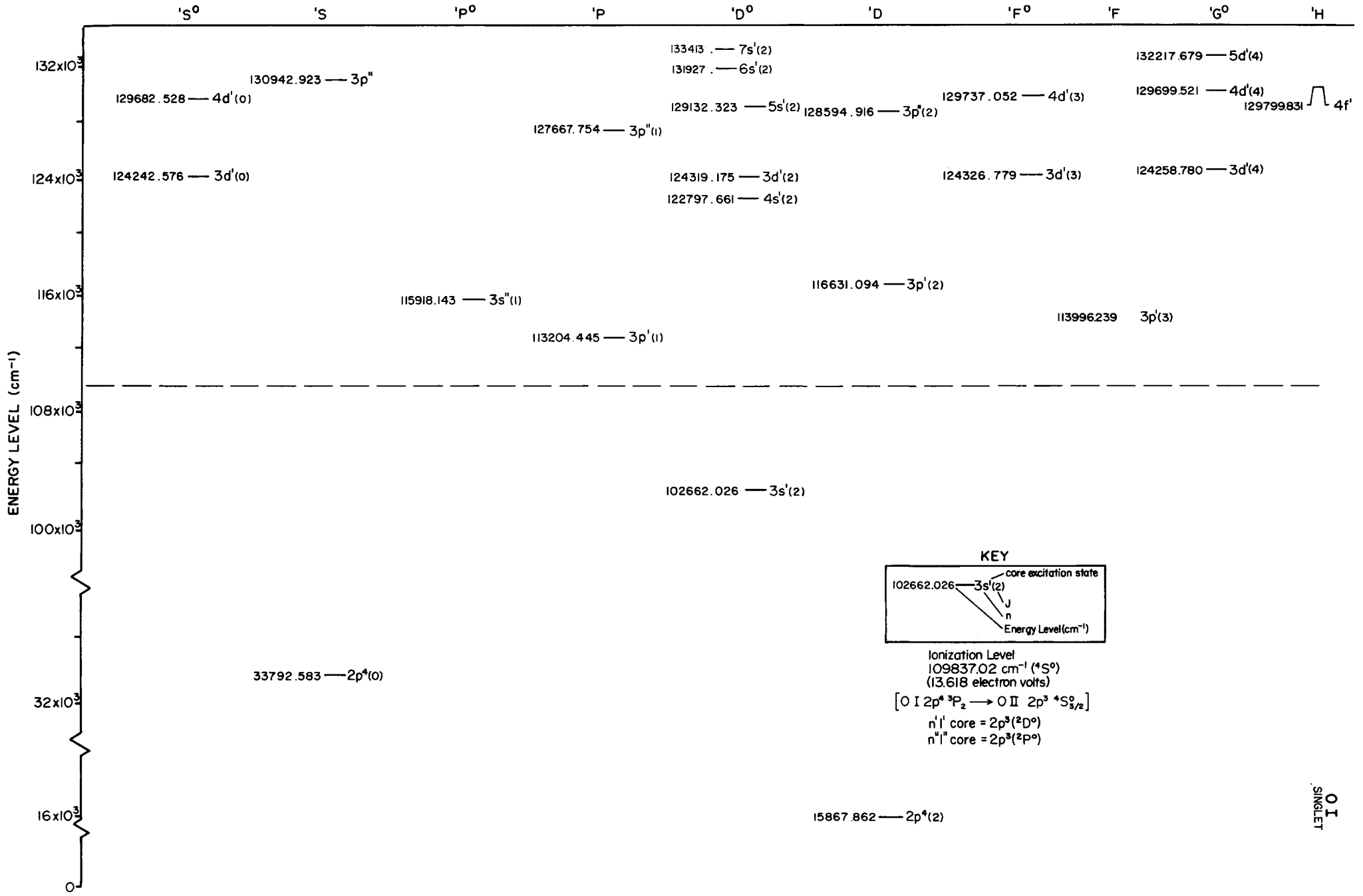
Authors give observed spectrum in range 16–400 Å.

Oxygen (O)

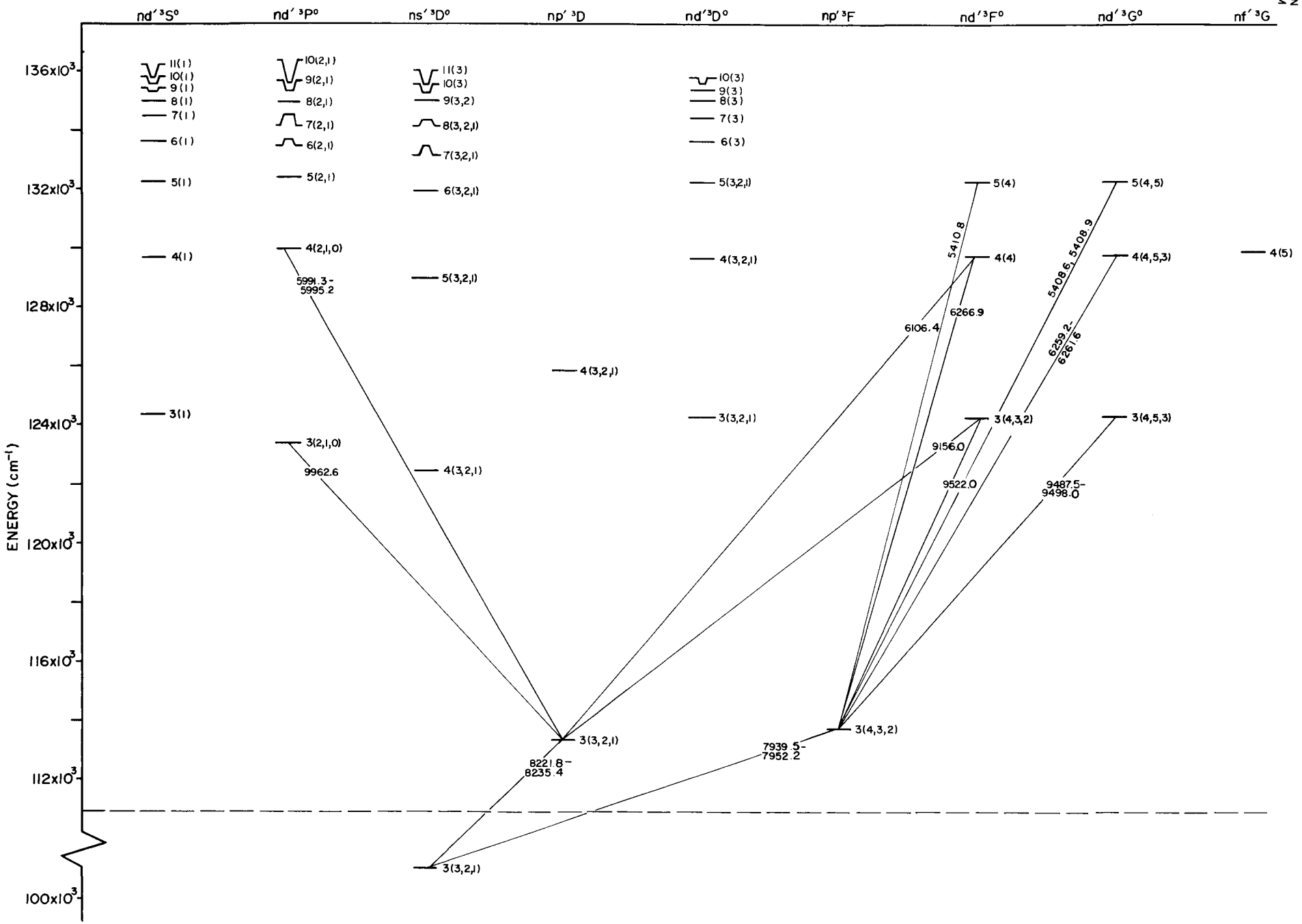

O I GROTRIAN DIAGRAM (8 electrons, Z = 8)
Configuration: 1s² 2p² 2p³nl, Singlet System
¹S°
¹S
¹P°
¹P
¹D°
¹D
¹F°
¹F
¹G°
ENERGY (cm⁻¹)
132x10³
124x10³
116x10³
108x10³
100x10³
32x10³
16x10³
0
4d'(0)
3d'(0)
3p''
6654
3p'(1)
8509
3s''(1)
1218
999
3p'(1)
2p⁴(0)
7s'(2)
6s'(2)
5s'(2)
883
862
851
7886
3p'(2)
3d'(2)
4s'(2)
935
226
3p'(2)
7157
9399 → 3p' ³D
3s'(2)
1152
2p⁴(2)
4d'(3)
878
3d'(3)
922
9677
8820
3p'(3)
5d'(4)
5493
4d'(4)
6374
3d'(4)
9761
5487 → 5d' ³G°
6366 → 4d' ³G°
9741, 9761 → 3d' ³G°
n'l' = 2p³(²D°)
n''l'' = 2p³(²P°)

O I ENERGY LEVELS (8 electrons, Z = 8)

Configuration: $1s^2 2p^2 2p^3 nl$, Singlet System

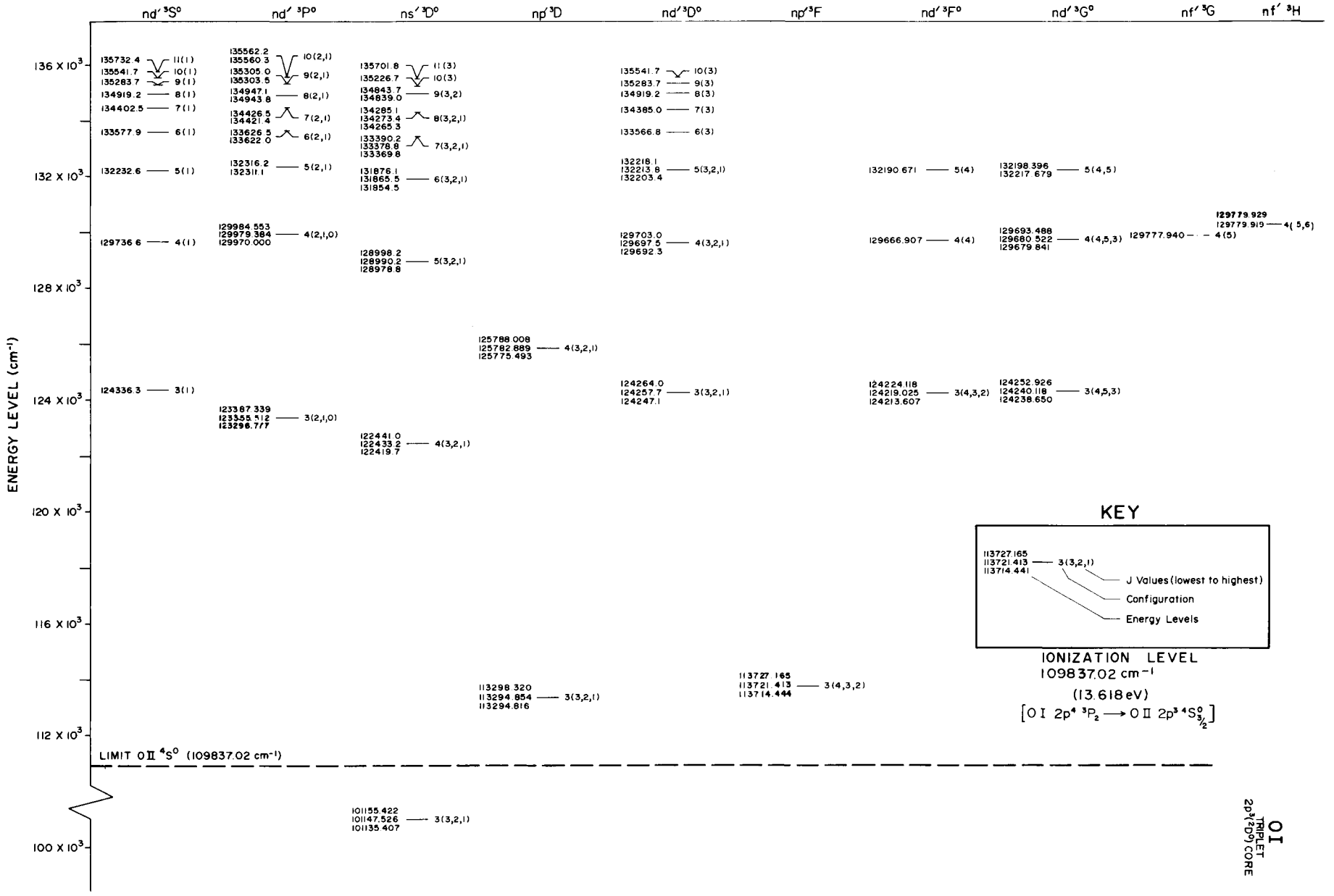


O I GROTRIAN DIAGRAM (8 electrons, Z = 8)
(Configuration: $1s^2 2s^2 2p^3(^2D^o)n'l'$ Triplet System)



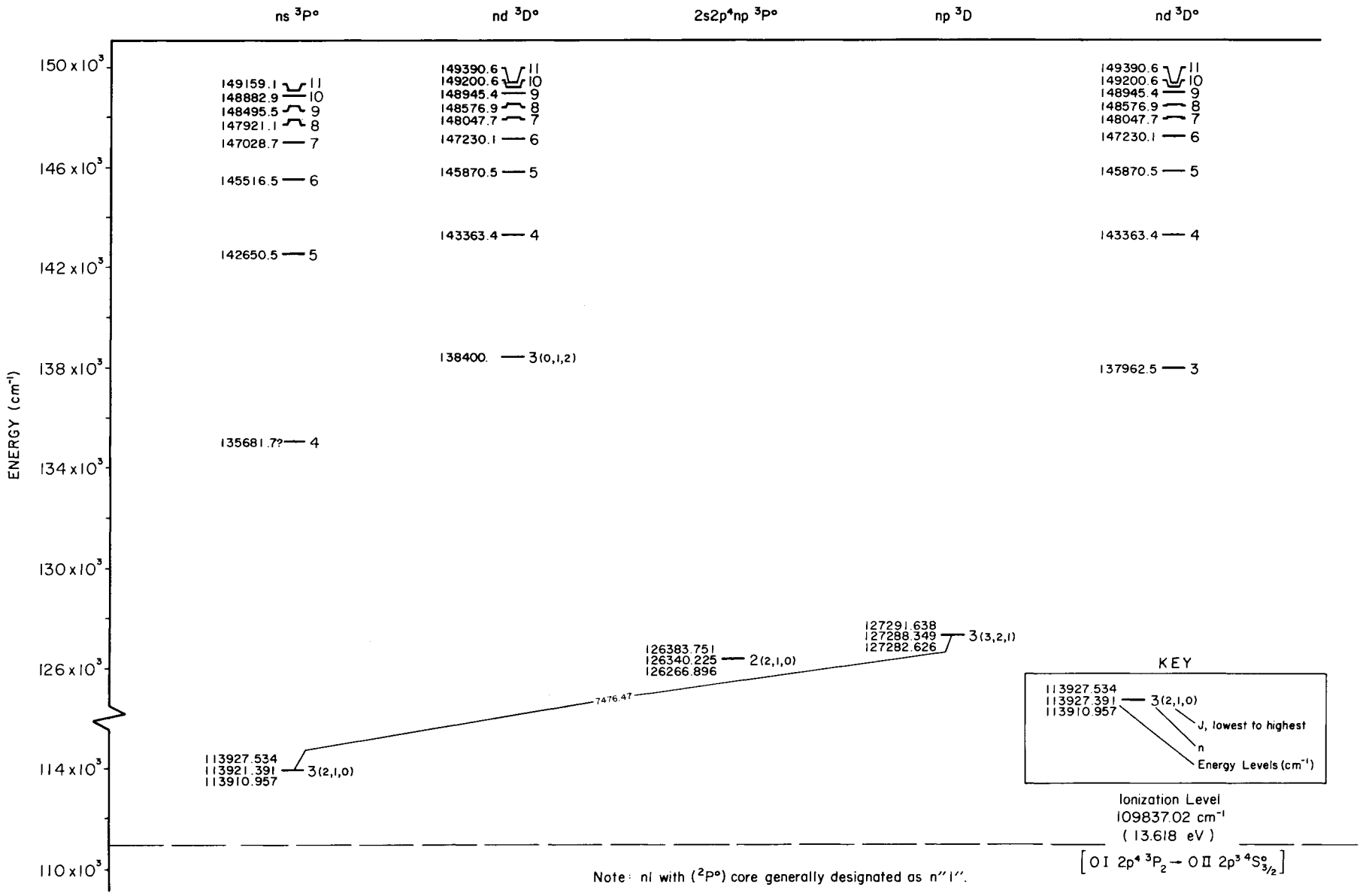
O I ENERGY LEVELS (8 electrons, Z = 8)

(Configuration: $1s^2 2s^2 2p^3(^2D^o)n'l'$ Triplet System)



OI ENERGY LEVELS (8 electrons, Z=8)

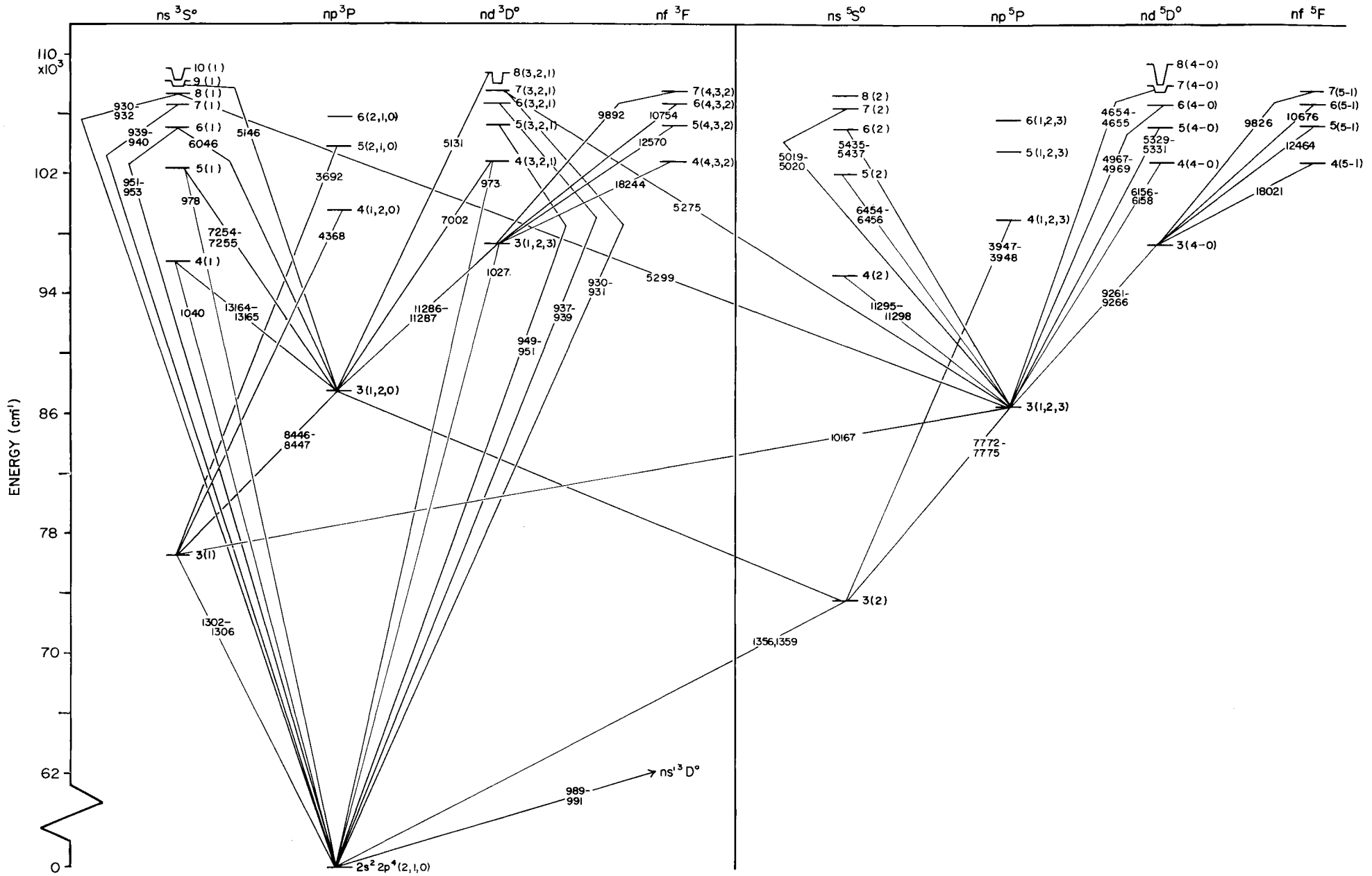
(Configuration: $1s^2 2s^2 2p^3(^2P^o)nl$, Autoionizing Triplet System)



Note: nl with ($^2P^o$) core generally designated as n″l″.

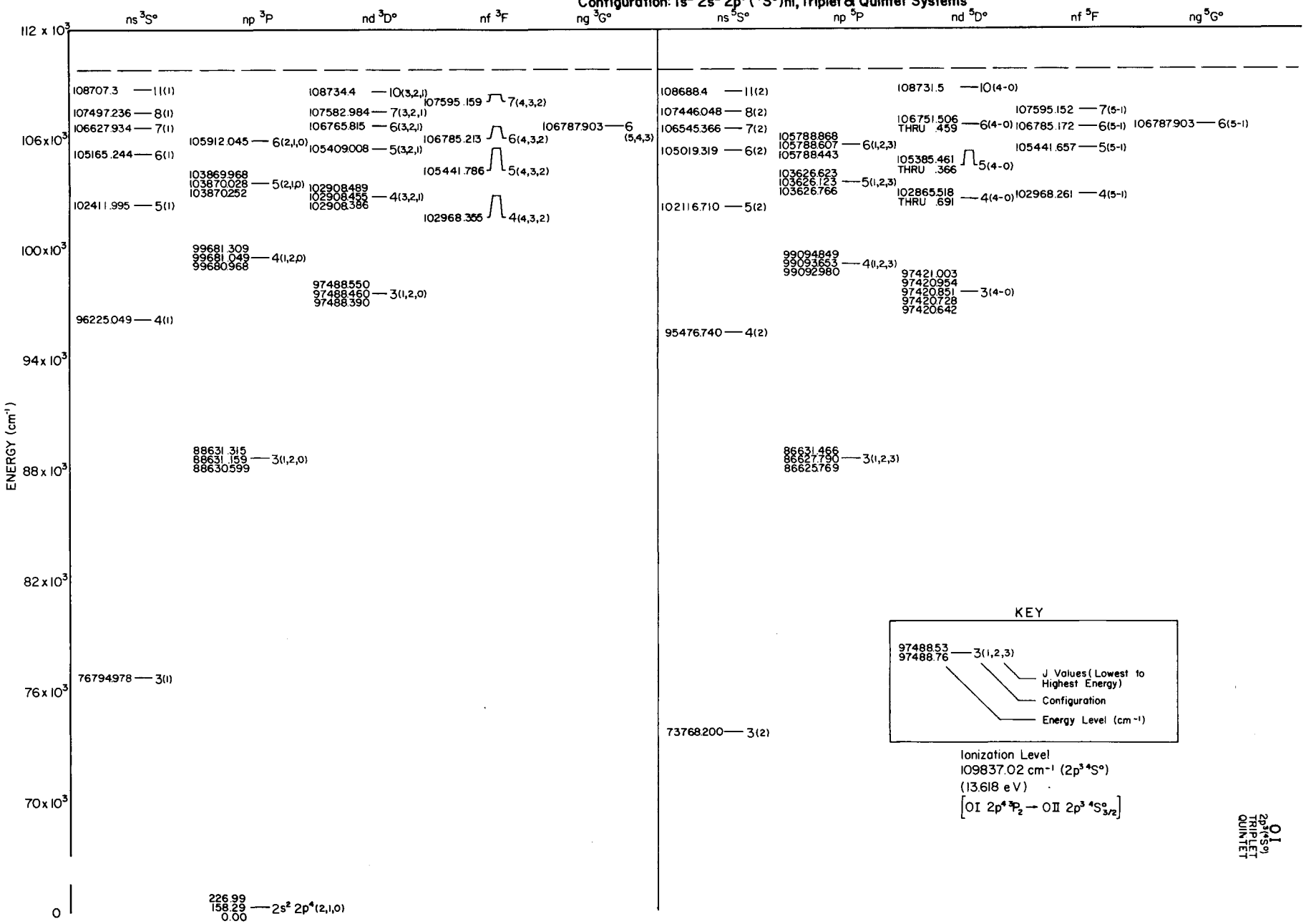
O I GROTRIAN DIAGRAM (8 electrons, Z = 8)

Configuration: $1s^2 2s^2 2p^3(^4S^o)nl$, Triplet & Quintet Systems

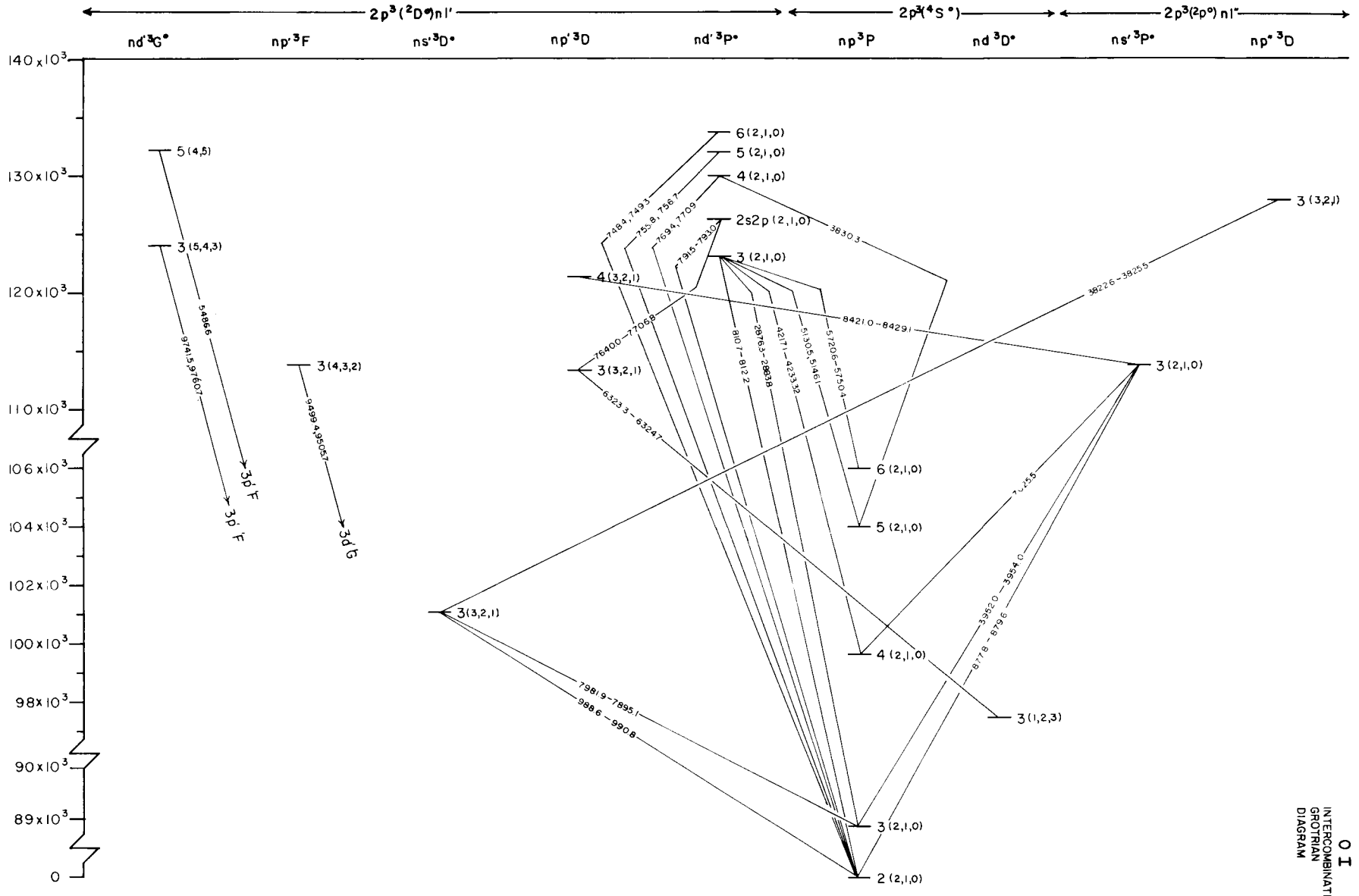


OI ENERGY LEVELS (8 electrons, Z=8)

Configuration: $1s^2\,2s^2\,2p^3\,(^4S^o)nl$, Triplet & Quintet Systems



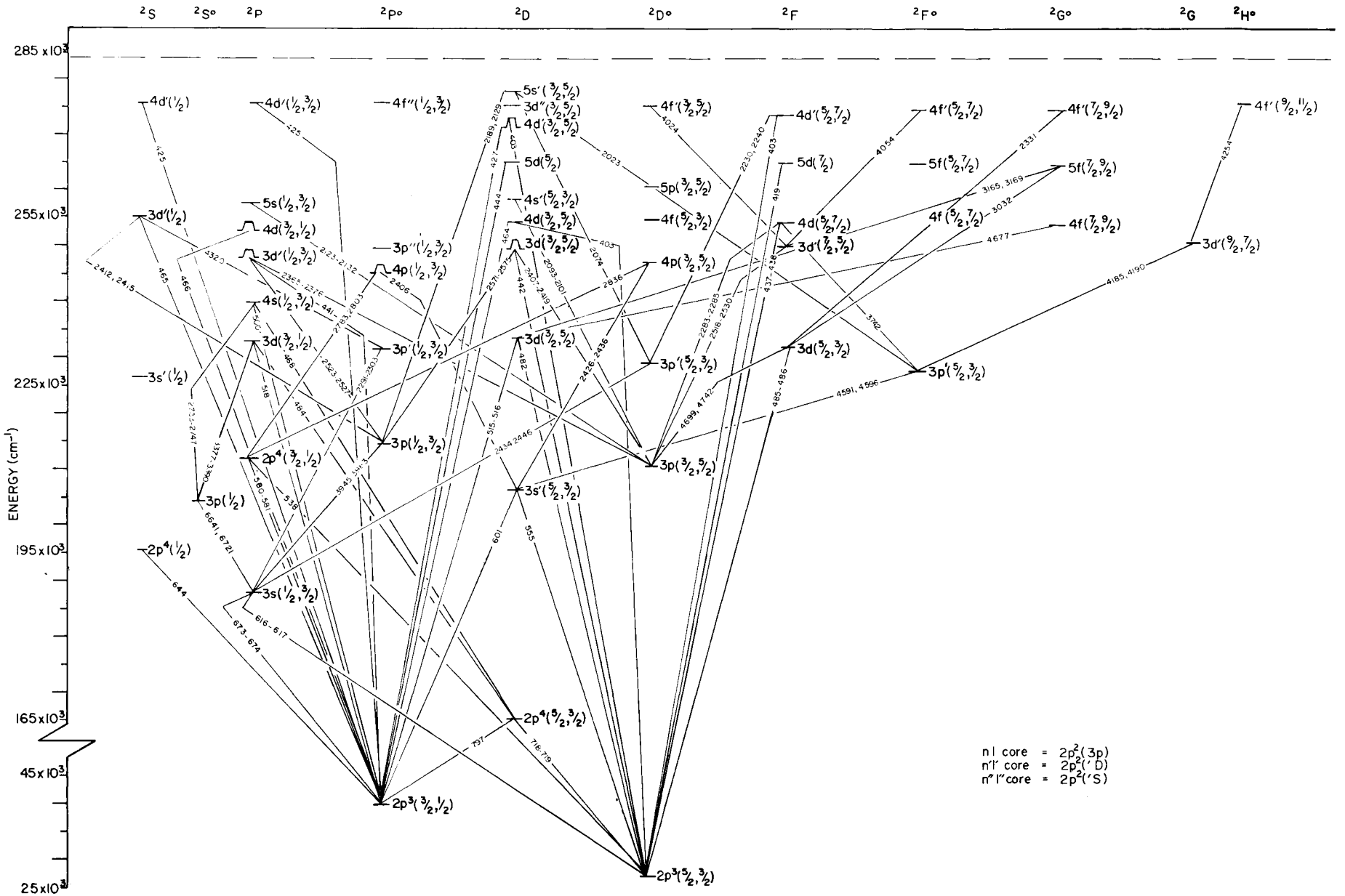
OI (8 eletrons, Z=8)
INTERCOMBINATION GROTRIAN DIAGRAM
(Triplet System: ($^4S^o$)—($^2P^o$)—($^2D^o$) Cores)



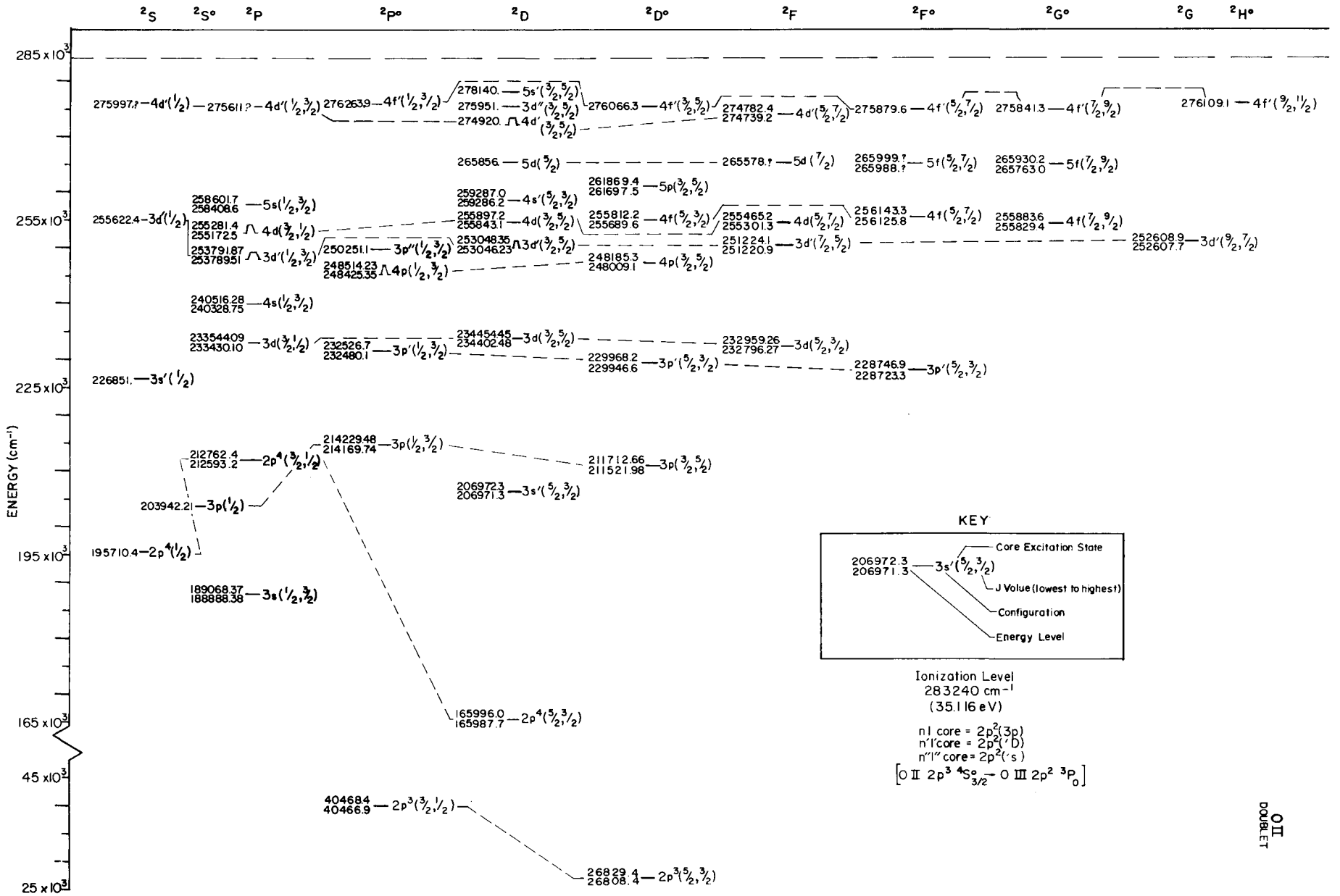
OI
INTERCOMBINATION
GROTRIAN
DIAGRAM

O II GROTRIAN DIAGRAM (7 electrons, Z=8)

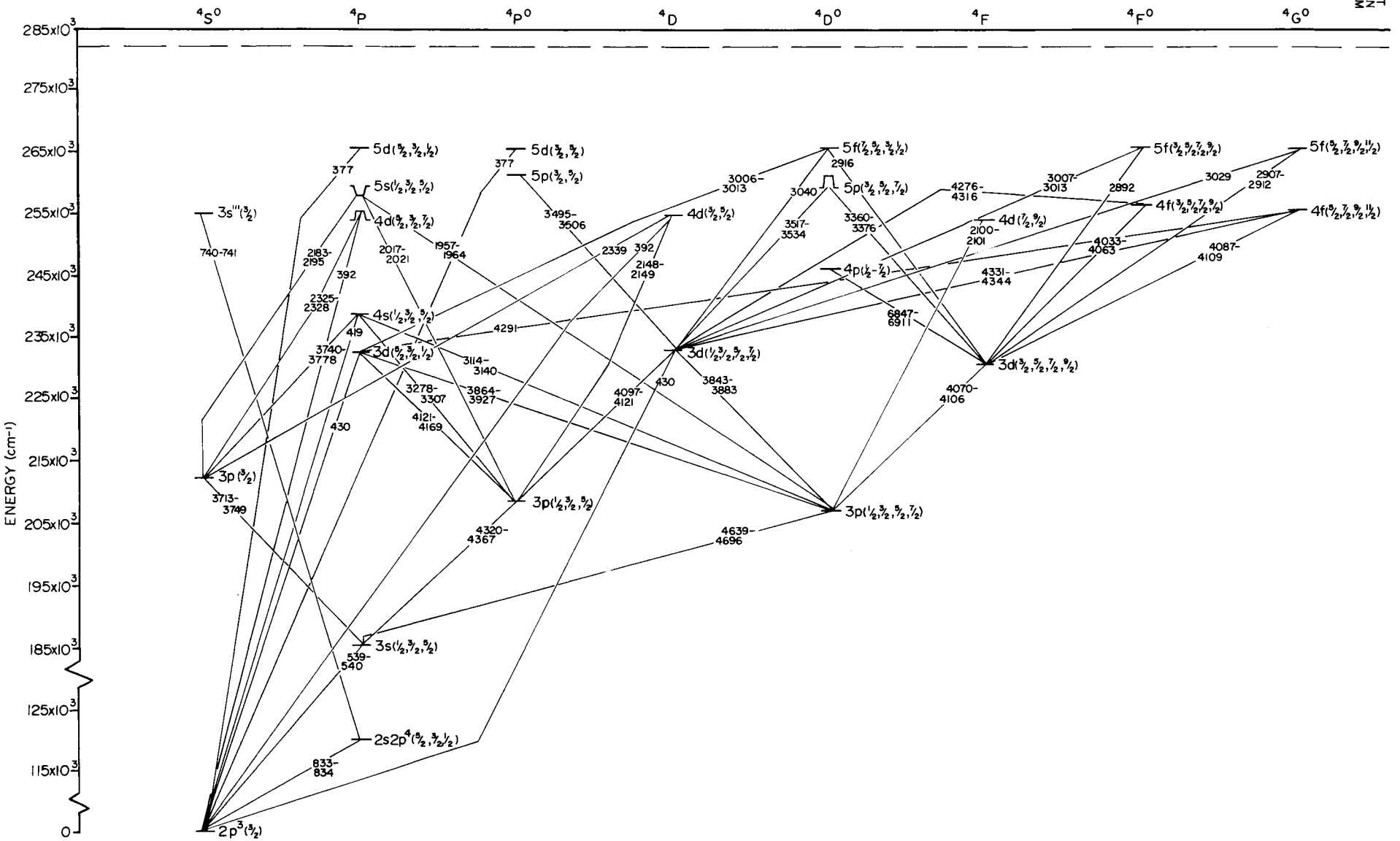
(N I Sequence, Configuration: $1s^2\,2s^2\,2p^2\,nl$, Doublet System)



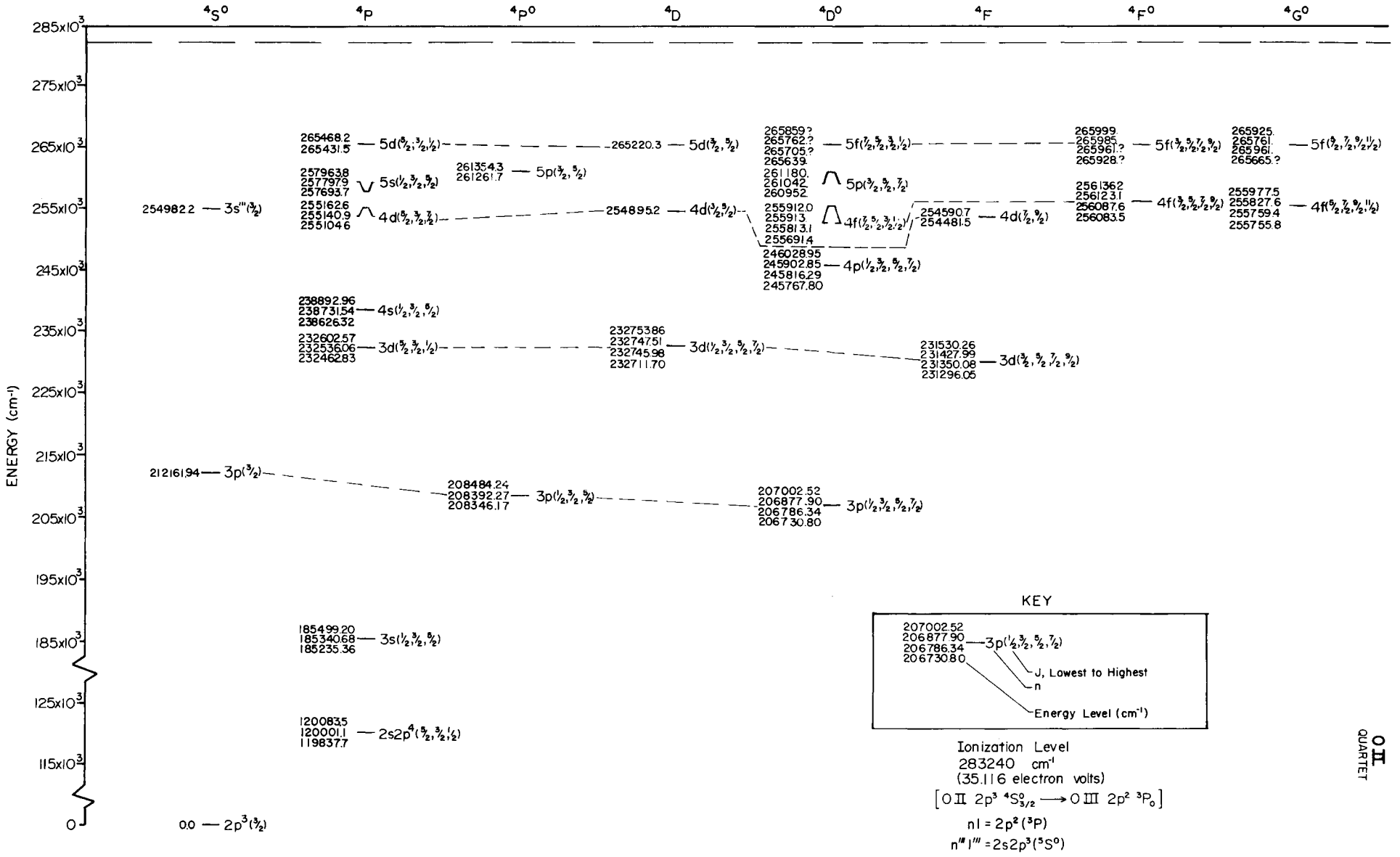
O II ENERGY LEVELS (7 electrons, Z = 8)
(N I Sequence, Configuration: $1s^2\,2s^2\,2p^2\,nl$, Doublet System)

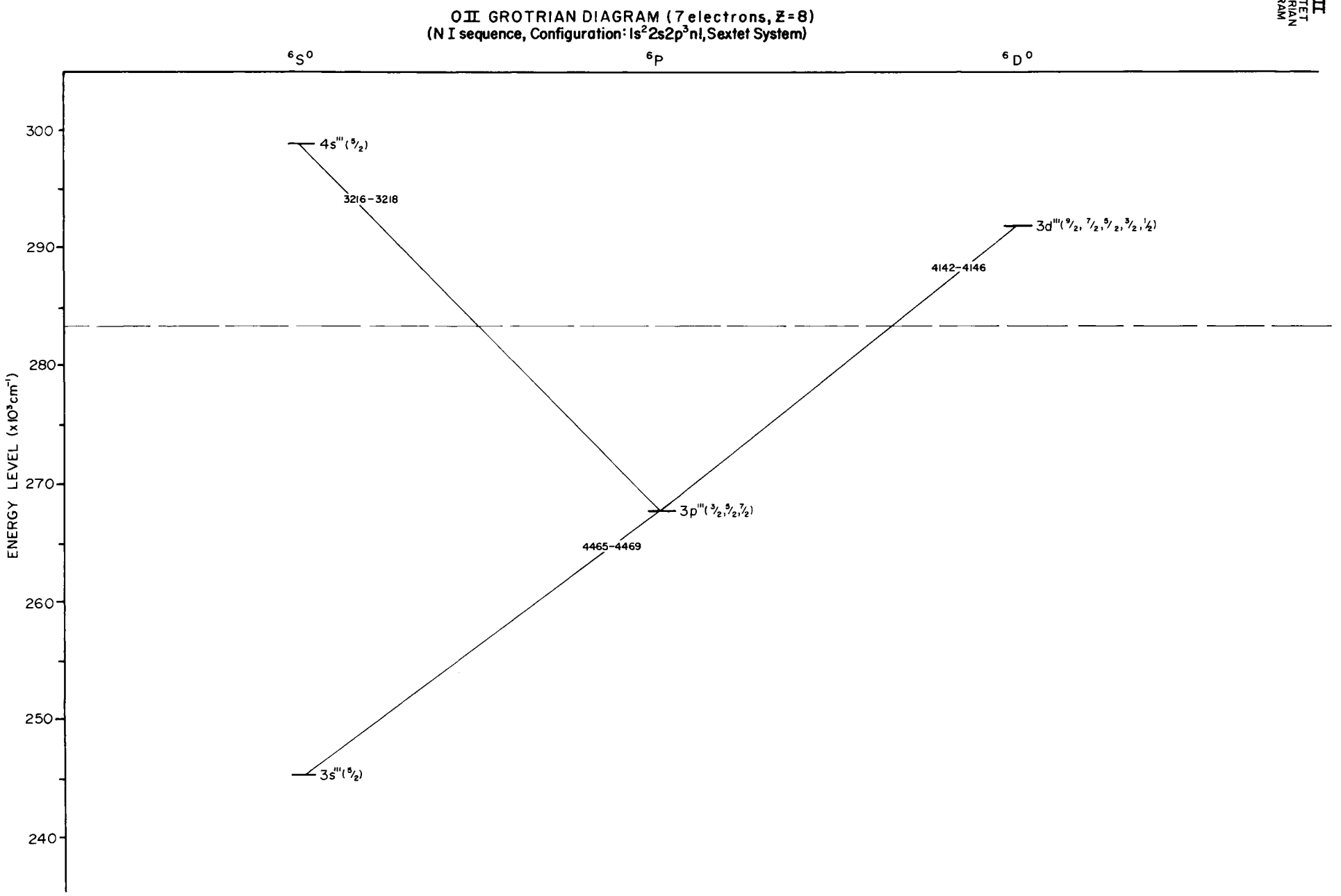


O II GROTRIAN DIAGRAM (7 electrons, Z = 8)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Quartet System)

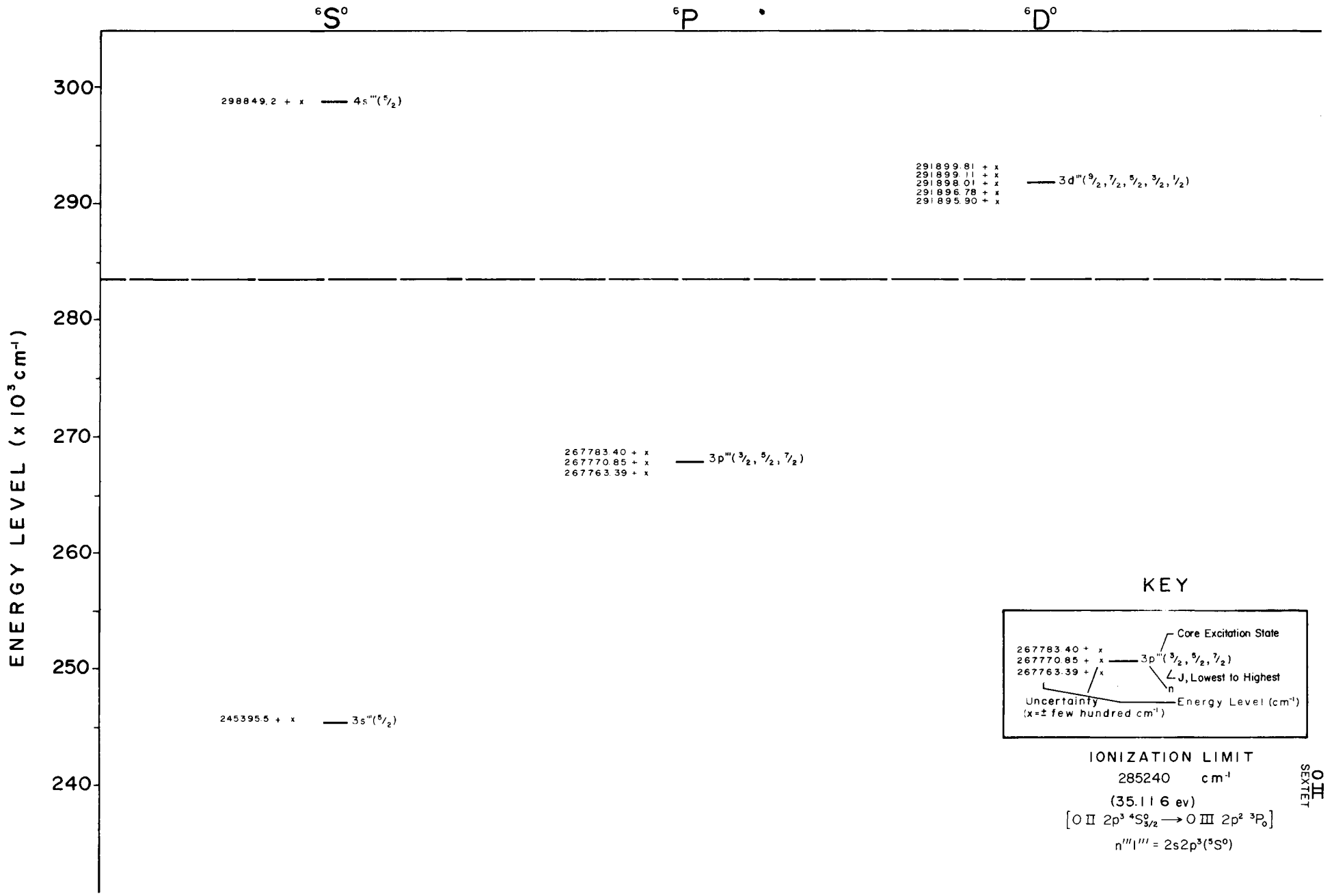


OII ENERGY LEVELS (7 electrons, Z=8)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Quartet System)

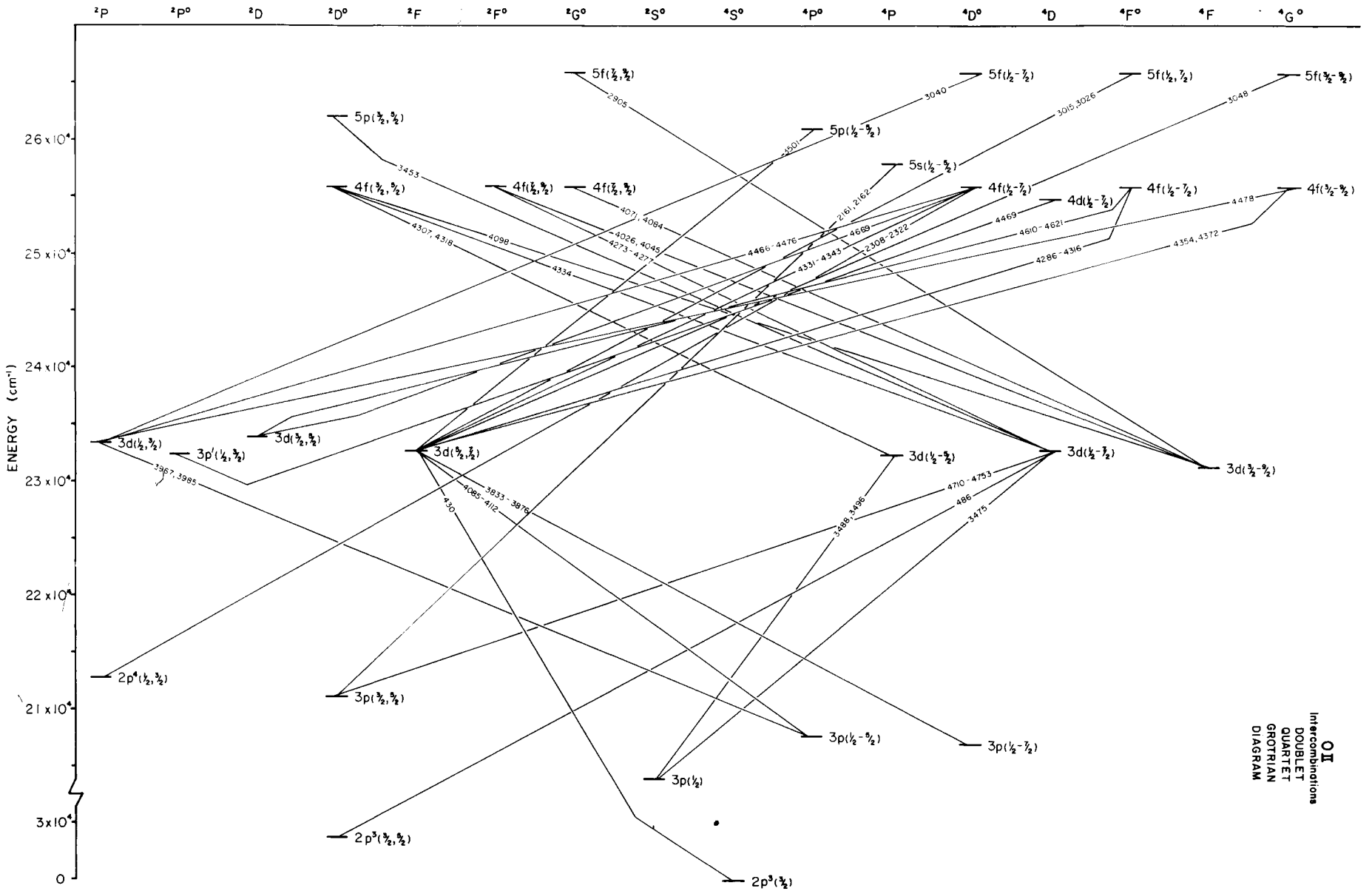



O II GROTRIAN DIAGRAM (7 electrons, Z=8)
(N I sequence, Configuration: 1s²2s2p³nl, Sextet System)
⁶S°
⁶P
⁶D°
ENERGY LEVEL (x10³cm⁻¹)
300
290
280
270
260
250
240
4s'''(5/2)
3216-3218
3d'''(9/2, 7/2, 5/2, 3/2, 1/2)
4142-4146
3p'''(3/2, 5/2, 7/2)
4465-4469
3s'''(5/2)

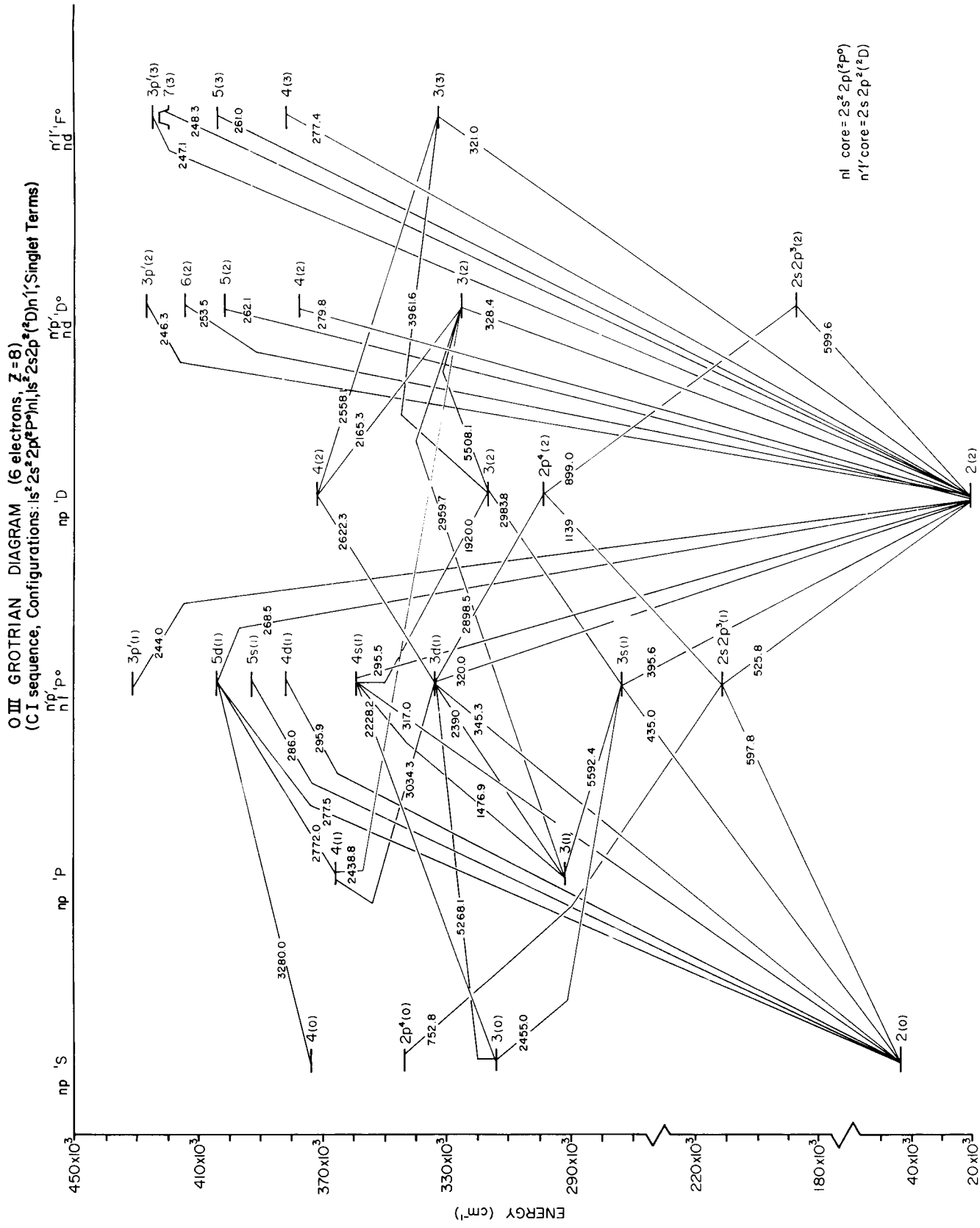
O II ENERGY LEVELS (7 electrons, Z=8)
(N I Sequence, Configuration: $1s^2\,2s2p^3\,nl$, Sextet Term System)

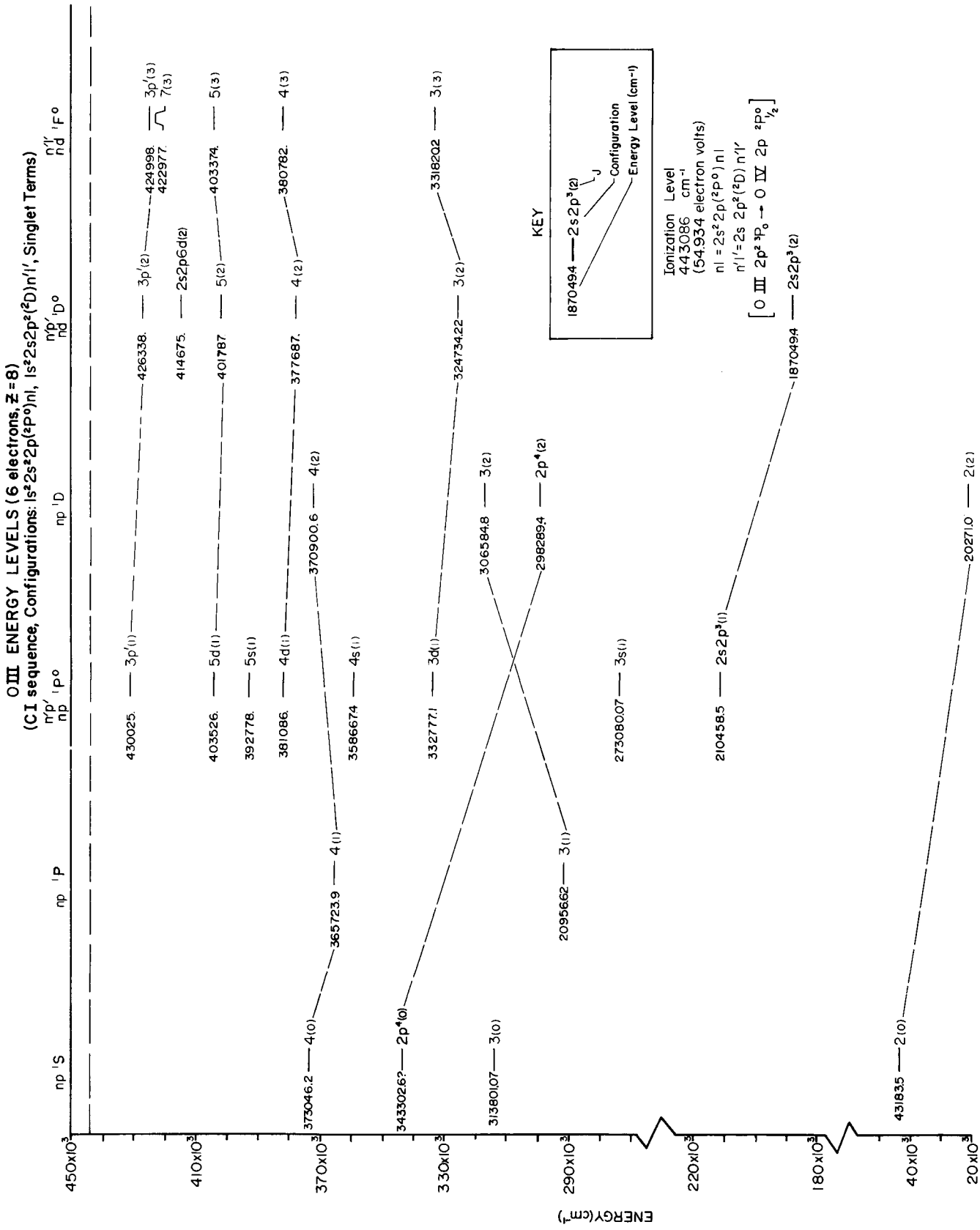


O II GROTRIAN DIAGRAM (7 electrons, Z = 8)
(Intercombinations: Doublet & Quartet Systems)

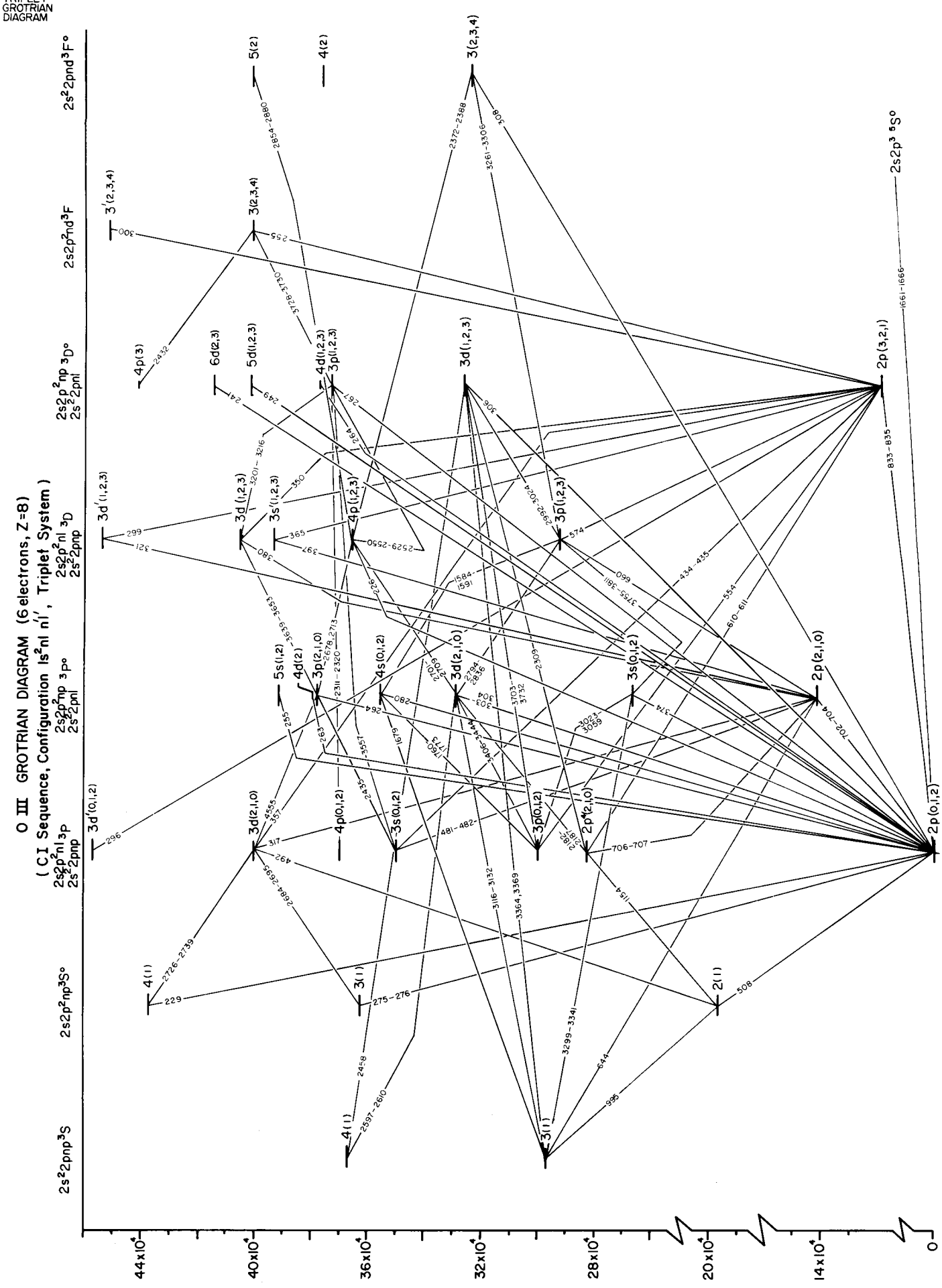


O II
Intercombinations
DOUBLET
QUARTET
GROTRIAN
DIAGRAM


O III GROTRIAN DIAGRAM (6 electrons, Z=8)
(C I sequence, Configurations: 1s²2s²2p²(³P)nl, 1s²2s2p³(²D)n'l', Singlet Terms)
nl core = 2s²2p(²P°)
n'l' core = 2s2p²(²D)
ENERGY (cm⁻¹)
450x10³
410x10³
370x10³
330x10³
290x10³
220x10³
180x10³
40x10³
20x10³
np ¹S
n'p' n'l' ¹P°
np ¹P
np ¹D
n'p' nd ¹D°
n'l' nd ¹F°
3p'(3)
7(3)
5(3)
4(3)
3(3)
3p'(2)
6(2)
5(2)
4(2)
3(2)
2s2p³(2)
2(2)
3p'(1)
5d(1)
5s(1)
4d(1)
4s(1)
3d(1)
3s(1)
2s2p³(1)
4(1)
3(1)
4(0)
2p⁴(0)
3(0)
2(0)
2p⁴(2)
247.1
248.3
261.0
277.4
321.0
246.3
253.5
262.1
279.8
328.4
599.6
2558.1
2165.3
3961.6
5508.1
2622.3
2959.7
1920.0
2983.8
899.0
1139
244.0
268.5
295.5
2898.5
320.0
286.0
295.9
2228.2
317.0
2390
345.3
395.6
525.8
435.0
597.8
2772.0
277.5
2438.8
3034.3
1476.9
5592.4
3280.0
5268.1
752.8
2455.0

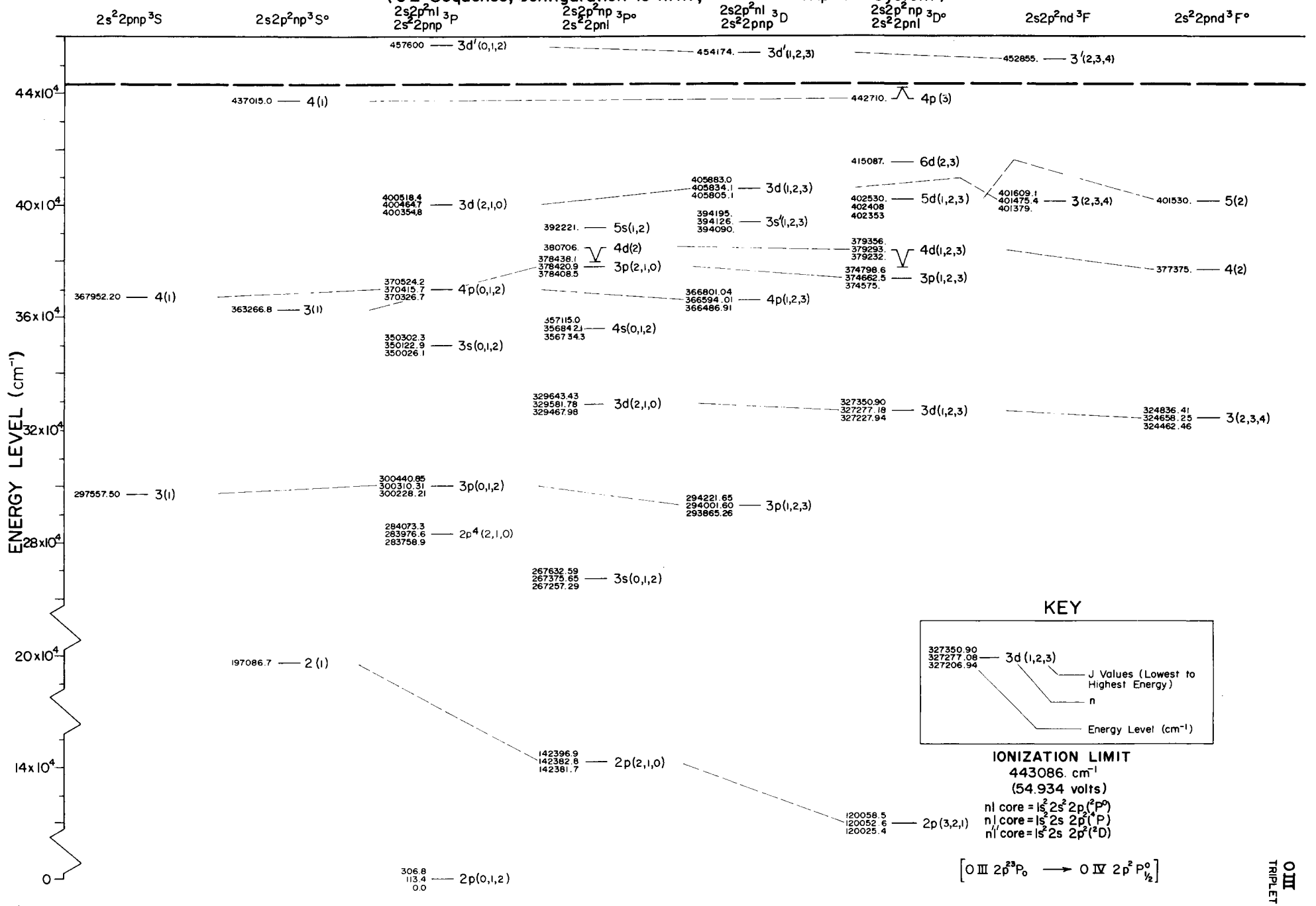

O III ENERGY LEVELS (6 electrons, Z=8)
(CI sequence, Configurations: 1s²2s²2p(²P°)nl, 1s²2s2p²(²D)n'l', Singlet Terms)
np ¹S
n'p' np ¹P°
np ¹P
np ¹D
n'p' nd ¹D°
n'l' nd ¹F°
430025.
3p'(1)
426338.
3p'(2)
424998.
422977.
3p'(3)
7(3)
403526.
5d(1)
392778.
5s(1)
414675.
2s2p6d(2)
401787
5(2)
403374.
5(3)
381086.
4d(1)
377687.
4(2)
380782.
4(3)
373046.2
4(0)
365723.9
4(1)
370900.6
4(2)
3586674
4s(1)
332777.1
3d(1)
3318202
3(3)
3247342.2
3(2)
3065848
3(2)
2982894
2p⁴(2)
3433026?
2p⁴(0)
3138101.07
3(0)
2095662
3(1)
27308007
3s(1)
2104585
2s2p³(1)
1870494
2s2p³(2)
431835
2(0)
202710
2(2)
KEY
1870494
2s2p³(2)
J
Configuration
Energy Level (cm⁻¹)
Ionization Level
443086 cm⁻¹
(54.934 electron volts)
nl = 2s²2p(²P°)nl
n'l' = 2s 2p²(²D) n'l'
[O III 2p² ³P₀ → O IV 2p ²P°½]
450x10³
410x10³
370x10³
330x10³
290x10³
220x10³
180x10³
40x10³
20x10³
ENERGY (cm⁻¹)

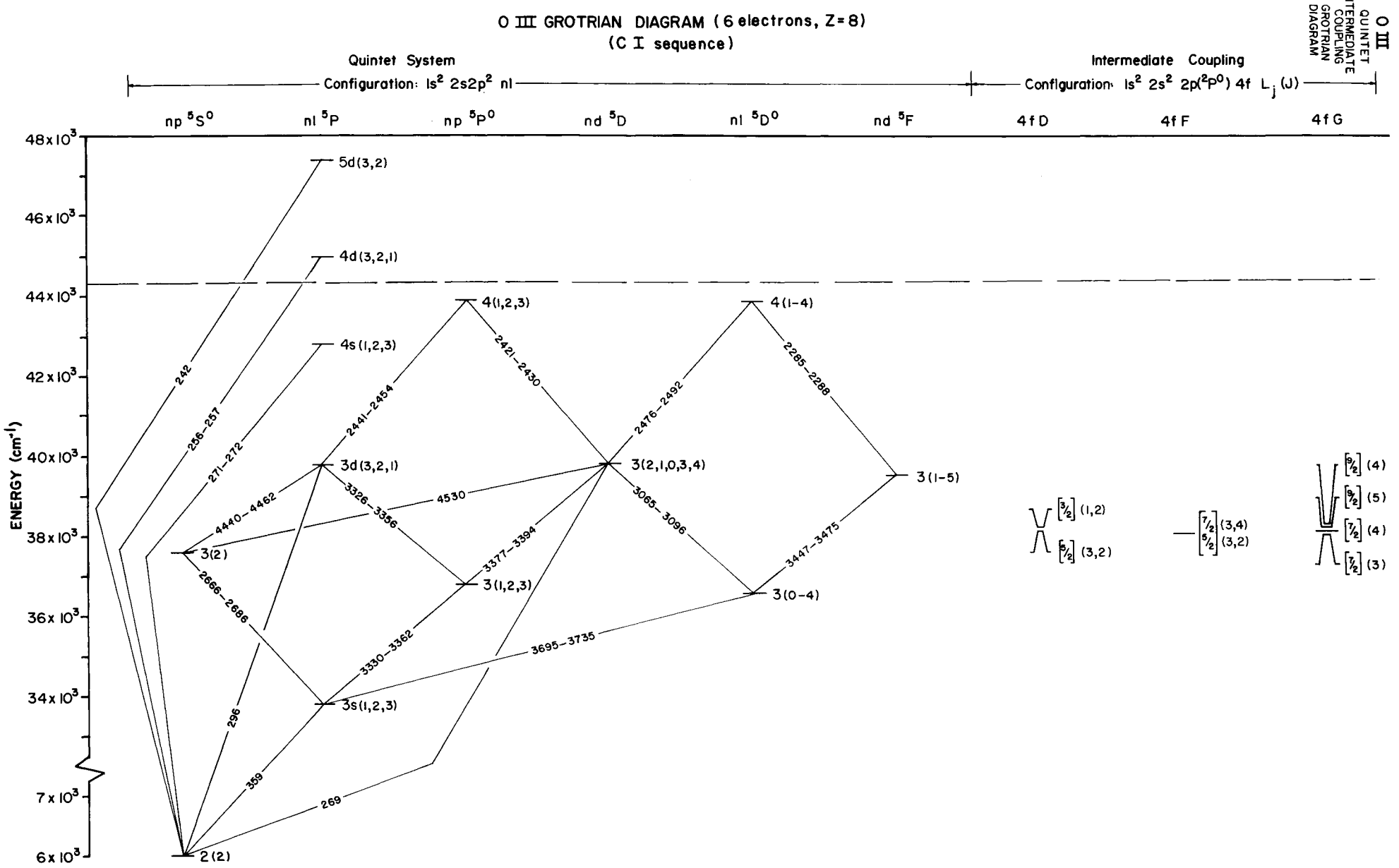
O III
TRIPLET
GROTRIAN
DIAGRAM



O III ENERGY LEVELS (6 electrons, Z = 8)

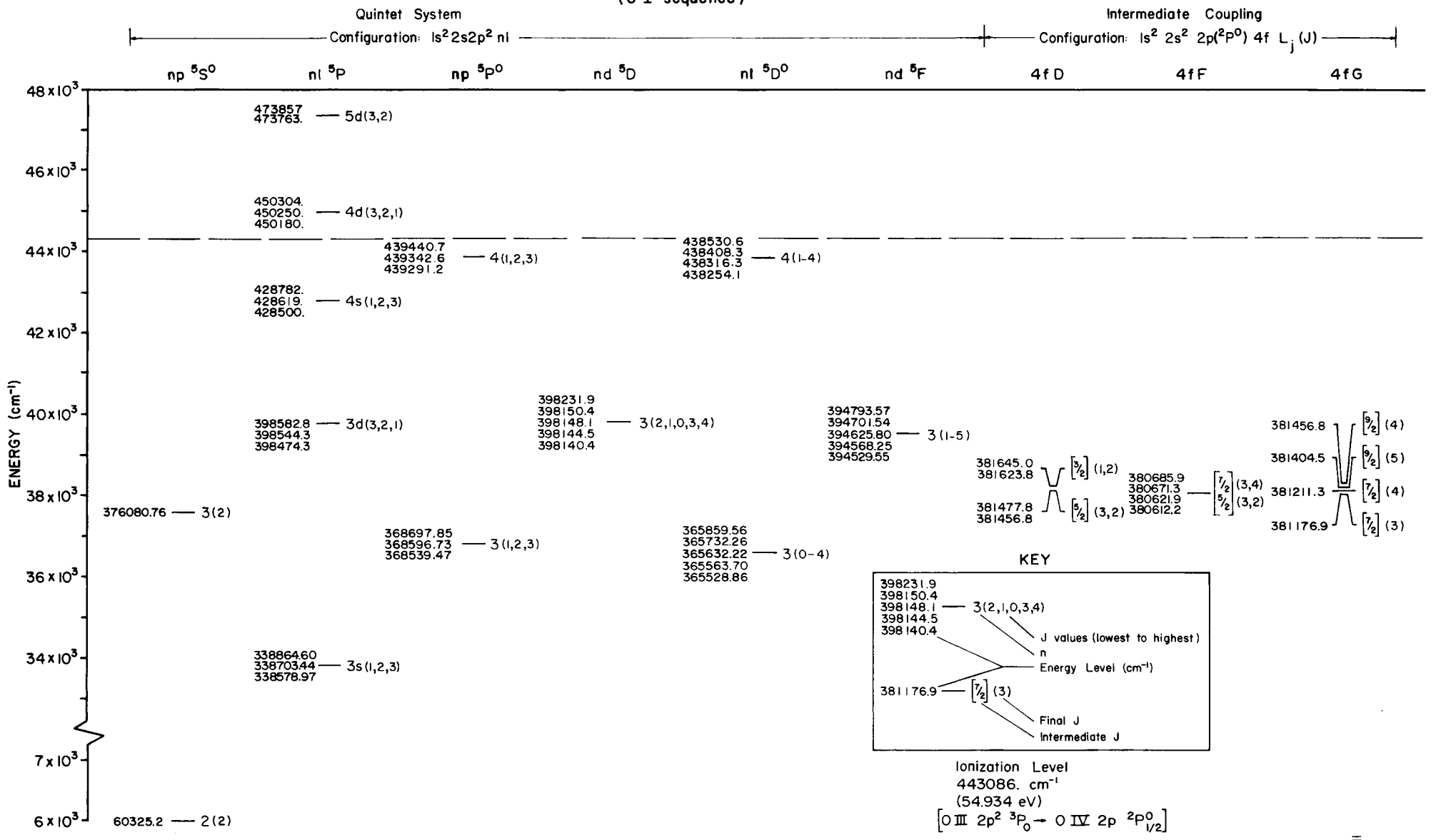
(C I Sequence, Configuration $1s^2nl\,n'l'$, Triplet System)




O III GROTRIAN DIAGRAM (6 electrons, Z=8)
(C I sequence)
Quintet System
Configuration: $1s^2\ 2s2p^2\ nl$
Intermediate Coupling
Configuration: $1s^2\ 2s^2\ 2p(^2P^0)\ 4f\ L_j\ (J)$
O III
QUINTET
INTERMEDIATE
COUPLING
GROTRIAN
DIAGRAM
np $^5S^0$
nl ^5P
np $^5P^0$
nd ^5D
nl $^5D^0$
nd ^5F
4f D
4f F
4f G
ENERGY (cm^{-1})
48x10^3
46x10^3
44x10^3
42x10^3
40x10^3
38x10^3
36x10^3
34x10^3
7x10^3
6x10^3
5d(3,2)
4d(3,2,1)
4s(1,2,3)
3d(3,2,1)
3(2)
3s(1,2,3)
2(2)
4(1,2,3)
3(1,2,3)
4(1-4)
3(2,1,0,3,4)
3(0-4)
3(1-5)
242
256-257
271-272
4440-4462
2666-2686
296
359
269
2441-2454
3326-3356
3330-3362
2421-2430
4530
3377-3394
2476-2492
3065-3096
3695-3735
2285-2288
3447-3475
[3/2] (1,2)
[5/2] (3,2)
[7/2] (3,4)
[5/2] (3,2)
[9/2] (4)
[9/2] (5)
[7/2] (4)
[7/2] (3)

O III ENERGY LEVELS (6 electrons, Z=8)

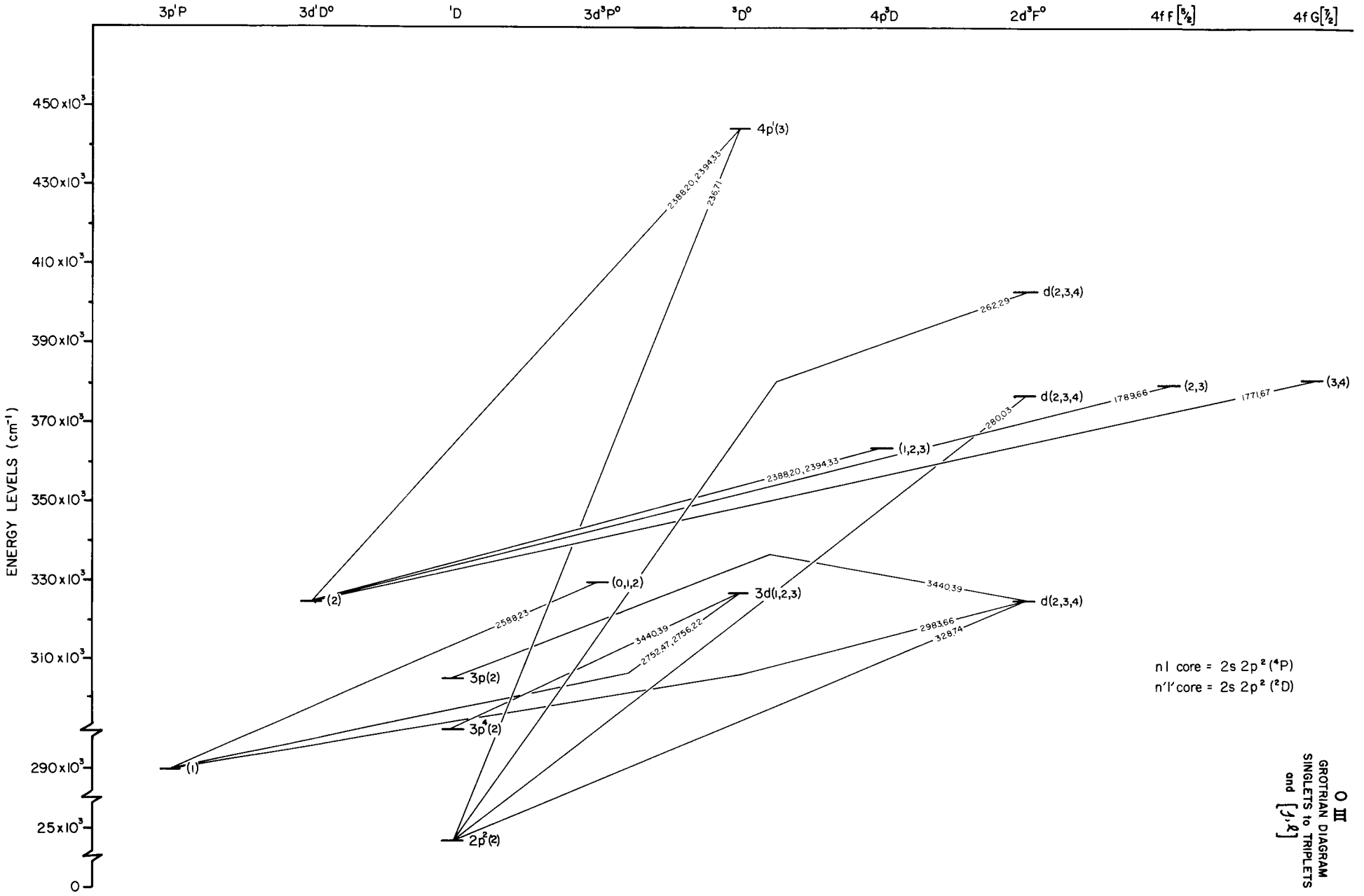
(C I sequence)



O III
QUINTET
INTERMEDIATE COUPLING

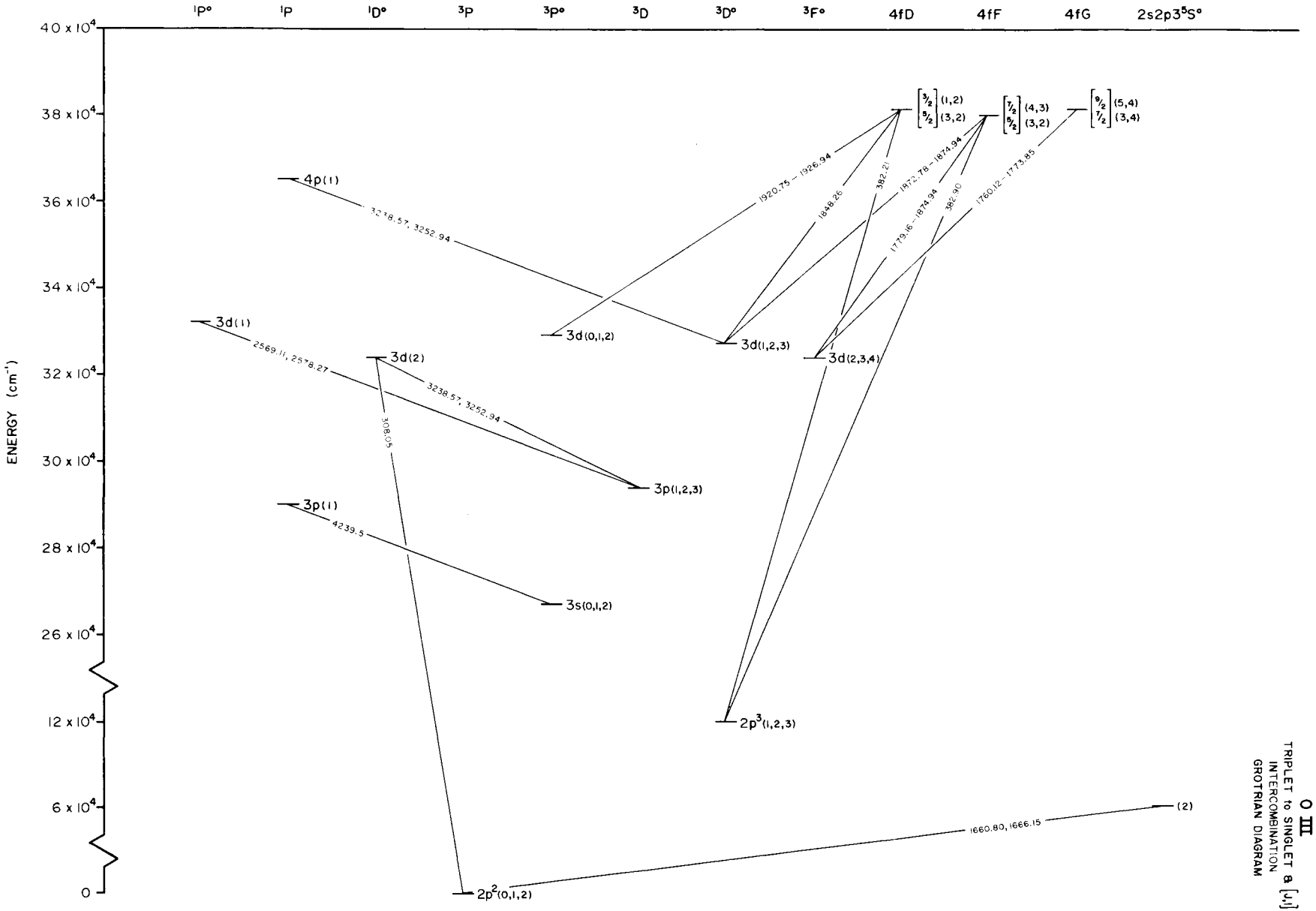
O III GROTRIAN DIAGRAM (6 electrons, Z=8)

(C I sequence, Intercombination: Singlet to Triplet and [J,J] Terms)



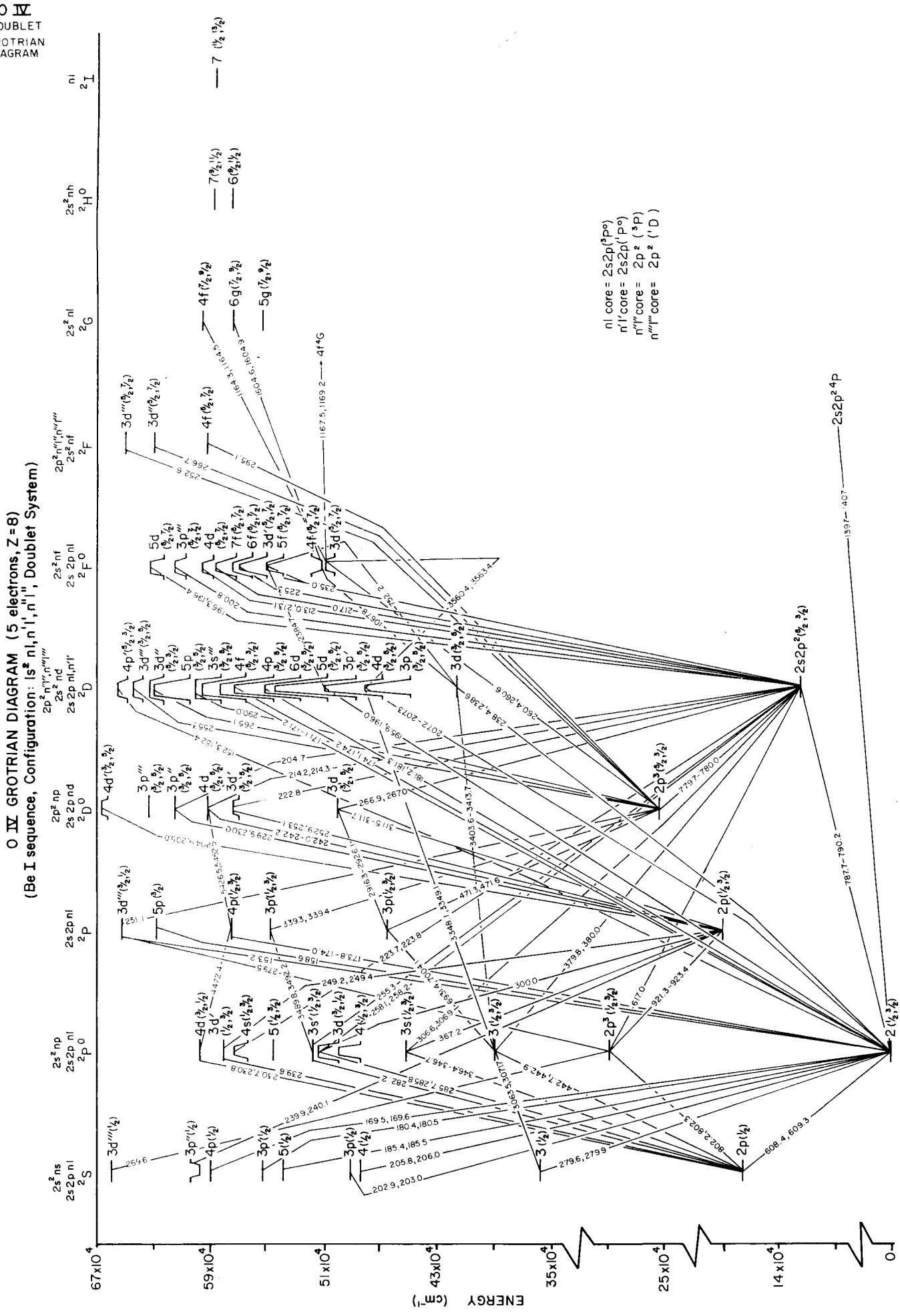
O III GROTRIAN DIAGRAM SINGLETS to TRIPLETS and [J,J]

O III (6 electrons, Z = 8)
(TRIPLET to SINGLET & [J,l] SYSTEMS)
INTERCOMBINATION GROTRIAN DIAGRAM



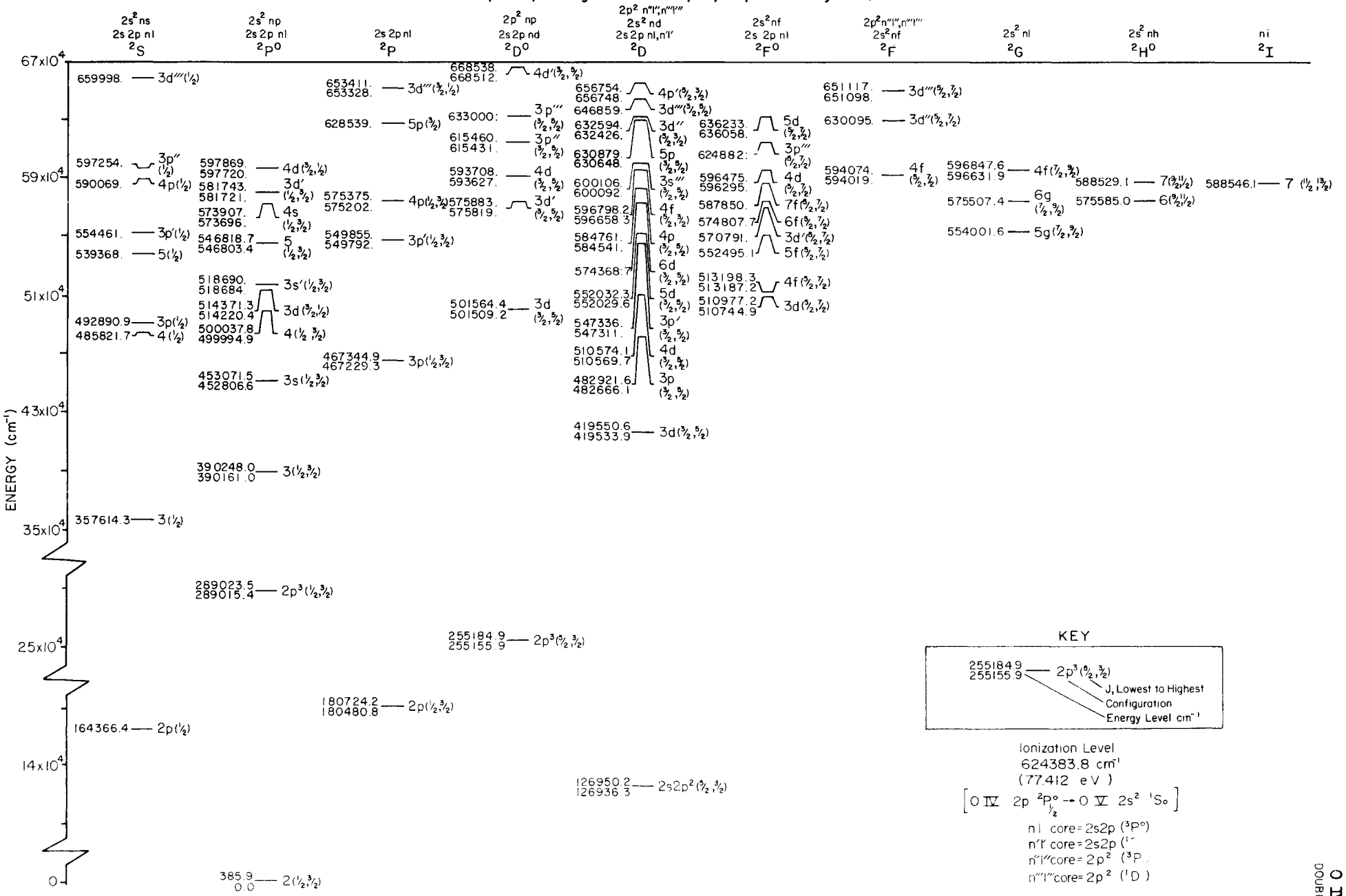
O III
TRIPLET to SINGLET & [J,l]
INTERCOMBINATION
GROTRIAN DIAGRAM

O IV
DOUBLET
GROTRIAN
DIAGRAM



O IV ENERGY LEVELS (5 electrons, Z=8)

(Be I sequence, Configuration: $1s^2\,nl, n'l', n''l''$, Doublet System)



KEY

2551849 — $2p^3(5/2,3/2)$
255155.9

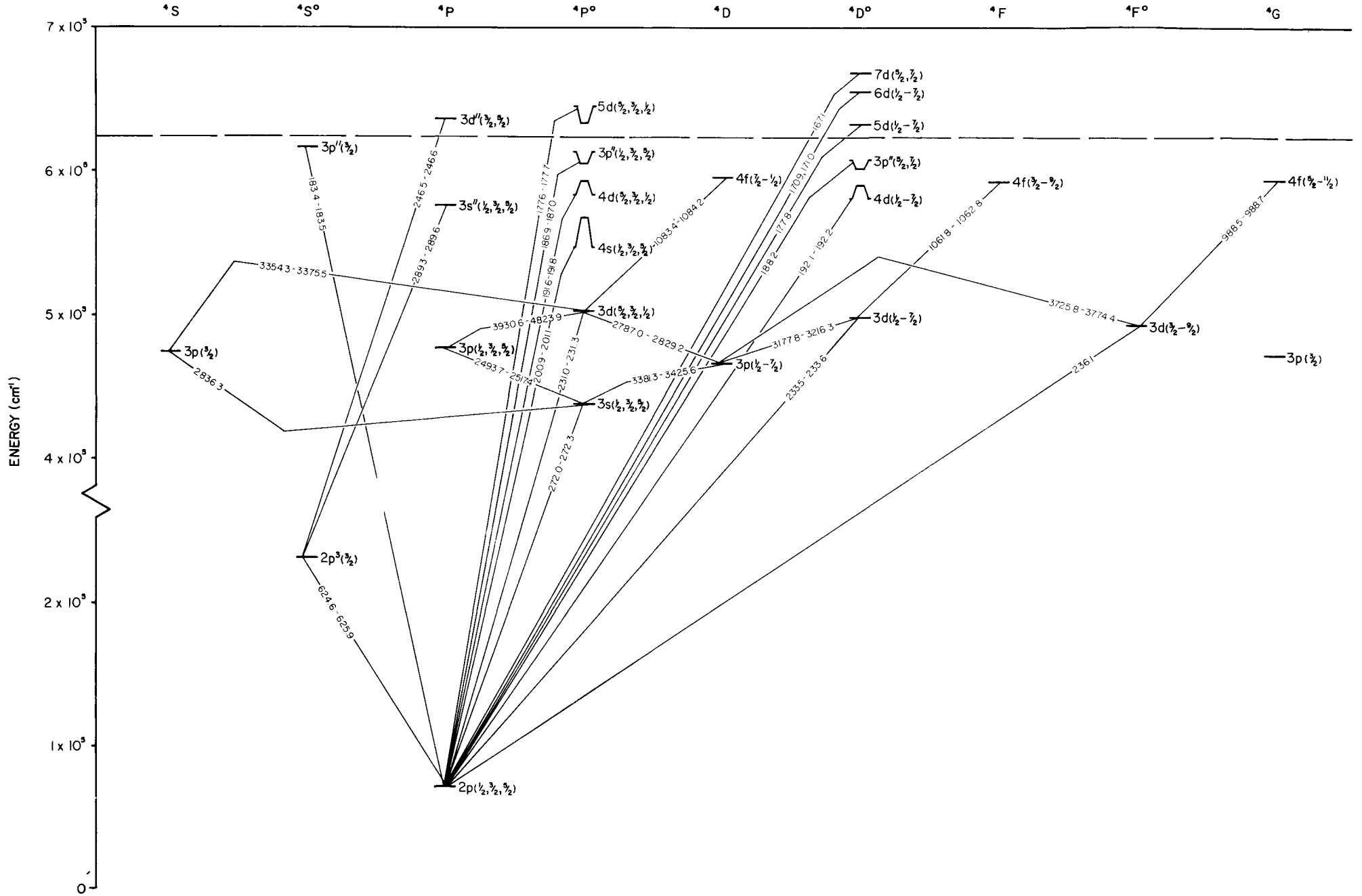
J, Lowest to Highest
Configuration
Energy Level cm⁻¹

Ionization Level
624383.8 cm⁻¹
(77.412 eV)
[O IV 2p ²P°½ → O V 2s² ¹S₀]

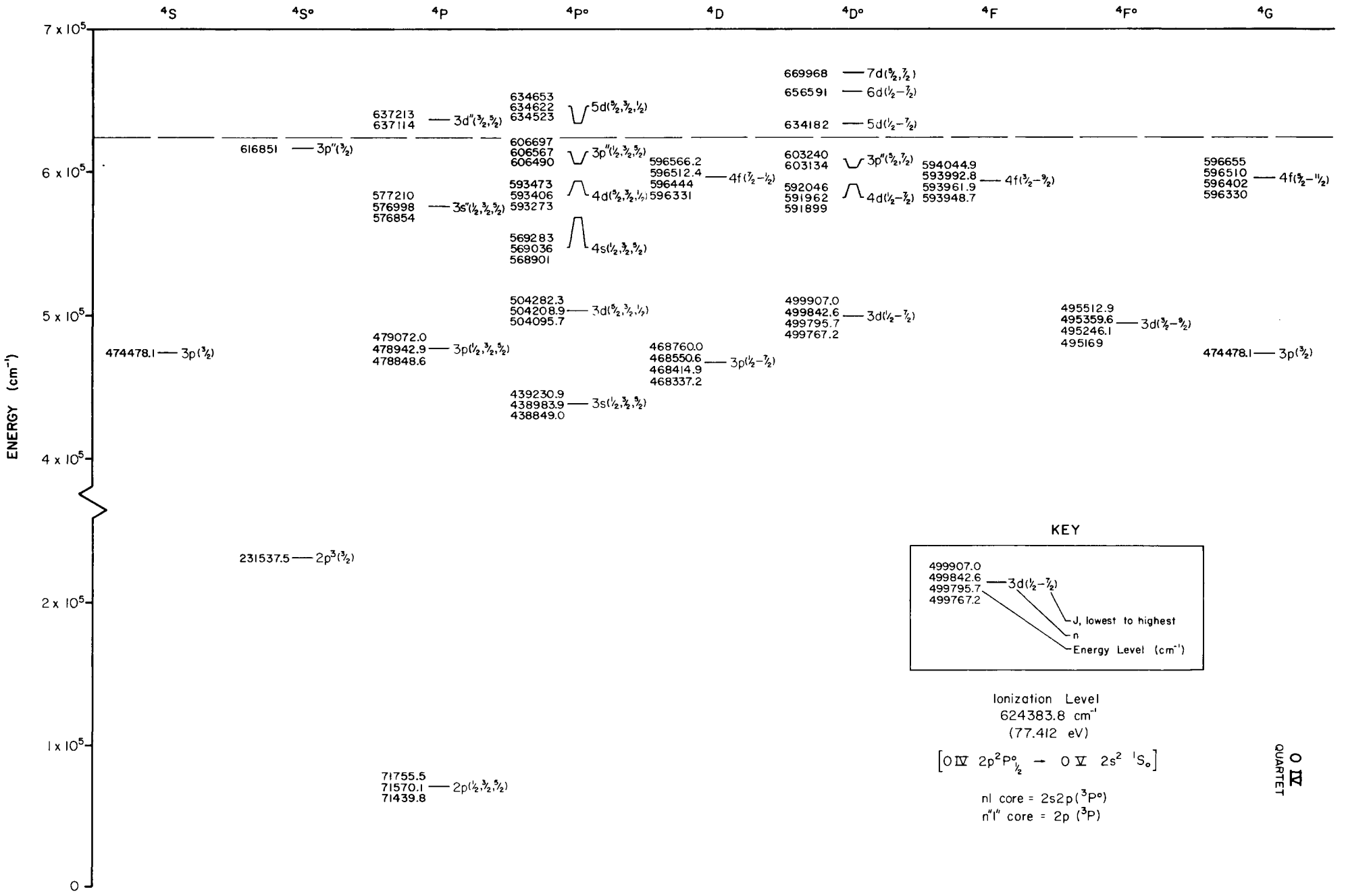
n l core = 2s2p (³P°)
n'l' core = 2s2p (¹
n''l'' core = 2p² (³P
n'''l''' core = 2p² (¹D)

O IV
DOUBLET

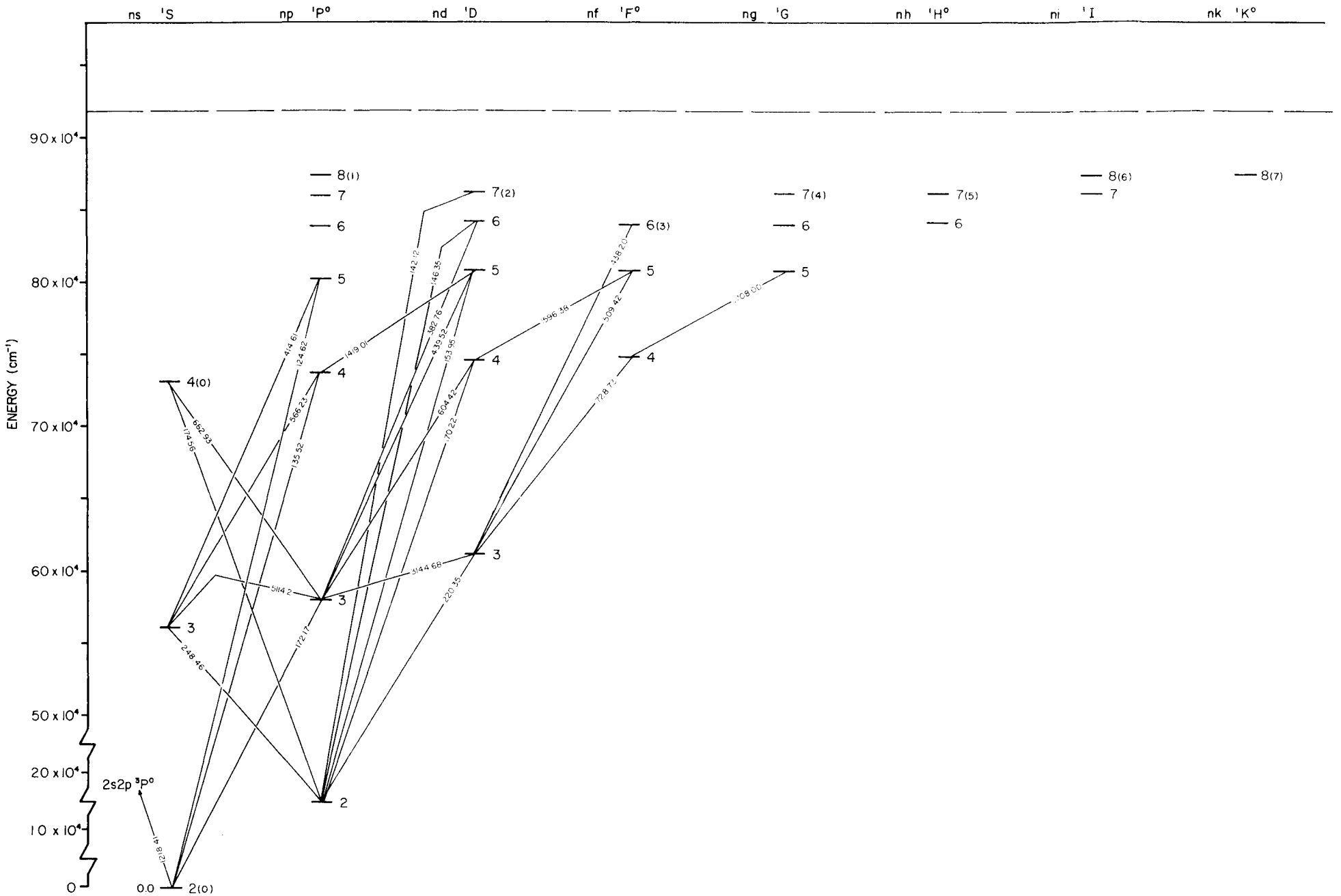
O IV GROTRIAN DIAGRAM (5 electrons, Z=8)
(Configuration: $1s^2nl\ n'l'\ n''l''$, Quartet System)
(B I sequence)



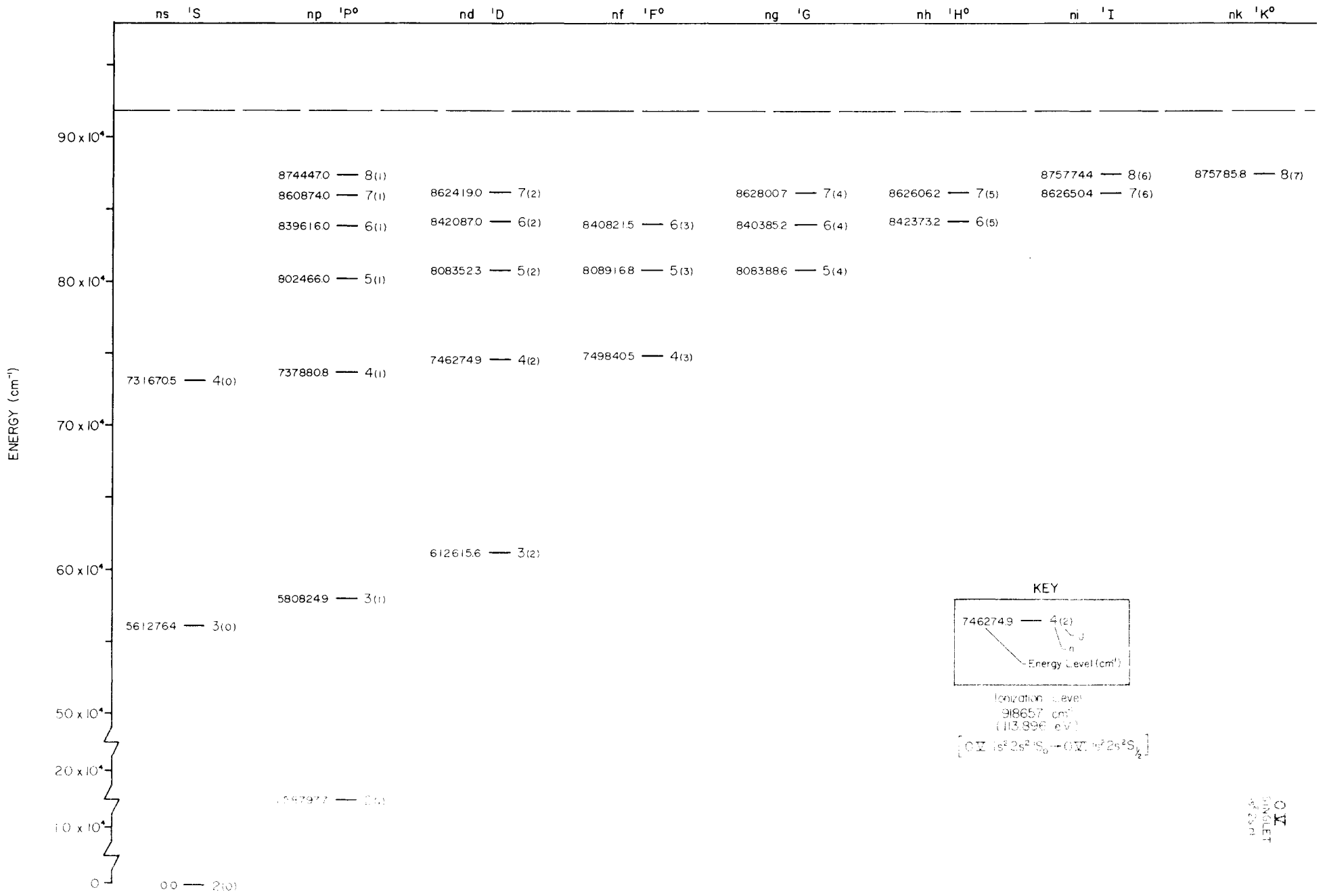
O IV ENERGY LEVELS (5 electrons, Z=8)
(Configuration: $1s^2 nln'l'n''l''$, Quartet System)
(B I sequence)

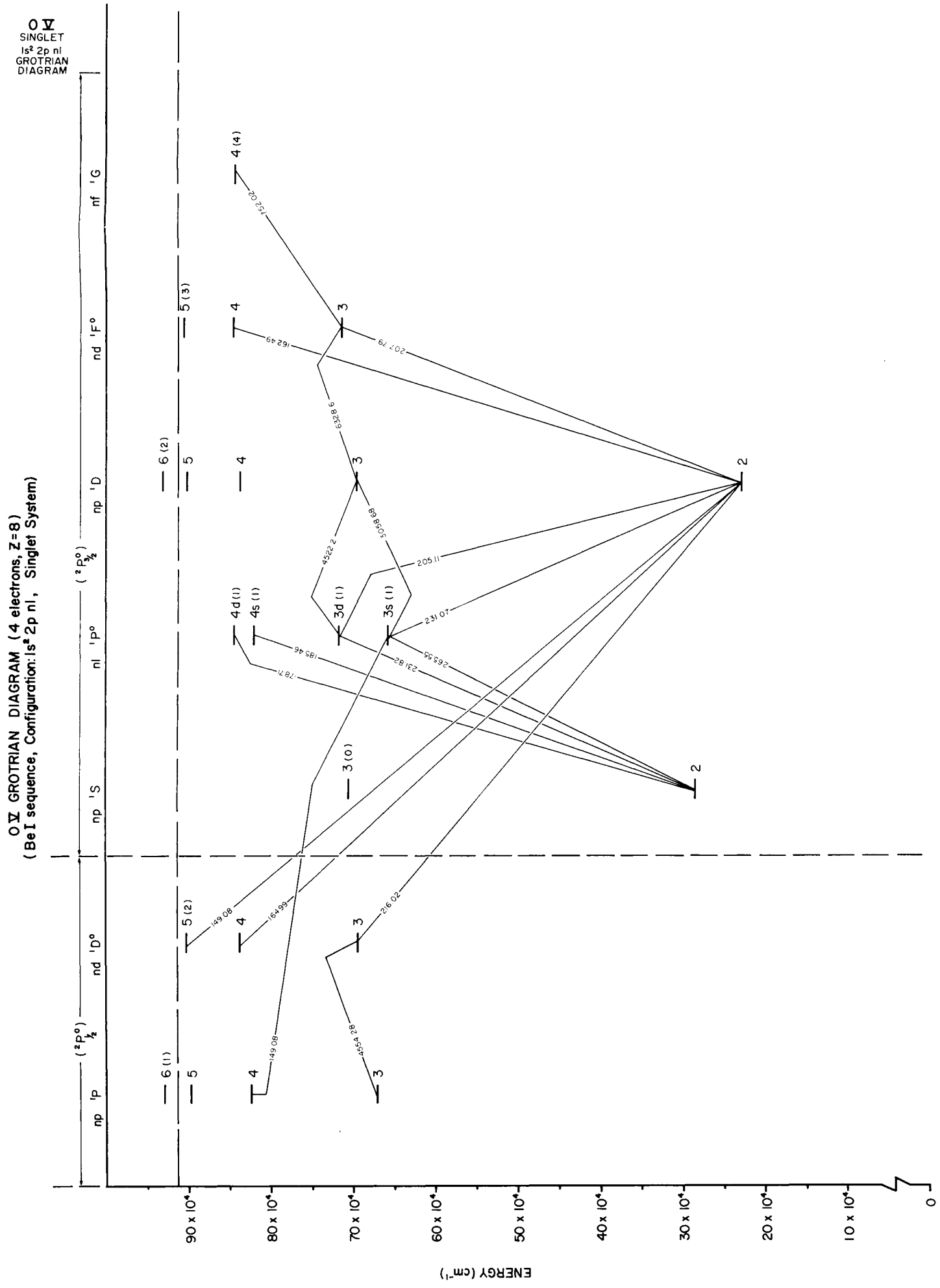


O V GROTRIAN DIAGRAM (4 electrons, Z = 8)
(Be I sequence, Configuration: $1s^2\,2s\,nl$, Singlet System)

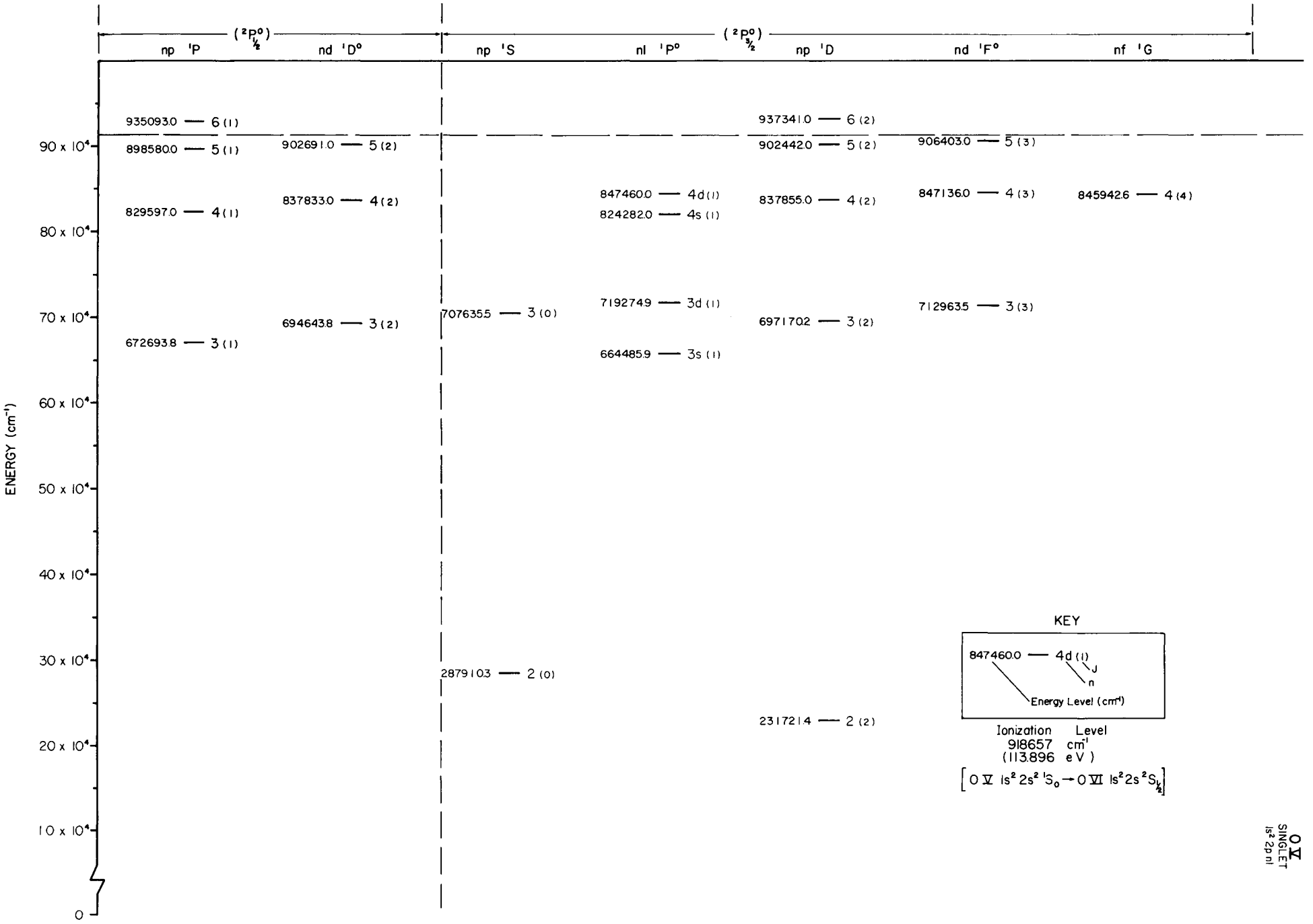


O V ENERGY LEVEL (4 electrons, Z=8)
(Be I sequence, Configuration: $1s^2\,2s\,nl$, Singlet System)

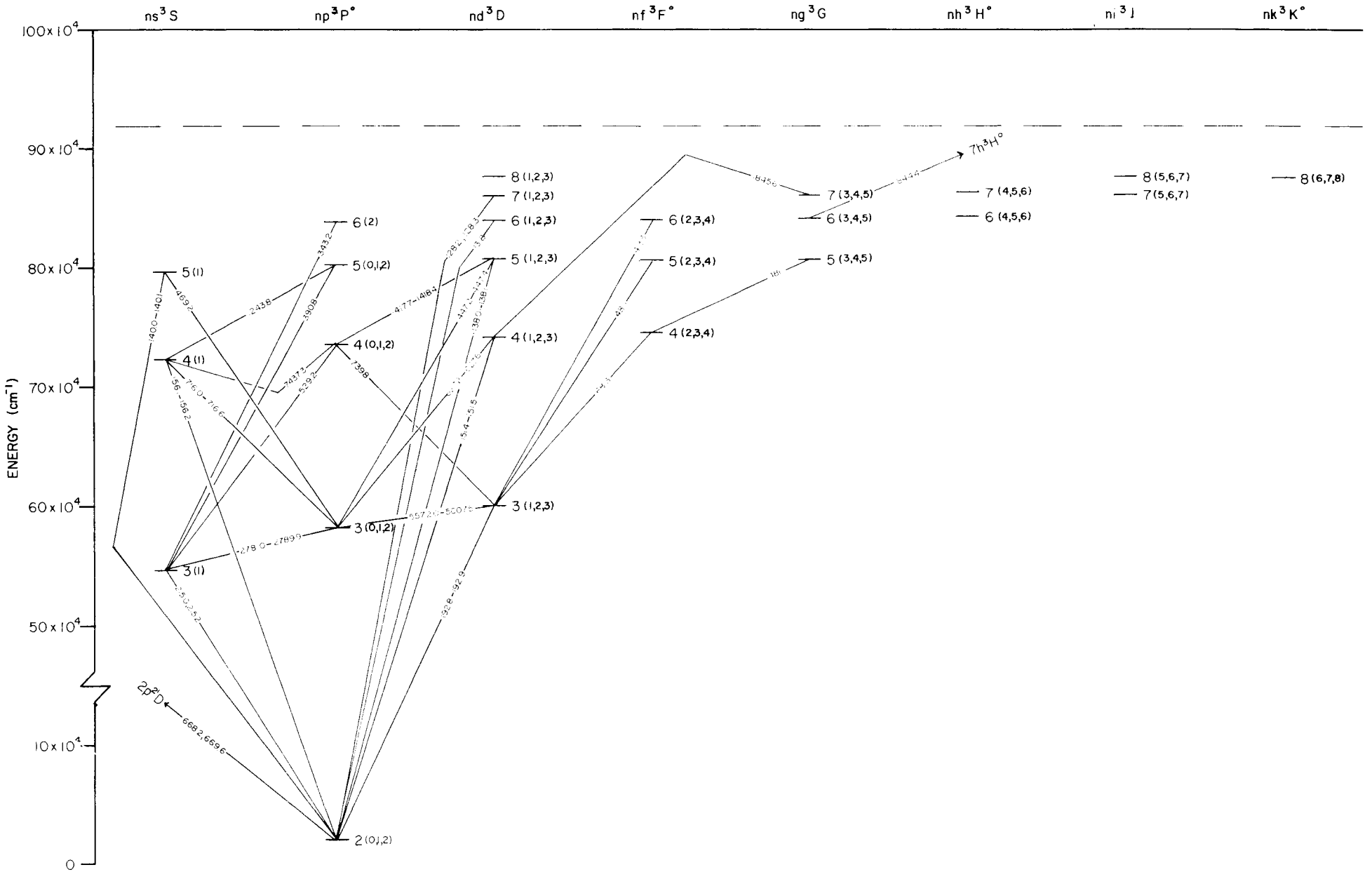



O V
SINGLET
1s² 2p nl
GROTRIAN
DIAGRAM
O V GROTRIAN DIAGRAM (4 electrons, Z=8)
(Be I sequence, Configuration: 1s² 2p nl, Singlet System)
np ¹P
(²P°½)
nd ¹D°
np ¹S
nl ¹P°
(²P°½)
np ¹D
nd ¹F°
nf ¹G
6 (1)
5
4
3
5 (2)
4
3
3 (0)
4d (1)
4s (1)
3d (1)
3s (1)
6 (2)
5
4
5 (3)
4
3
4 (4)
2
2
149.08
149.08
164.99
216.02
4554.28
78.71
185.46
231.82
265.55
231.07
205.11
4522.2
3058.68
6328.9
162.49
207.79
152.02
90 x 10⁴
80 x 10⁴
70 x 10⁴
60 x 10⁴
50 x 10⁴
40 x 10⁴
30 x 10⁴
20 x 10⁴
10 x 10⁴
0
ENERGY (cm⁻¹)

O V ENERGY LEVELS (4 electrons, Z=8)
(Be I sequence, Configuration: $1s^2 2p\,nl$, Singlet System)

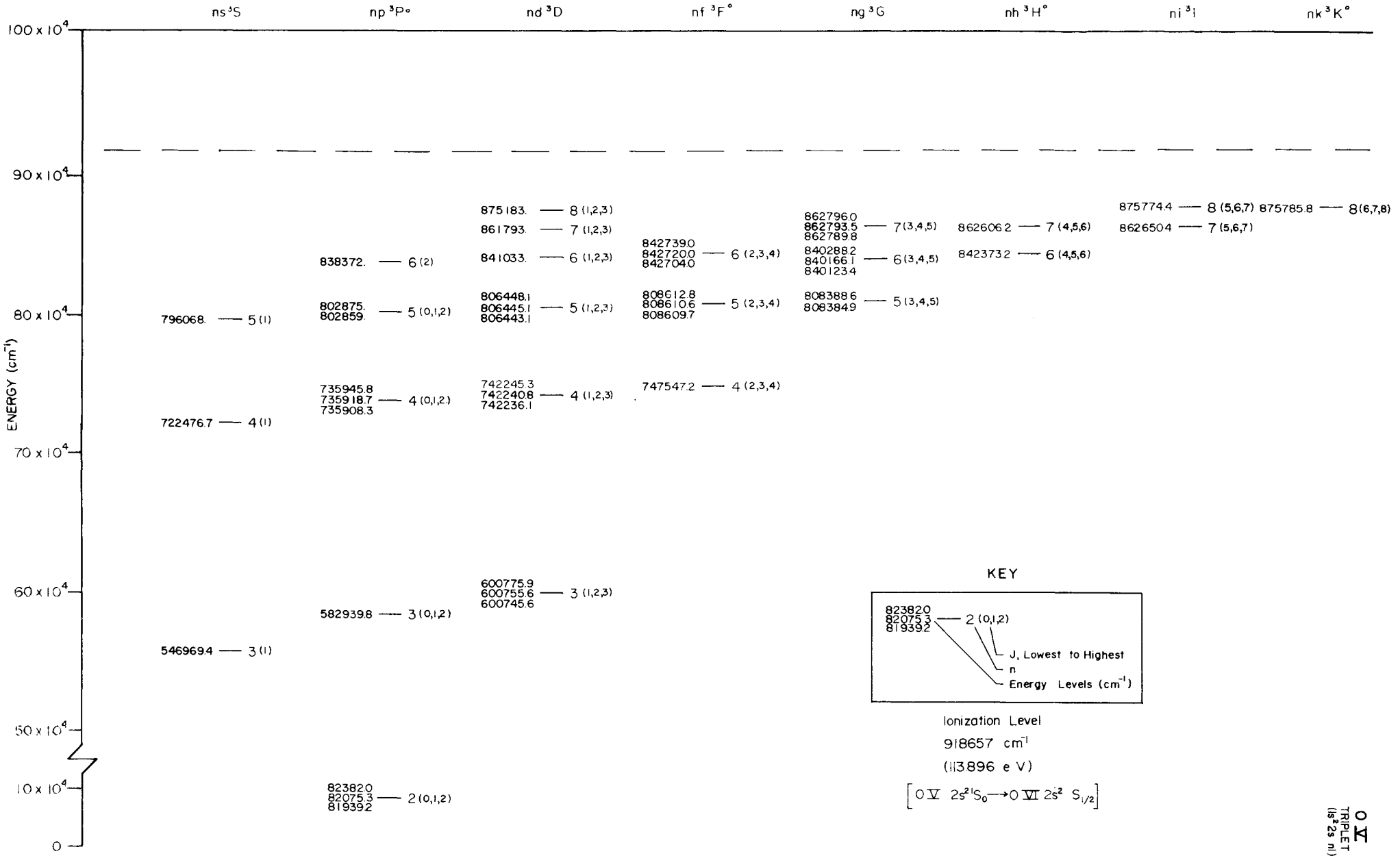


O V GROTRIAN DIAGRAM (4 electrons, Z=8)
(Be I sequence, Configuration: $1s^2 2s\ nl$, Triplet System)

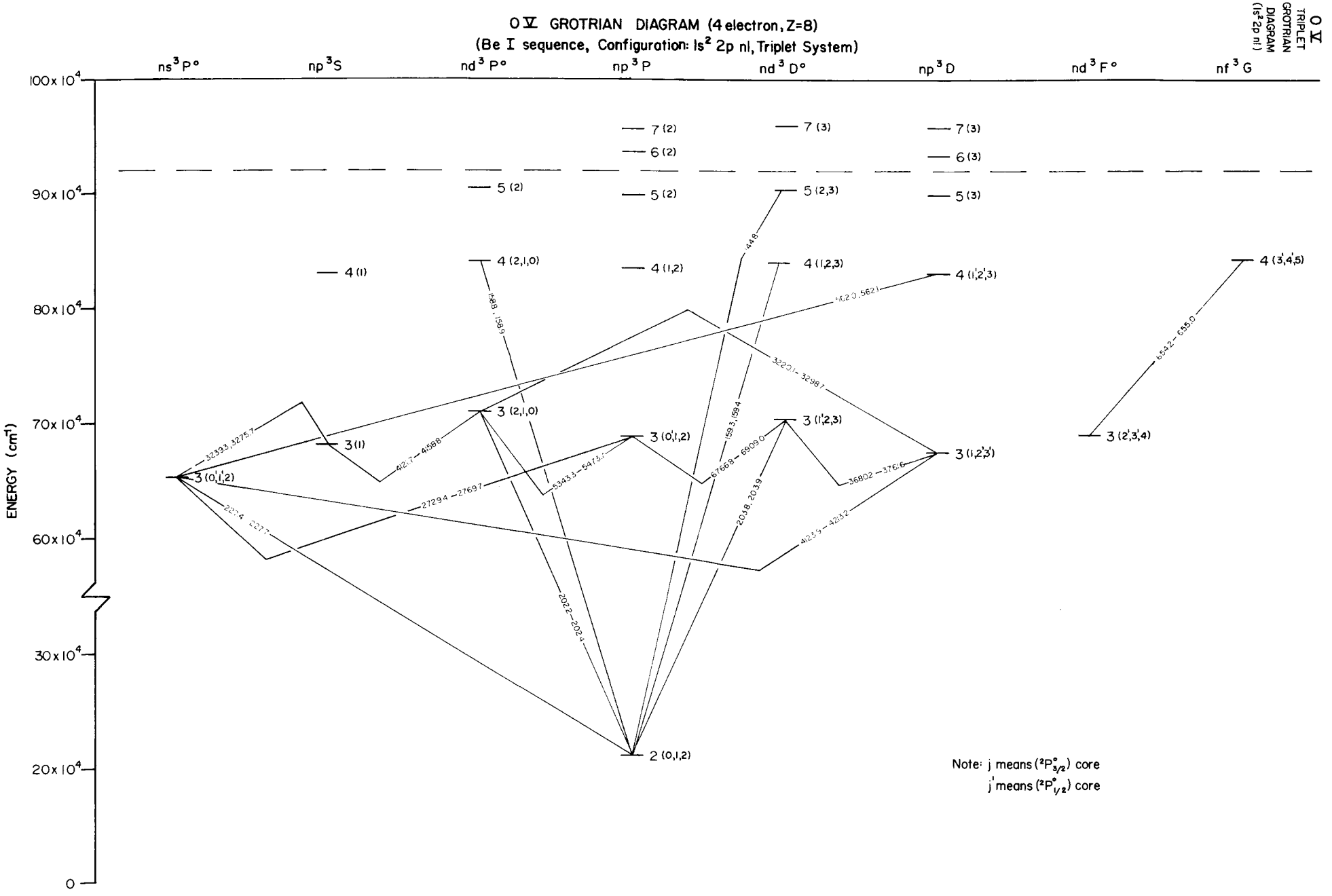


O V ENERGY LEVELS (4 electrons, Z=8)

(Be I sequence, Configuration: $1s^2\ 2s\ nl$, Triplet System)



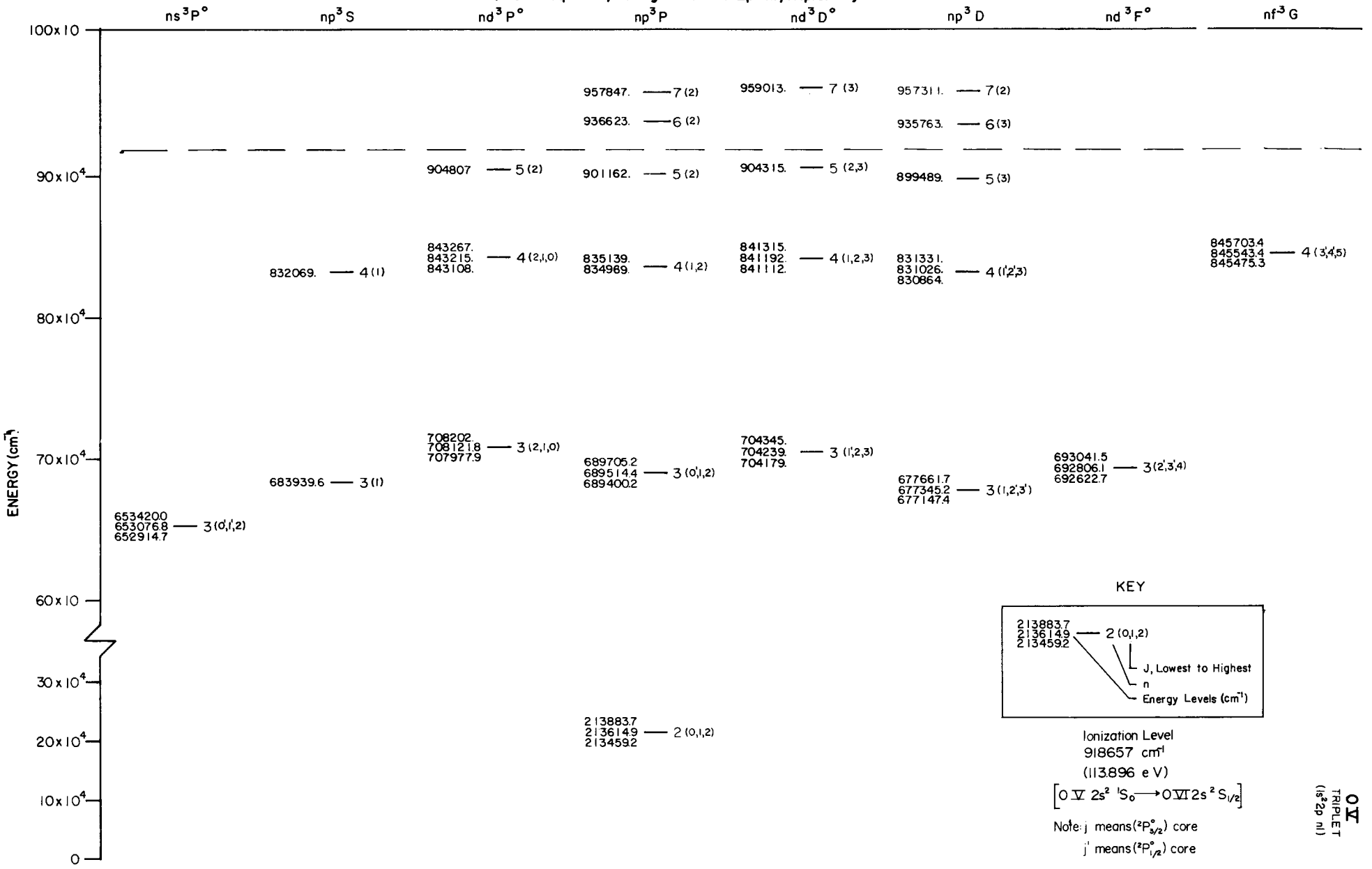
O V
TRIPLET
($1s^2 2s\ nl$)



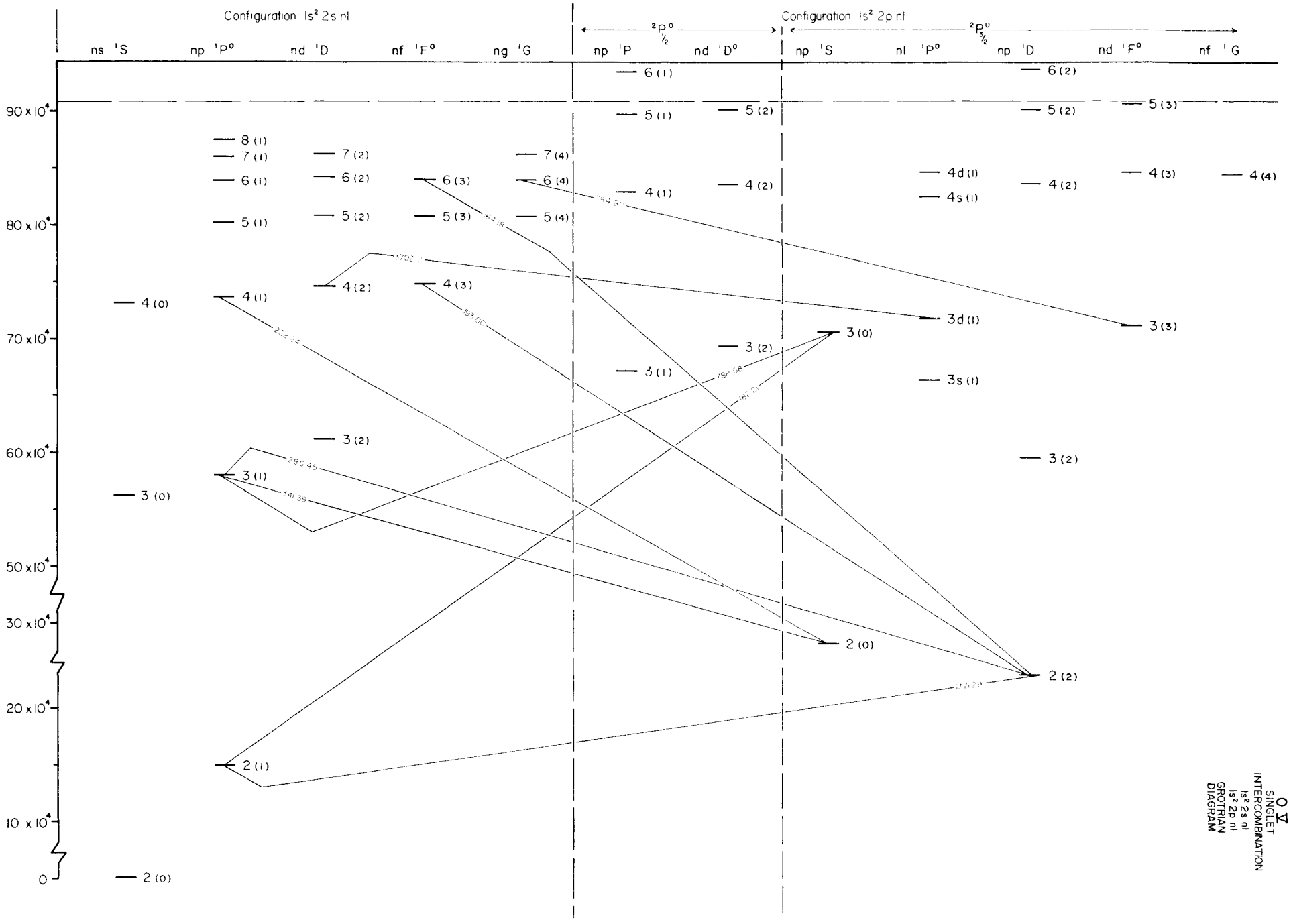
Note: j means ($^2P^\circ_{3/2}$) core
j' means ($^2P^\circ_{1/2}$) core

O V ENERGY LEVELS (4 electrons, Z=8

(Be I sequence, Configuration: $1s^2 2p\ nl$, Triplet System)



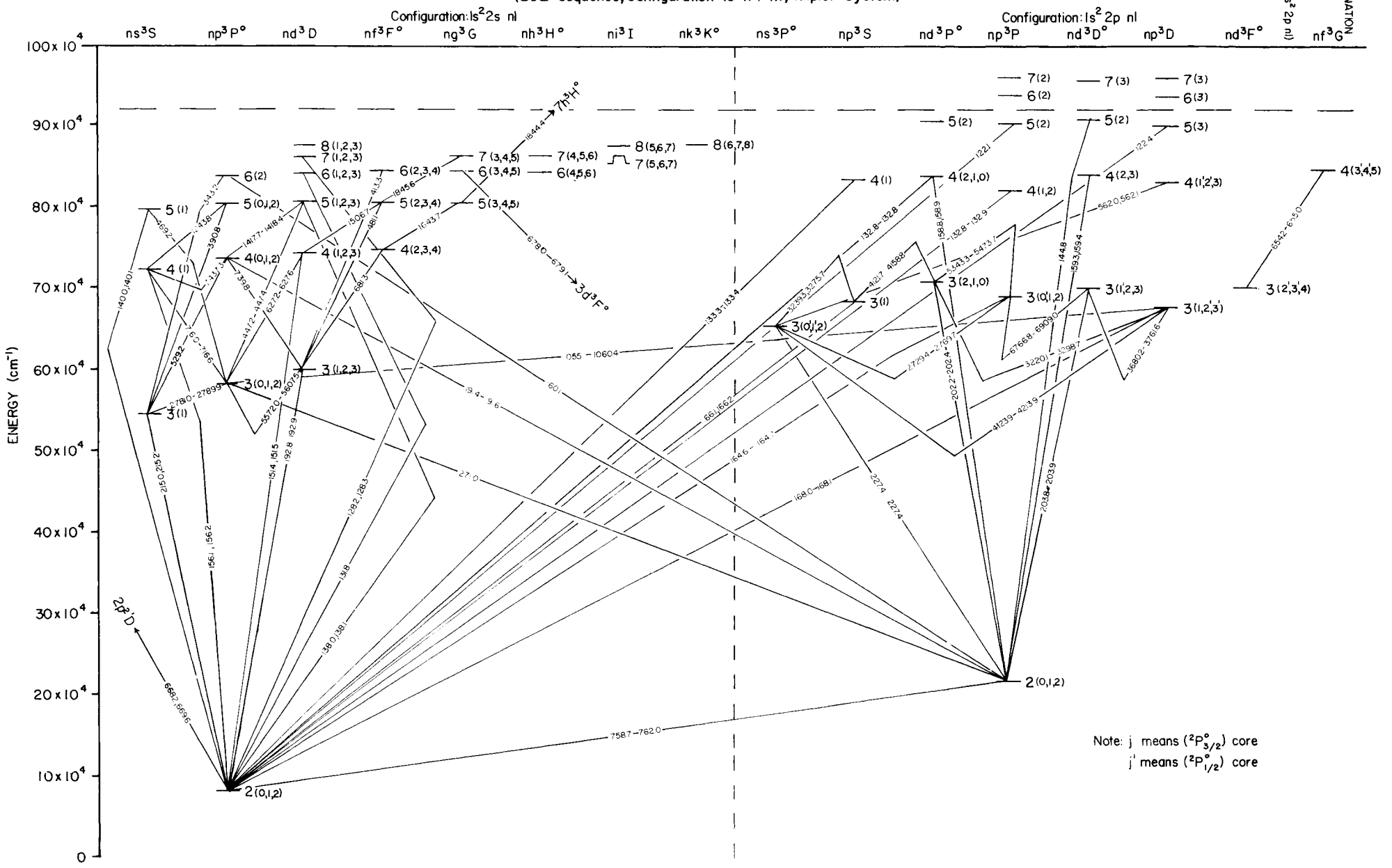
O V GROTRIAN DIAGRAM (4 electrons, Z=8)
(Be I sequence, Configuration: $1s^2 nl\, n'l'$, Intercombination, Singlet System)



O V
SINGLET
INTERCOMBINATION
$1s^2 2s\, nl$
$1s^2 2p\, nl$
GROTRIAN
DIAGRAM

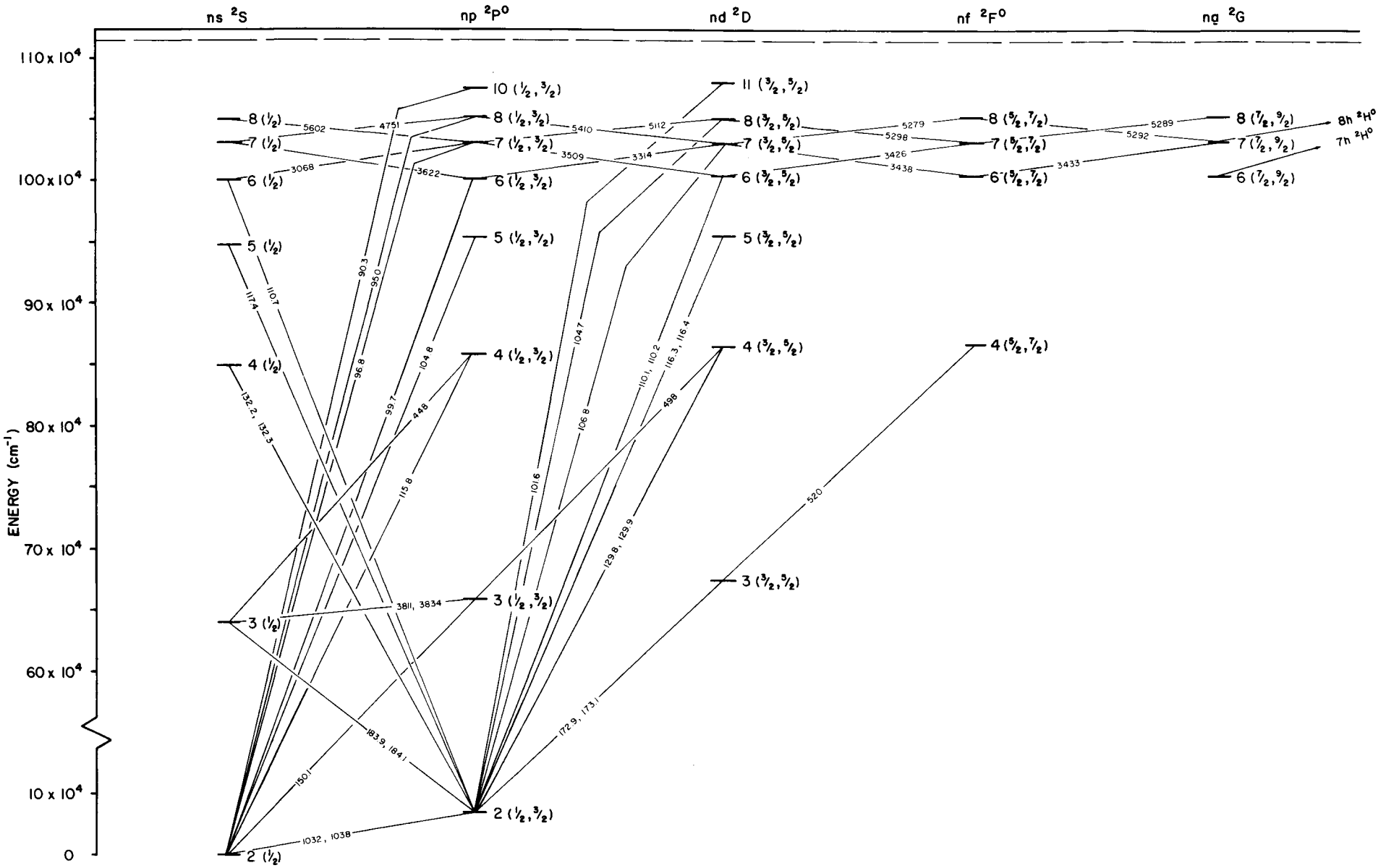
O V INTERCOMBINATION GROTRIAN DIAGRAM (4 electrons, Z=8)

(Be I sequence, Configuration: $1s^2 n'l'\,nl$, Triplet System)



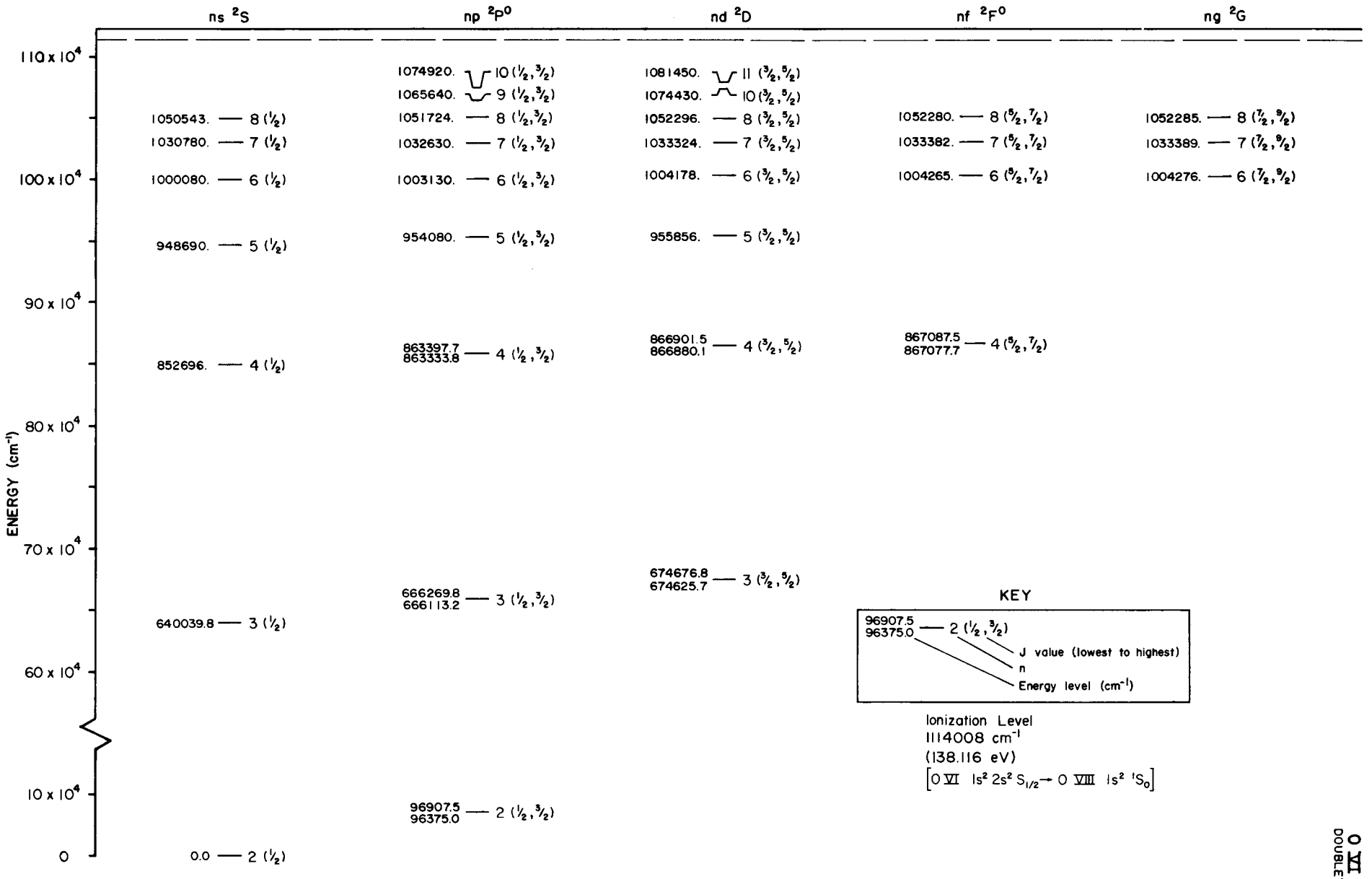
O VI GROTRIAN DIAGRAM (3 electrons, Z=8)

(Li I sequence, Configuration: $1s^2\,nl$, Doublet System)

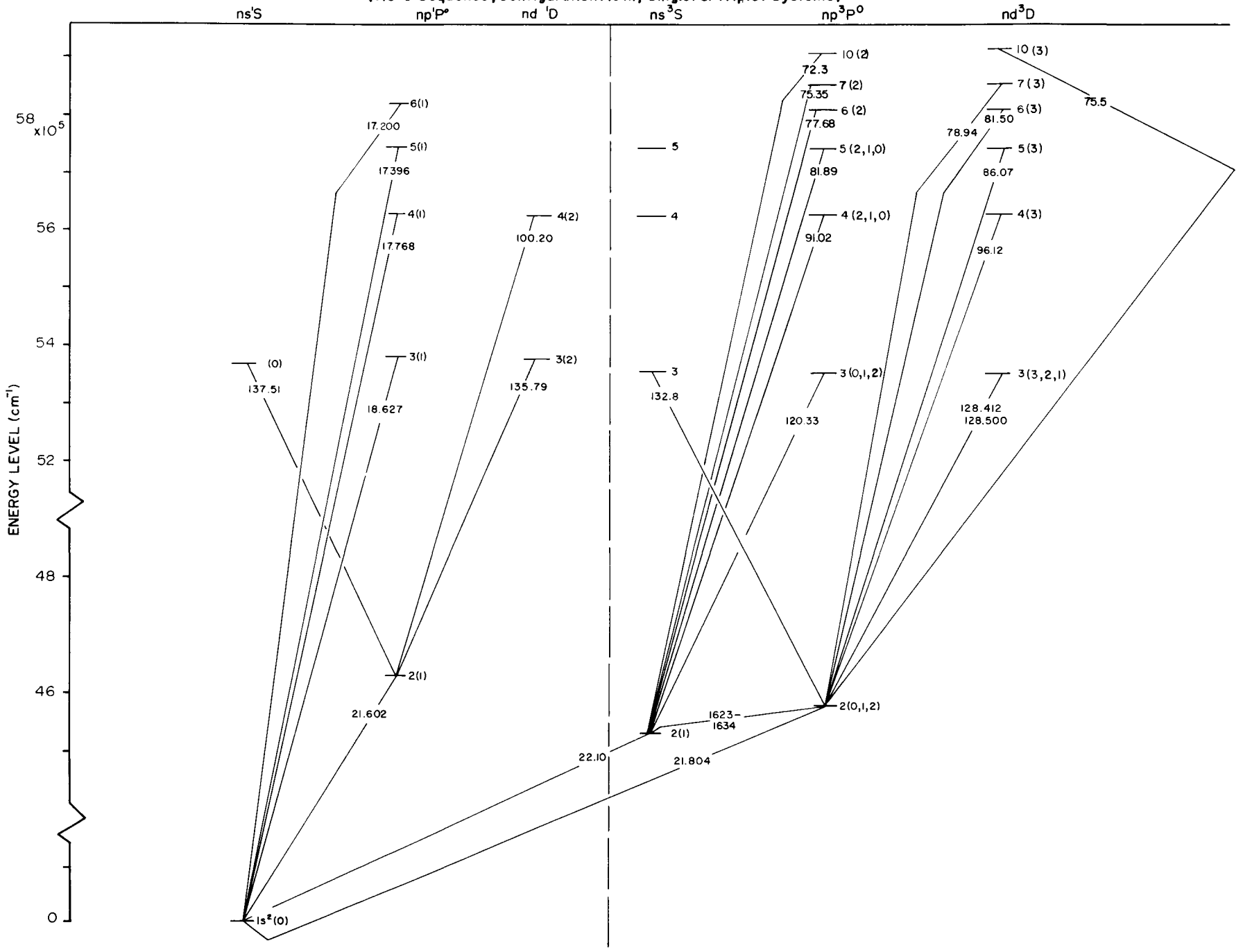


O VI ENERGY LEVELS (3 electrons, Z=8)

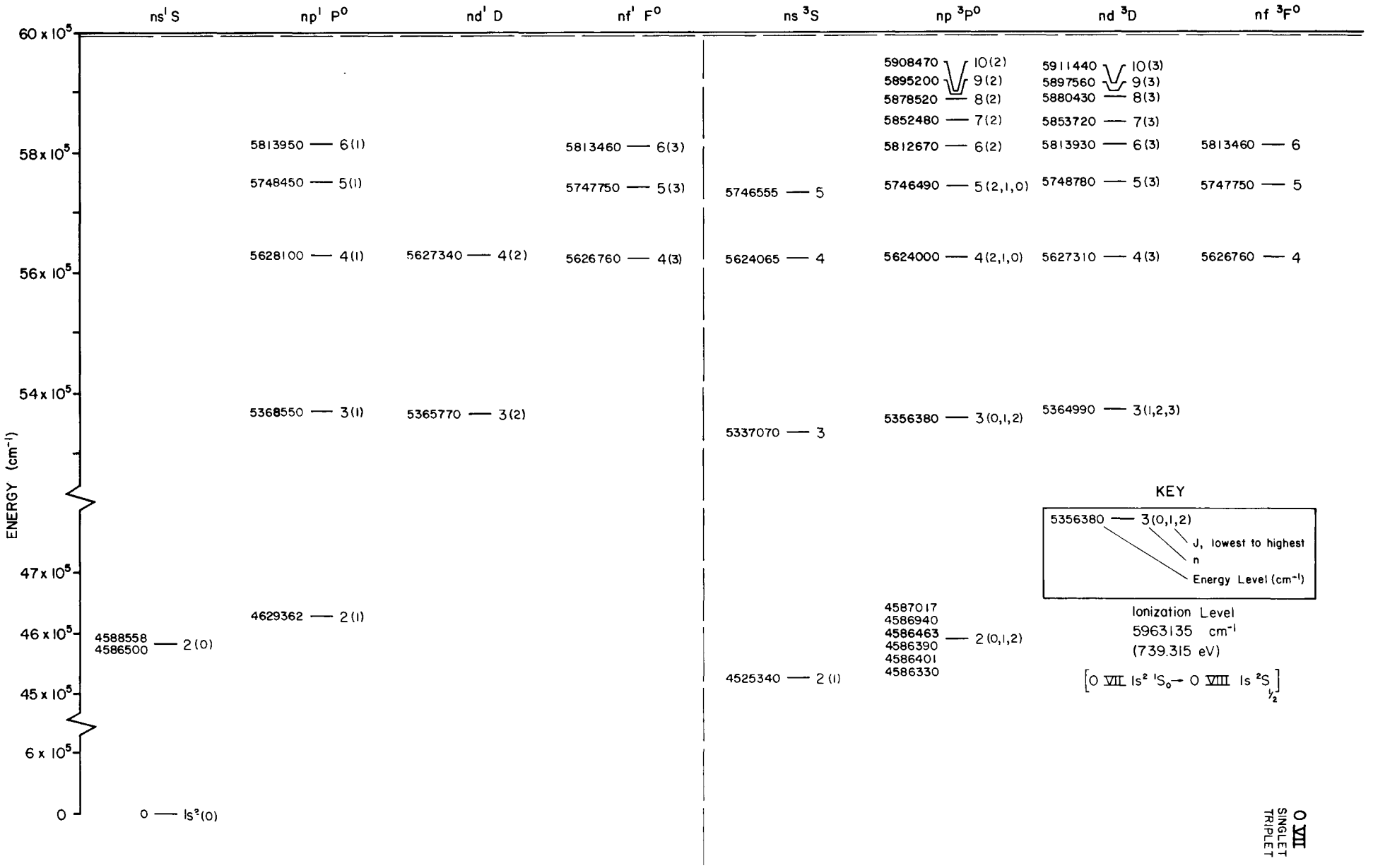
(Li I sequence, Configuration: $1s^2\,nl$, Doublet System)

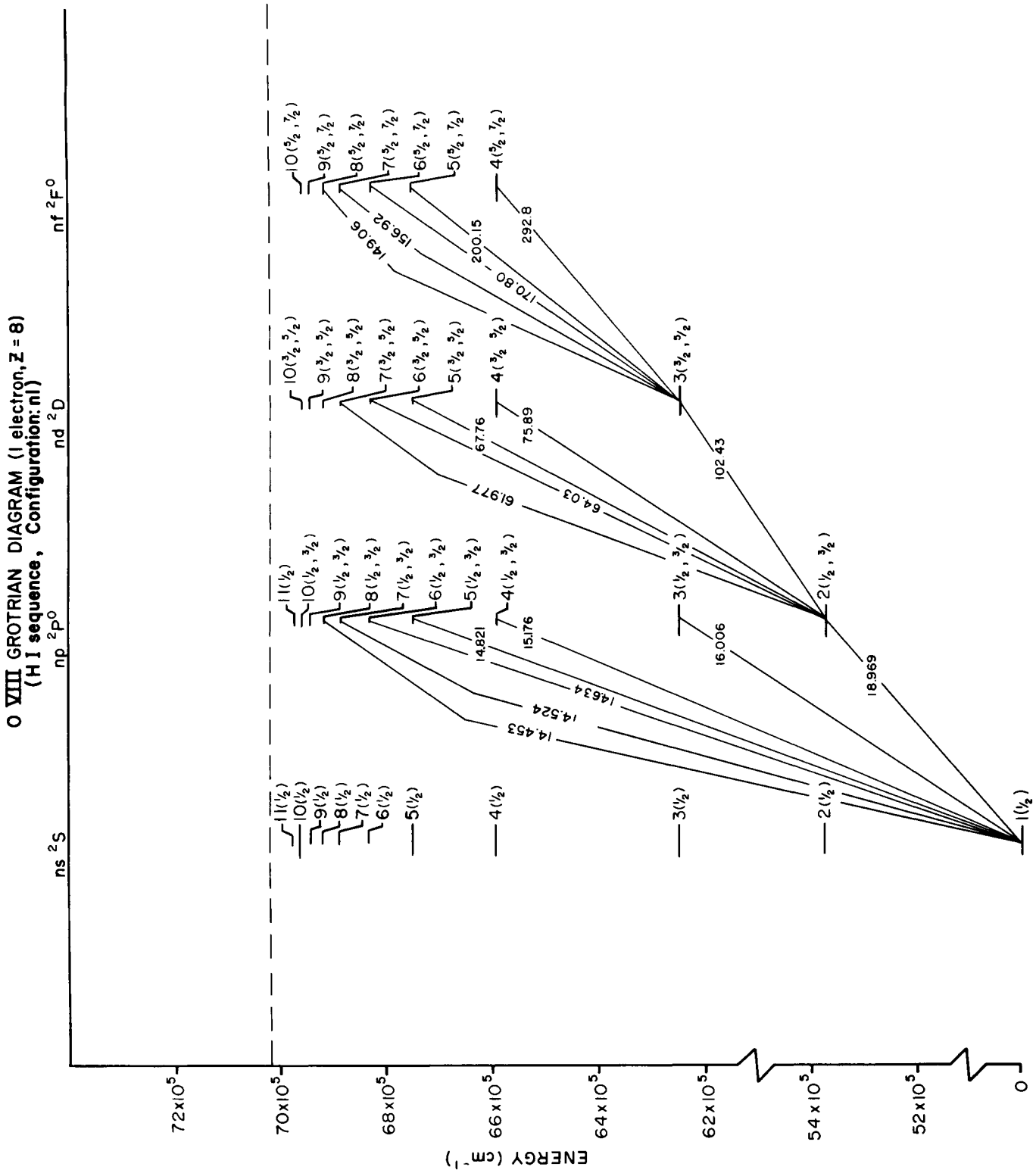


O VII GROTRIAN DIAGRAM (2 electrons, Z = 8)
(He I Sequence, Configuration: 1s nl, Singlet & Triplet Systems)

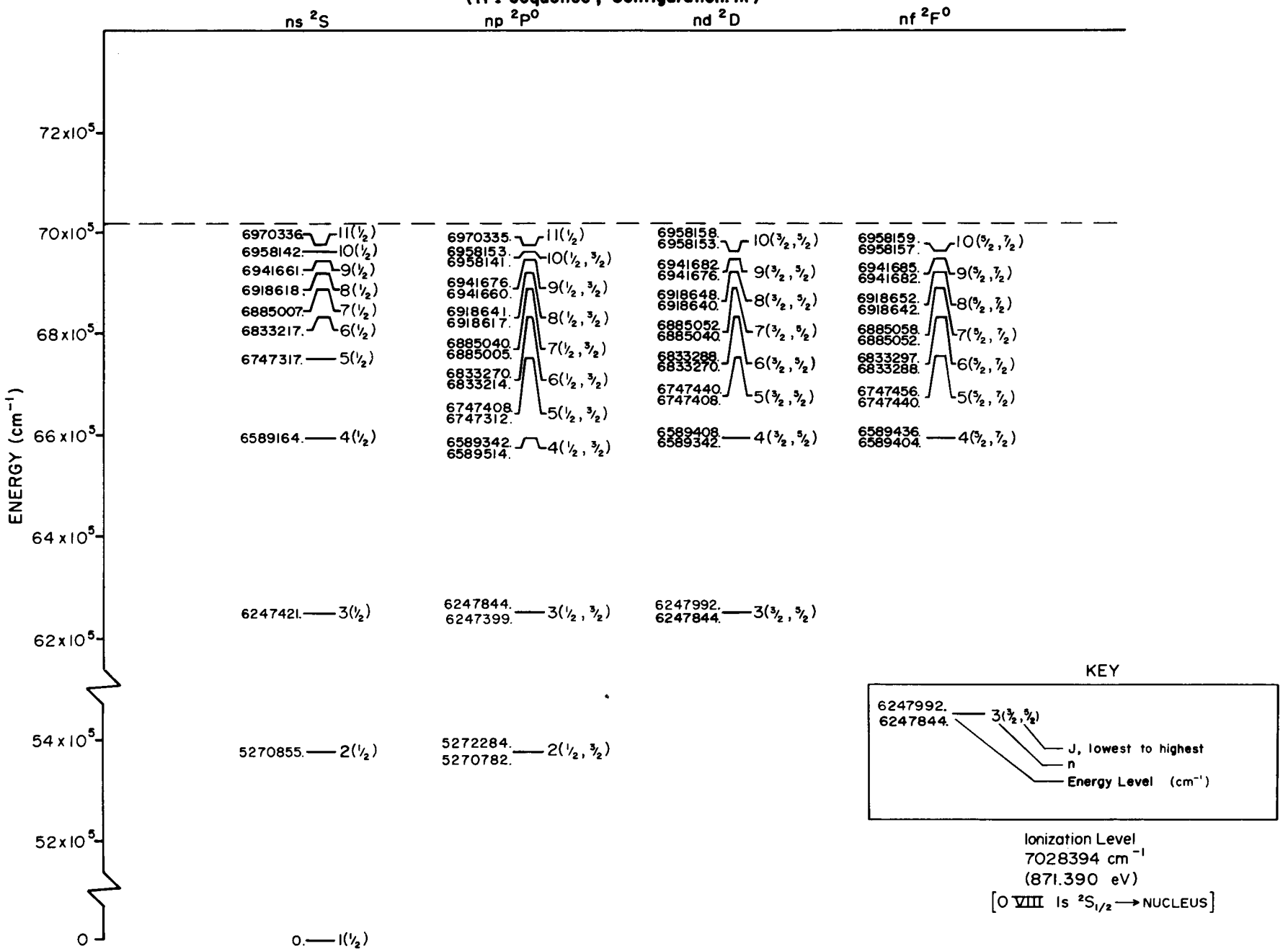


O VII ENERGY LEVELS (2=electrons, Z=8)
(He I Sequence, Configuration: 1s nl, Singlet and Triplet System)




O VIII GROTRIAN DIAGRAM (1 electron, Z = 8)
(H I sequence, Configuration: nl)
ns ²S
np ²P⁰
nd ²D
nf ²F⁰
ENERGY (cm⁻¹)
72x10⁵
70x10⁵
68x10⁵
66x10⁵
64x10⁵
62x10⁵
54x10⁵
52x10⁵
0
14.453
14.524
14.634
14.821
15.176
16.006
18.969
61.977
64.03
67.76
75.89
102.43
149.06
156.92
170.80
200.15
292.8

O VIII ENERGY LEVELS (1 electron, Z = 8)
(H I sequence, Configuration: nl)



O I $Z = 8$ 8 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives transition wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular observations.

K.B.S. Eriksson, Ark. Fys. **30**, 199 (1965).

Author gives observed transition wavelengths and energy levels of the ground configuration.

R.E. Huffman, J.C. Larrabee, and Y. Tanaka, J. Chem. Phys. **46**, 2213 (1967).

Authors give line and energy level tables from observed absorption spectra in the vacuum ultraviolet. Spectrograms and an energy level diagram are included.

Comment on autoionizing triplet levels: The source is Huffman et al., (1967). Correction: Please note that the wavelengths for the transition 3s $^5S^\circ$–3p ^3P should be 6726.28, 6726.54.

O II $Z = 8$ 7 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives transition wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular observations.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give calculated and observed wavelengths of lines in ion gas lasers.

T. Sasaki, N. Kaifu, N. Itoh, K. Sakai, and I. Shimada, Sci. of Light **14**, 142 (1965).

Authors give Grotrian diagrams.

O III $Z = 8$ 6 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives transition wavelengths from nebular observations.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give calculated and observed wavelengths of lines in ion gas lasers.

T. Sasaki, N. Kaifu, N. Itoh, K. Sakai, and I. Shimada, Sci. of Light **14**, 142 (1965).

Authors give Grotrian diagrams.

Comment on intermediate coupling: The system is similar to that for the isoelectronic system, N II. Please see that entry for the details.

O IV $Z = 8$ 5 electrons

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give calculated and observed wavelengths of lines in ion gas lasers.

O V $Z = 8$ 4 electrons

Please see the general references.

O VI $Z = 8$ 3 electrons

Please see the general references.

O VII $Z = 8$ 2 electrons

R.L. Blake, T.A. Chubb, H. Friedman, and A.E. Unzicker, Science **146**, 1037 (1964).

Authors give a table of lines observed in the solar spectrum below 25 Å.

B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

Authors identify spectral lines attributed to O VII.

E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculate energies nonrelativistically for the He I isoelectronic sequence.

G.A. Sawyer, A.J. Bearden, I. Henins, F.C. Jahoda, and F.L. Ribe, Phys. Rev. **131**, 1891 (1963).

Authors give transition wavelengths of lines in the region 15–25 Å from calculations and observations.

O VIII $Z = 8$ 1 electron

R.L. Blake, T.A. Chubb, H. Friedman, and A.E. Unzicker, Science **146**, 1037 (1964).

Authors give a table of lines observed in the solar spectrum below 25 Å.

B.C. Fawcett, A.H. Gabriel, W.G. Griffin, B.B. Jones, and R. Wilson, Nature **200**, 1303 (1963).

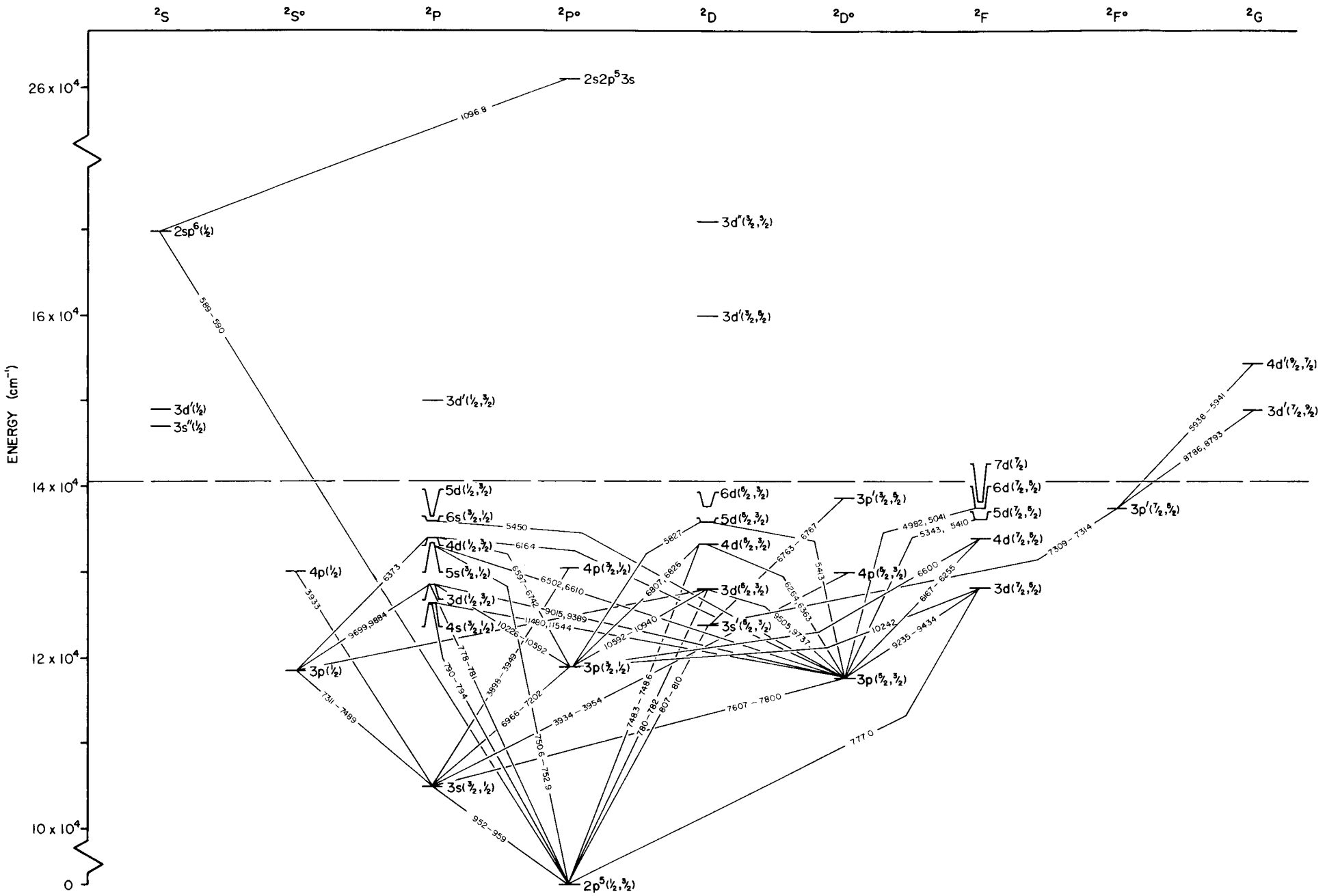
Authors give observed spectral lines in the range 16–400 Å.

G.A. Sawyer, A.J. Bearden, J. Henins, F.C. Jahoda, and F.L. Ribe, Phys. Rev. **131**, 1891 (1963).

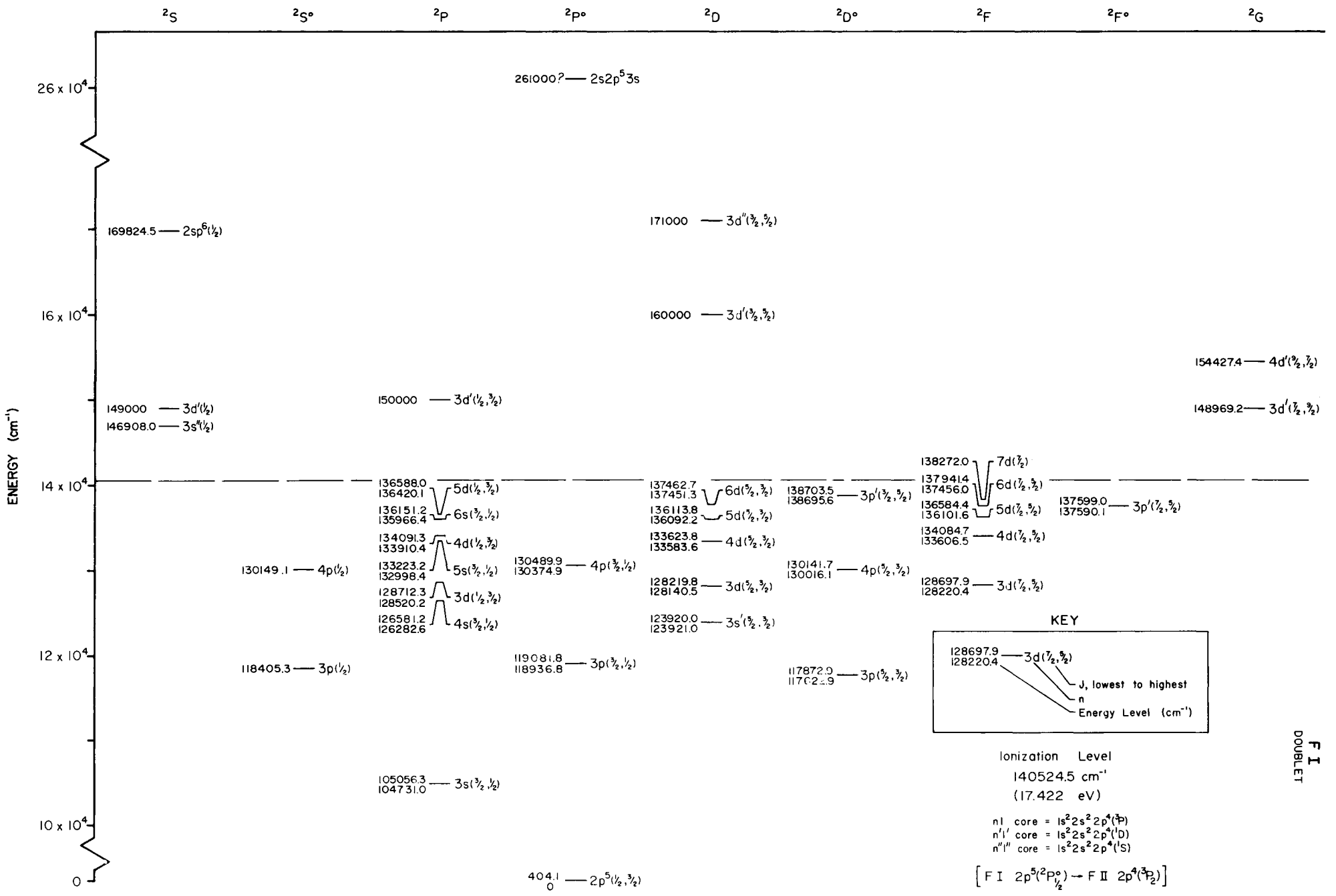
Authors give observed lines of several series.

Fluor (F)

F I GROTRIAN DIAGRAM (9 electrons, Z = 9)
(Configuration: $1s^2 2s^2 2p^4 nl$, Doublet System)

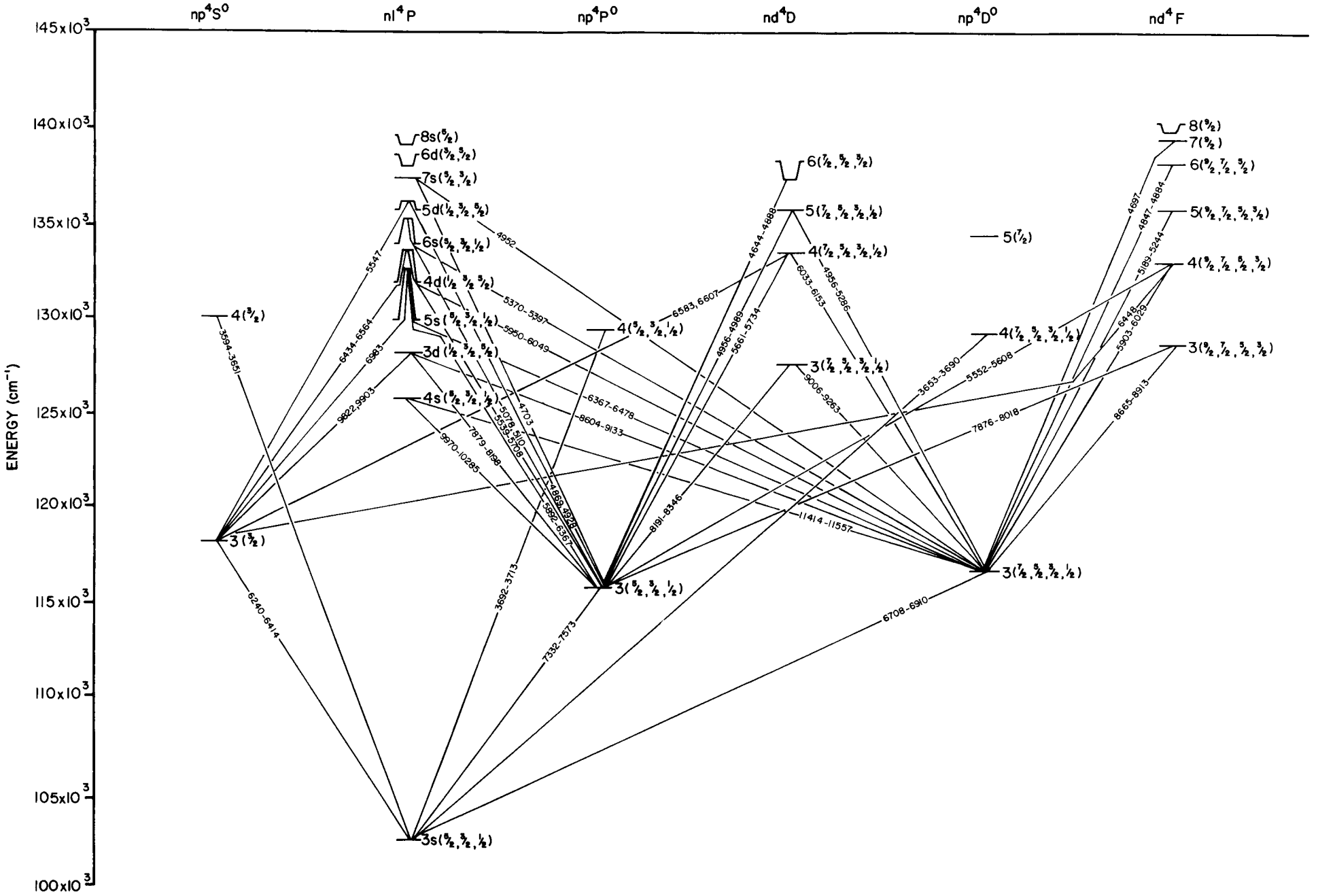


F I ENERGY LEVELS (9 electrons, Z=9)
(Configuration: $1s^2\,2s^2\,2p^4nl$, Doublet System)

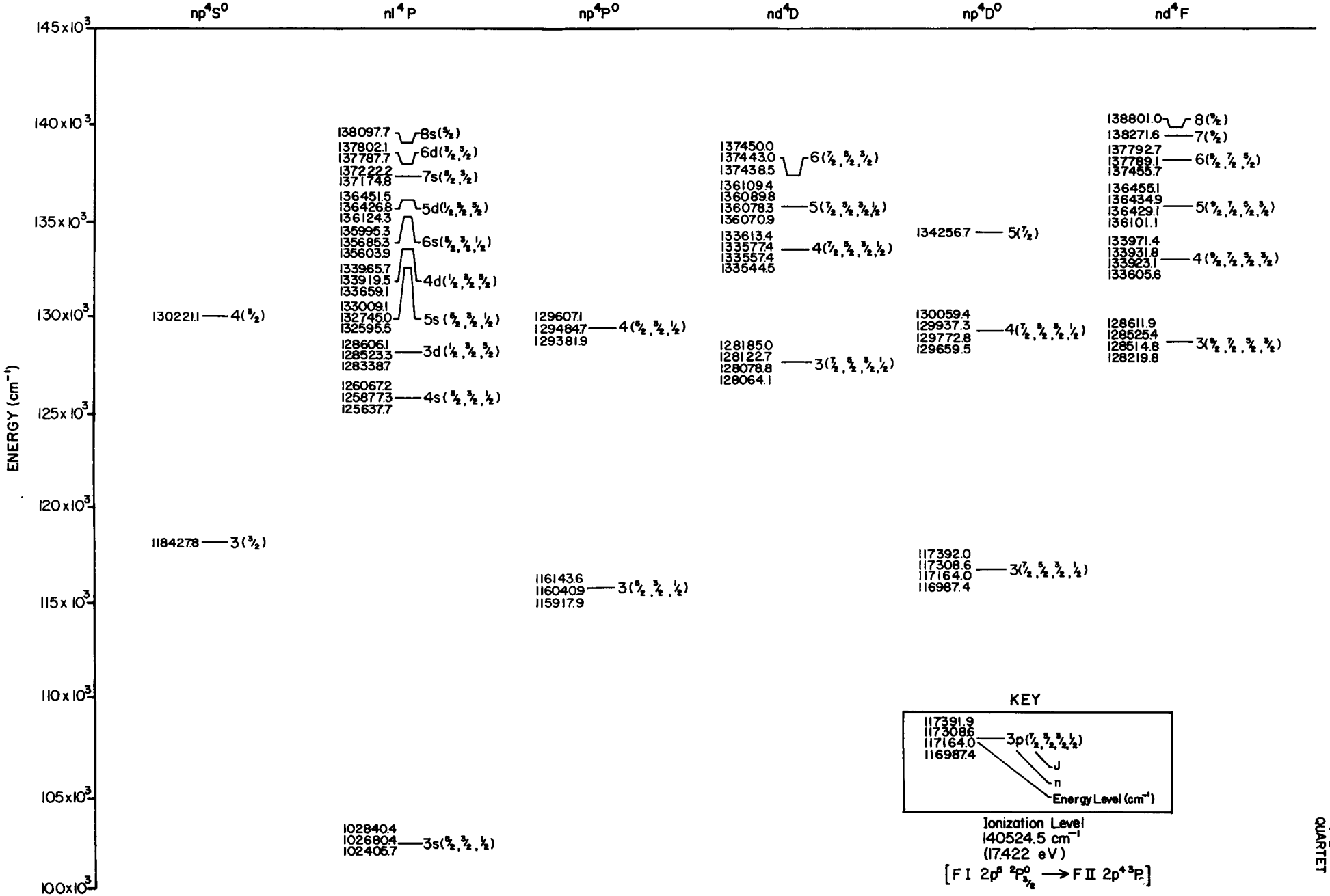


F I
DOUBLET

F I GROTRIAN DIAGRAM (9 electrons, Z=9)
(Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)

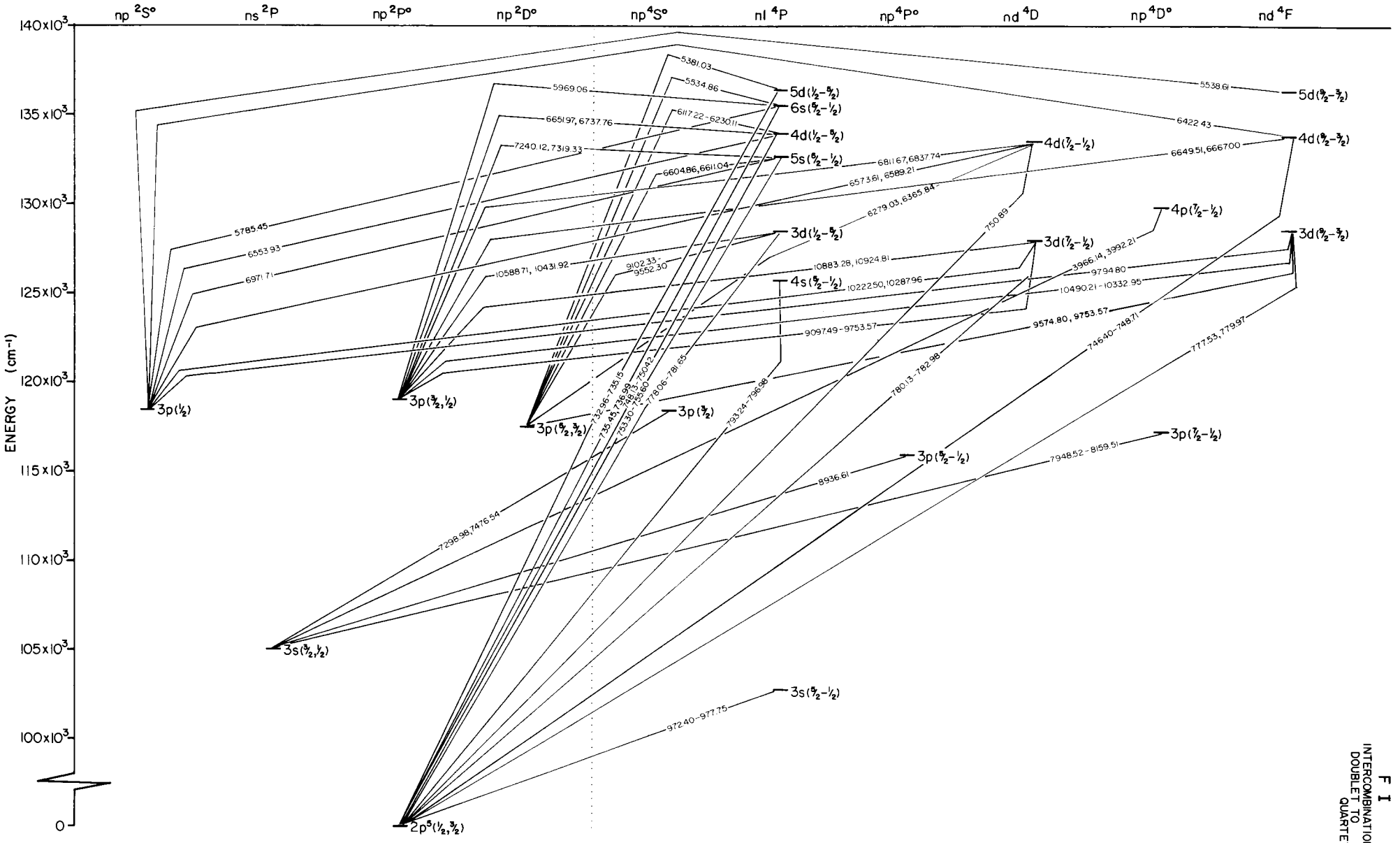


F I ENERGY LEVELS (9 electrons, Z=9)
(Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)



F I INTERCOMBINATION GROTRIAN DIAGRAM (9 electrons, Z=9)

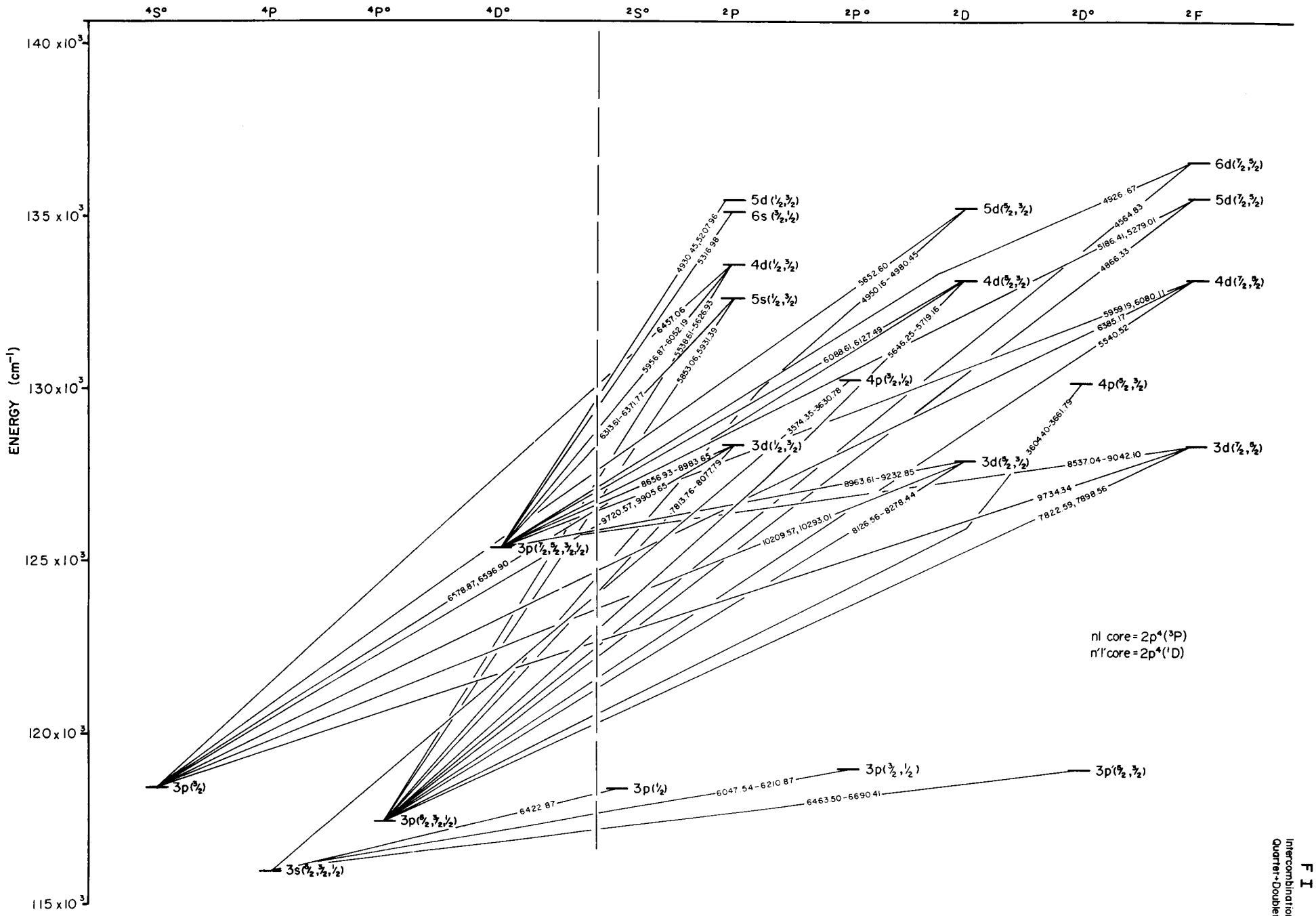
Configuration: $1s^2\,2s^2\,2p^4\,nl$, Doublet to Quartet System



F I
INTERCOMBINATION
DOUBLET TO
QUARTET

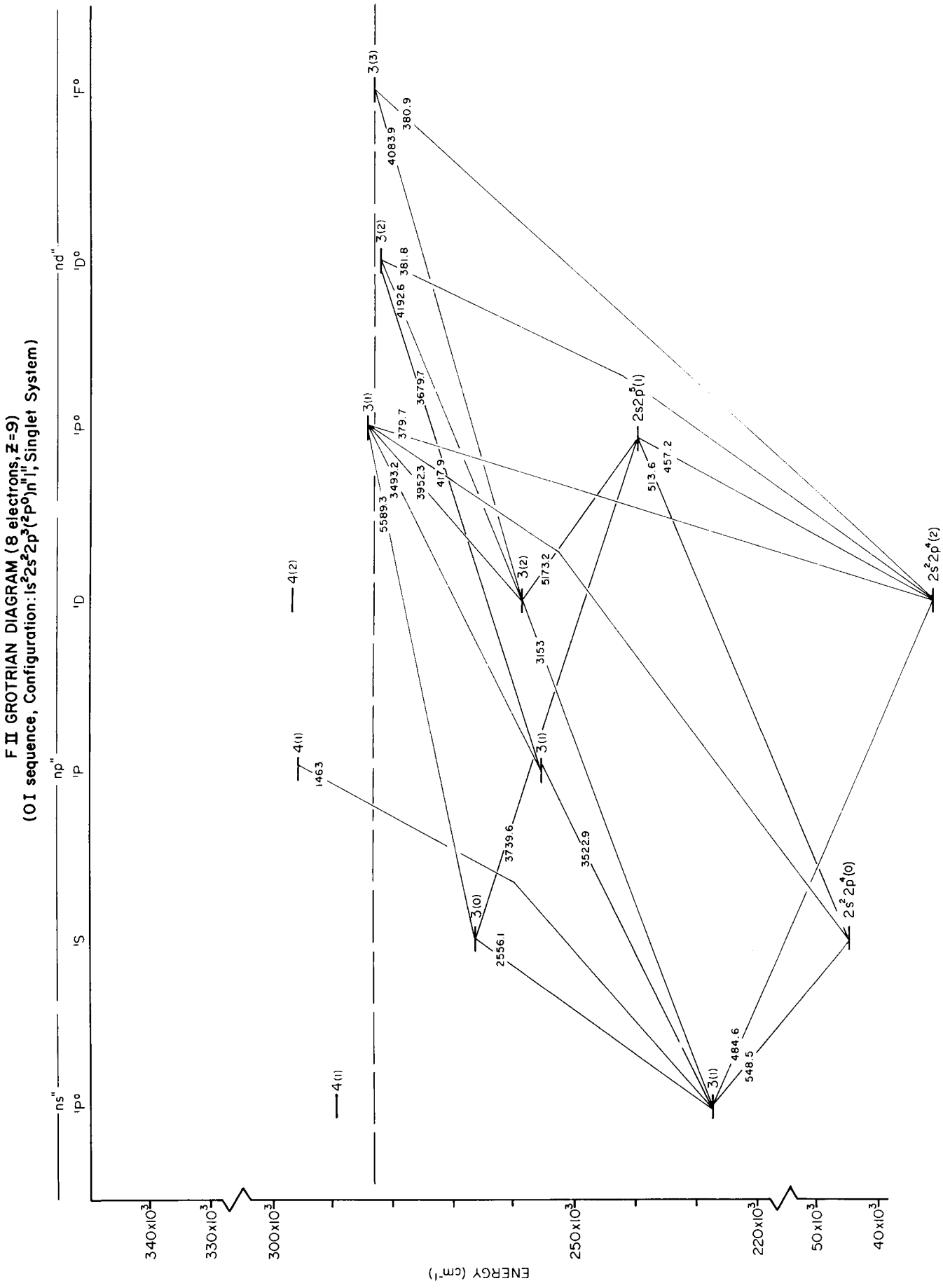
F I GROTRIAN DIAGRAM (9 electrons, Z=9)

(Configuration: $1s^2 2s^2 2p^4 nl$, Intercombinations, Quartet to Doublet Term System)



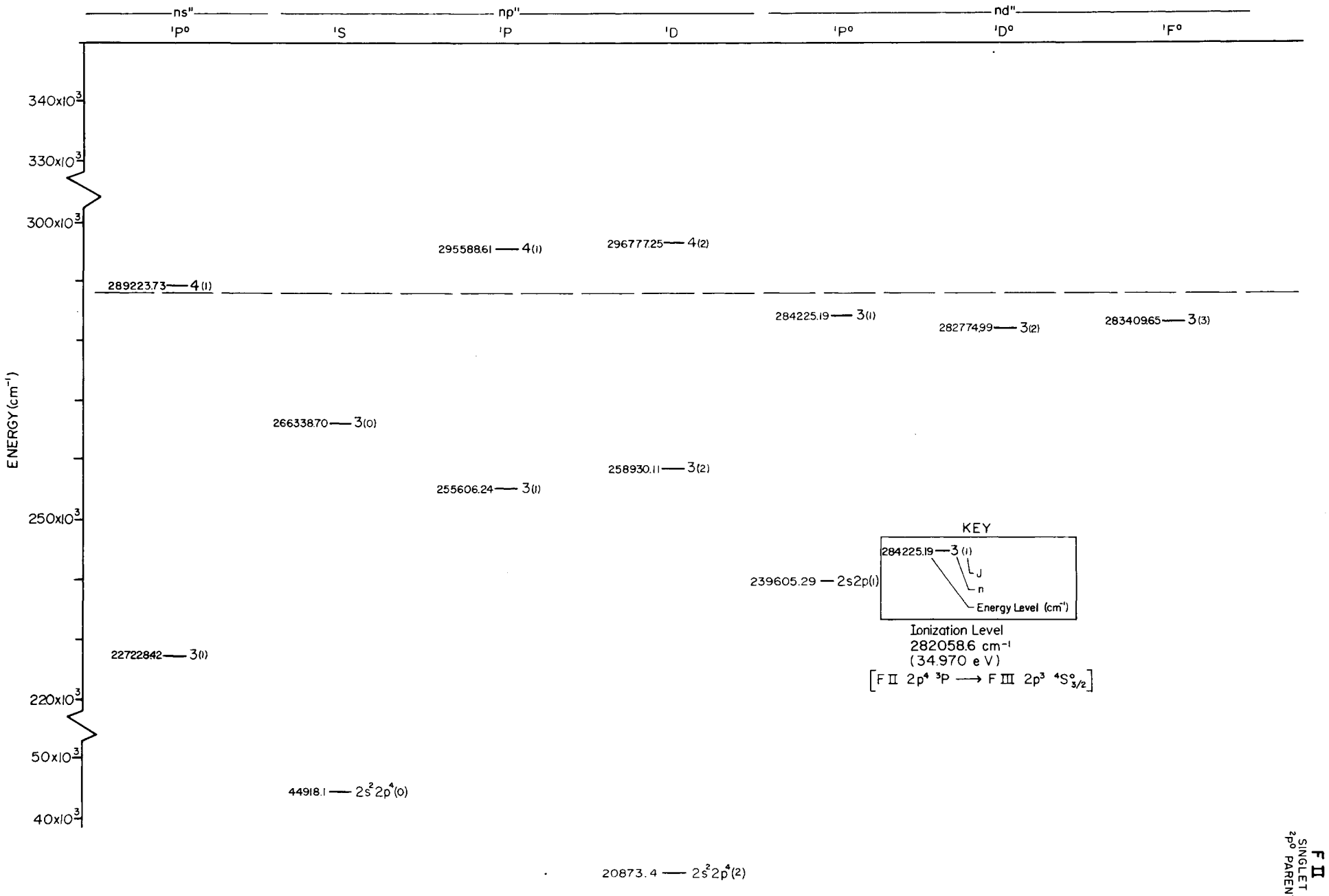
F I
Intercombination
Quartet+Doublet

F II
SINGLET
$^2P^o$ PARENT
GROTRIAN
DIAGRAM

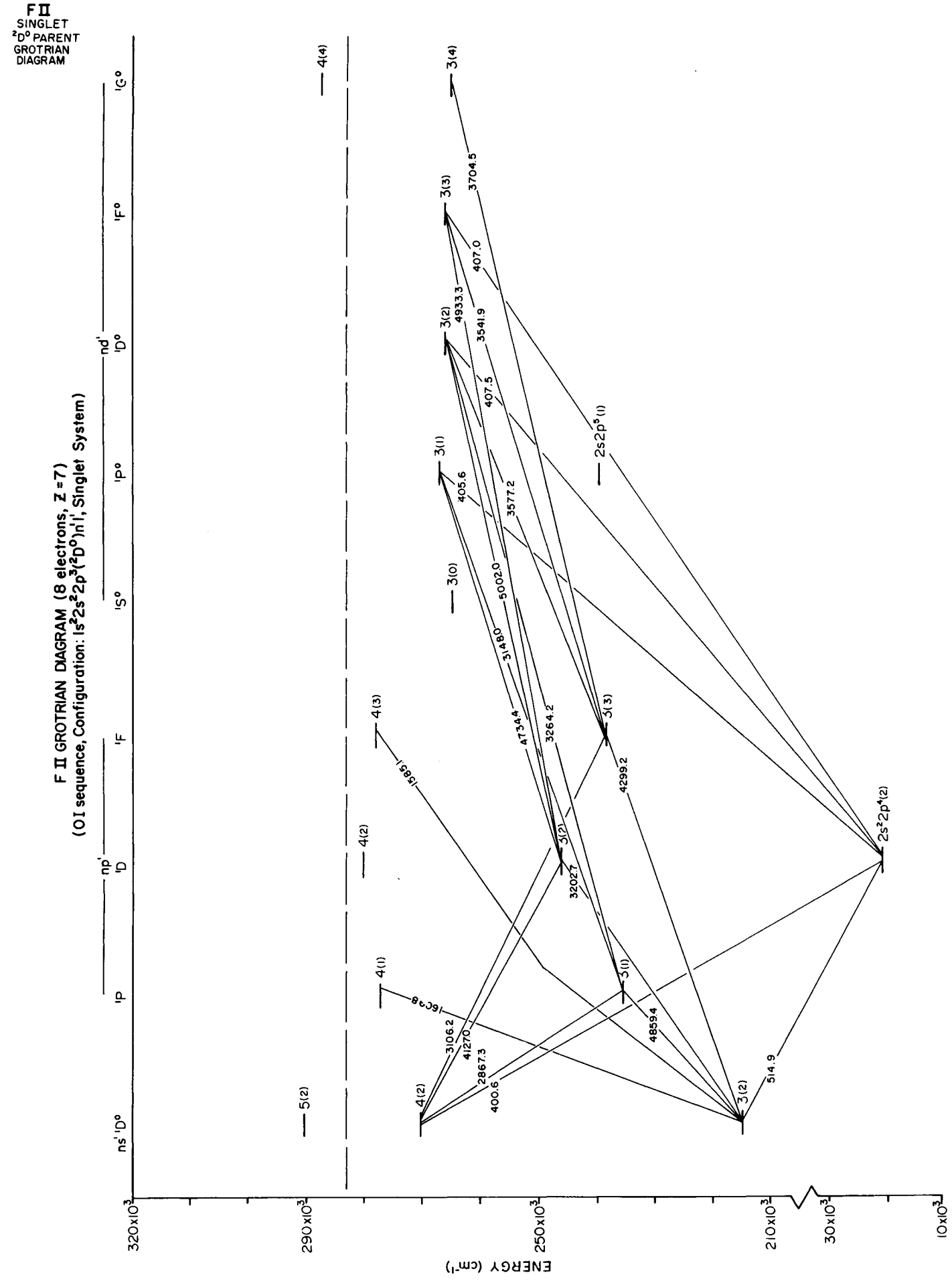


F II ENERGY LEVELS (8 electrons, Z=9)

(O I sequence, Configuration: $1s^2 2s^2 2p^3 (^2P^0) n\ell$, Singlet System)

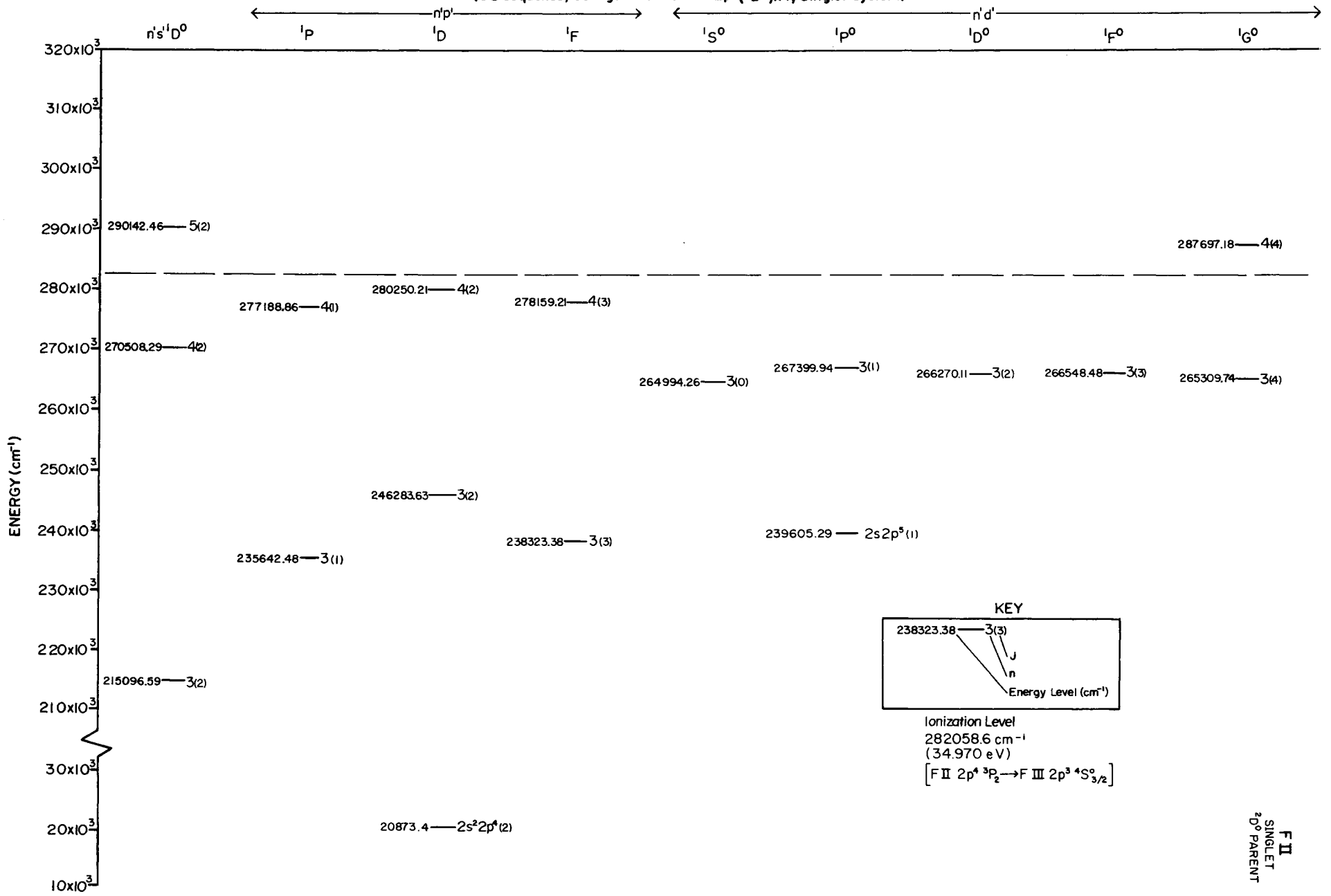


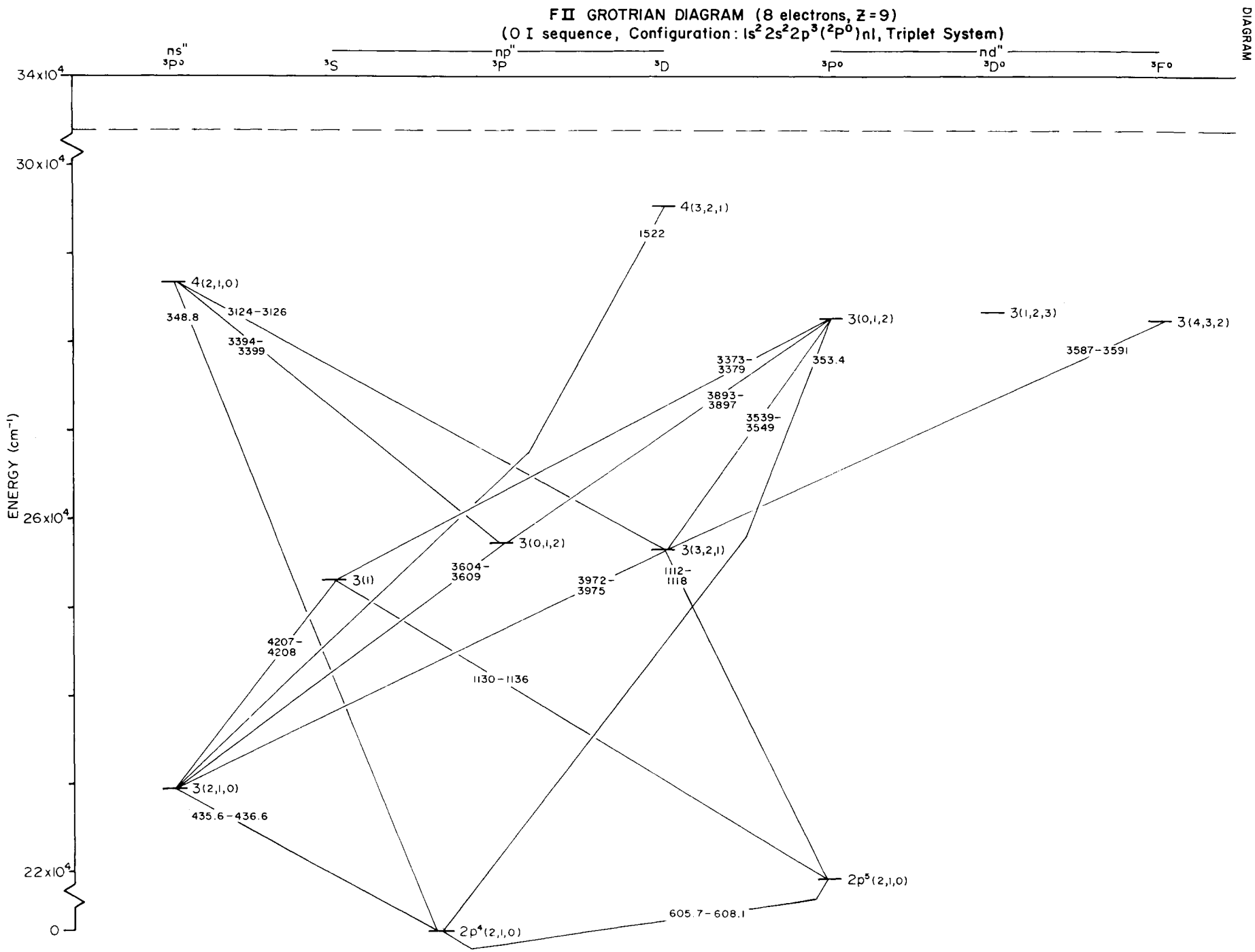
F II
SINGLET
²P° PARENT


F II
SINGLET
$^2D^o$ PARENT
GROTRIAN
DIAGRAM
F II GROTRIAN DIAGRAM (8 electrons, Z = 7)
(O I sequence, Configuration: $1s^22s^22p^3(^2D^o)n'l'$, Singlet System)
ns' $^1D^o$
np'
^1P
^1D
^1F
nd'
$^1S^o$
$^1P^o$
$^1D^o$
$^1F^o$
$^1G^o$
ENERGY (cm^{-1})
320x10^3
290x10^3
250x10^3
210x10^3
30x10^3
10x10^3
$2s^22p^4(2)$
$2s2p^5(1)$
5(2)
4(4)
4(3)
4(2)
4(1)
3(4)
3(3)
3(2)
3(1)
3(0)
1585.1
1603.8
3106.2
4127.0
2867.3
400.6
3202.7
4859.4
514.9
4299.2
3264.2
4734.4
3148.0
5002.0
3577.2
405.6
407.5
3541.9
4933.3
407.0
3704.5

F II ENERGY LEVELS (8 electrons, Z=9)

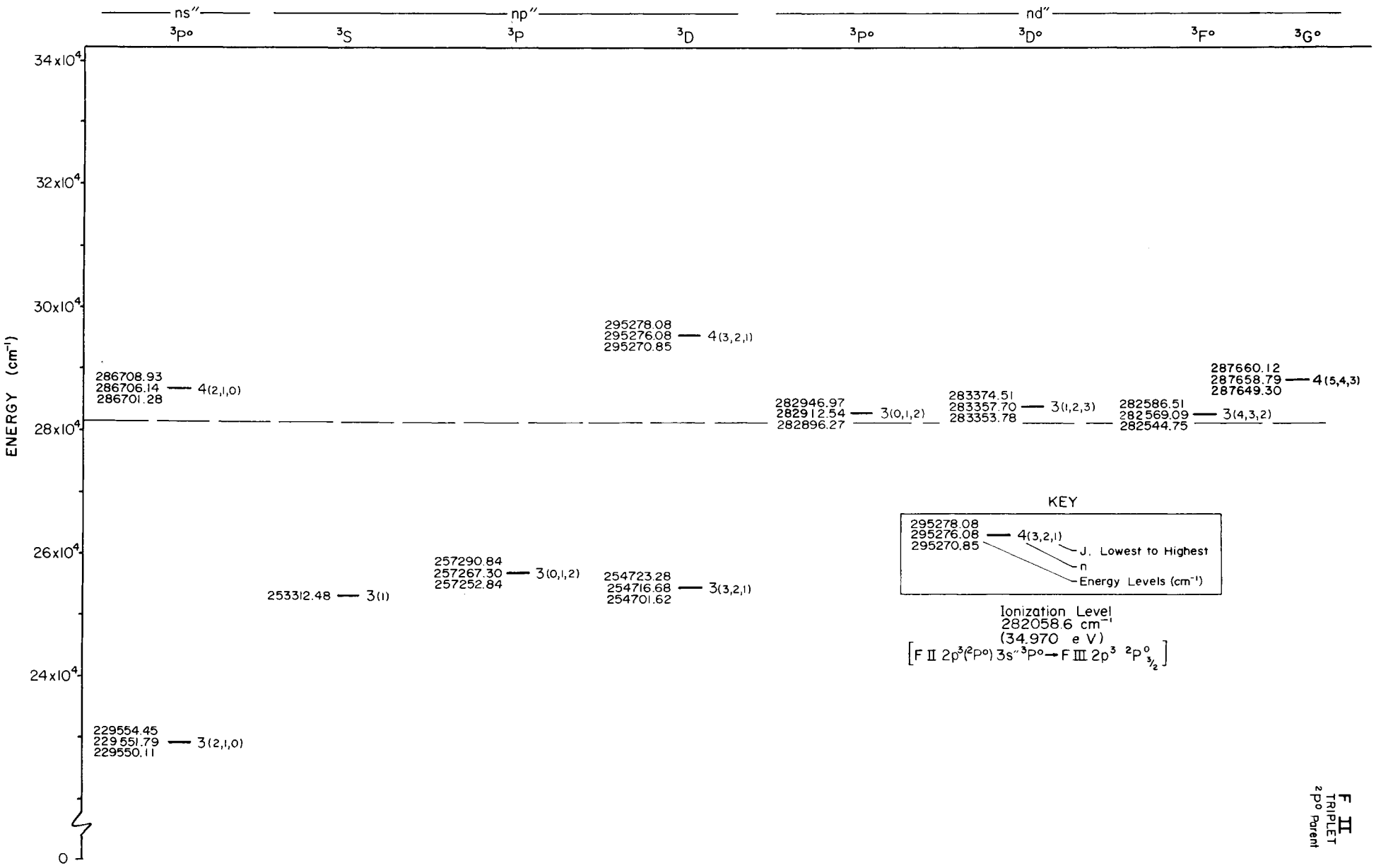
(OI sequence, Configuration: $1s^2 2s^2 2p^3(^2D^o)n'l'$, Singlet System)



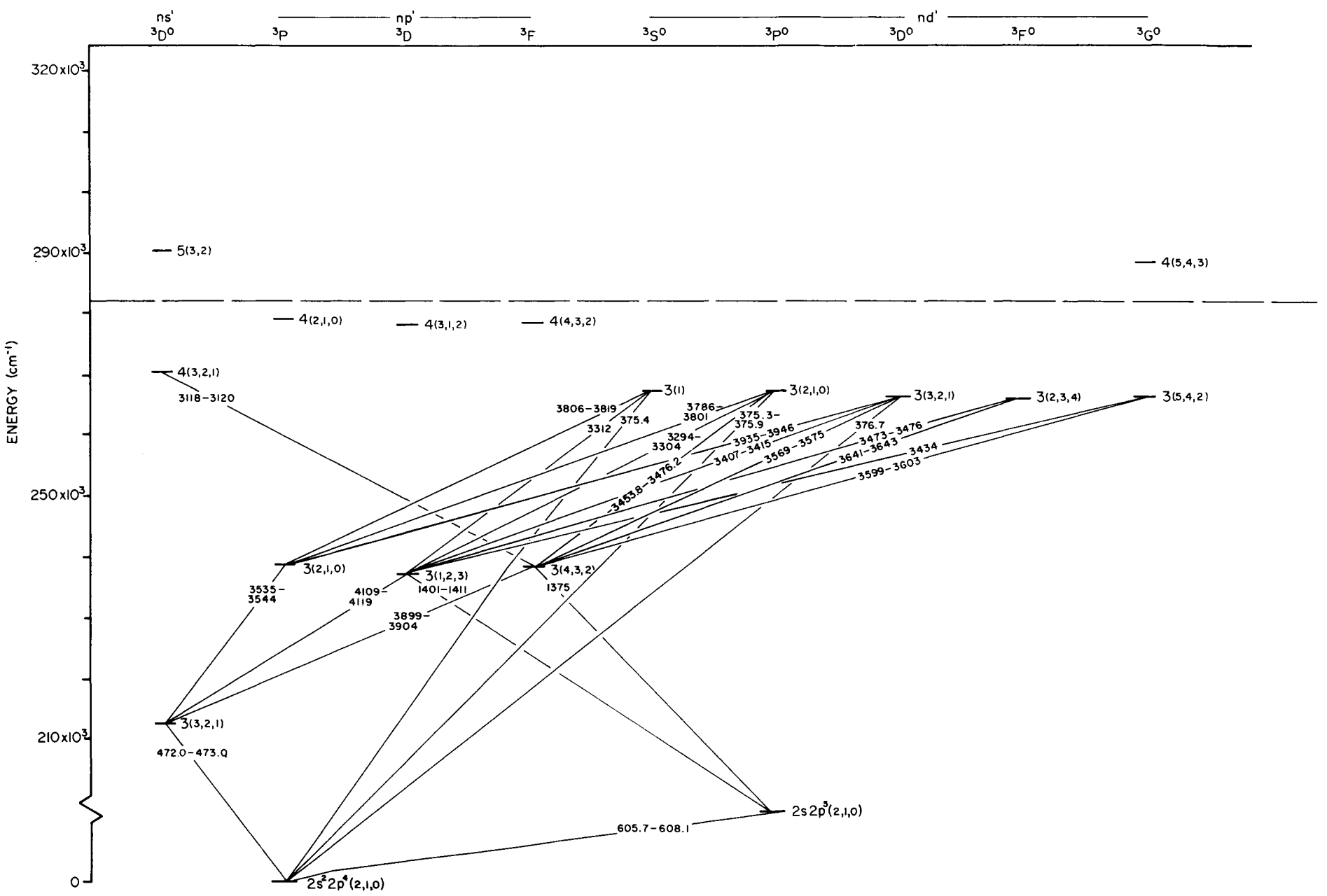


F II
TRIPLET
$^2P^o$ PARENT
GROTRIAN
DIAGRAM

F II ENERGY LEVELS (8 electrons, Z=9)
(O I sequence, Configuration: $1s^2 2s^2 2p^3 (^2P^o)nl''$, Triplet System)

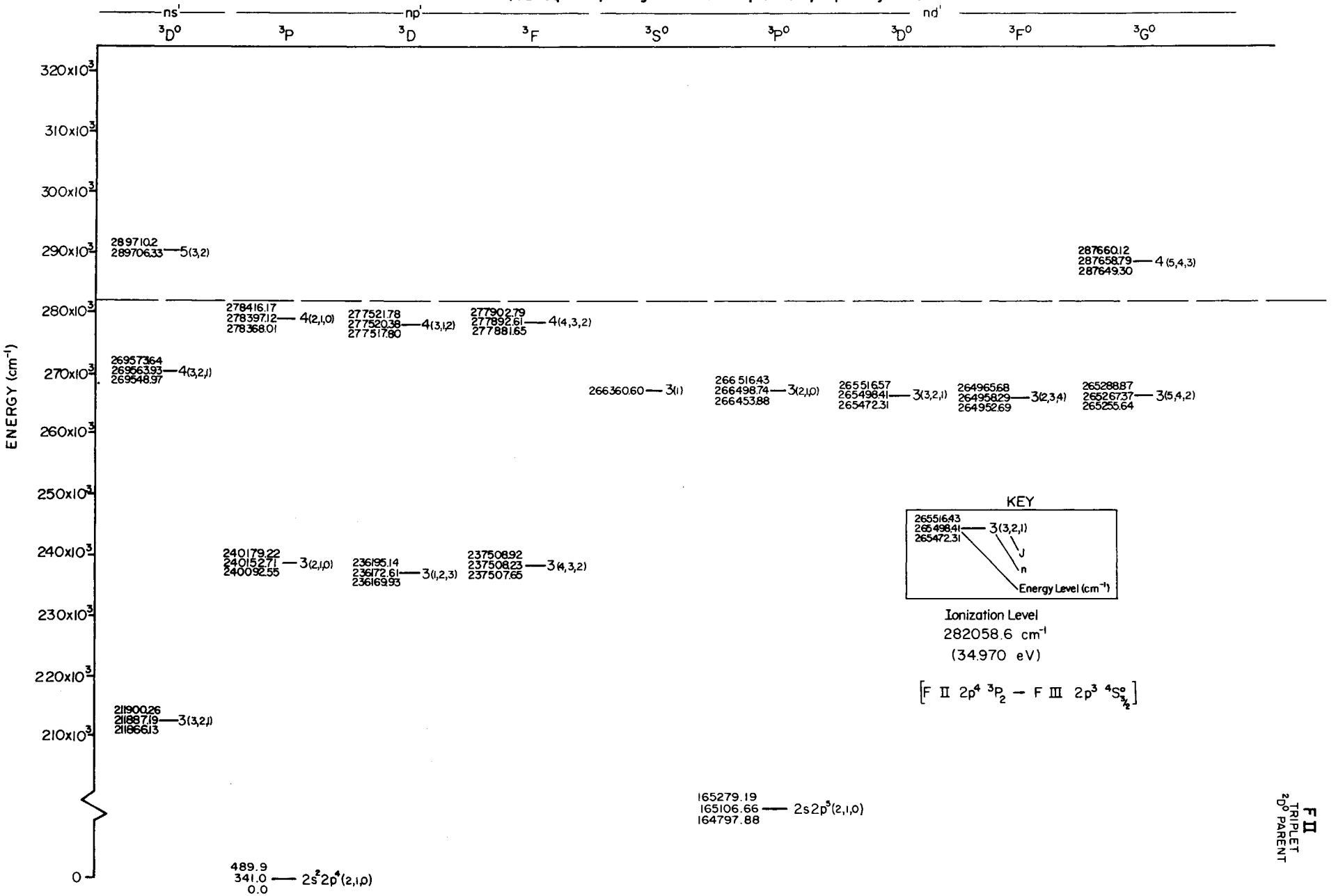


F II
TRIPLET
$^2P^o$ Parent

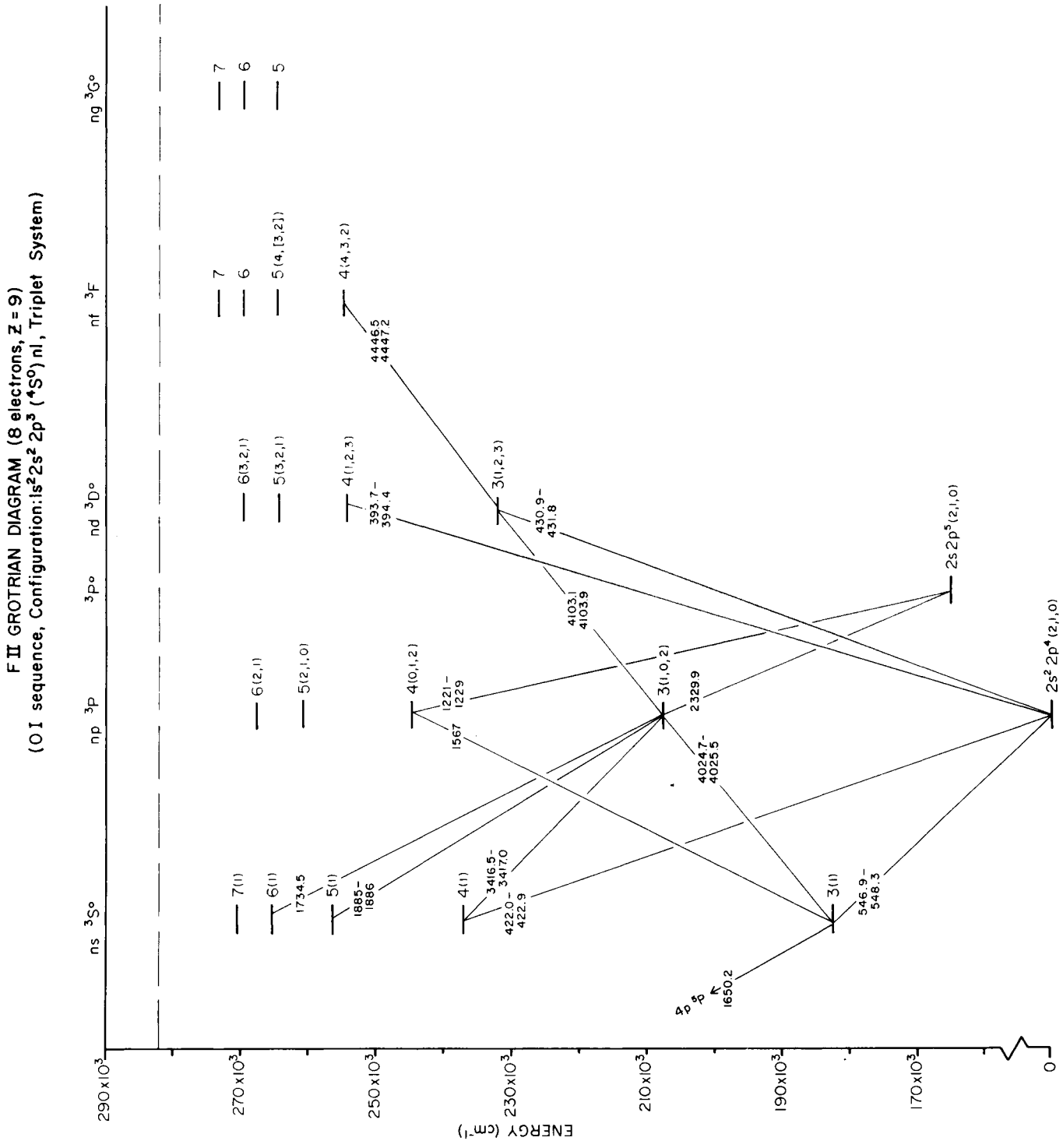

F II GROTRIAN DIAGRAM (8 electrons, Z = 9)
(O I sequence, Configuration : $1s^2 2s^2 2p^3(^2D^0)n'l'$, Triplet System)
ns'
np'
nd'
$^3D^0$
^3P
^3D
^3F
$^3S^0$
$^3P^0$
$^3D^0$
$^3F^0$
$^3G^0$
ENERGY (cm^{-1})
320x10^3
290x10^3
250x10^3
210x10^3
0
5(3,2)
4(5,4,3)
4(2,1,0)
4(3,1,2)
4(4,3,2)
4(3,2,1)
3118-3120
3(1)
3(2,1,0)
3(3,2,1)
3(2,3,4)
3(5,4,2)
3806-3819
3312
375.4
3786-3801
3294-3304
375.3-375.9
3935-3946
3407-3415
3569-3575
376.7
3473-3476
3641-3643
3434
3599-3603
3453.8-3476.2
3(2,1,0)
3535-3544
3(1,2,3)
4109-4119
1401-1411
3899-3904
3(4,3,2)
1375
3(3,2,1)
472.0-473.0
605.7-608.1
$2s2p^3(2,1,0)$
$2s^2 2p^4(2,1,0)$

F II ENERGY LEVELS (8 electrons, Z=9)

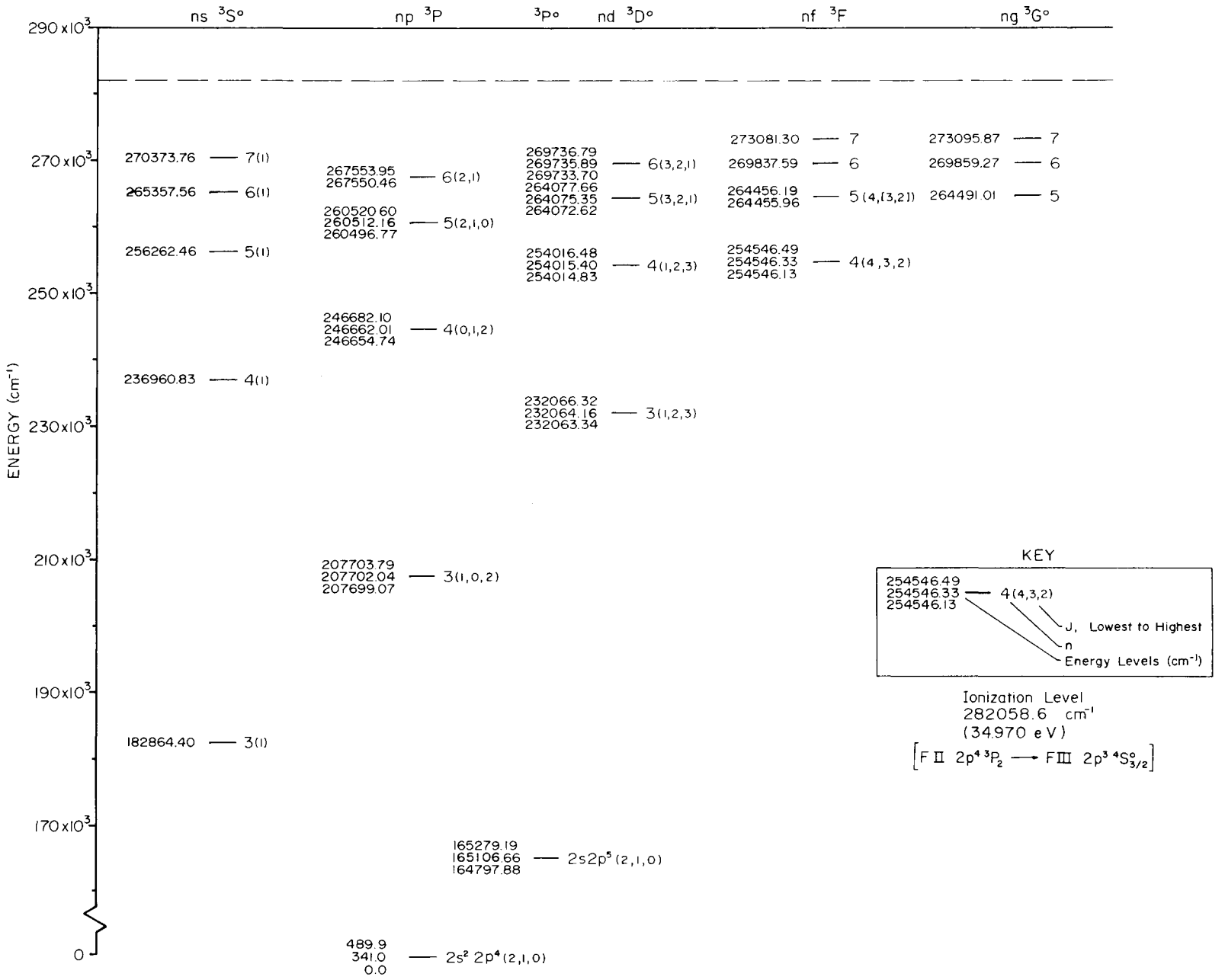
(OI sequence, Configuration: $1s^2 2s^2 2p^3(^2D^o)n'l'$, Triplet System)



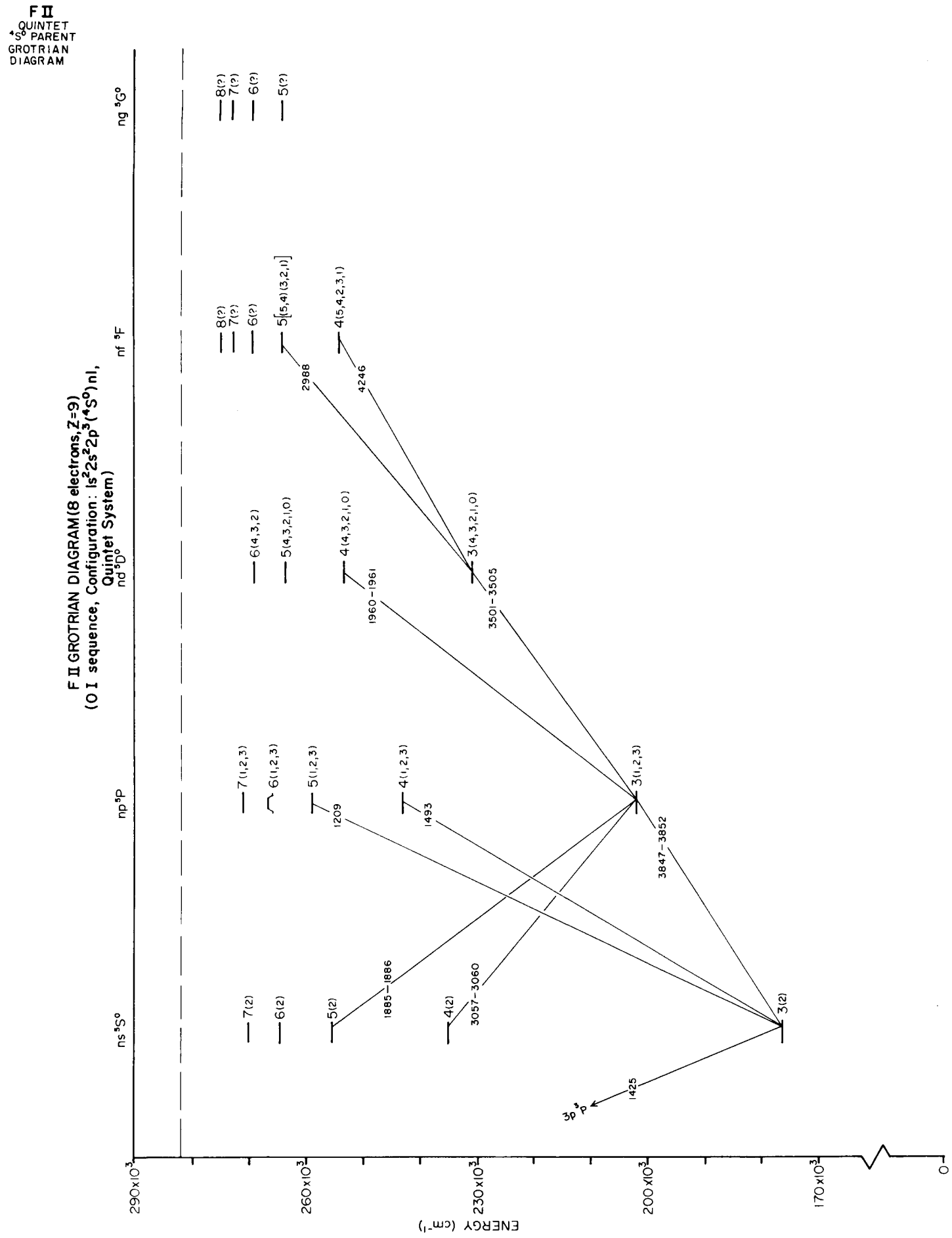
F II
TRIPLET
$^4S^o$ PARENT
GROTRIAN
DIAGRAM



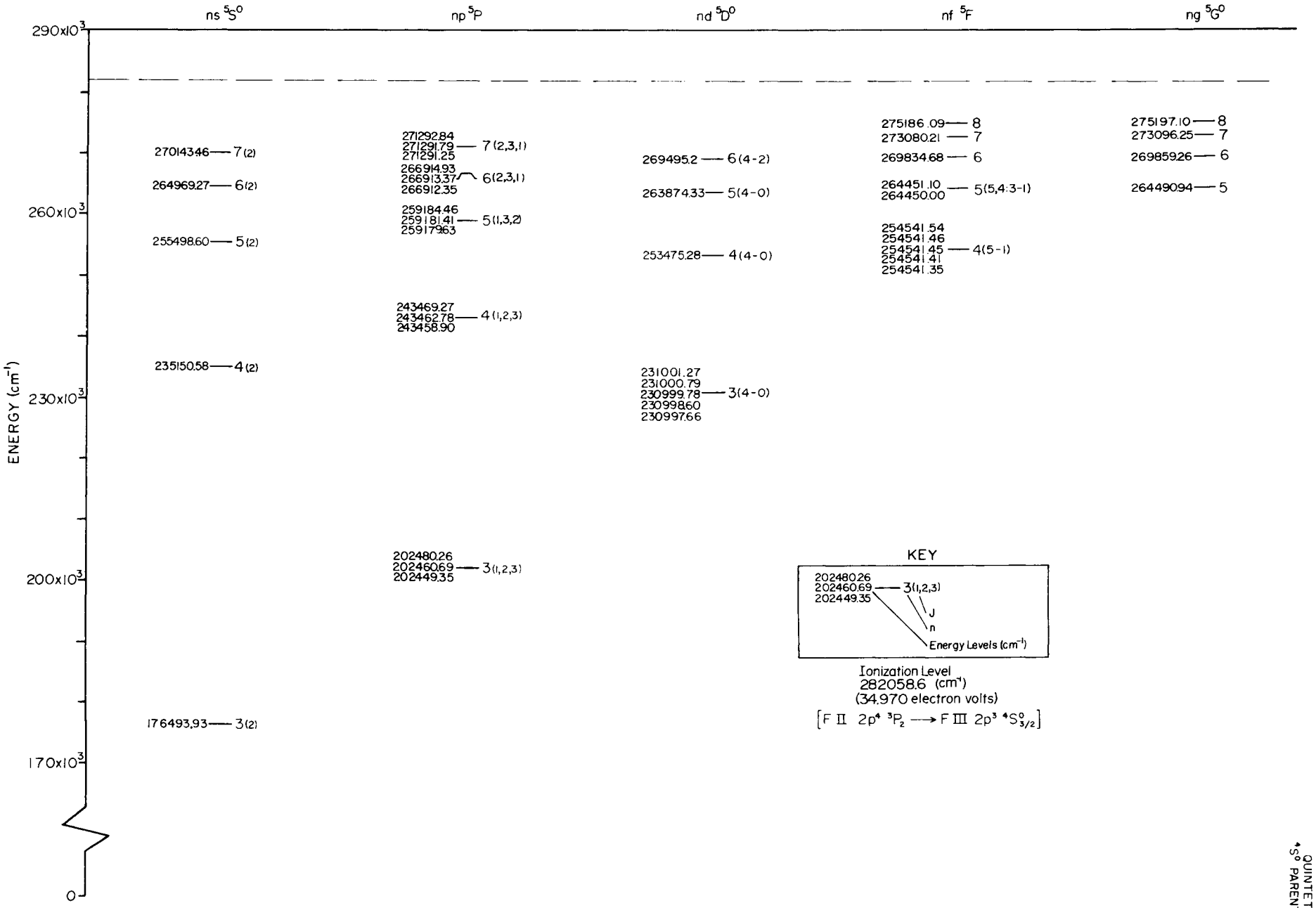
F II ENERGY LEVELS (8 electrons, Z = 9)
(O I sequence, Configuration: $1s^2 2s^2 2p^3$ ($^4S^o$) nl, Triplet System)



F II
TRIPLET
$^4S^o$ PARENT


F II
QUINTET
$^4S^o$ PARENT
GROTRIAN
DIAGRAM
F II GROTRIAN DIAGRAM(8 electrons, Z=9)
(O I sequence, Configuration: $1s^2 2s^2 2p^3(^4S^o)nl$,
Quintet System)
$ns\,^5S^o$
$np\,^5P$
$nd\,^5D^o$
$nf\,^5F$
$ng\,^5G^o$
7(2)
6(2)
5(2)
4(2)
3(2)
7(1,2,3)
6(1,2,3)
5(1,2,3)
4(1,2,3)
3(1,2,3)
6(4,3,2)
5(4,3,2,1,0)
4(4,3,2,1,0)
3(4,3,2,1,0)
8(?)
7(?)
6(?)
5[(5,4)(3,2,1)]
4(5,4,2,3,1)
8(?)
7(?)
6(?)
5(?)
1425
1885–1886
3057–3060
1209
1493
3847–3852
1960–1961
3501–3505
2988
4246
$3p\,^3P$
290×10^3
260×10^3
230×10^3
200×10^3
170×10^3
0
ENERGY (cm^{-1})

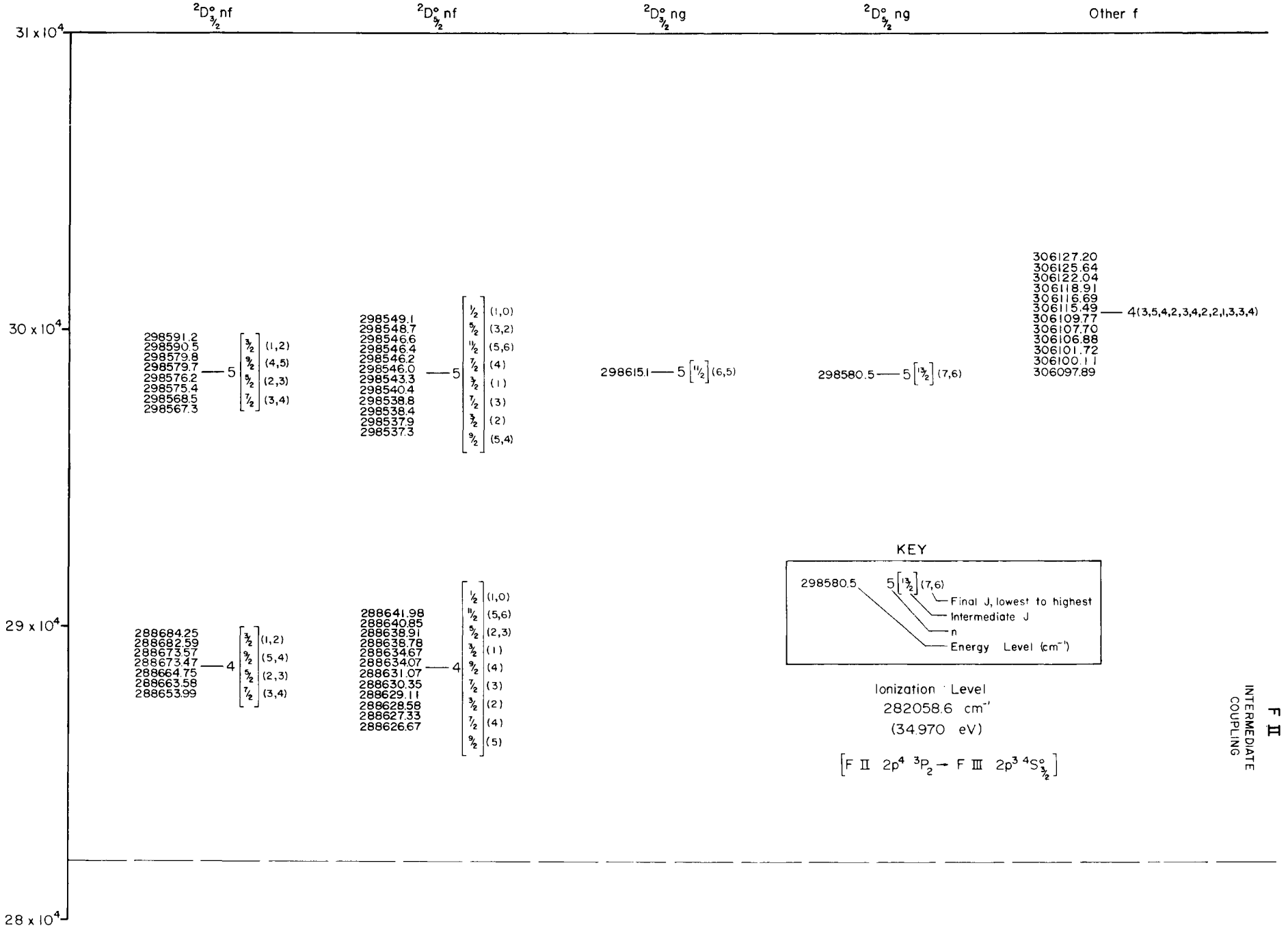
F II ENERGY LEVELS (8 electrons, Z=9)
(OI sequence, Configuration: $1s^2 2s^2 2p^3(^4S^0)nl$, Quintet System)



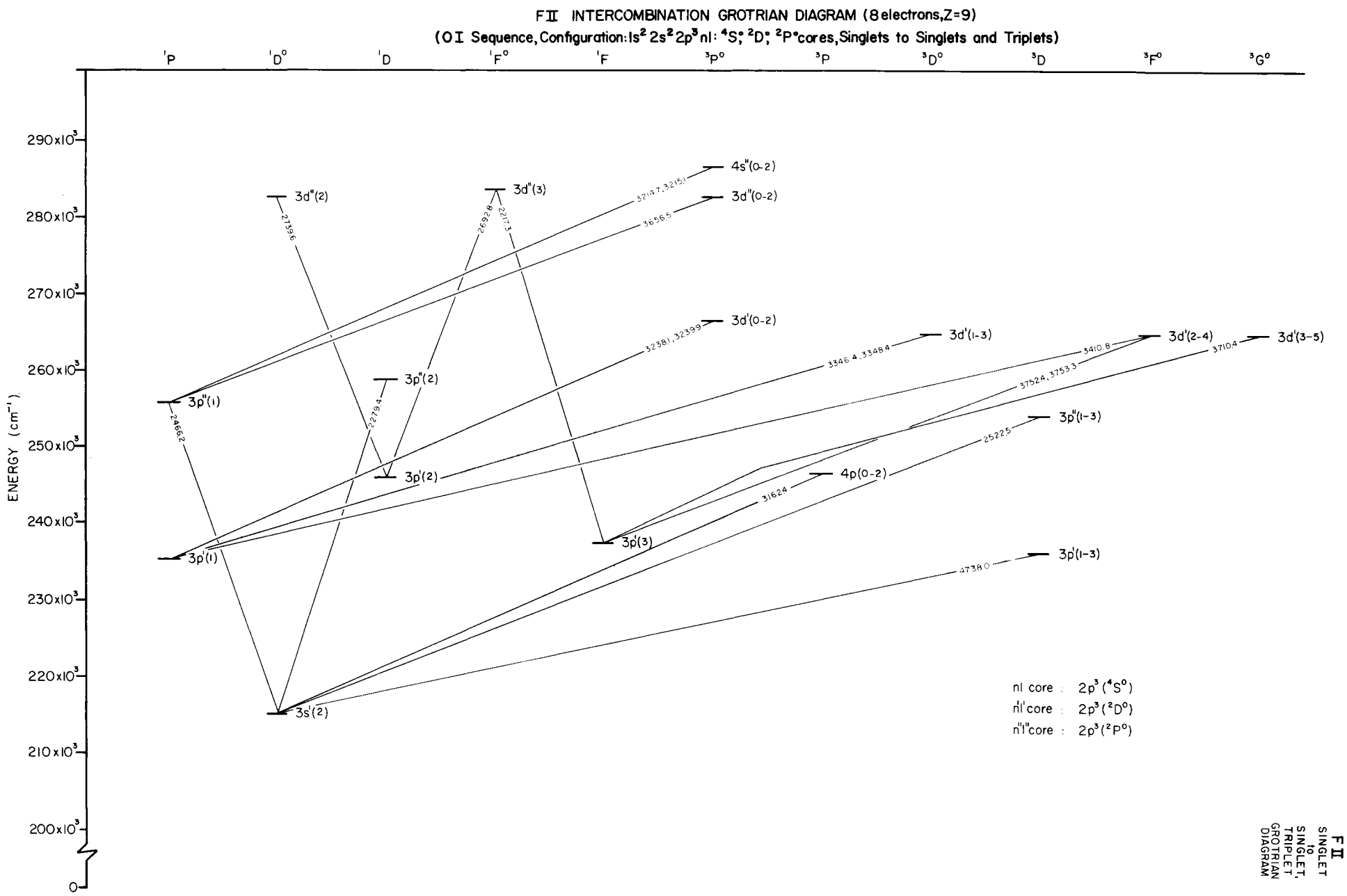
F II ENERGY LEVELS (8 electrons, Z = 9)

(Intermediate Coupling, Configuration: $1s^2\,2s^2\,2p^3\,(^2D^\circ)\,nl$)

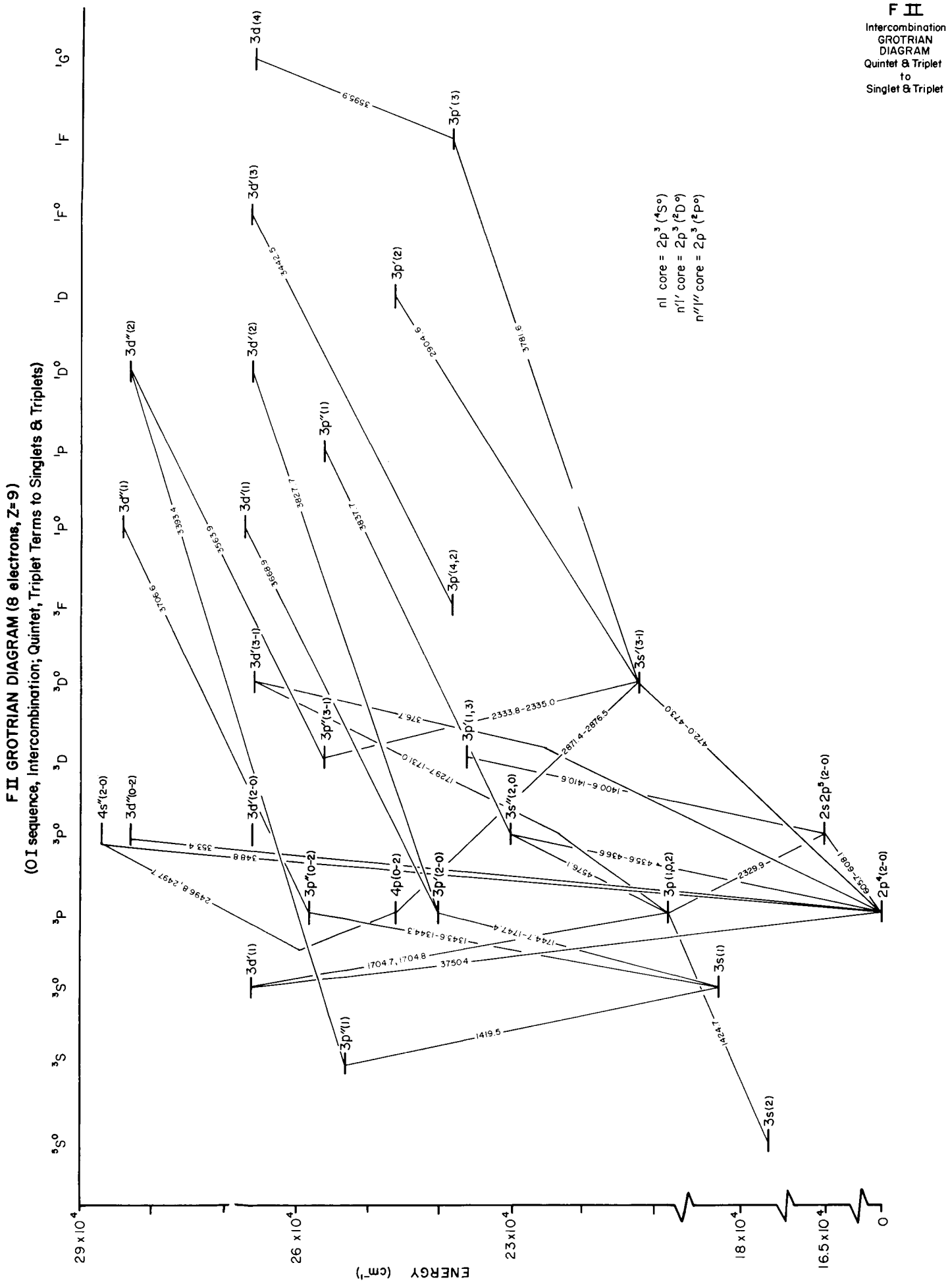
(O I sequence)



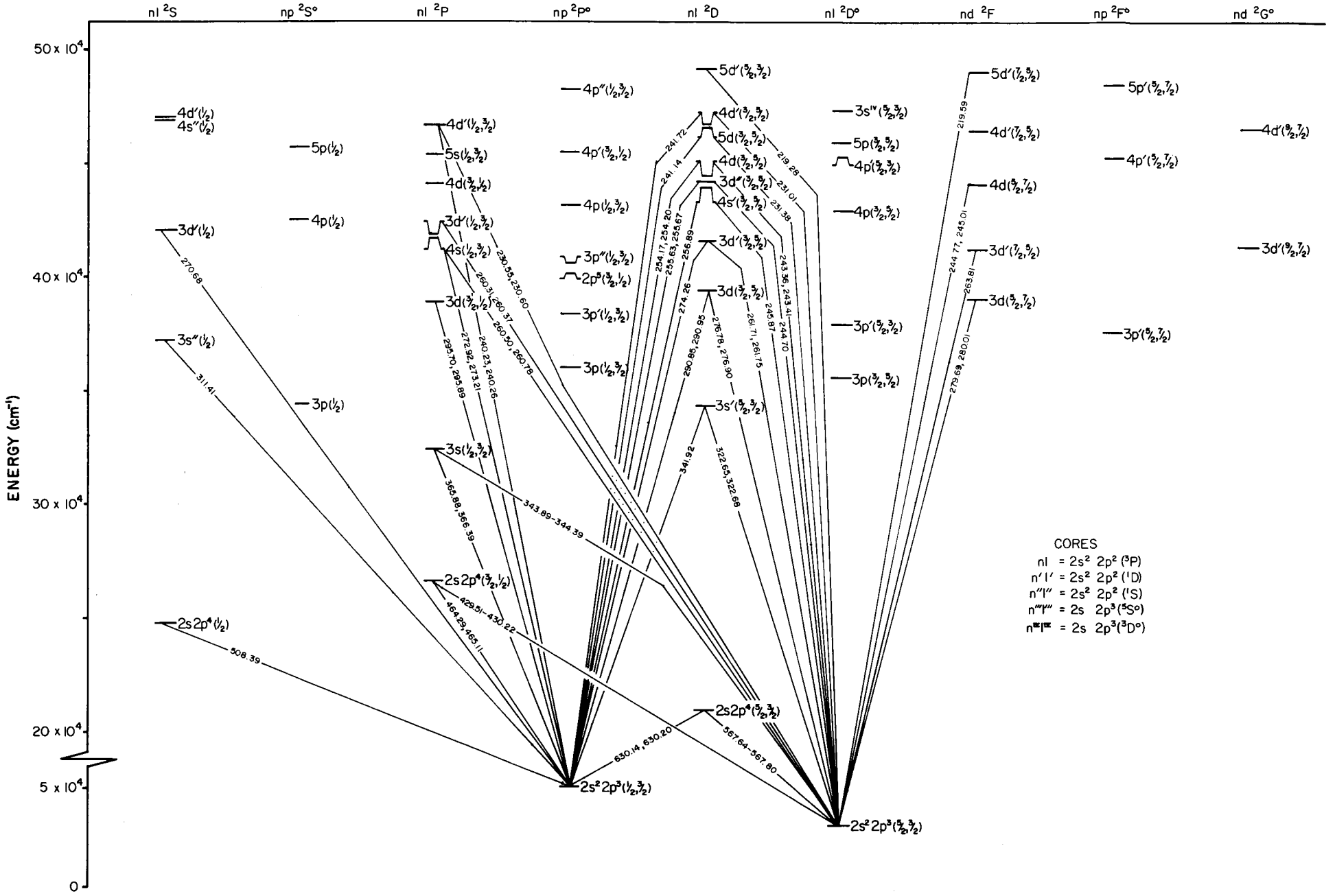
F II
INTERMEDIATE COUPLING



FII SINGLET TO SINGLET, TRIPLET GROTRIAN DIAGRAM

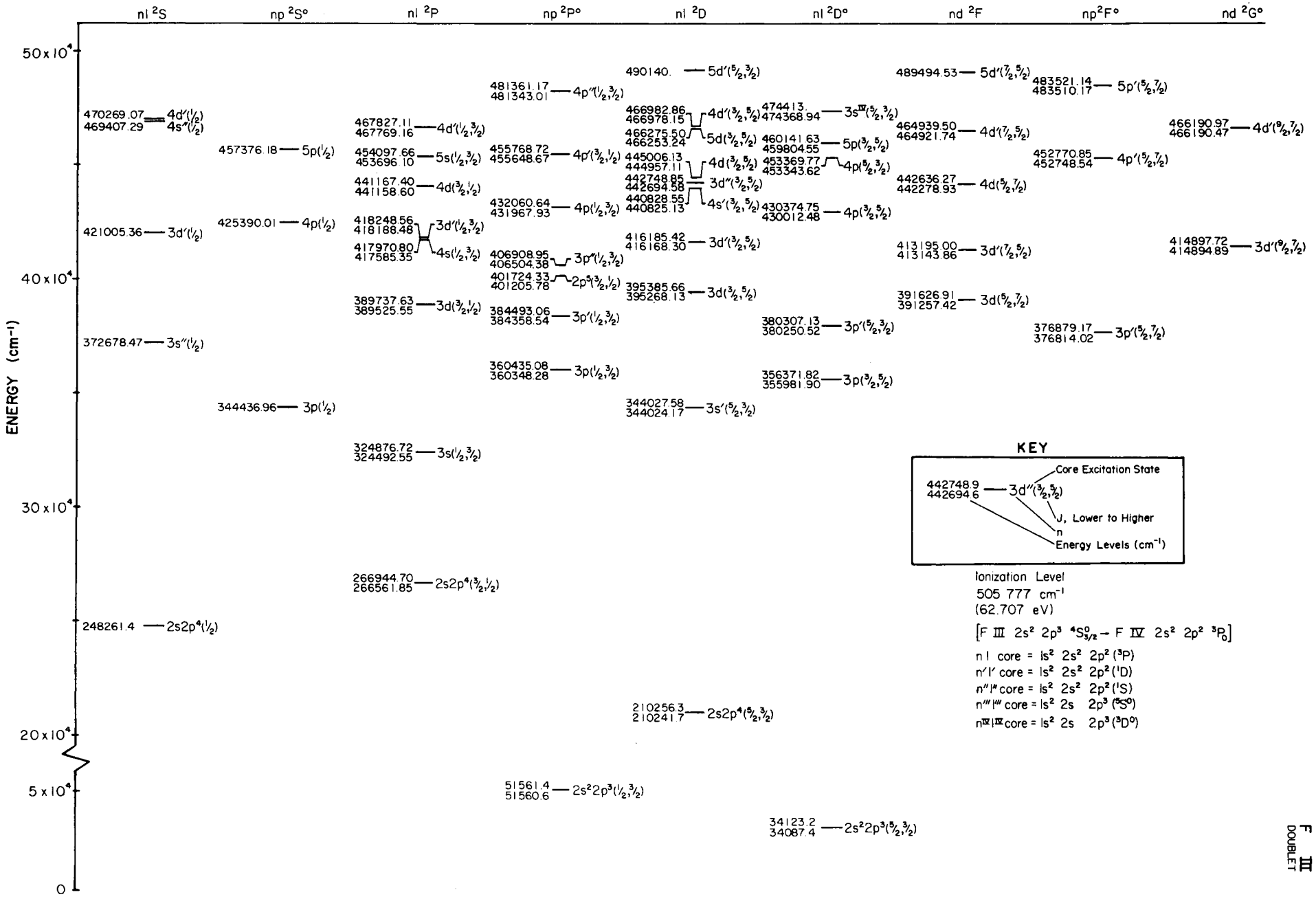

F II
Intercombination
GROTRIAN
DIAGRAM
Quintet & Triplet
to
Singlet & Triplet
F II GROTRIAN DIAGRAM (8 electrons, Z=9)
(O I sequence, Intercombination; Quintet, Triplet Terms to Singlets & Triplets)
nl core = 2p³ (⁴S°)
n'l' core = 2p³ (²D°)
n''l'' core = 2p³ (²P°)
ENERGY (cm⁻¹)
29 x 10⁴
26 x 10⁴
23 x 10⁴
18 x 10⁴
16.5 x 10⁴
0
⁵S°
³S
³S°
³P
³P°
³D
³D°
³F
¹P°
¹P
¹D°
¹D
¹F°
¹F
¹G°
4s''(2-0)
3d''(0-2)
3d''(1)
3d''(2)
3d'(1)
3d'(2-0)
3d'(3-1)
3d'(2)
3d'(3)
3d(4)
3p''(0-2)
3p''(1)
3p''(3-1)
3p''(1)
3p'(2-0)
3p'(1,3)
3p'(4,2)
3p'(2)
3p'(3)
4p(0-2)
3p(1,0,2)
3s''(2,0)
3s'(3-1)
3s(1)
3s(2)
2s2p⁵(2-0)
2p⁴(2-0)
2496.8, 2497.7
3534
3488
3706.6
3393.4
3565.8
3968.9
3827.7
3873.7
3442.5
3181.6
2904.6
3595.9
1704.7, 1704.8
3750.4
1419.5
1424.7
1744.7-1747.4
1343.6-1344.3
1729.7-1731.0
376.7
2333.8-2335.0
2871.4-2876.5
1400.6-1410.6
4356-4356
4576.1
2329.9
472.0-473.0
605.7-608.1

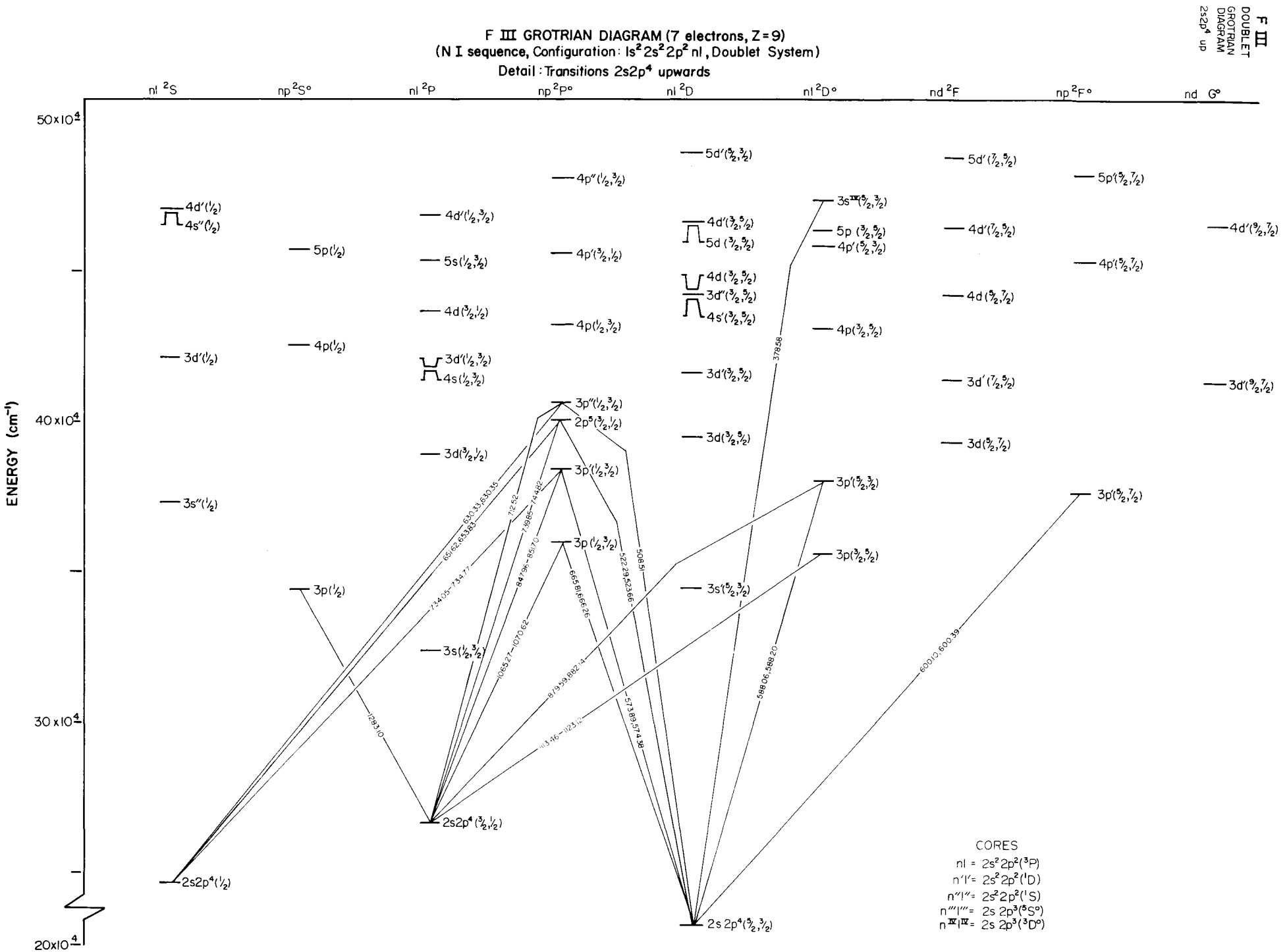
F III GROTRIAN DIAGRAM (7 electrons, Z=9)
(N I sequence, $2s^2 2p^3$ Levels Upward, Doublet System)



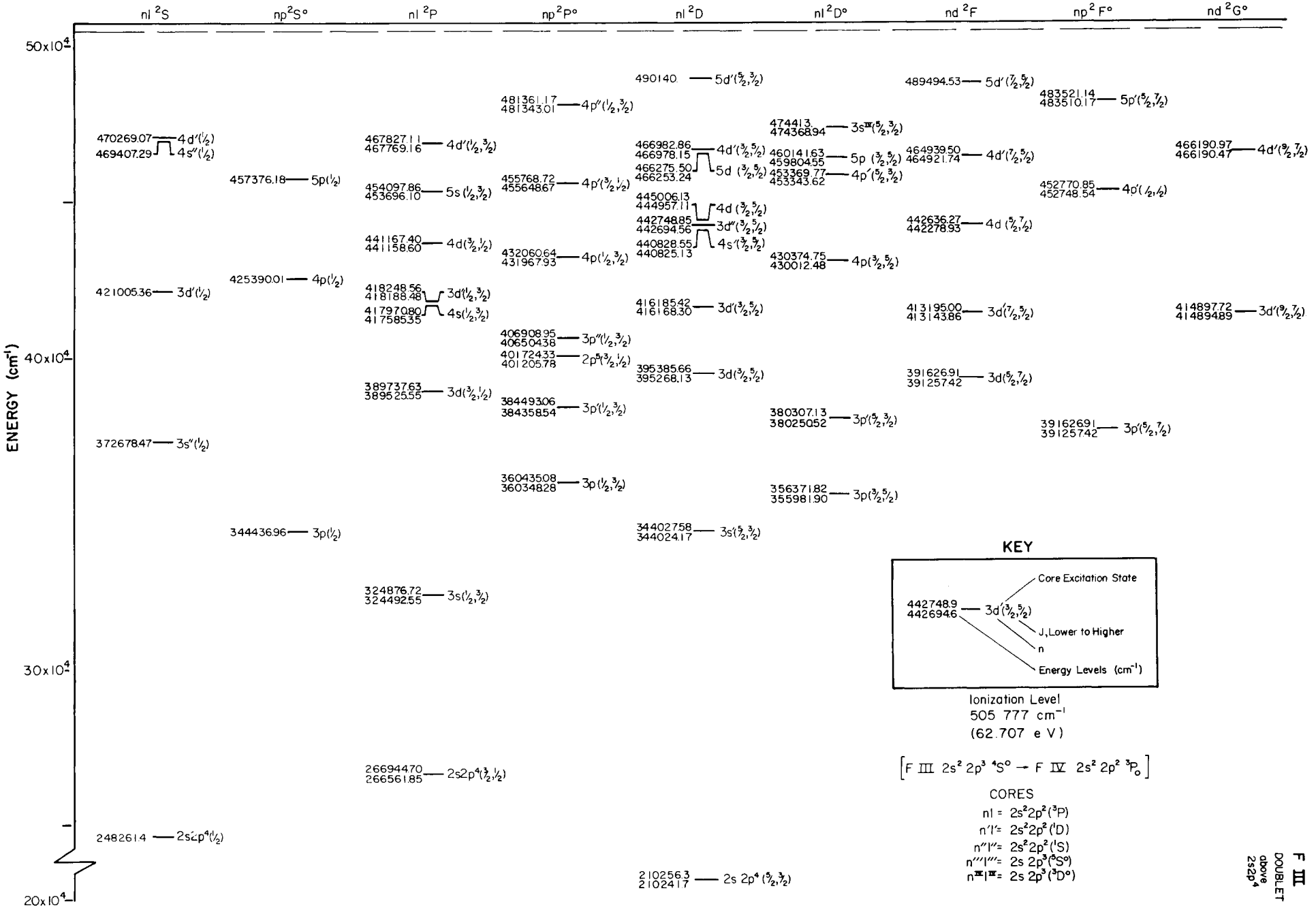
F III ENERGY LEVELS (7 electrons, Z=9)

(N I sequence, Configuration $1s^2 2s^2 2p^2 nl$, Doublet System)

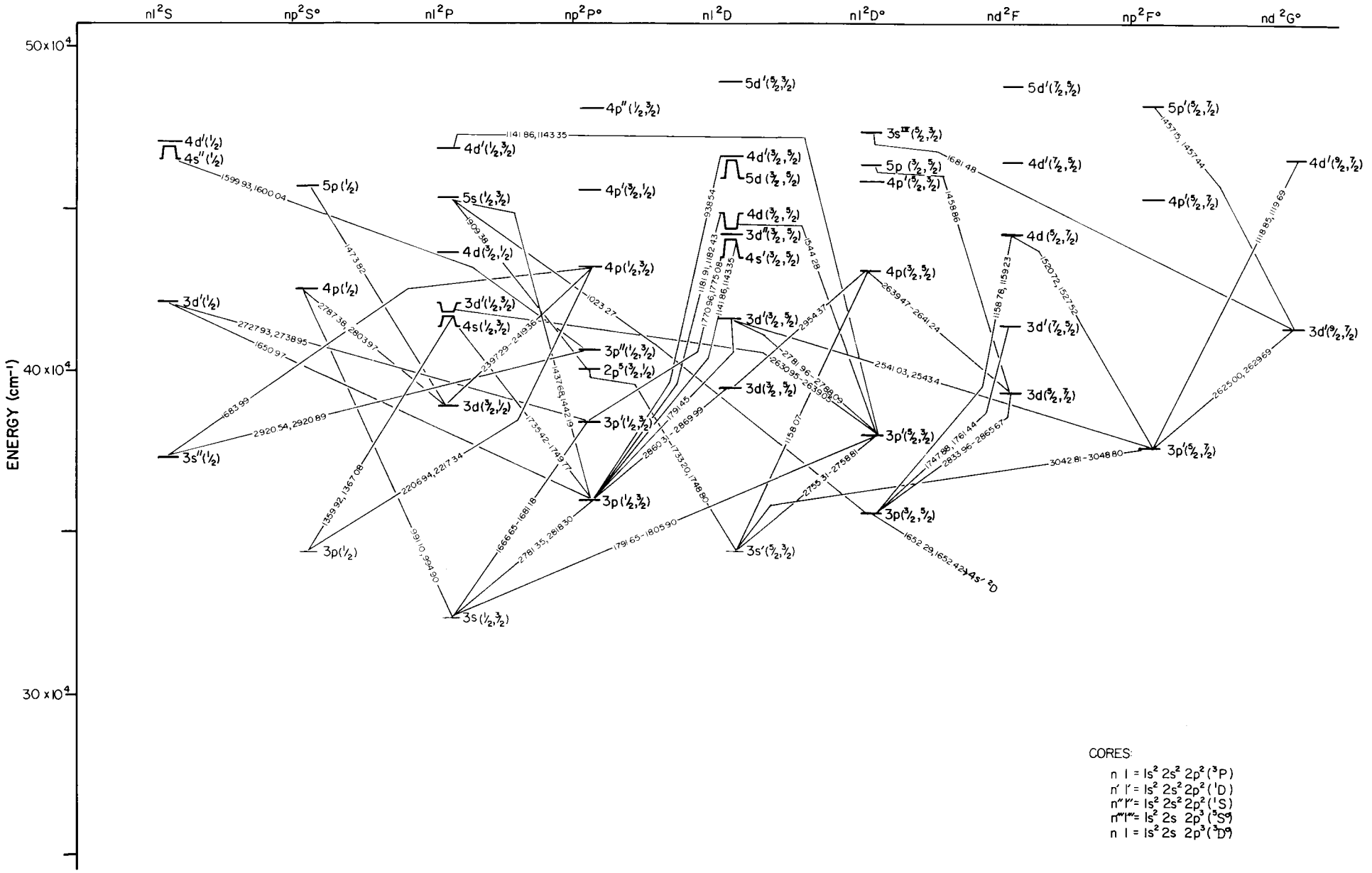



F III GROTRIAN DIAGRAM (7 electrons, Z=9)
(N I sequence, Configuration: 1s²2s²2p²nl, Doublet System)
Detail: Transitions 2s2p⁴ upwards
F III DOUBLET GROTRIAN DIAGRAM 2s2p⁴ up
nl ²S
np ²S°
nl ²P
np ²P°
nl ²D
nl ²D°
nd ²F
np ²F°
nd G°
ENERGY (cm⁻¹)
50x10⁴
40x10⁴
30x10⁴
20x10⁴
4d'(1/2)
4s''(1/2)
3d'(1/2)
3s''(1/2)
5p(1/2)
4p(1/2)
3p(1/2)
2s2p⁴(1/2)
4d'(1/2,3/2)
5s(1/2,3/2)
4d(3/2,1/2)
3d'(1/2,3/2)
4s(1/2,3/2)
3d(3/2,1/2)
3s(1/2,3/2)
2s2p⁴(3/2,1/2)
4p''(1/2,3/2)
4p'(3/2,1/2)
4p(1/2,3/2)
3p''(1/2,3/2)
2p⁵(3/2,1/2)
3p'(1/2,3/2)
3p(1/2,3/2)
5d'(5/2,3/2)
4d'(3/2,5/2)
5d(3/2,5/2)
4d(3/2,5/2)
3d''(3/2,5/2)
4s'(3/2,5/2)
3d'(3/2,5/2)
3d(3/2,5/2)
3s'(5/2,3/2)
2s 2p⁴(5/2,3/2)
3s^IV(5/2,3/2)
5p(3/2,5/2)
4p'(5/2,3/2)
4p(3/2,5/2)
3p'(5/2,3/2)
3p(3/2,5/2)
5d'(7/2,5/2)
4d'(7/2,5/2)
4d(5/2,7/2)
3d'(7/2,5/2)
3d(5/2,7/2)
5p'(5/2,7/2)
4p'(5/2,7/2)
3p'(5/2,7/2)
4d'(9/2,7/2)
3d'(9/2,7/2)
630.33,630.35
652,653.83
734.05–734.77
712.52
719.85–744.92
847.95–851.70
1065.27–1070.62
1293.10
1113.46–1123.12
665.81,666.26
522.29,523.66
508.51
573.89,574.39
378.58
588.06,588.20
600.10,600.39
CORES
nl = 2s²2p²(³P)
n'l' = 2s²2p²(¹D)
n''l'' = 2s²2p²(¹S)
n'''l''' = 2s 2p³(⁵S°)
n^IV l^IV = 2s 2p³(³D°)

F III ENERGY LEVELS (7 electrons, Z=9)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)
(Detail: Levels Above $2s2p^4\ ^2D$)



F III GROTRIAN DIAGRAM (7 electrons, Z=9)
(NI sequence: Configuration $1s^2\,2s^2\,2p^2\,nl$, Doublet System)
Detail: Transitions above $3p\ ^2D^o$

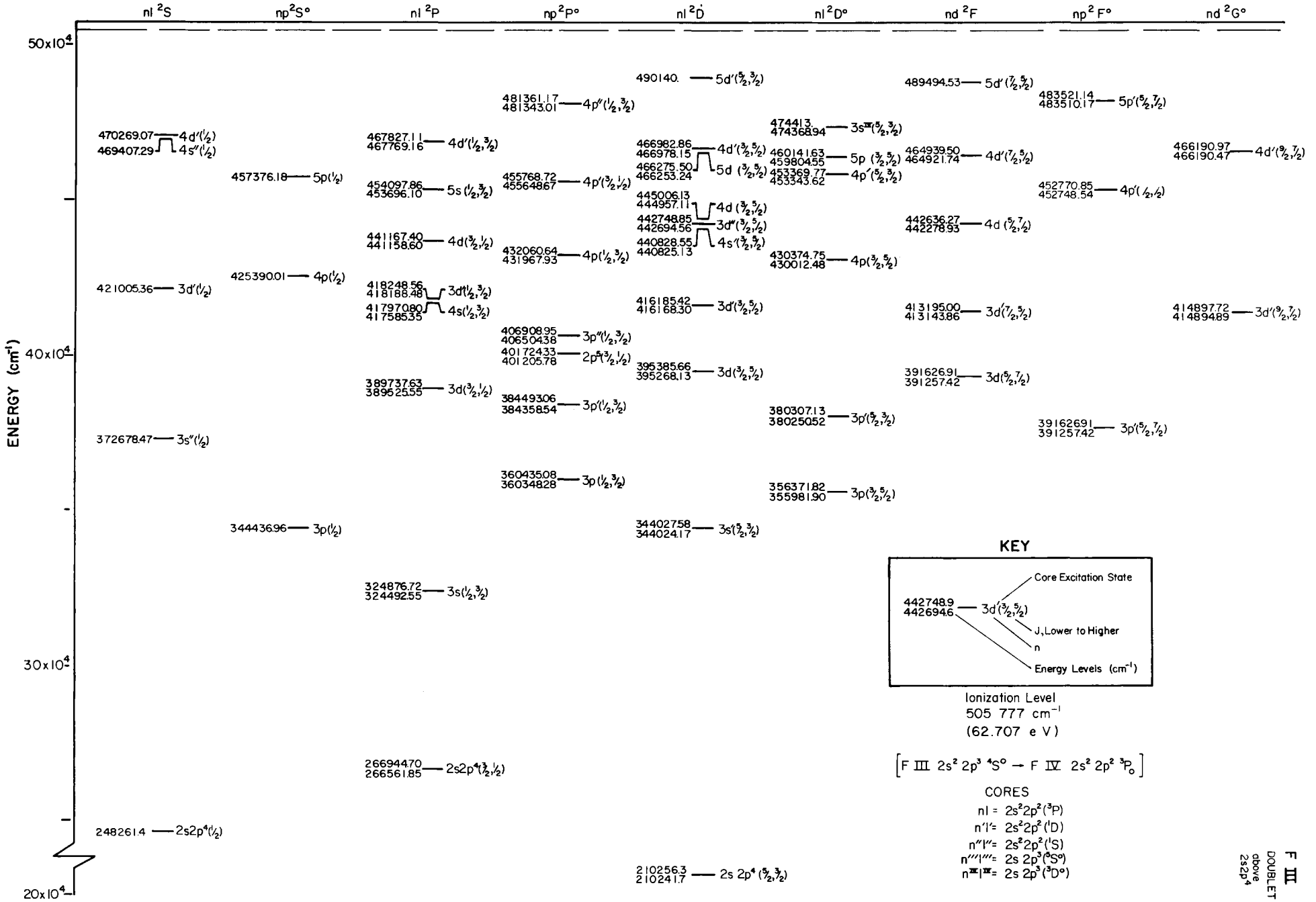


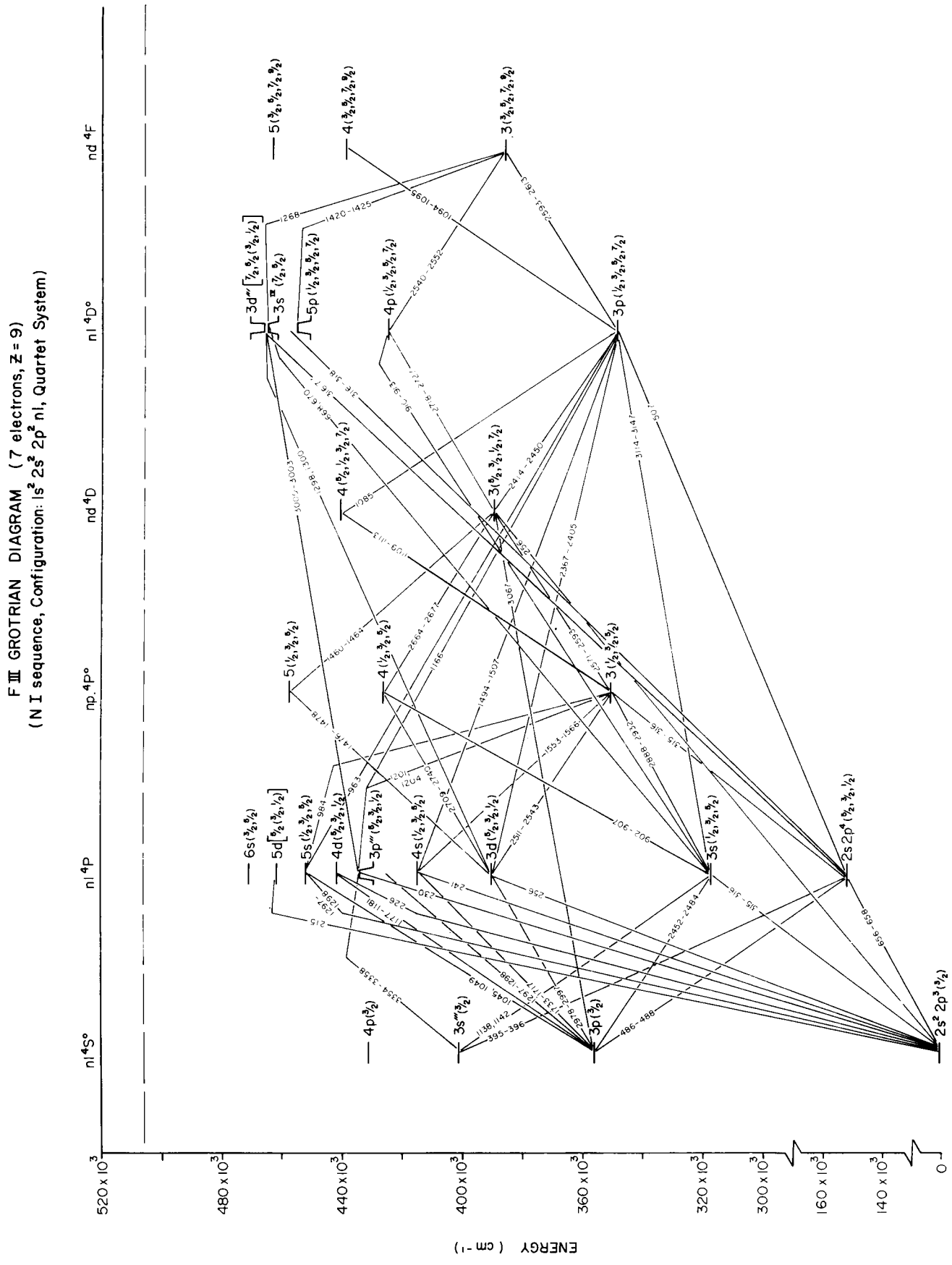
CORES:

$n\,l = 1s^2\,2s^2\,2p^2\,(^3P)$
$n'\,l' = 1s^2\,2s^2\,2p^2\,(^1D)$
$n''\,l'' = 1s^2\,2s^2\,2p^2\,(^1S)$
$n'''\,l''' = 1s^2\,2s\,2p^3\,(^5S^o)$
$n\,l = 1s^2\,2s\,2p^3\,(^3D^o)$

F III DOUBLET GROTRIAN DIAGRAM 3s ²P up

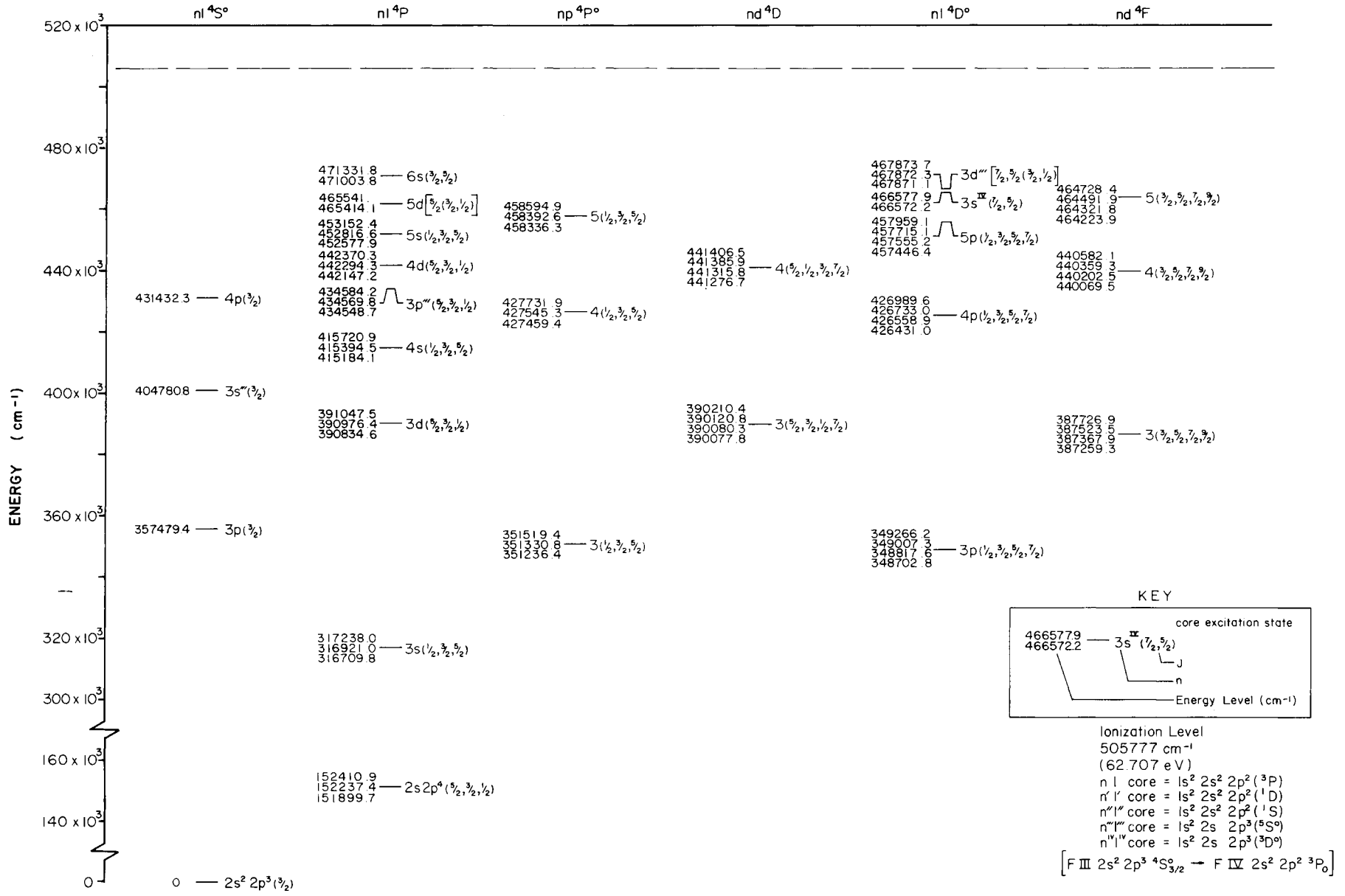
F III ENERGY LEVELS (7 electrons, Z=9)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)
(Detail: Levels Above $2s2p^4\ ^2D$)




F III GROTRIAN DIAGRAM (7 electrons, Z = 9)
(N I sequence, Configuration: 1s² 2s² 2p² nl, Quartet System)
nl ⁴S°
nl ⁴P
np ⁴P°
nd ⁴D
nl ⁴D°
nd ⁴F
ENERGY (cm⁻¹)
520 x 10³
480 x 10³
440 x 10³
400 x 10³
360 x 10³
320 x 10³
300 x 10³
160 x 10³
140 x 10³
0
2s² 2p³ (3/2)
2s 2p⁴ (3/2, 3/2, 1/2)
3s (1/2, 3/2, 3/2)
3p (1/2, 3/2, 3/2, 7/2)
3p (3/2)
3s''' (3/2)
4p (3/2)
3d (5/2, 3/2, 1/2)
4s (1/2, 3/2, 5/2)
3p'' (5/2, 3/2, 1/2)
4d (5/2, 3/2, 1/2)
5s (1/2, 3/2, 5/2)
5d [5/2 (3/2, 1/2)]
6s (3/2, 5/2)
3 (1/2, 3/2, 5/2)
4 (1/2, 3/2, 5/2)
5 (1/2, 3/2, 5/2)
3 (5/2, 3/2, 1/2, 7/2)
4 (5/2, 1/2, 3/2, 7/2)
4p (1/2, 3/2, 5/2, 7/2)
5p (1/2, 3/2, 5/2, 7/2)
3s'' (7/2, 5/2)
3d''' [7/2, 5/2 (3/2, 1/2)]
3 (3/2, 5/2, 1/2, 7/2, 9/2)
4 (3/2, 5/2, 1/2, 7/2, 9/2)
5 (3/2, 5/2, 7/2, 9/2)

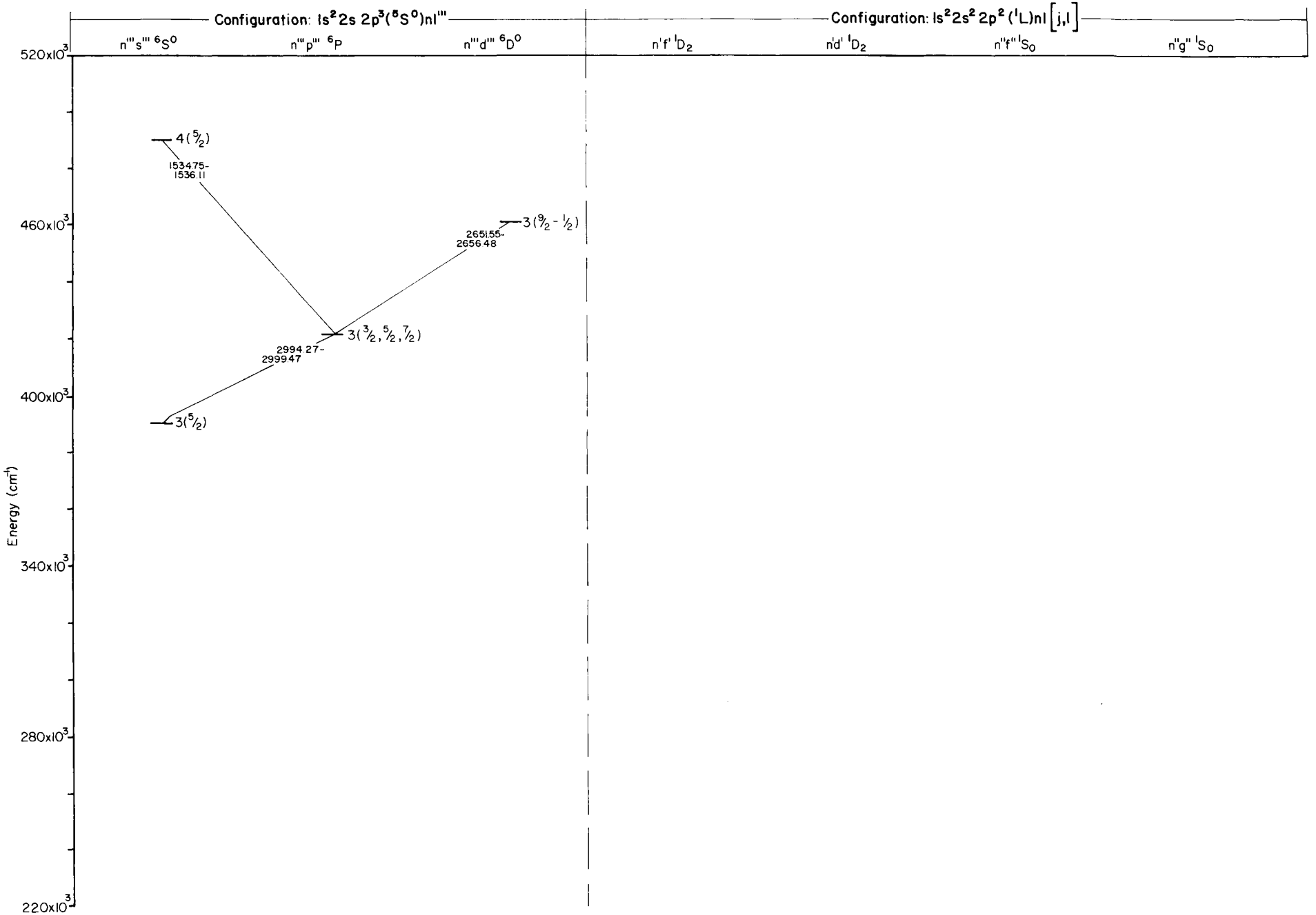
F III ENERGY LEVELS (7 electrons, Z = 9)

(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Quartet System)



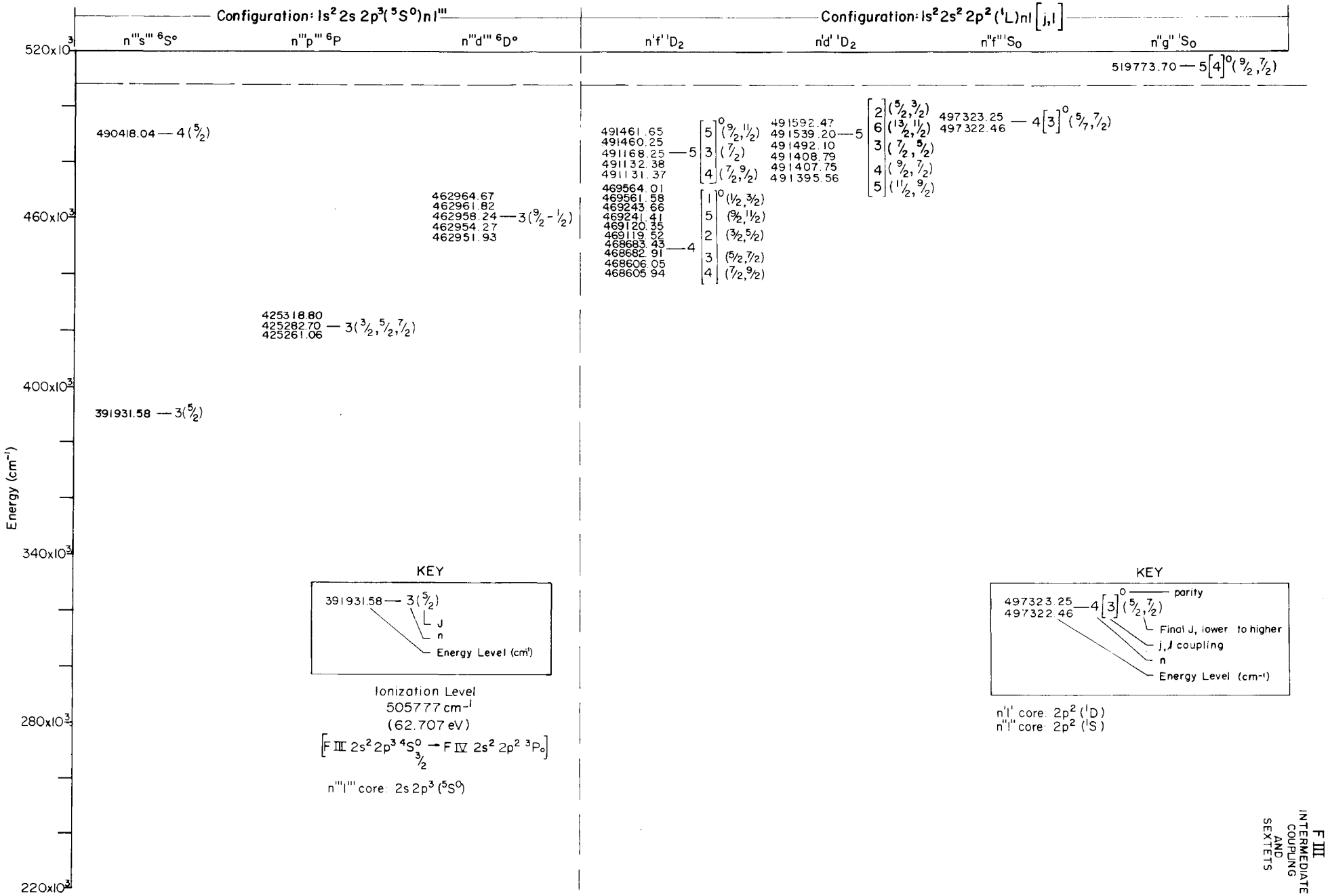
F III GROTRIAN DIAGRAM (7 electrons, Z=9)

(N I Sequence, Sextet and Intermediate Coupling)



F III ENERGY LEVELS (7 electrons, Z=9)

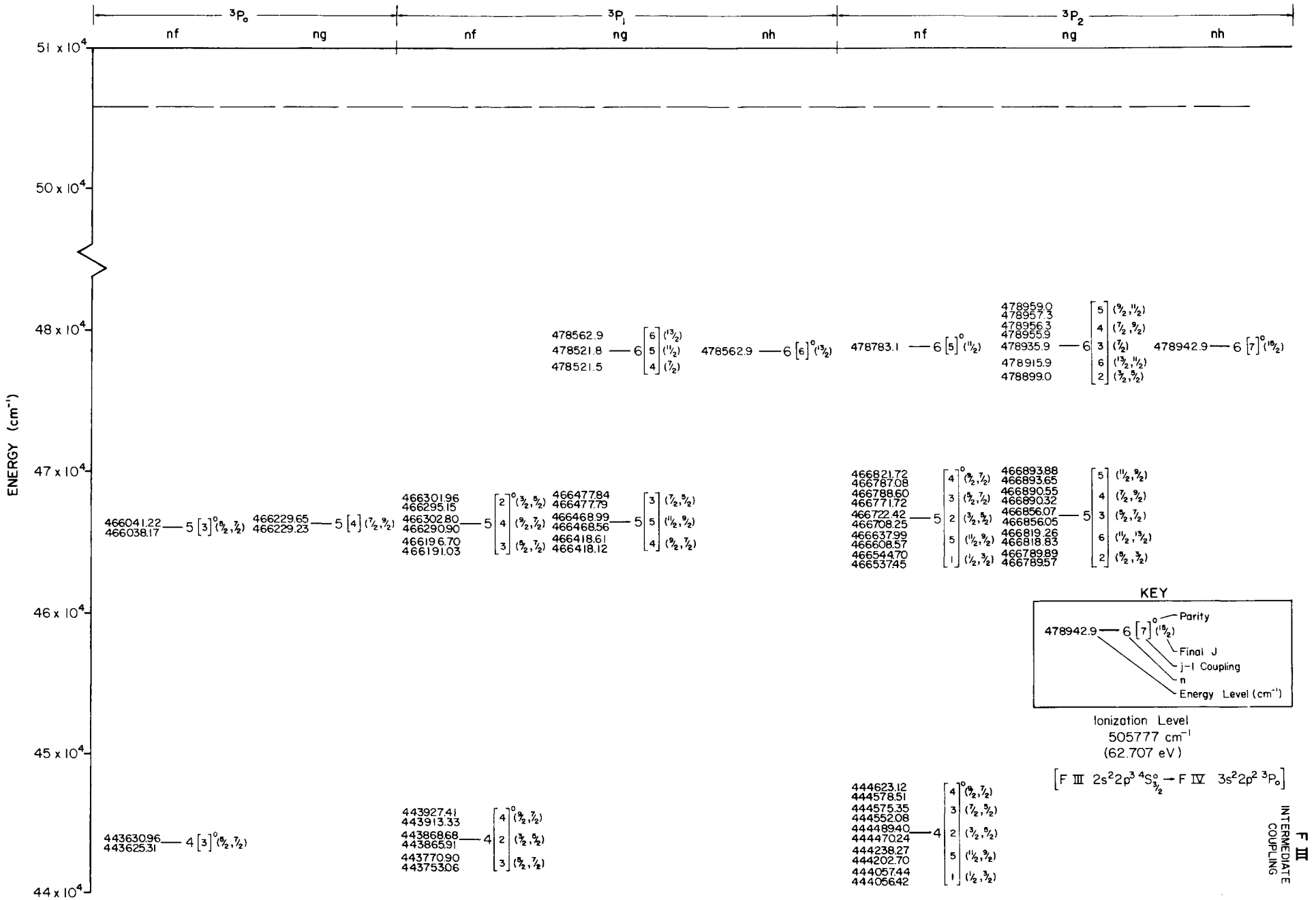
(N I Sequence, Sextet and Intermediate Coupling)



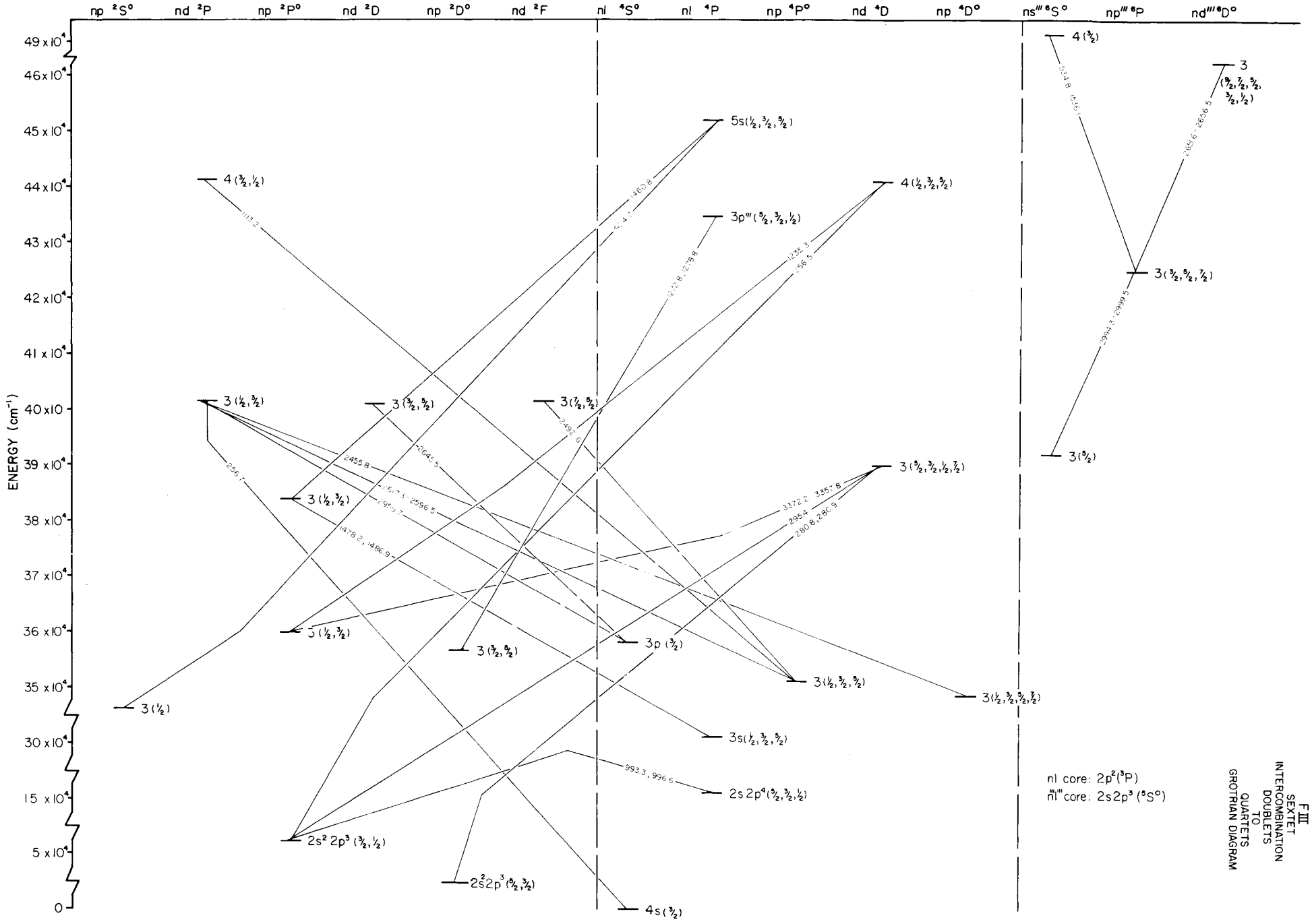
F III
INTERMEDIATE COUPLING AND SEXTETS

F III ENERGY LEVELS (7 electrons, Z = 9)

(N I sequence, Configuration: $1s^2 2s^2 2p^2 (^3P) nl[j,l](J)$, Intermediate Coupling)

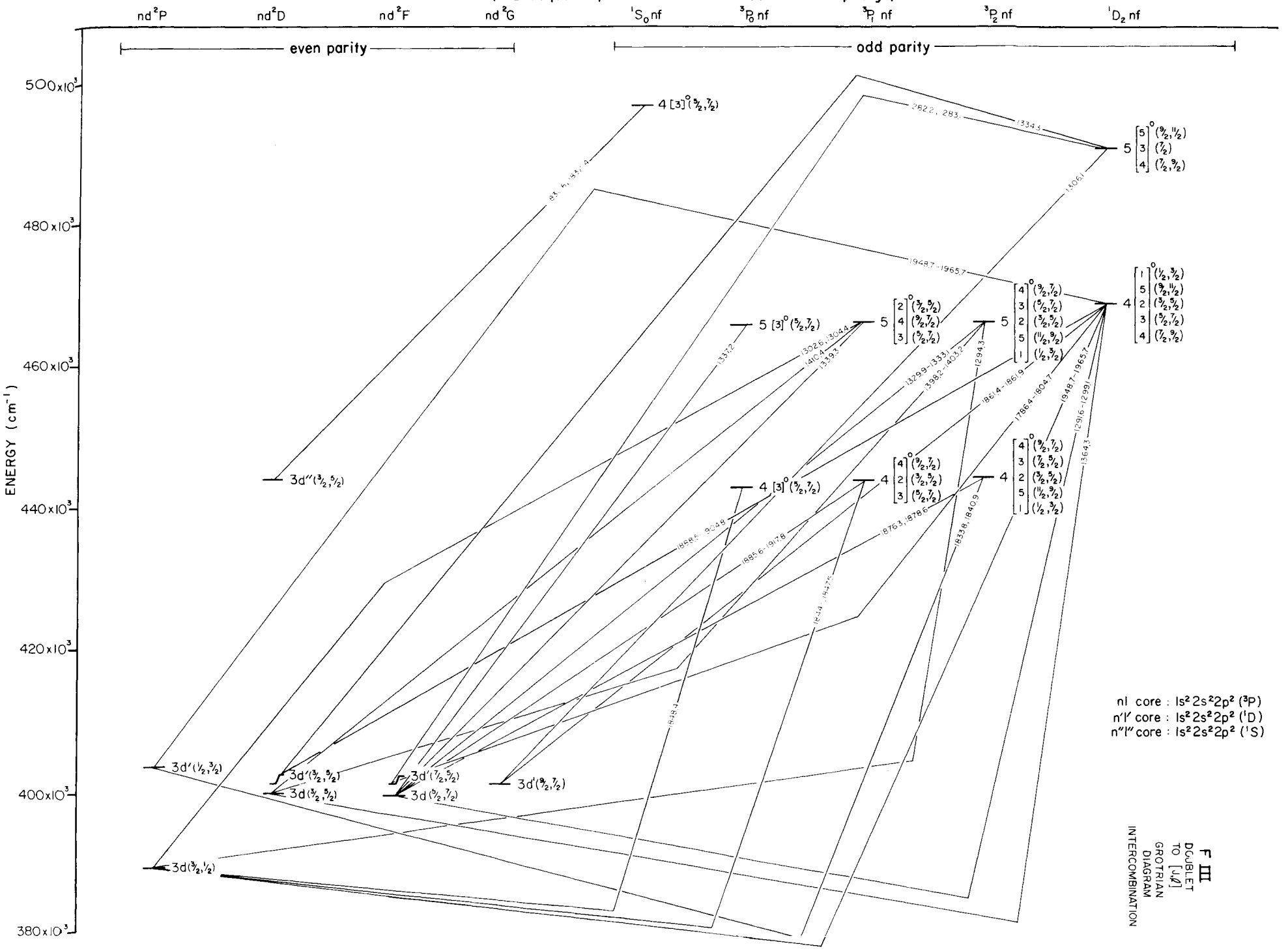


F III GROTRIAN DIAGRAM (7 electrons, Z=9)
(N I Sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Sextet System, Intercombinations: Doublet, Quartet)



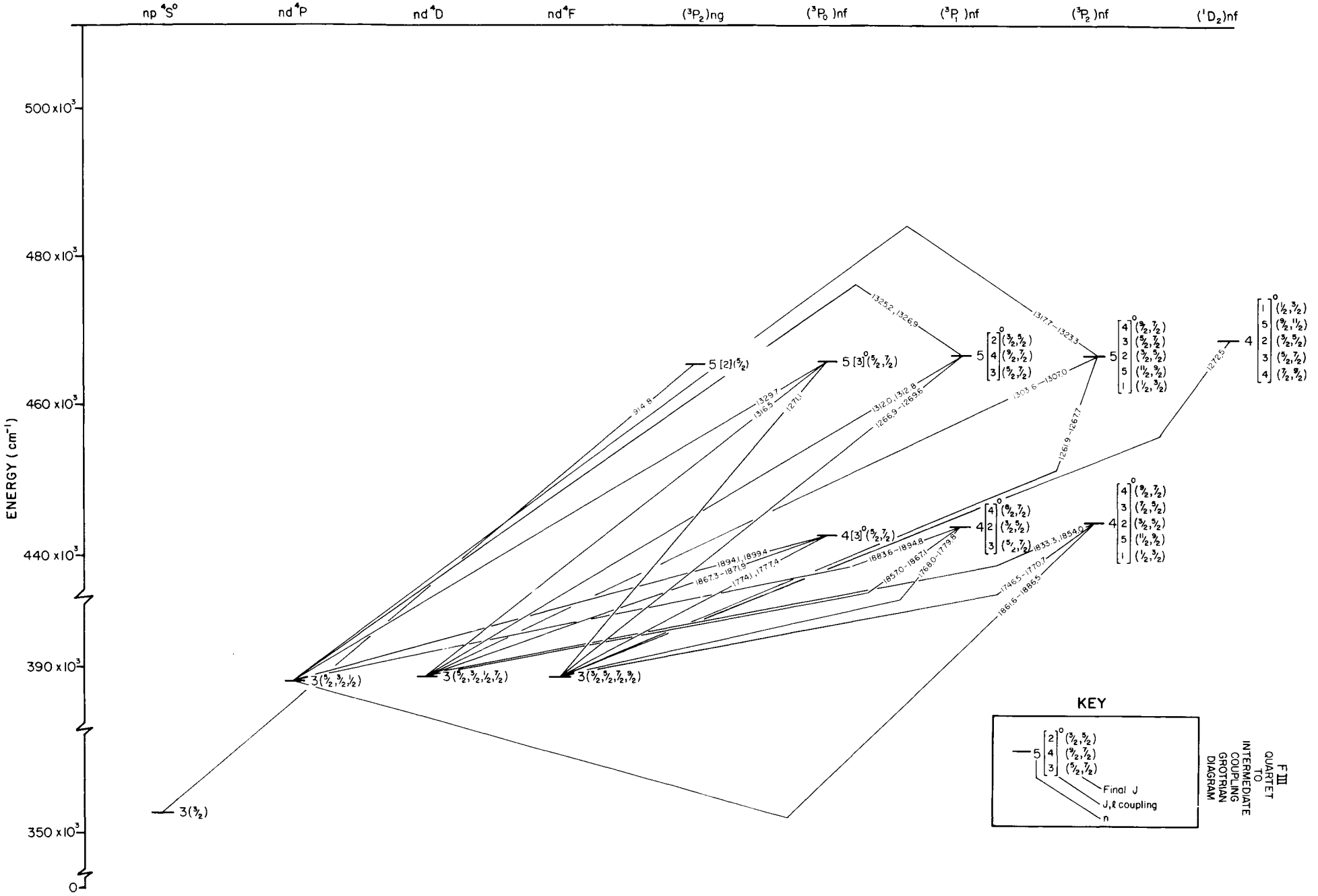
F III
SEXTET
INTERCOMBINATION
DOUBLETS
TO
QUARTETS
GROTRIAN DIAGRAM

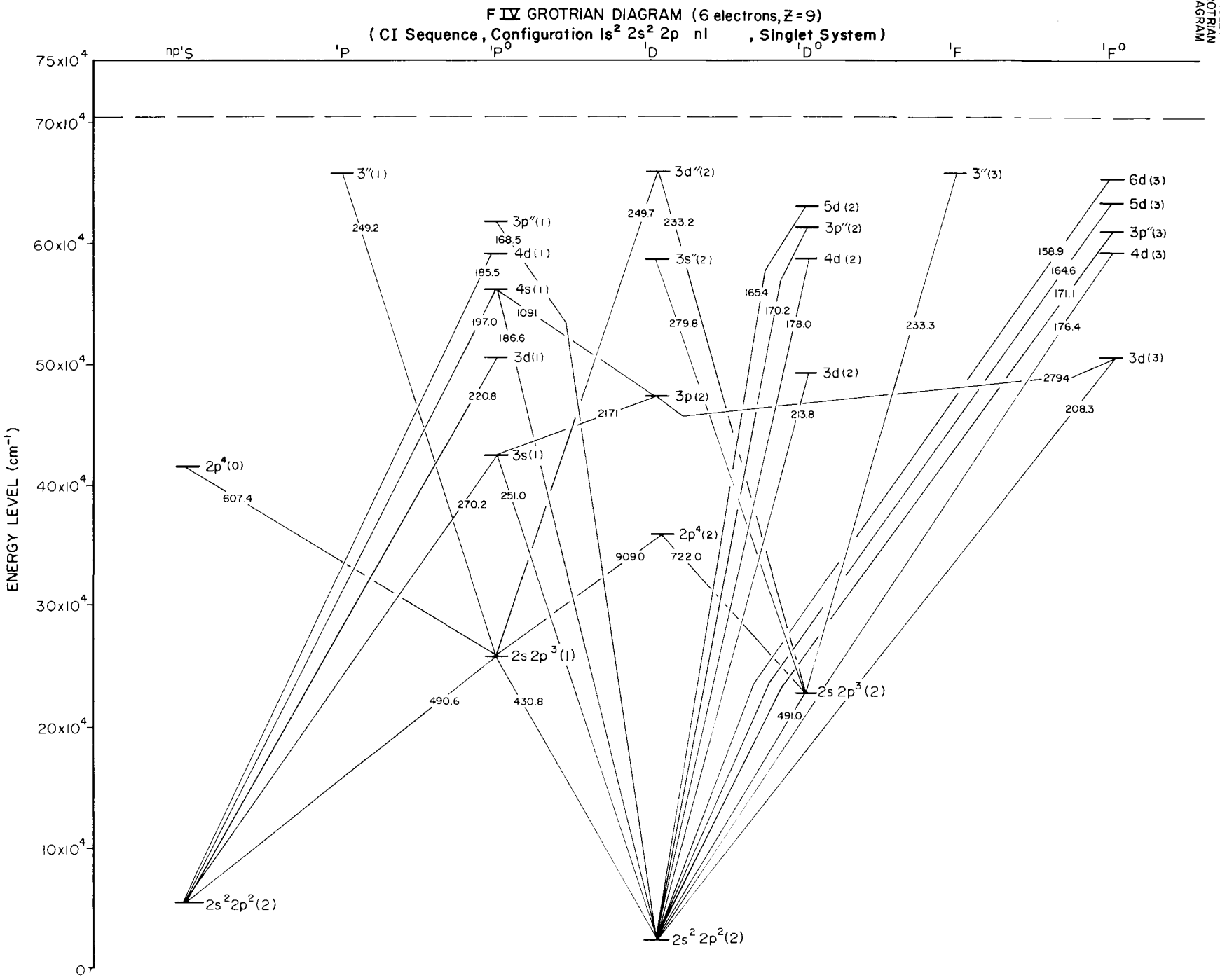
INTERCOMBINATION
F III GROTRIAN DIAGRAM (7 electrons, Z = 9)
(NI Sequence, Doublet to Intermediate Coupling)



F III
DOUBLET
TO [J,l]
GROTRIAN
DIAGRAM
INTERCOMBINATION

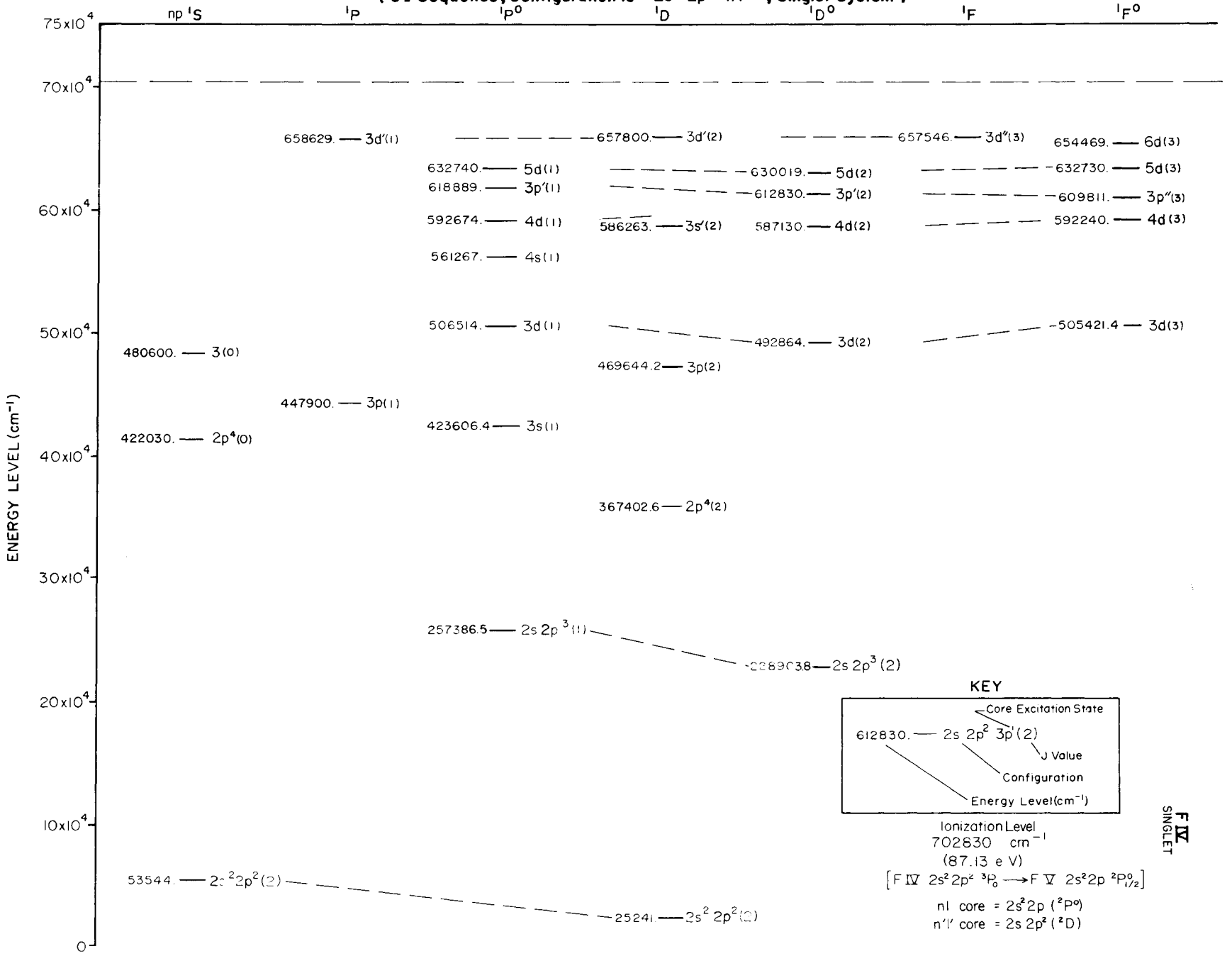
F III INTERCOMBINATION GROTRIAN DIAGRAM (7 electrons, Z=9)
(N I Sequence, Configuration $1s^2 2s^2 2p^2 nl$, Quartet to Intermediate Coupling)

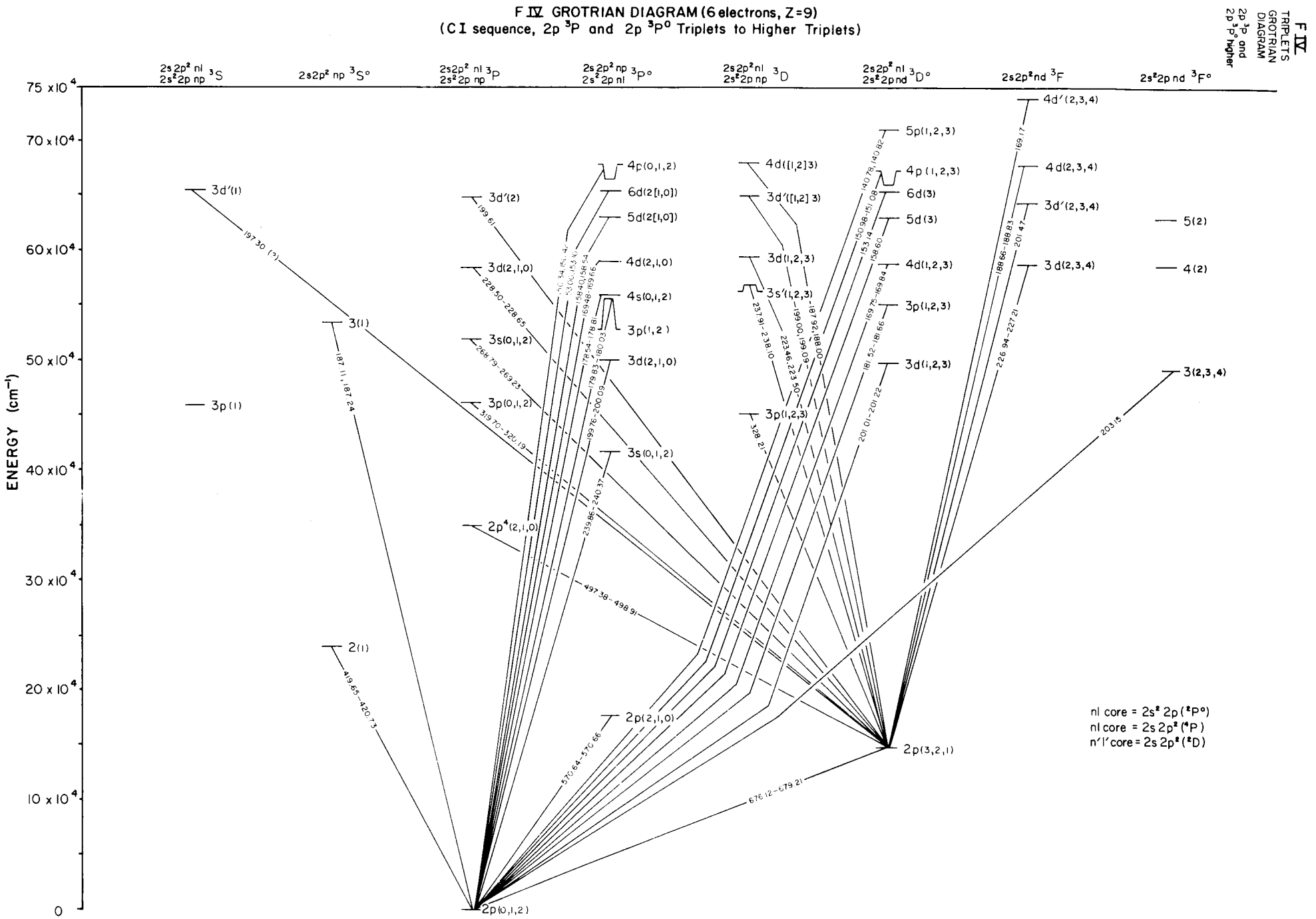



F IV GROTRIAN DIAGRAM (6 electrons, Z = 9)
(CI Sequence, Configuration 1s² 2s² 2p nl , Singlet System)
np'S
¹P
¹P°
¹D
¹D°
¹F
¹F°
ENERGY LEVEL (cm⁻¹)
75x10⁴
70x10⁴
60x10⁴
50x10⁴
40x10⁴
30x10⁴
20x10⁴
10x10⁴
0
3''(1)
3p''(1)
4d(1)
4s(1)
3d(1)
3s(1)
2p⁴(0)
2s 2p³(1)
2s²2p²(2)
3d''(2)
3s''(2)
3p(2)
2p⁴(2)
2s²2p²(2)
5d(2)
3p''(2)
4d(2)
3d(2)
2s 2p³(2)
3''(3)
6d(3)
5d(3)
3p''(3)
4d(3)
3d(3)
249.2
168.5
185.5
197.0
186.6
109.1
220.8
270.2
251.0
607.4
490.6
430.8
249.7
233.2
279.8
217.1
909.0
722.0
165.4
170.2
178.0
213.8
491.0
233.3
158.9
164.6
171.1
176.4
279.4
208.3

F IV ENERGY LEVELS (6 electrons, Z=9)

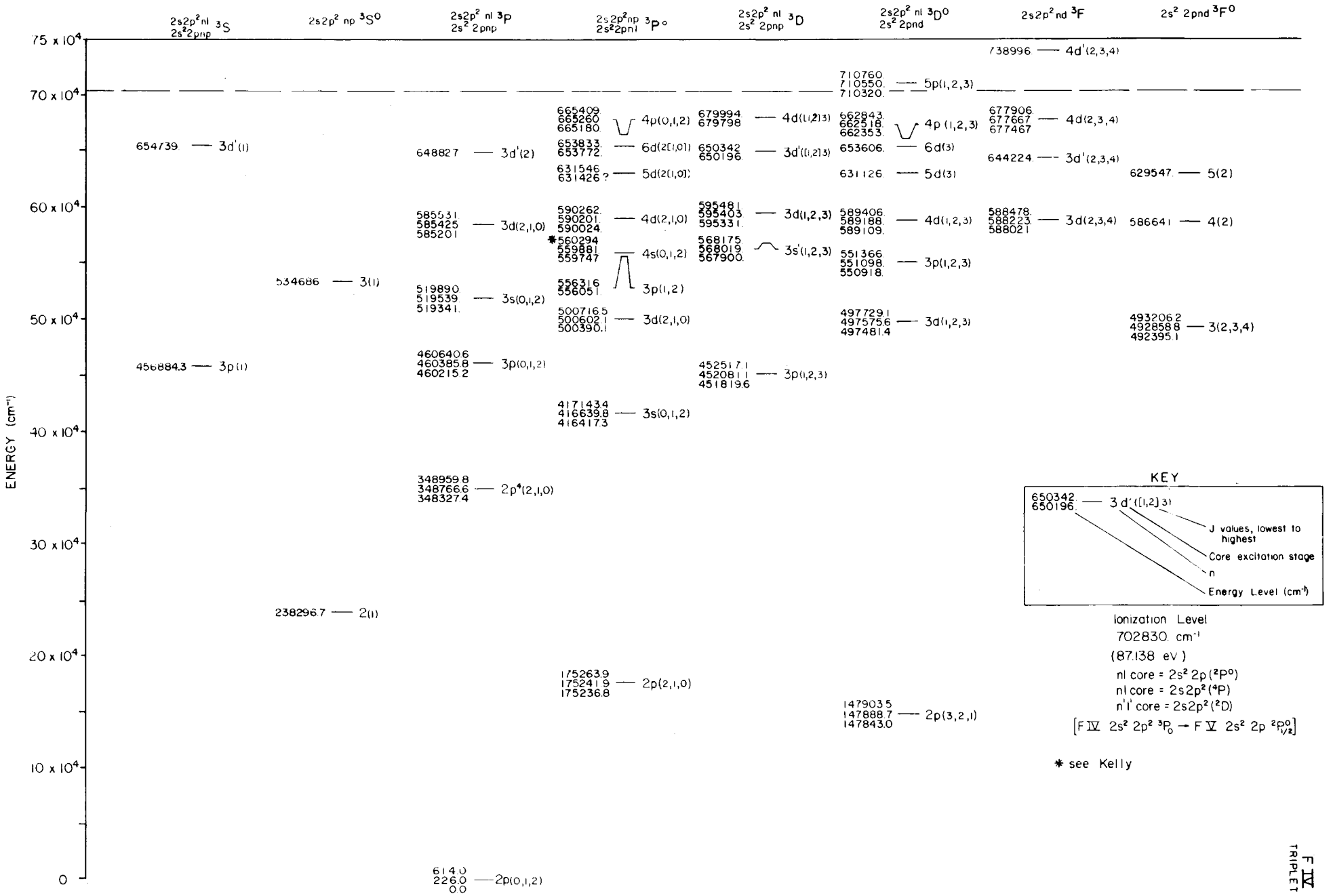
(CI Sequence, Configuration $1s^2\ 2s^2\ 2p\ \ nl$, Singlet System)



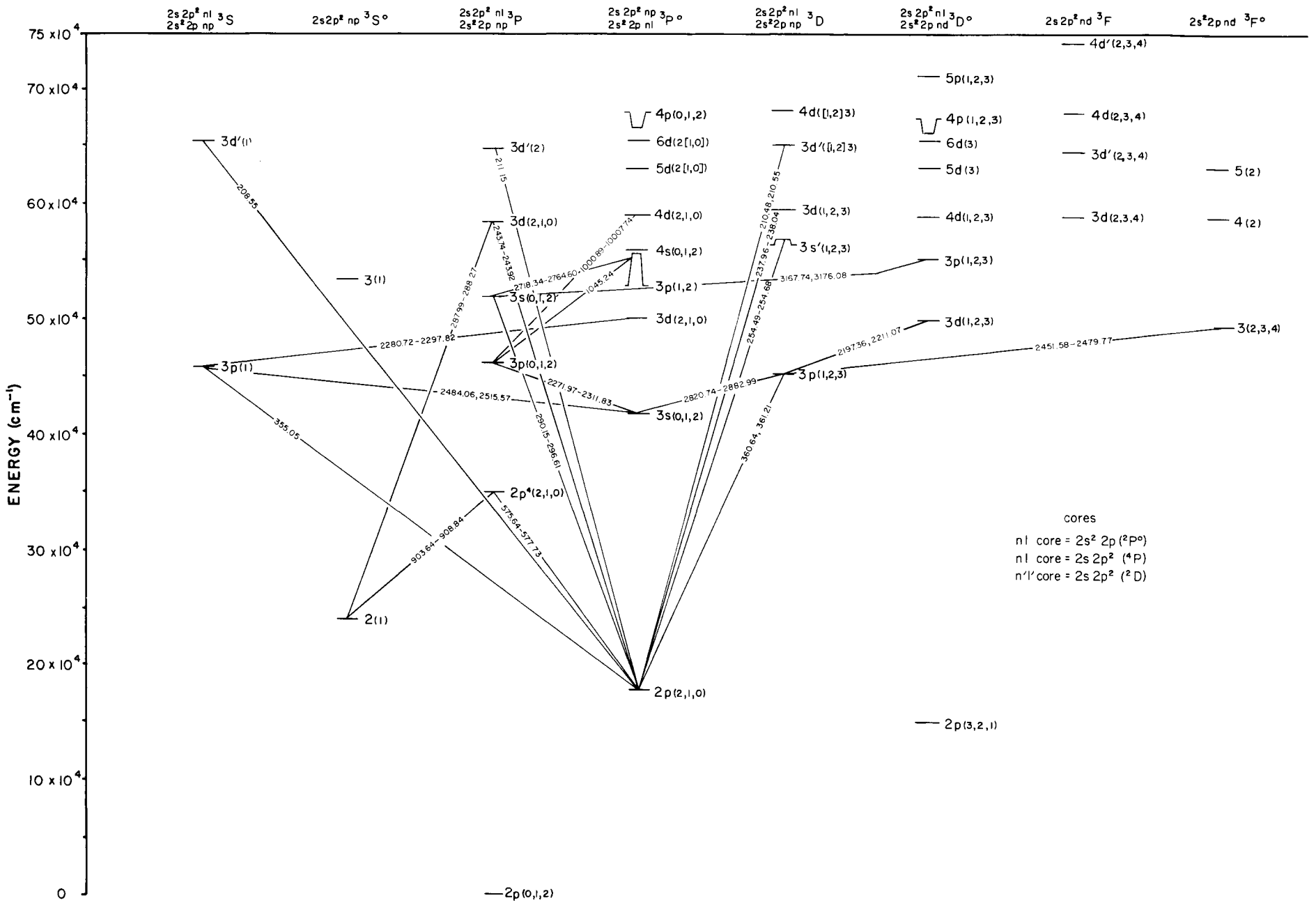

F IV GROTRIAN DIAGRAM (6 electrons, Z=9)
(C I sequence, 2p ³P and 2p ³P⁰ Triplets to Higher Triplets)
F IV
TRIPLETS
GROTRIAN
DIAGRAM
2p ³P and
2p ³P° higher
2s2p² nl
2s²2p np ³S
2s2p² np ³S°
2s2p² nl ³P
2s²2p np
2s2p² np ³P°
2s²2p nl
2s2p² nl ³D
2s²2p np
2s2p² nl ³D°
2s²2p nd
2s2p²nd ³F
2s²2p nd ³F°
ENERGY (cm⁻¹)
75 x10⁴
70 x10⁴
60 x10⁴
50 x10⁴
40 x10⁴
30 x10⁴
20 x10⁴
10 x10⁴
0
3d′(1)
3p(1)
3(1)
2(1)
3d′(2)
3d(2,1,0)
3s(0,1,2)
3p(0,1,2)
2p⁴(2,1,0)
2p(0,1,2)
4p(0,1,2)
6d(2[1,0])
5d(2[1,0])
4d(2,1,0)
4s(0,1,2)
3p(1,2)
3d(2,1,0)
3s(0,1,2)
2p(2,1,0)
4d([1,2]3)
3d′([1,2]3)
3d(1,2,3)
3s′(1,2,3)
3p(1,2,3)
2p(3,2,1)
5p(1,2,3)
4p(1,2,3)
6d(3)
5d(3)
4d(1,2,3)
3p(1,2,3)
3d(1,2,3)
4d′(2,3,4)
4d(2,3,4)
3d′(2,3,4)
3d(2,3,4)
5(2)
4(2)
3(2,3,4)
197.30 (?)
228.50-228.65
264.79-269.23
319.70-320.19
187.11,187.24
419.65-420.73
199.61
169.48-169.66
178.81
179.54-180.03
179.83-200.09
199.76-200.09
239.86-240.37
497.38-498.91
570.64-570.66
678.12-679.21
237.91-238.10
223.46,223.50
199.00,199.09
187.92,188.00
328.21
140.78,140.82
150.98-151.08
153.14
158.60
169.75-169.84
181.52-181.56
201.01-201.22
169.17
188.66-188.83
201.47
226.94-227.21
203.15
nl core = 2s² 2p (²P°)
nl core = 2s 2p² (⁴P)
n′l′ core = 2s 2p² (²D)

F IV ENERGY LEVELS (6 electrons, Z=9)

(CI sequence, Configuration: $1s^2\,2s^2\,2p\,nl$ and $1s^2\,2s2p^2\,nl$, Triplet System)

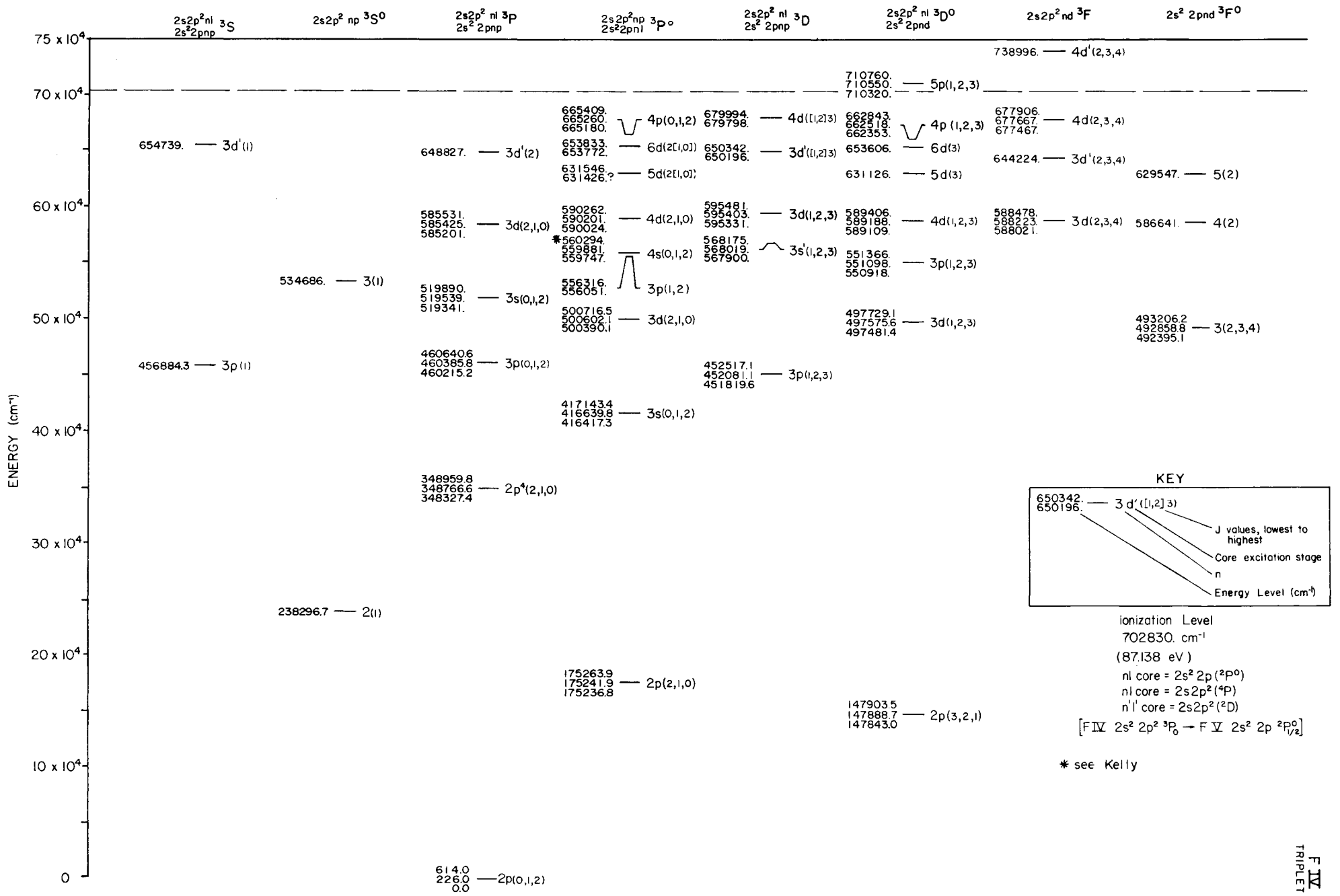


F IV GROTRIAN DIAGRAM (6 electrons, Z=9)
(C I sequence, Transitions Above 2p ³D° to Higher Triplets)



F IV ENERGY LEVELS (6 electrons, Z=9)

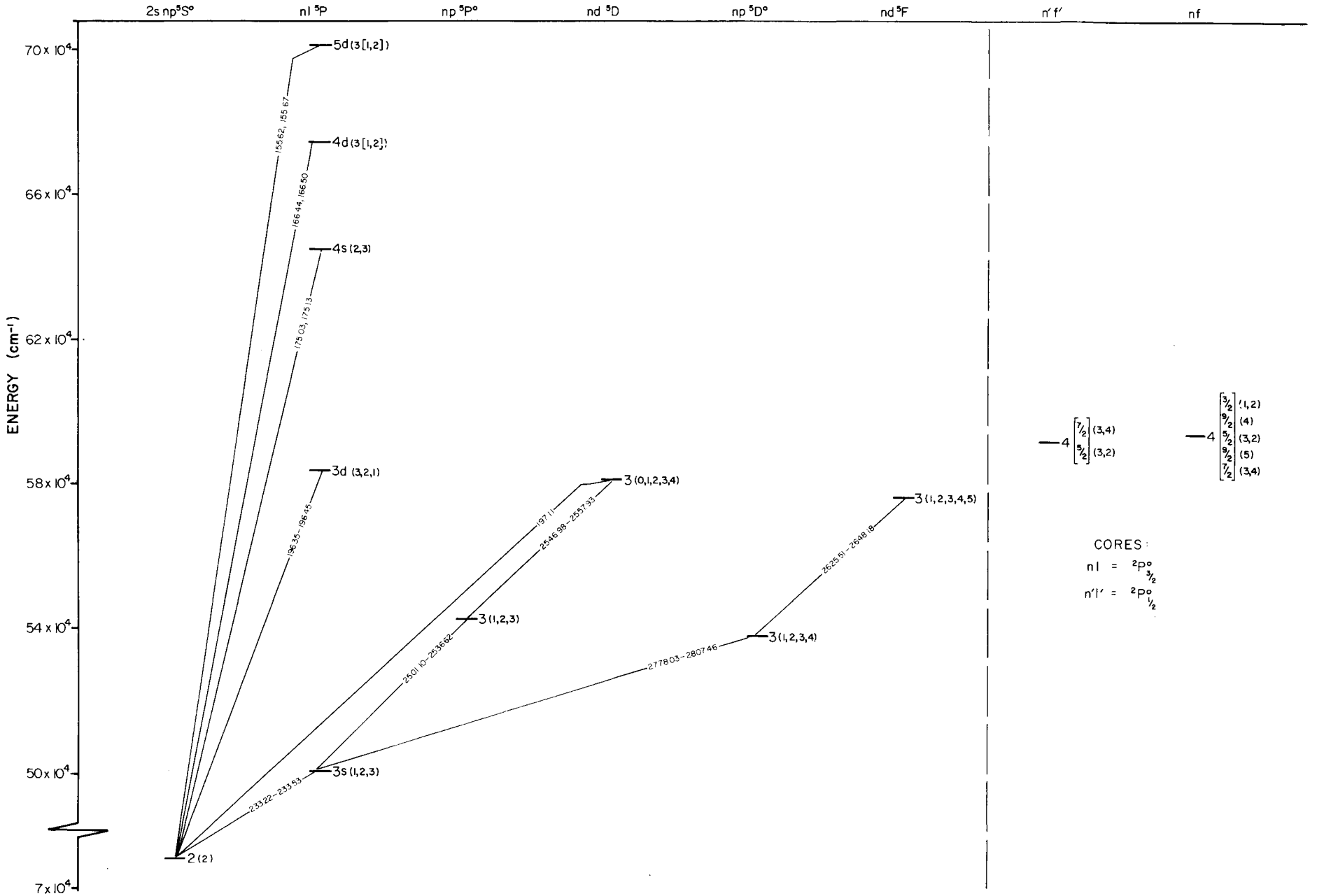
(CI sequence, Configuration: $1s^2\,2s^2\,2p\,nl$ and $1s^2\,2s2p^2\,nl$, Triplet System)



F IV
TRIPLET

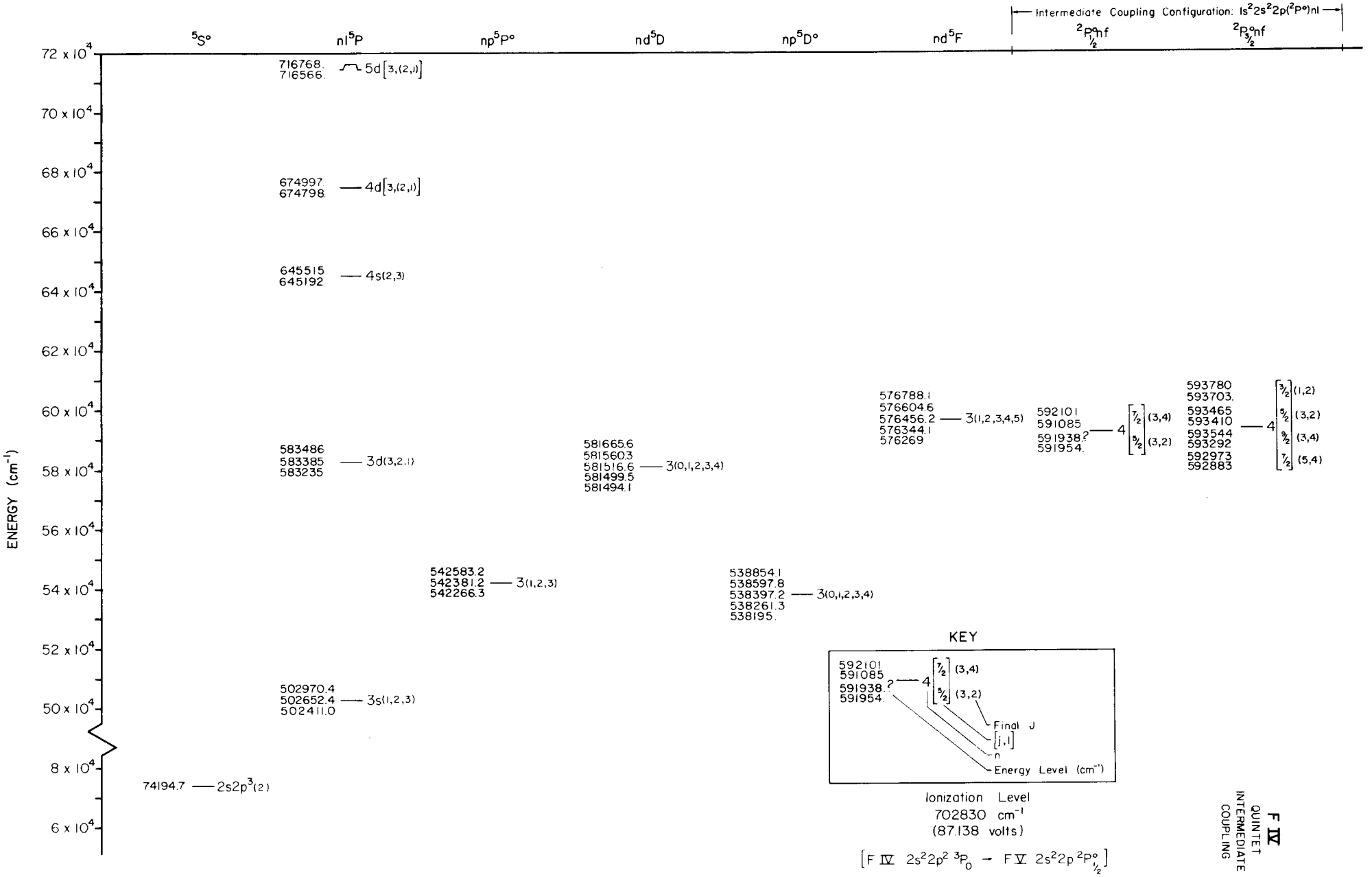
F IV GROTRIAN DIAGRAM (6 electrons, Z=9)

(C I sequence, Configuration: $1s^2\ 2s\ 2p^2\ (^4P)nl$, Quintet, Configuration: $1s^2\ 2s^2\ 2p\ (^2P^o)nl$, Intermediate Coupling)

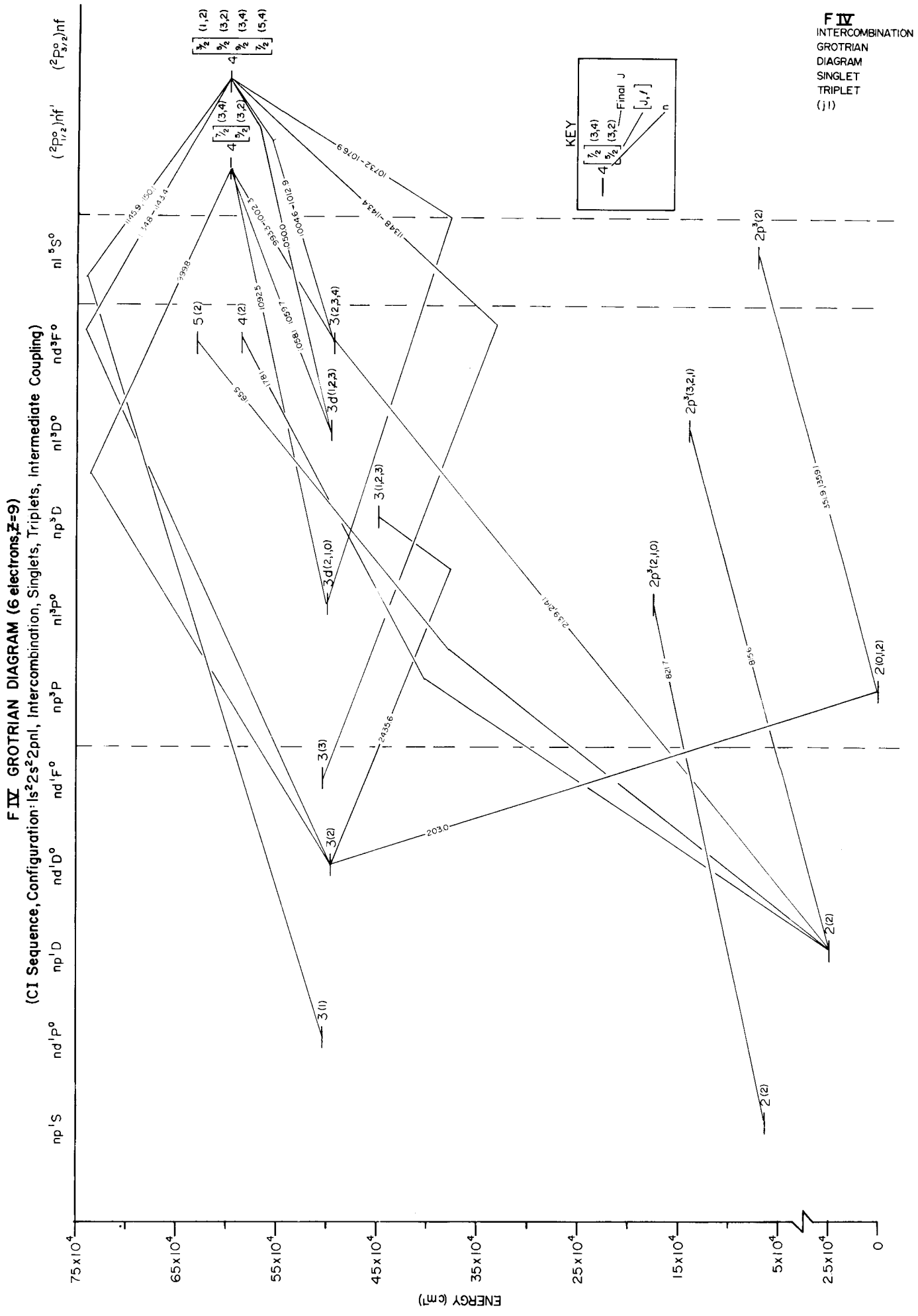


F IV ENERGY LEVELS (6 electrons, Z = 9)

(C I Sequence, Configuration: $1s^2 2s^2 2p^2(^4P)nl$, Quintet System & Intermediate Coupling)

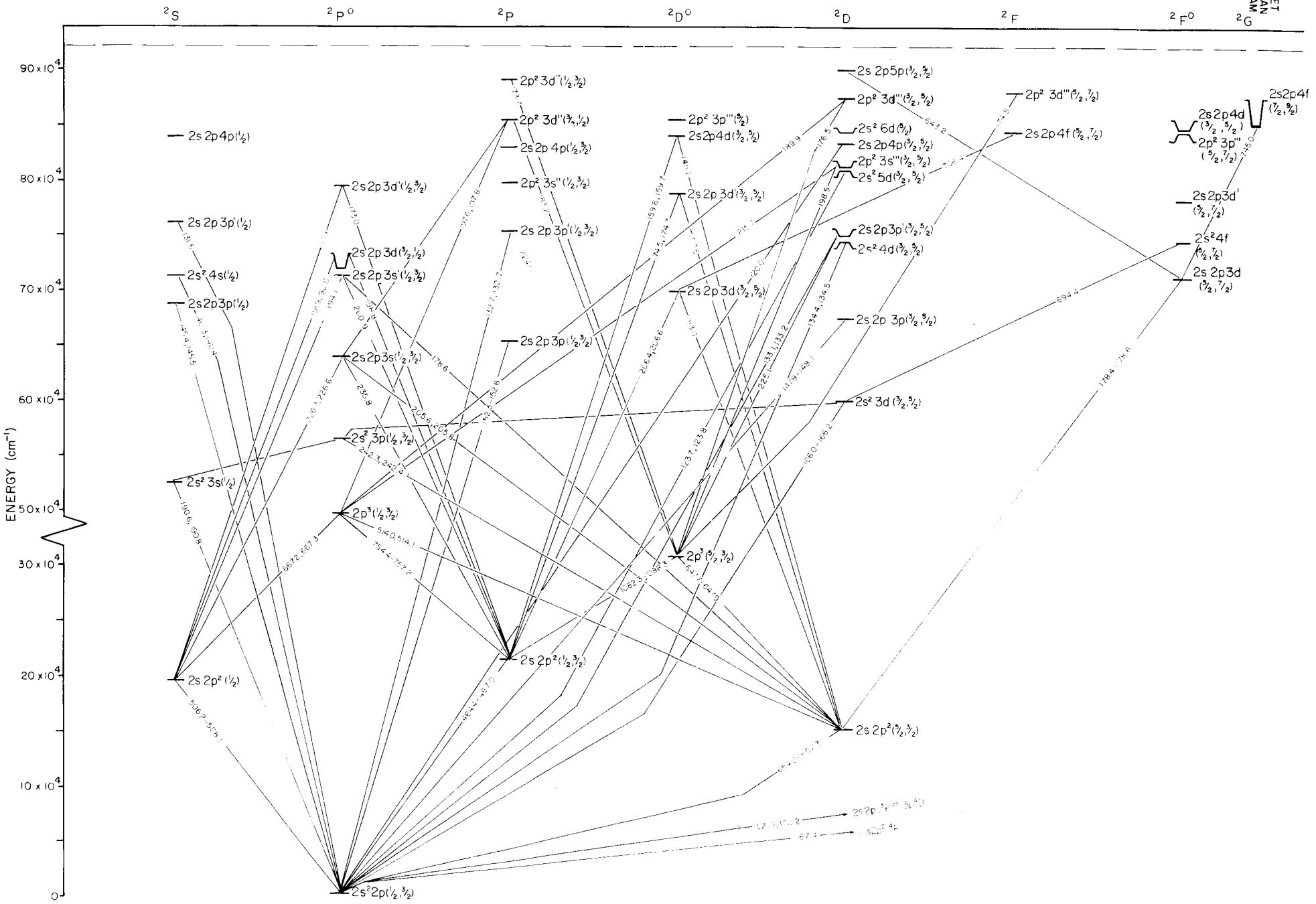


F IV
QUINTET
INTERMEDIATE
COUPLING


F IV GROTRIAN DIAGRAM (6 electrons, Z=9)
(CI Sequence, Configuration: 1s²2s²2pnl, Intercombination, Singlets, Triplets, Intermediate Coupling)
F IV
INTERCOMBINATION
GROTRIAN
DIAGRAM
SINGLET
TRIPLET
(jl)
KEY
Final J
ENERGY (cm⁻¹)
75x10⁴
65x10⁴
55x10⁴
45x10⁴
35x10⁴
25x10⁴
15x10⁴
5x10⁴
2.5x10⁴
0
np¹S
nd¹P°
np¹D
nd¹D°
nd¹F°
np³P
nl³P°
np³D
nl³D°
nd³F°
nl⁵S°
(²P°1/2)nf'
(²P°3/2)nf
2p³(2)
2p³(3,2,1)
2p³(2,1,0)
2(0,1,2)
2(2)
3(1)
3(2)
3(3)
3d(2,1,0)
3(1,2,3)
3d(1,2,3)
3(2,3,4)
4(2)
5(2)
2030
2435.6
2139.241
1348-1434
1732-1769
1046-1012.9
1000
993.3-1002.3
968
926.5
655
781
1659.1359.1
821.7
859.8

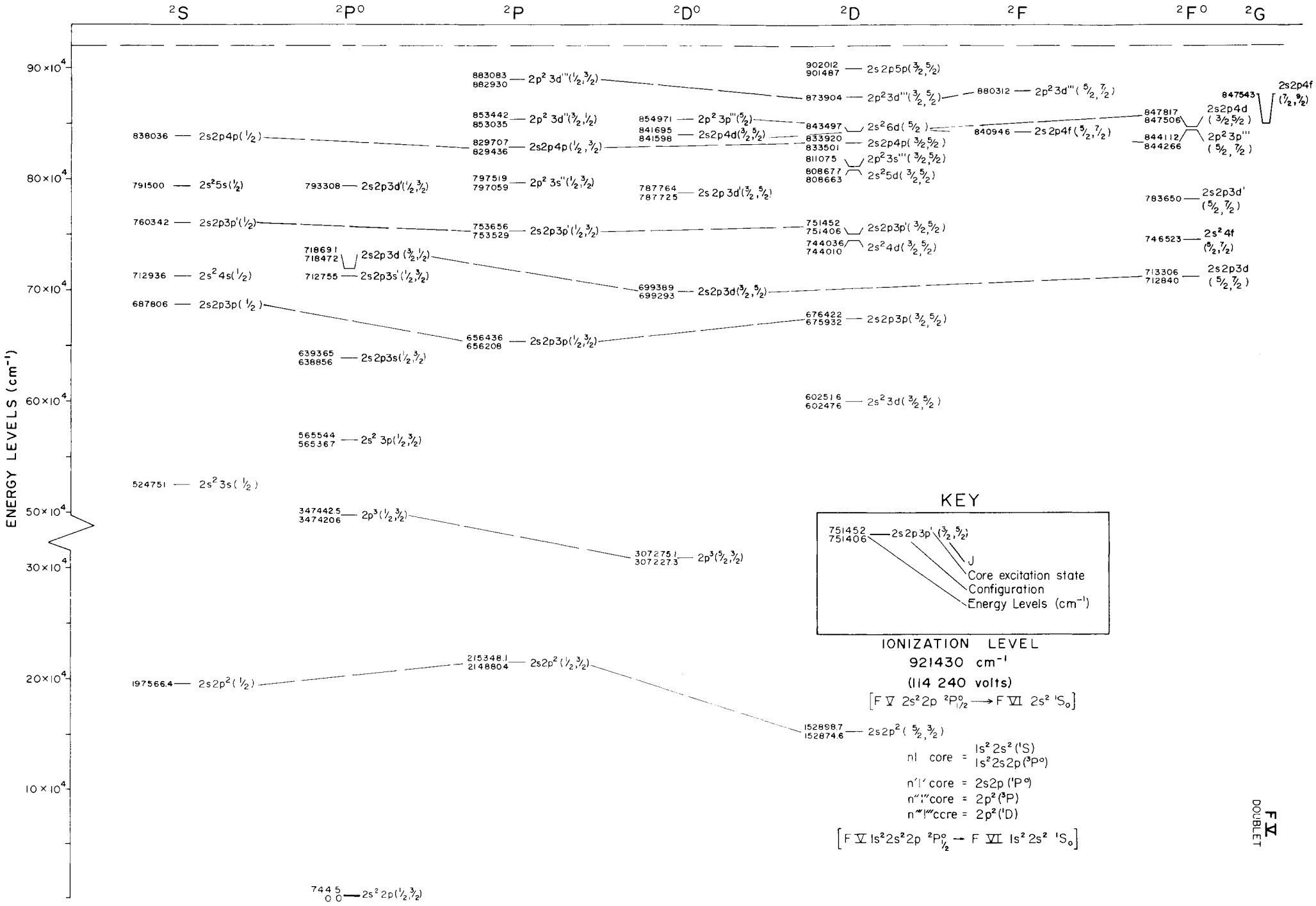
F V GROTRIAN DIAGRAM (5 electrons, Z=9)
(B I sequence, Configuration: $1s^2nl\,n'l'\,n''l''$, Doublet System)

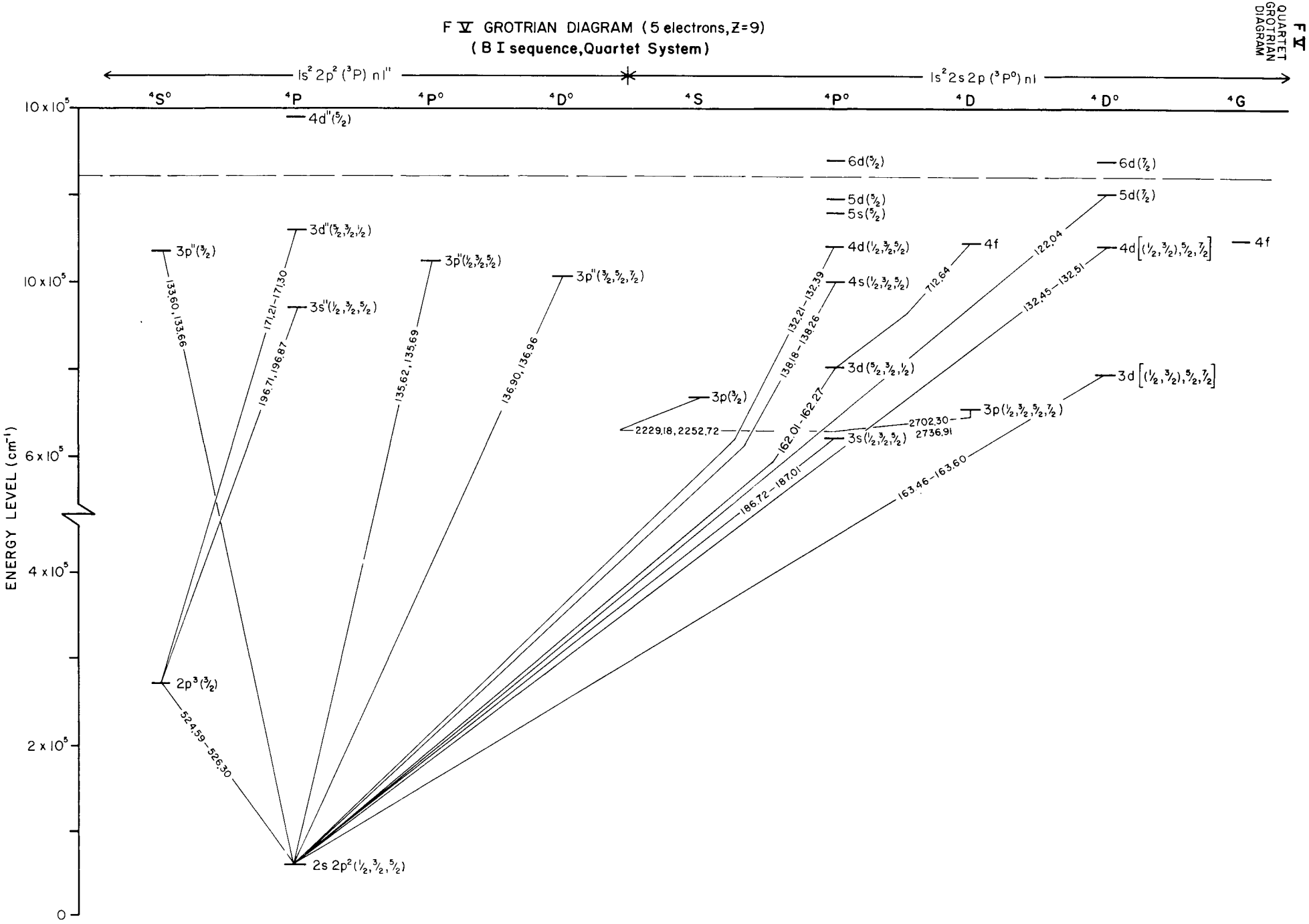
F V DOUBLET GROTRIAN DIAGRAM



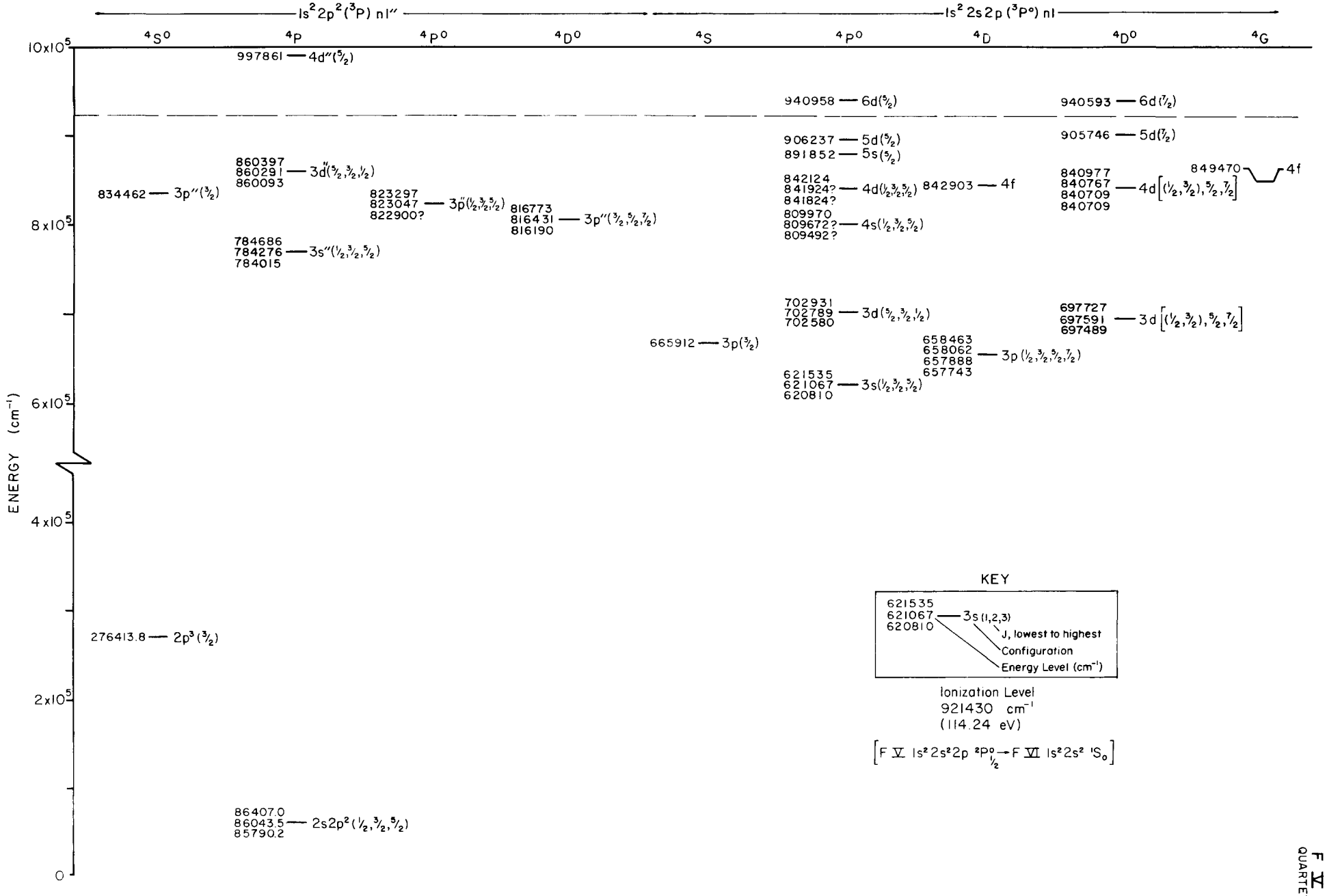
F V ENERGY LEVELS (5 electrons, Z = 9)

B I Sequence, Configurations: $1s^2\,2s^2(^1S)nl$ & $1s^2\,2s2p(^3P^o)nl$, Doublet System)

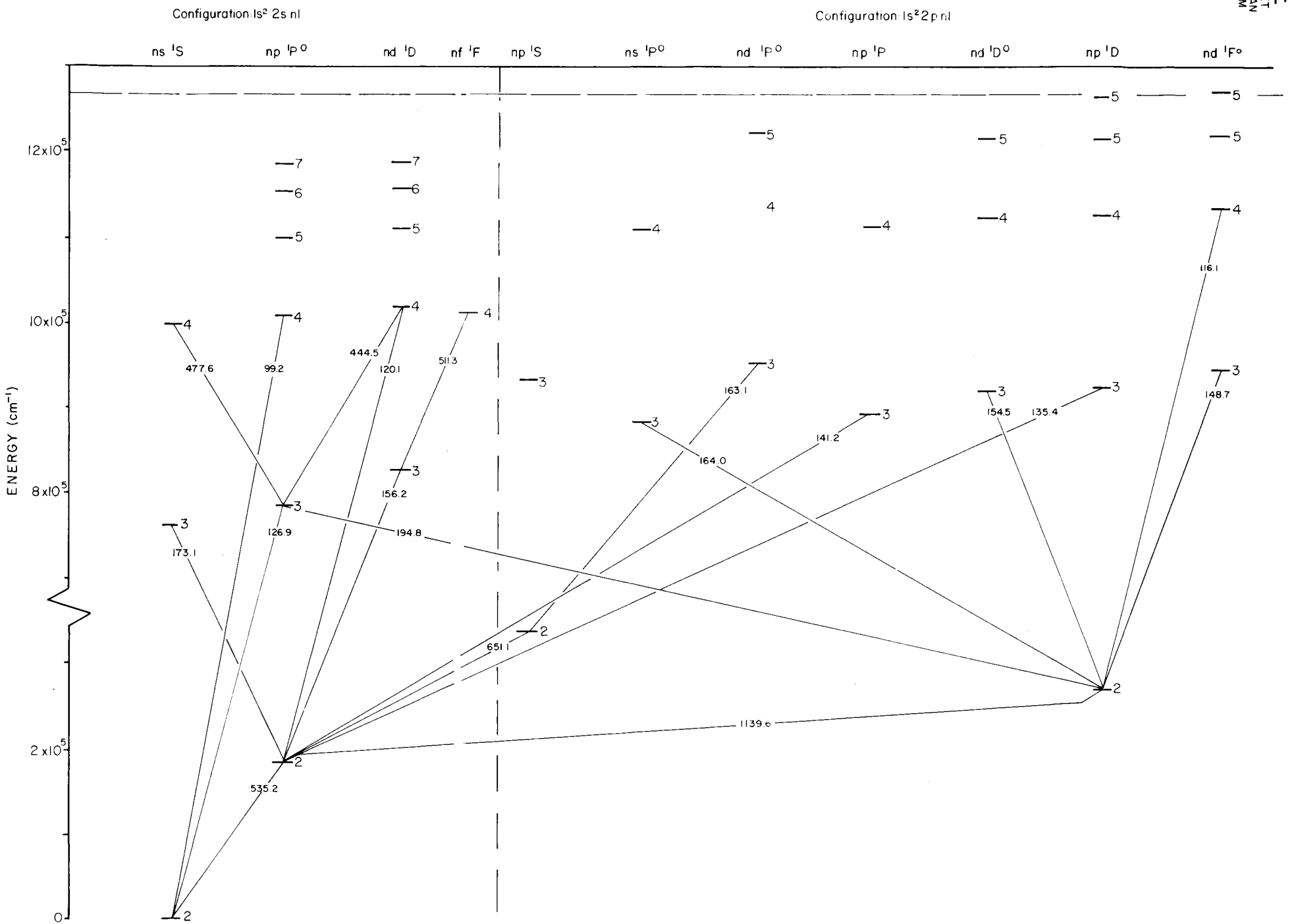



F V GROTRIAN DIAGRAM (5 electrons, Z=9)
(B I sequence, Quartet System)
1s² 2p² (³P) nl'
1s² 2s 2p (³P°) nl
⁴S°
⁴P
⁴P°
⁴D°
⁴S
⁴P°
⁴D
⁴D°
⁴G
ENERGY LEVEL (cm⁻¹)
10 x 10⁵
10 x 10⁵
6 x 10⁵
4 x 10⁵
2 x 10⁵
0
4d''(5/2)
6d(5/2)
6d(7/2)
5d(5/2)
5s(5/2)
5d(7/2)
3d''(5/2,3/2,1/2)
3p''(3/2)
3p''(1/2,3/2,5/2)
3p''(3/2,5/2,7/2)
4d(1/2,3/2,5/2)
4f
4d[(1/2,3/2),5/2,7/2]
4f
3s''(1/2,3/2,5/2)
4s(1/2,3/2,5/2)
3d(5/2,3/2,1/2)
3d[(1/2,3/2),5/2,7/2]
3p(3/2)
3p(1/2,3/2,5/2,7/2)
2229.18, 2252.72
2702.30-
2736.91
3s(1/2,3/2,5/2)
2p³(3/2)
2s 2p²(1/2,3/2,5/2)
133.60, 133.66
171.21-171.30
196.71, 196.87
135.62, 135.69
136.90, 136.96
132.21-132.39
138.18-138.26
162.01-162.27
186.72-187.01
712.64
122.04
132.45-132.51
163.46-163.60
524.59-526.30

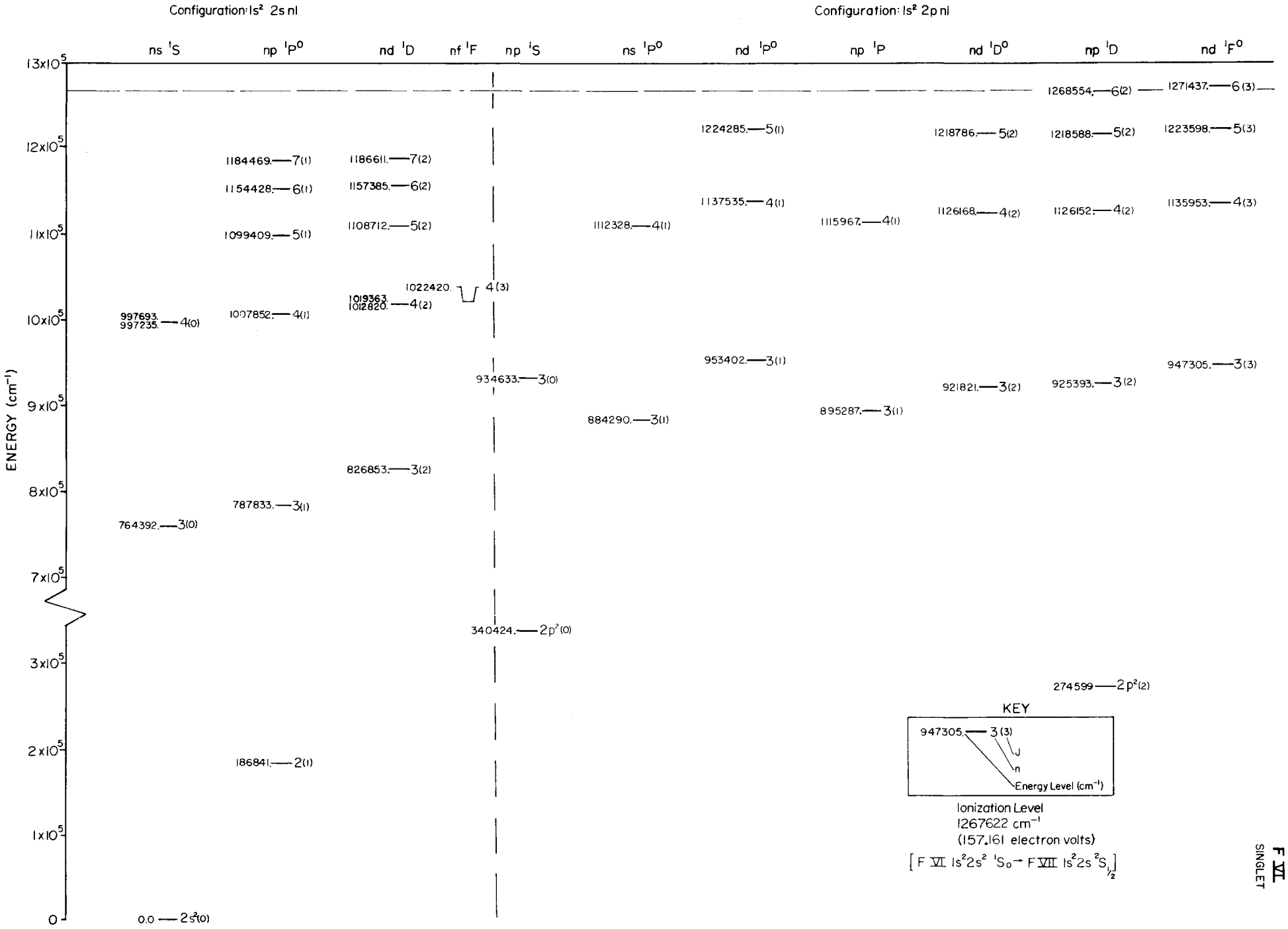
F V ENERGY LEVELS (5 electrons, Z = 9)
(B I sequence, Quartet System)



F VI GROTRIAN DIAGRAM (4 electrons, Z=9)
(Be I sequence, Configuration: $1s^2 n'l' nl$, Singlet System)

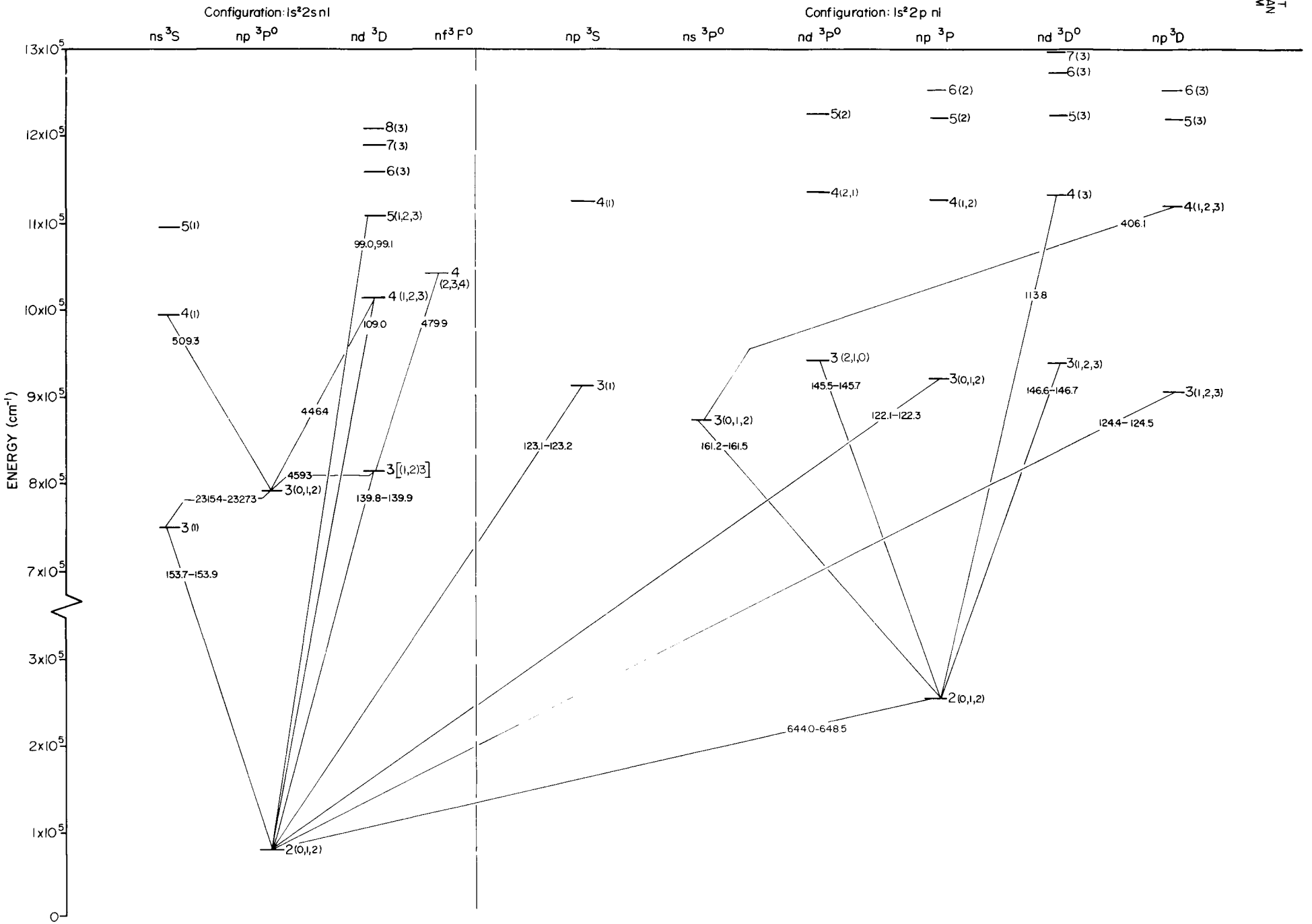


F VI ENERGY LEVELS (4 electrons, Z=9)
(Be I sequence, Configuration: $1s^2\ n'l'\ nl$, Singlet System)

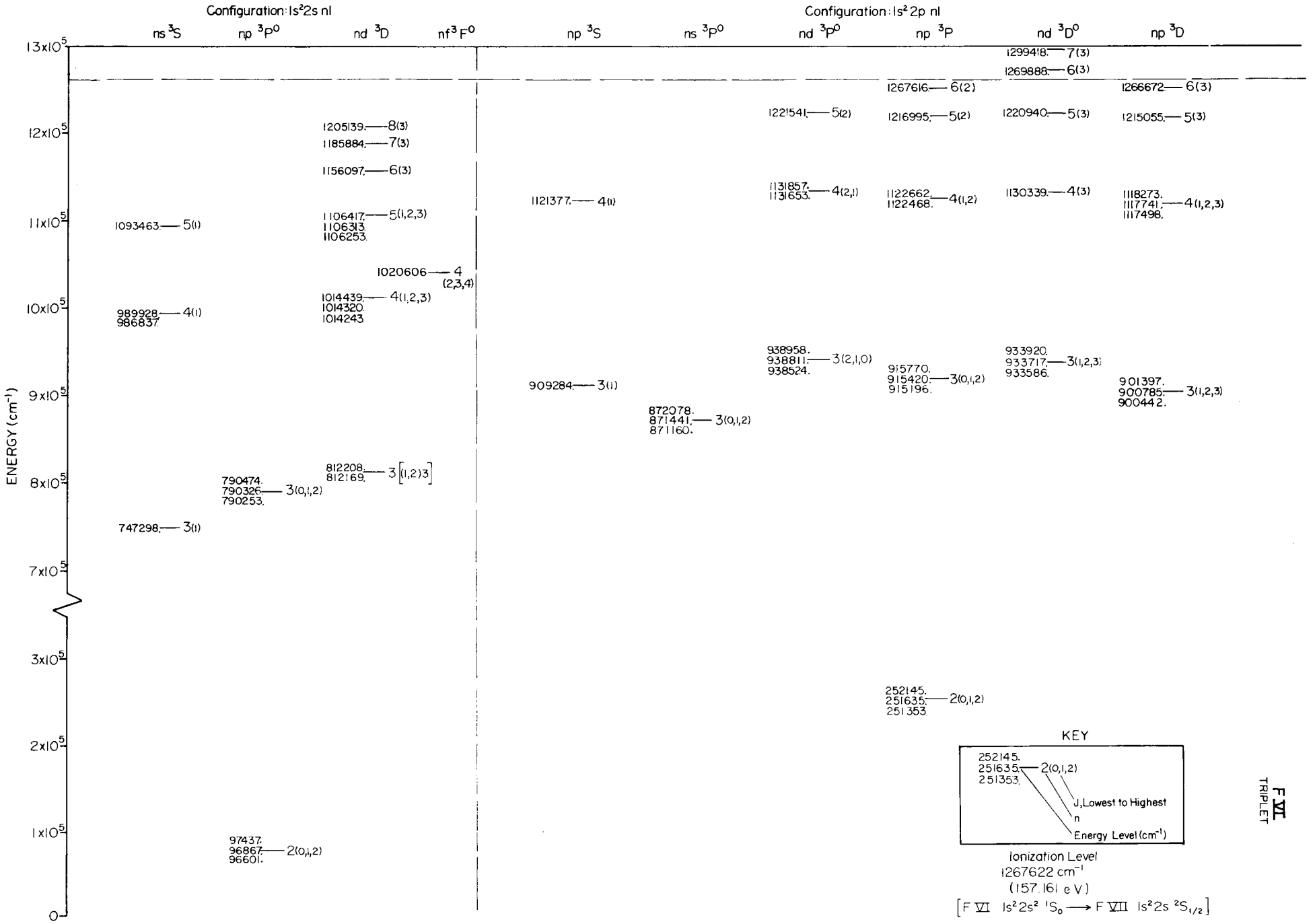


F VI
SINGLET

F VI GROTRIAN DIAGRAM (4 electrons, Z = 9)
(Be I sequence, Configuration: $1s^2 n l n' l'$, Triplet Term System)

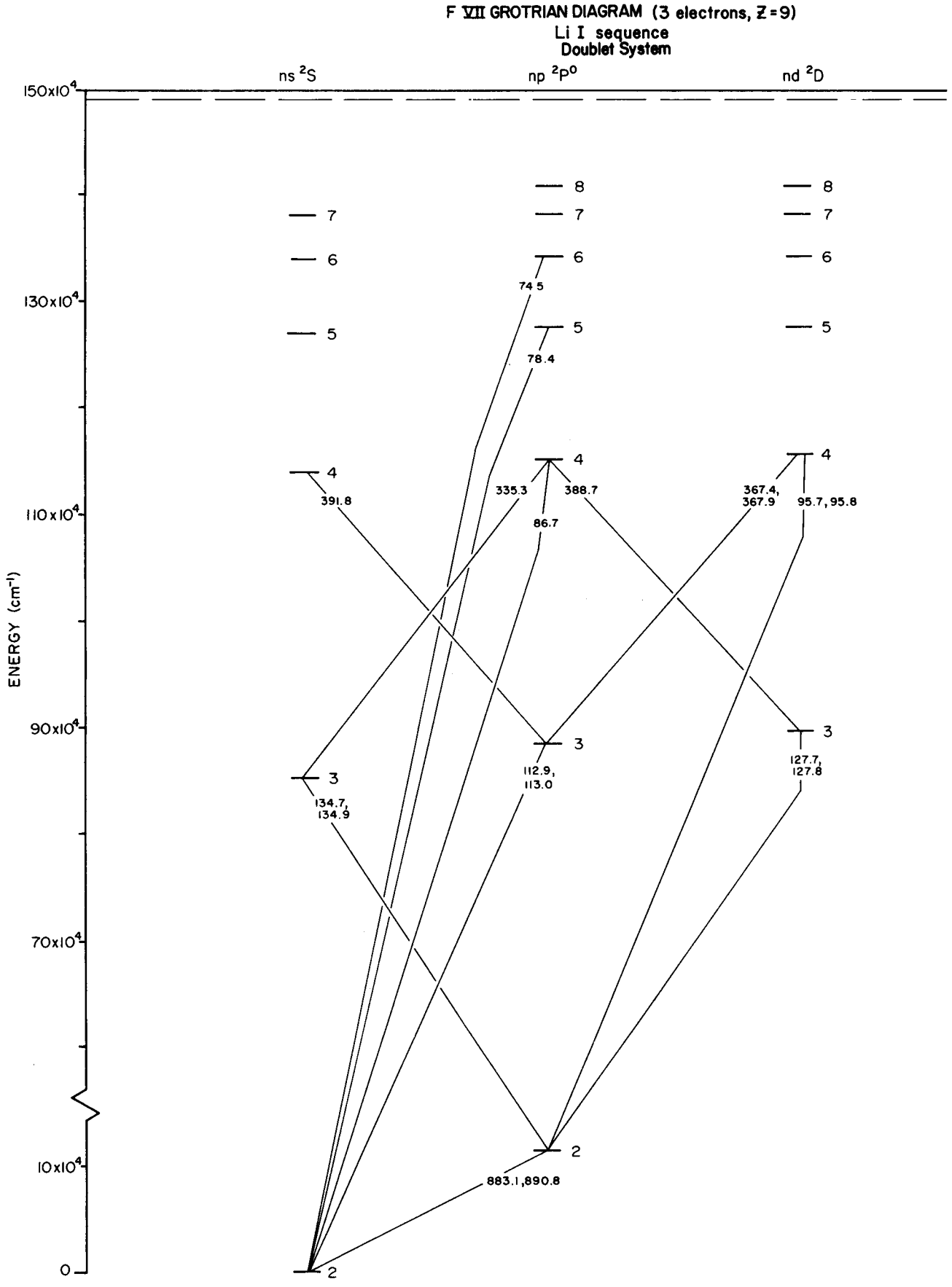


F VI ENERGY LEVELS (4 electrons, Z=9)
(Be I sequence, Configuration; $1s^2 nl n'l'$, Triplet Term System)



F VI
TRIPLET

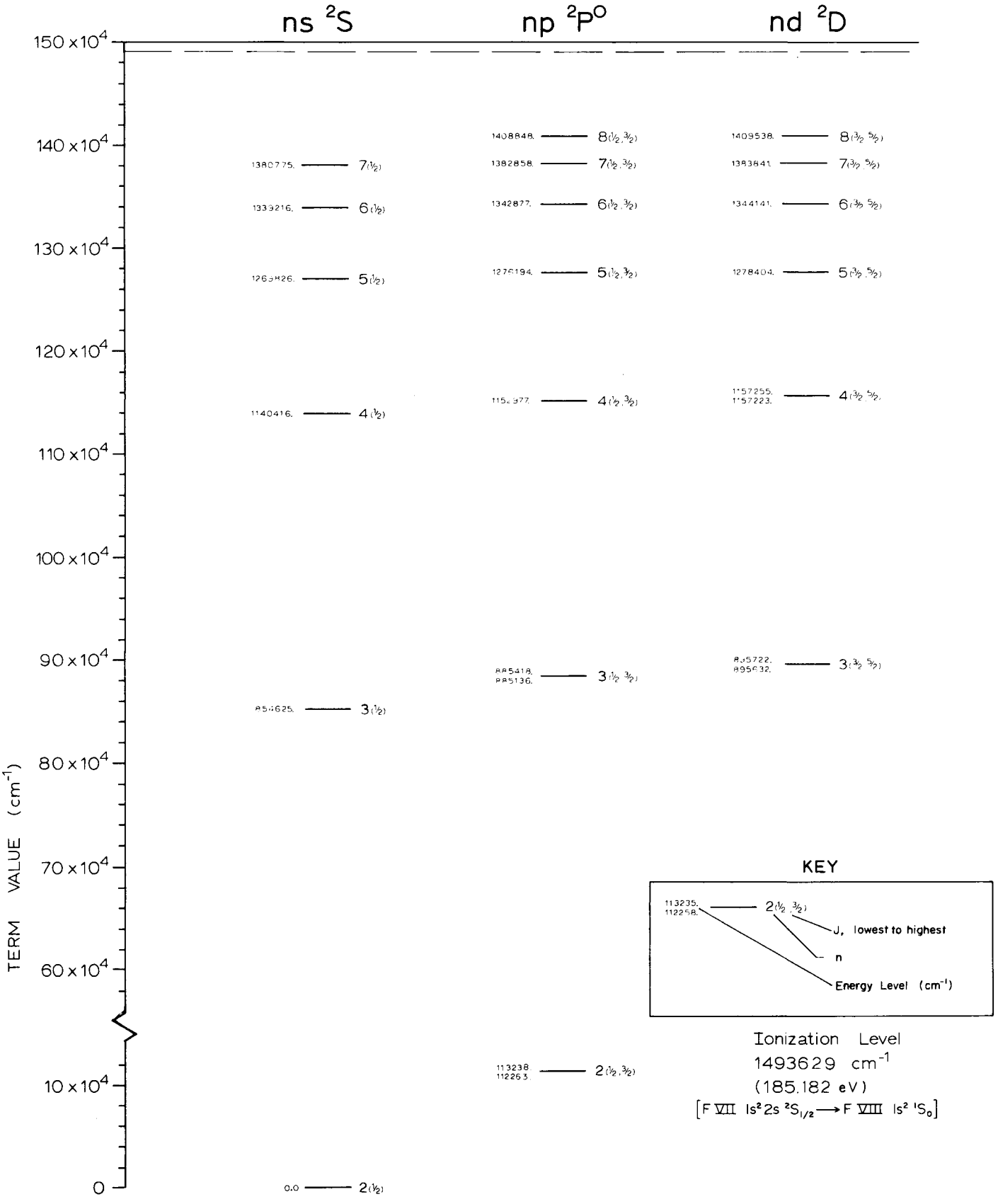
F VII
DOUBLET
GROTRIAN
DIAGRAM



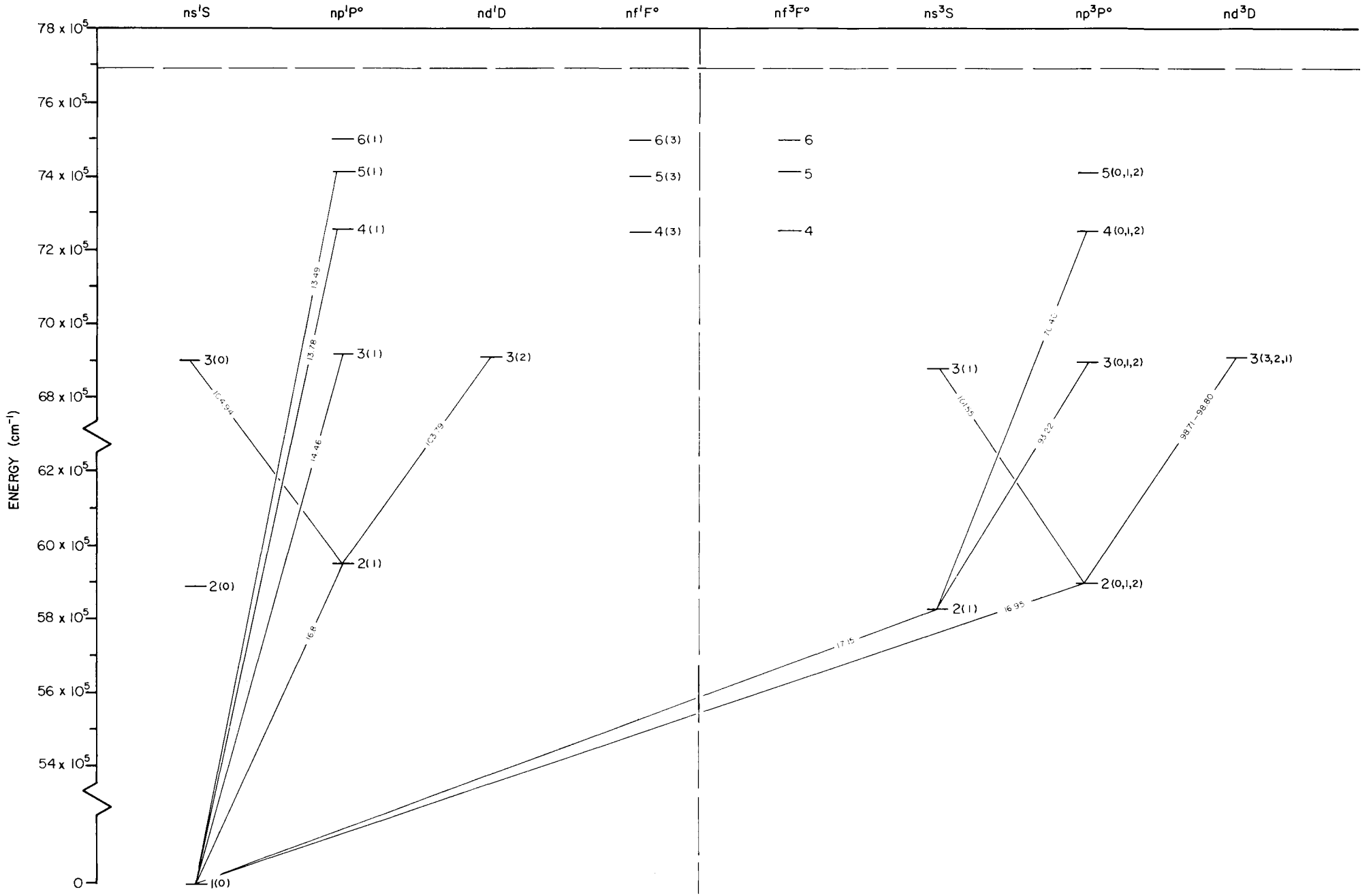
F VII ENERGY LEVELS (3 electrons, Z = 9)

(Li I sequence, Configuration : $1s^2\ nl$)

Doublet System

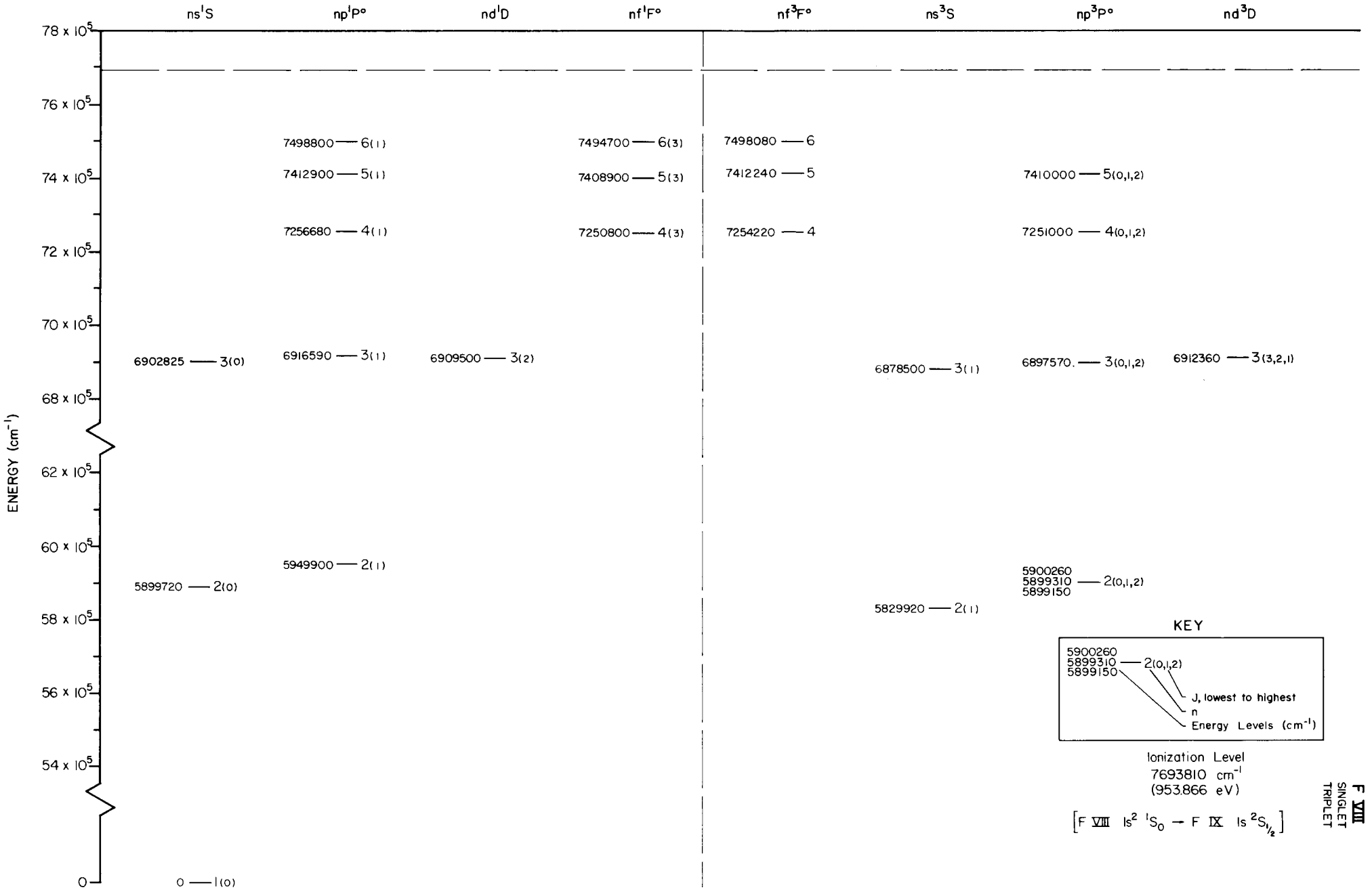


F VIII GROTRIAN DIAGRAM (2 electrons, Z = 9)
(He I sequence, Configuration: 1s nl)
(Singlet & Triplet Systems)

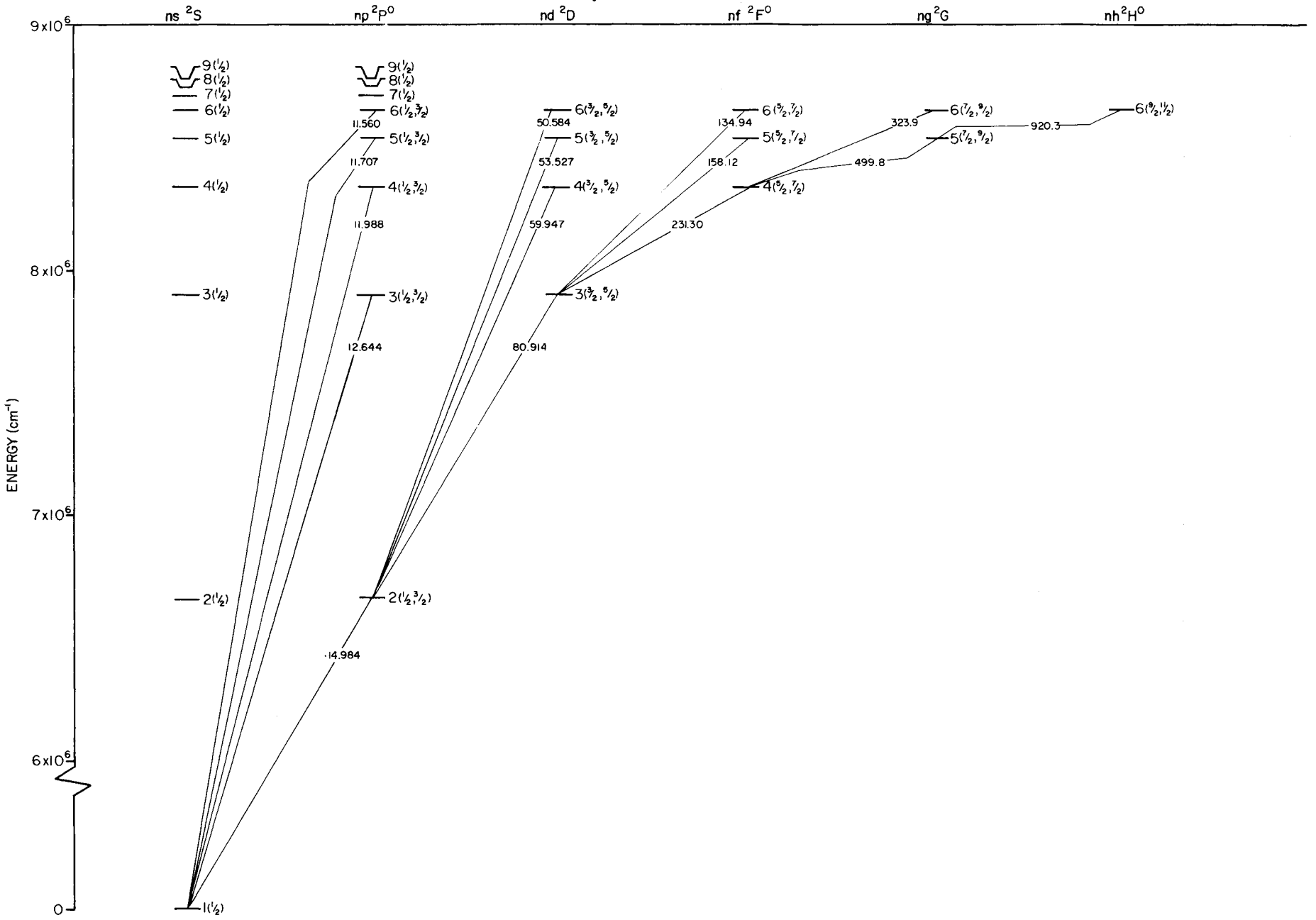


F VIII ENERGY LEVELS (2 electrons, Z = 9)

(He I sequence, Configuration: 1s nl)
(Singlet & Triplet Systems)



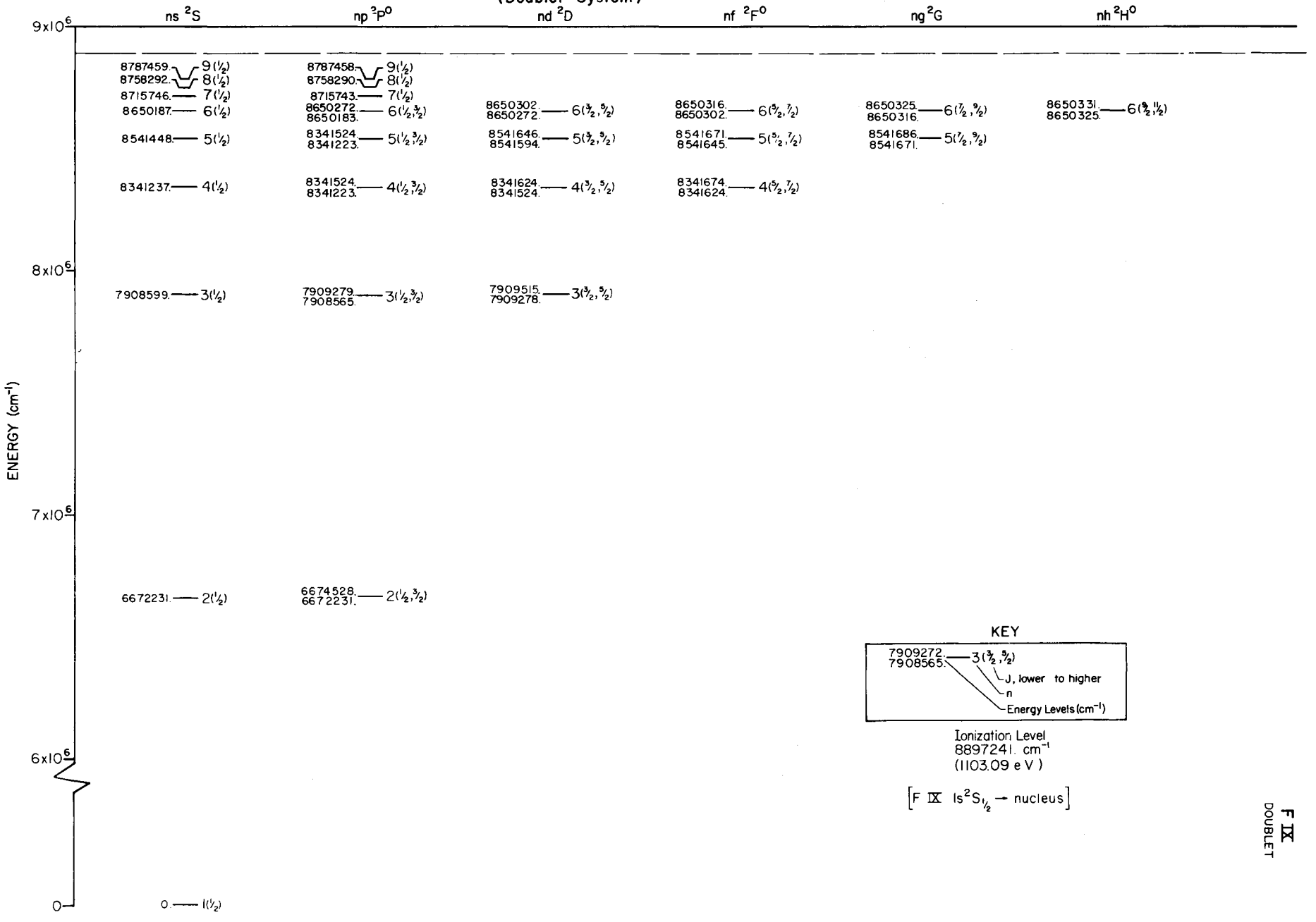
F IX GROTRIAN DIAGRAM (1 electron, Z = 9)
(H I sequence, Configuration: nl)
Doublet System



F IX ENERGY LEVELS (1 electron, Z=9)

(H I sequence, Configuration: nl)

(Doublet System)



F I $Z = 9$ 9 electrons

J.E. Hansen and W. Persson, Physica Scripta **8**, 197 (1973).

Authors give $2p^4$ *n*s and $2p^4$ *n*d configurations in F I and Ne II.

F II $Z = 9$ 8 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives observed wavelengths.

H. Palenius, J. Opt. Soc. Amer. **56**, 828 (1966).

Author gives transition wavelengths.

Comment on intermediate coupling: According to H. Palenius, Ark. Fys. **39**, 15 (1968), coupling with f-electrons does not produce clear configurations. The pair-coupling approximation (please see N II) is used to describe some of the spectroscopic terms, but terms we list under "other f" cannot be so identified.

F III $Z = 9$ 7 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives observed wavelengths.

For the intermediate-coupling designation, please see H. Palenius, Physica Scripta **1**, 113 (1970).

F IV $Z = 9$ 6 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives transition wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives wavelengths from nebular observations.

For the intermediate-coupling designation, please see H. Palenius, University of Lund (Sweden) Report (May, 1971).
Note: The first triplet Grotrian diagram is labeled 2p ^{3}P and 2p ^{3}P$^\circ$. The correct designation is 2p ^{3}P and 2p ^{3}D$^\circ$. The corner designation should read 2p ^{3}P and 2p ^{3}D$^\circ$ to higher triplets.

F V $Z = 9$ 5 electrons

Please see the general references.

F VI $Z = 9$ 4 electrons

Please see the general references. Note, also, that a line has been omitted: $2s^2$ ^{1}S–2s 2p ^{3}P$^\circ$: 1032.34.

F VII $Z = 9$ 3 electrons

Please see the general references.

F VIII $Z = 9$ 2 electrons

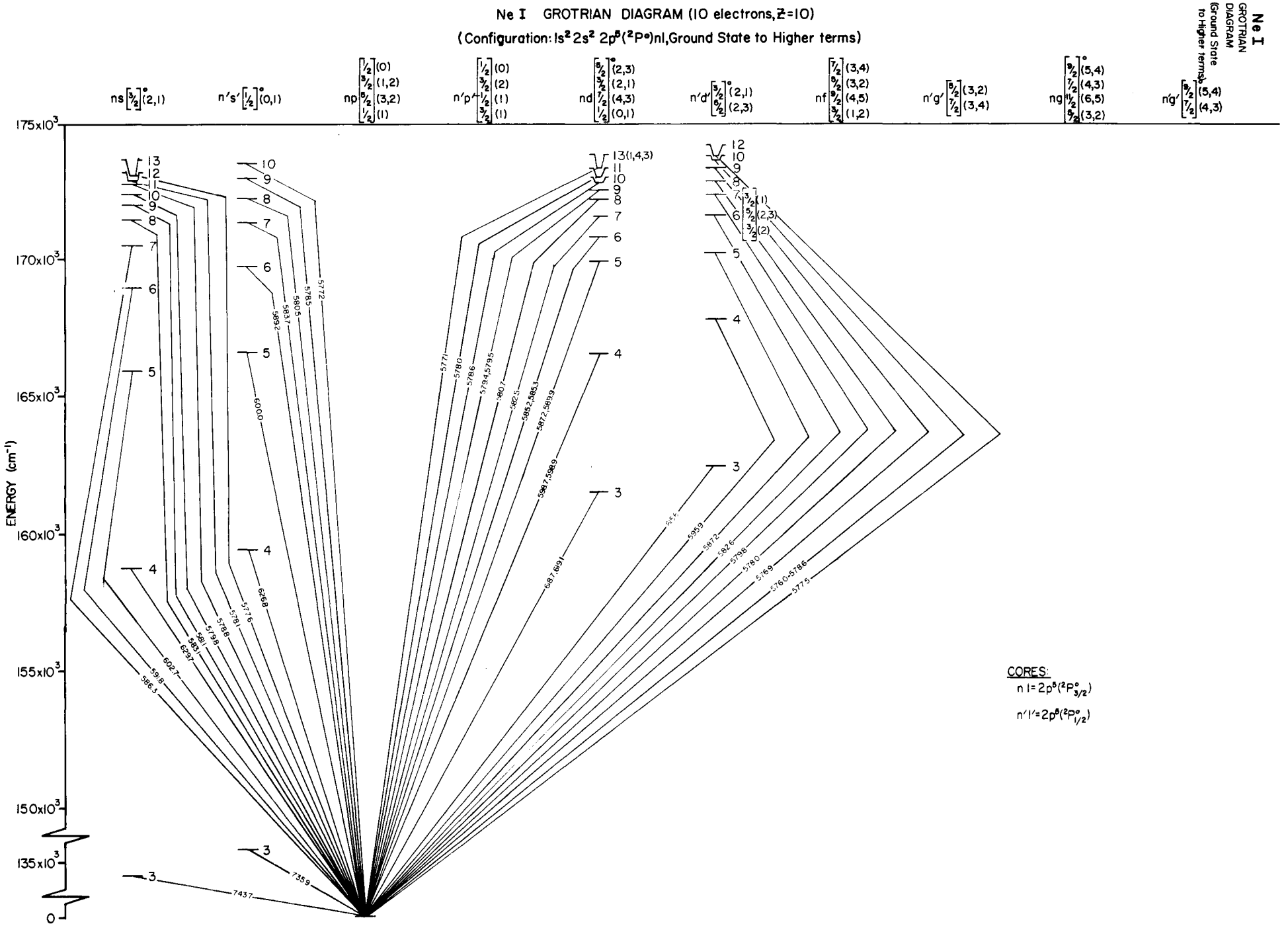
E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculate energies nonrelativistically in treatment of He I isoelectronic sequence.

F IX $Z = 9$ 1 electron

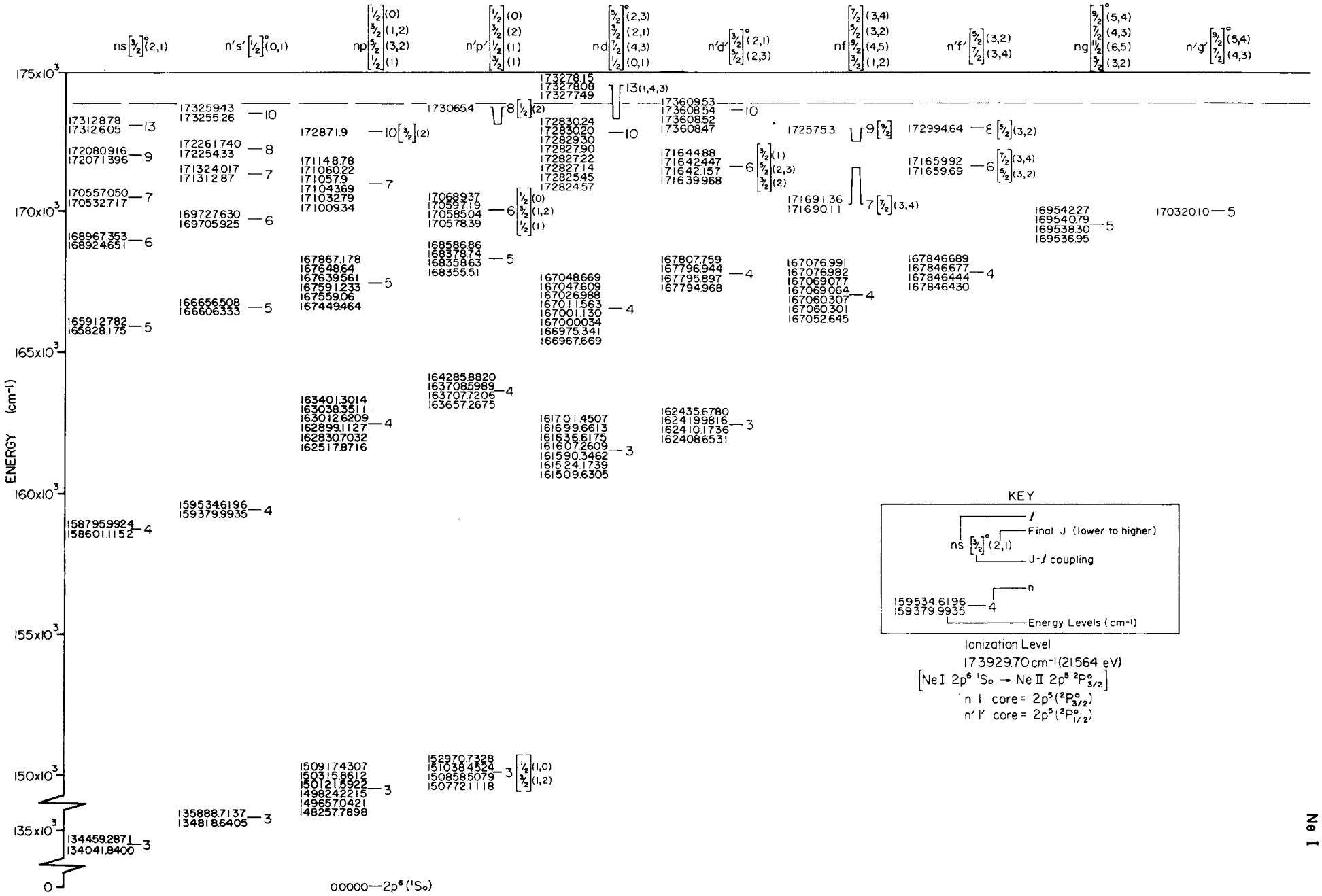
Please see the general references.

Neon (Ne)


Ne I GROTRIAN DIAGRAM (10 electrons, Z=10)
(Configuration: 1s² 2s² 2p⁵(²P°)nl, Ground State to Higher terms)
ns [3/2]°(2,1)
n's' [1/2]°(0,1)
np [1/2 3/2 5/2 1/2] (0 (1,2) (3,2) (1)
n'p' [1/2 3/2 3/2] (0 (2) (1) (1)
nd [5/2 3/2 3/2 7/2 1/2]° (2,3 (2,1) (4,3) (0,1)
n'd' [3/2 5/2]° (2,1 (2,3)
nf [7/2 5/2 9/2 3/2] (3,4 (3,2) (4,5) (1,2)
n'g' [5/2 7/2] (3,2 (3,4)
ng [9/2 7/2 11/2 9/2]° (5,4 (4,3 (6,5 (3,2)
n'g' [9/2 7/2] (5,4 (4,3)
Ne I GROTRIAN DIAGRAM (Ground State to Higher terms)
ENERGY (cm⁻¹)
175x10³
170x10³
165x10³
160x10³
155x10³
150x10³
135x10³
0
CORES:
n l = 2p⁵(²P°3/2)
n'l' = 2p⁵(²P°1/2)

Ne I ENERGY LEVELS (10 electrons, Z=10)

Configuration: $1s^2\,2s^2\,2p^5(^2P^o)\,nl$



KEY

Ionization Level

173929.70 cm⁻¹ (21.564 eV)

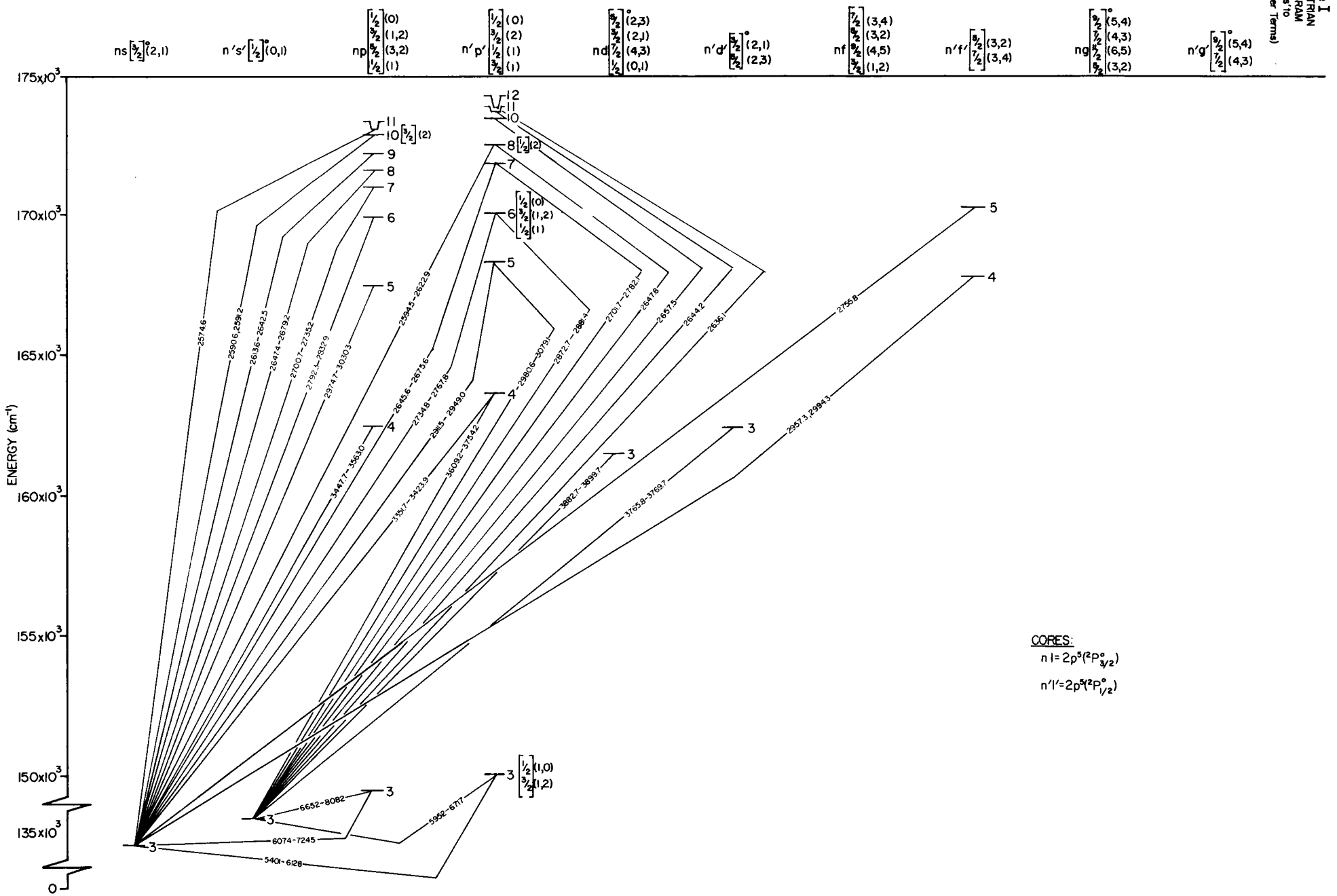
$[\text{Ne I } 2p^6\ ^1S_0 \rightarrow \text{Ne II } 2p^5\ ^2P^o_{3/2}]$

n l core = $2p^5(^2P^o_{3/2})$

n′ l′ core = $2p^5(^2P^o_{1/2})$

Ne I GROTRIAN DIAGRAM (10 electrons, Z = 10)

(Configuration: $1s^2 2s^2 2p^5 (^2P^\circ) nl, 3s$ and $3s'$ to Higher Terms)



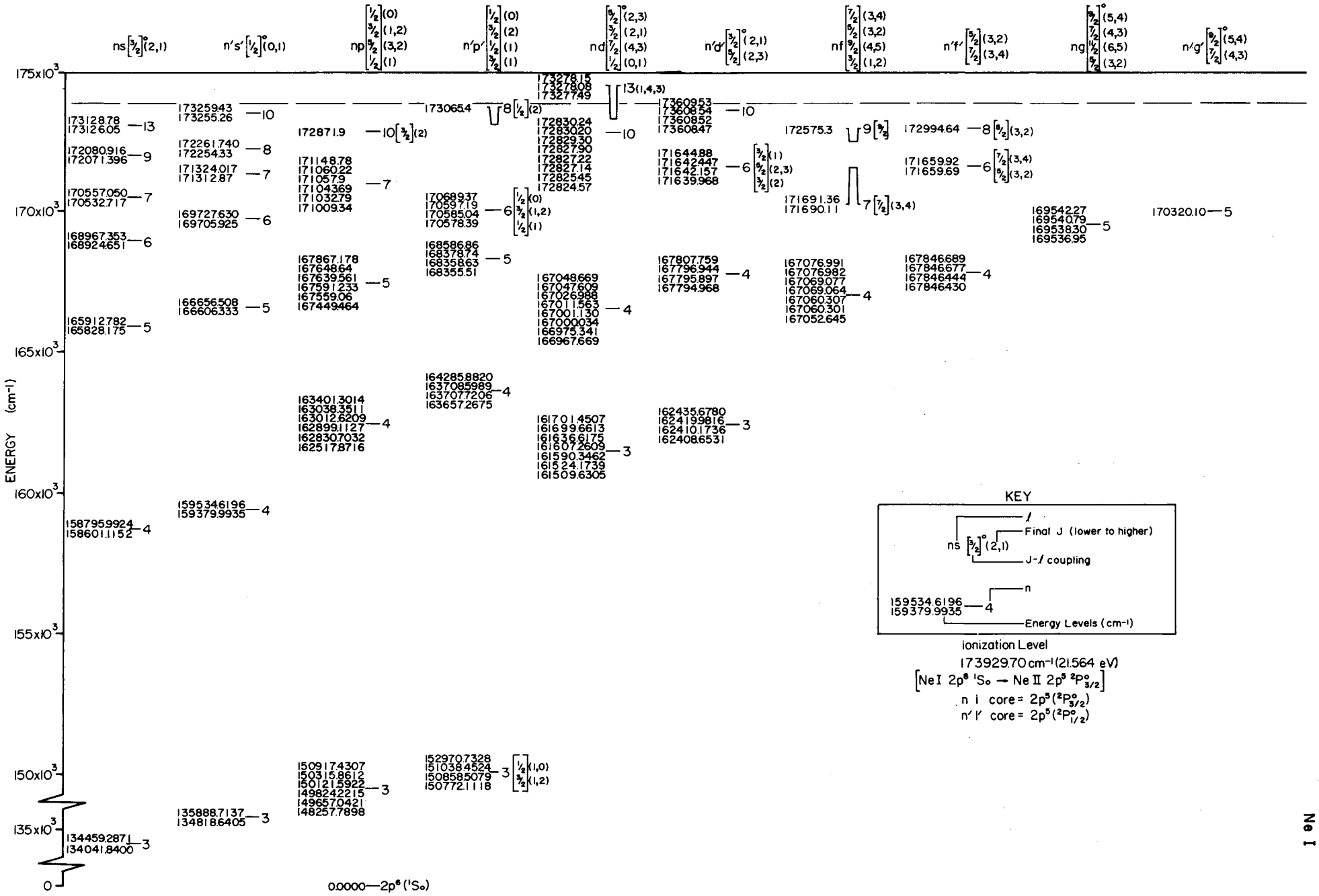
CORES:

$n l = 2p^5(^2P^\circ_{3/2})$

$n'l' = 2p^5(^2P^\circ_{1/2})$

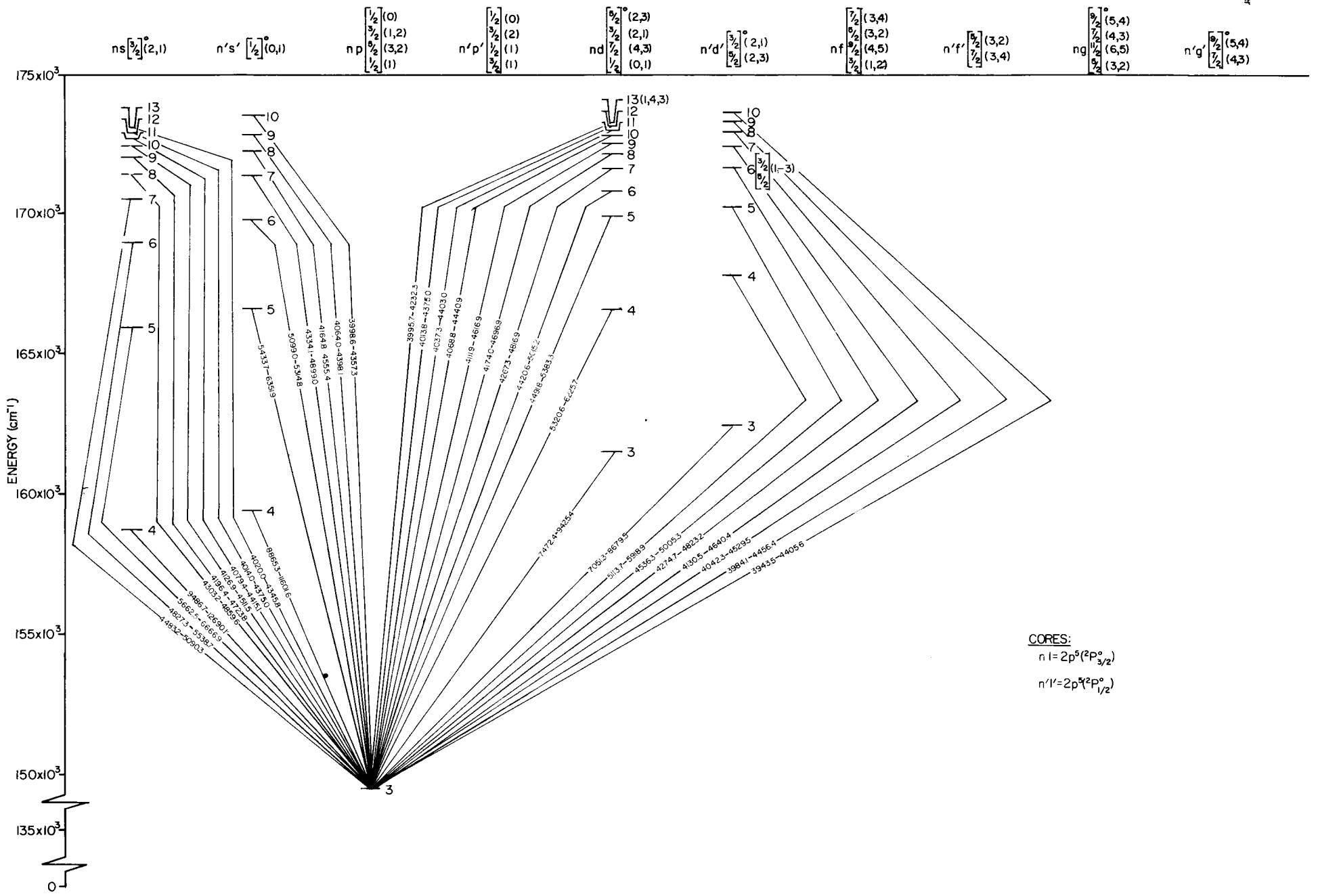
Ne I ENERGY LEVELS (10 electrons, Z=10)

Configuration: $1s^2\,2s^2\,2p^5(^2P^o)\,nl$



Ne I GROTRIAN DIAGRAM (10 electrons, Z=10)

(Configuration: $1s^2\ 2s^2\ 2p^5\ (^2P^\circ)nl, 3p$ to Higher Terms)



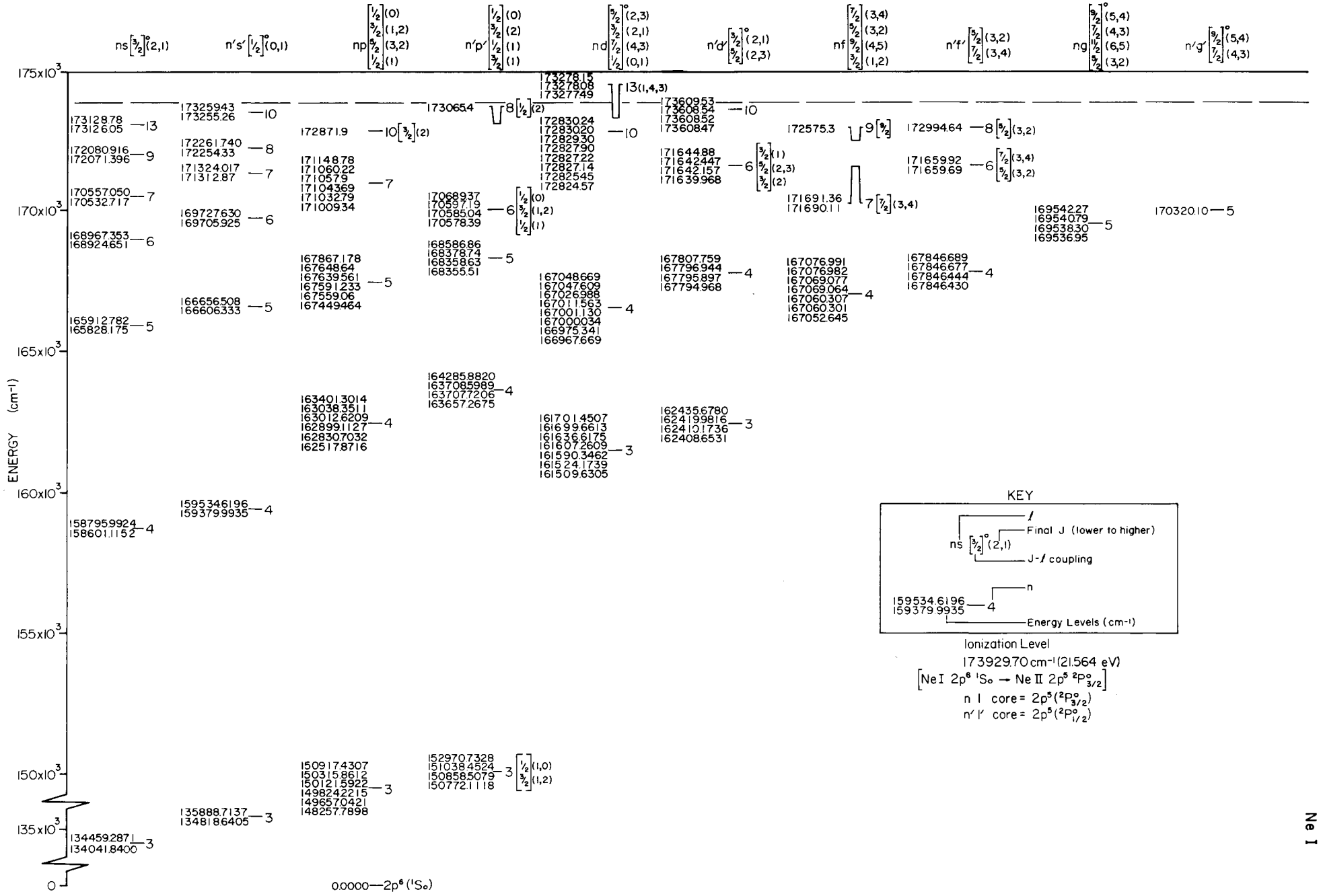
CORES:

$nl = 2p^5(^2P^\circ_{3/2})$

$n'l' = 2p^5(^2P^\circ_{1/2})$

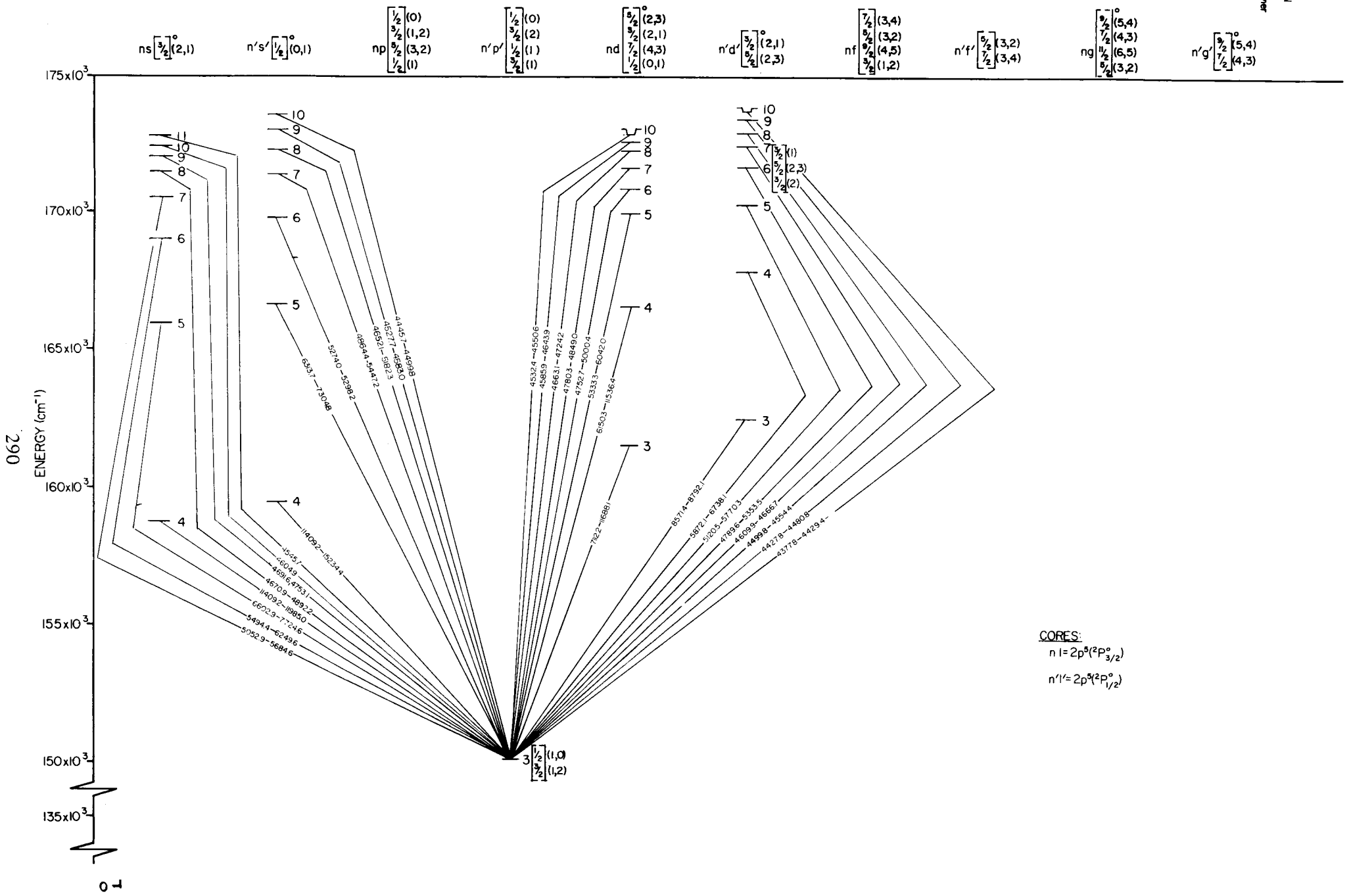
Ne I ENERGY LEVELS (10 electrons, Z=10)

Configuration: $1s^2\,2s^2\,2p^5(^2P^o)\,nl$



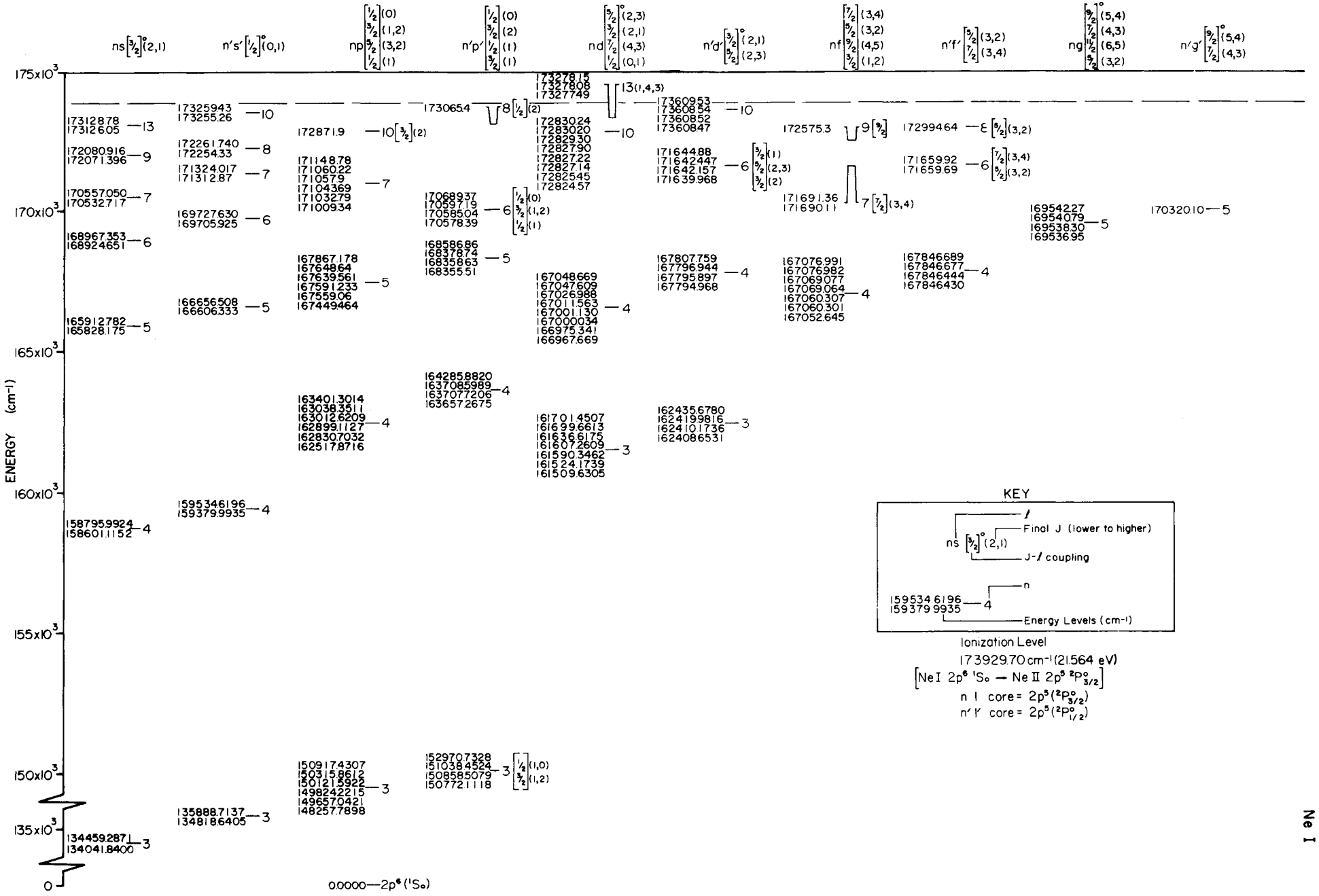
Ne I GROTRIAN DIAGRAM (10 electrons, Z=10)

(Configuration: $1s^2 2s^2 2p^5(^2P^o)nl$, $3p'$ to Higher terms)



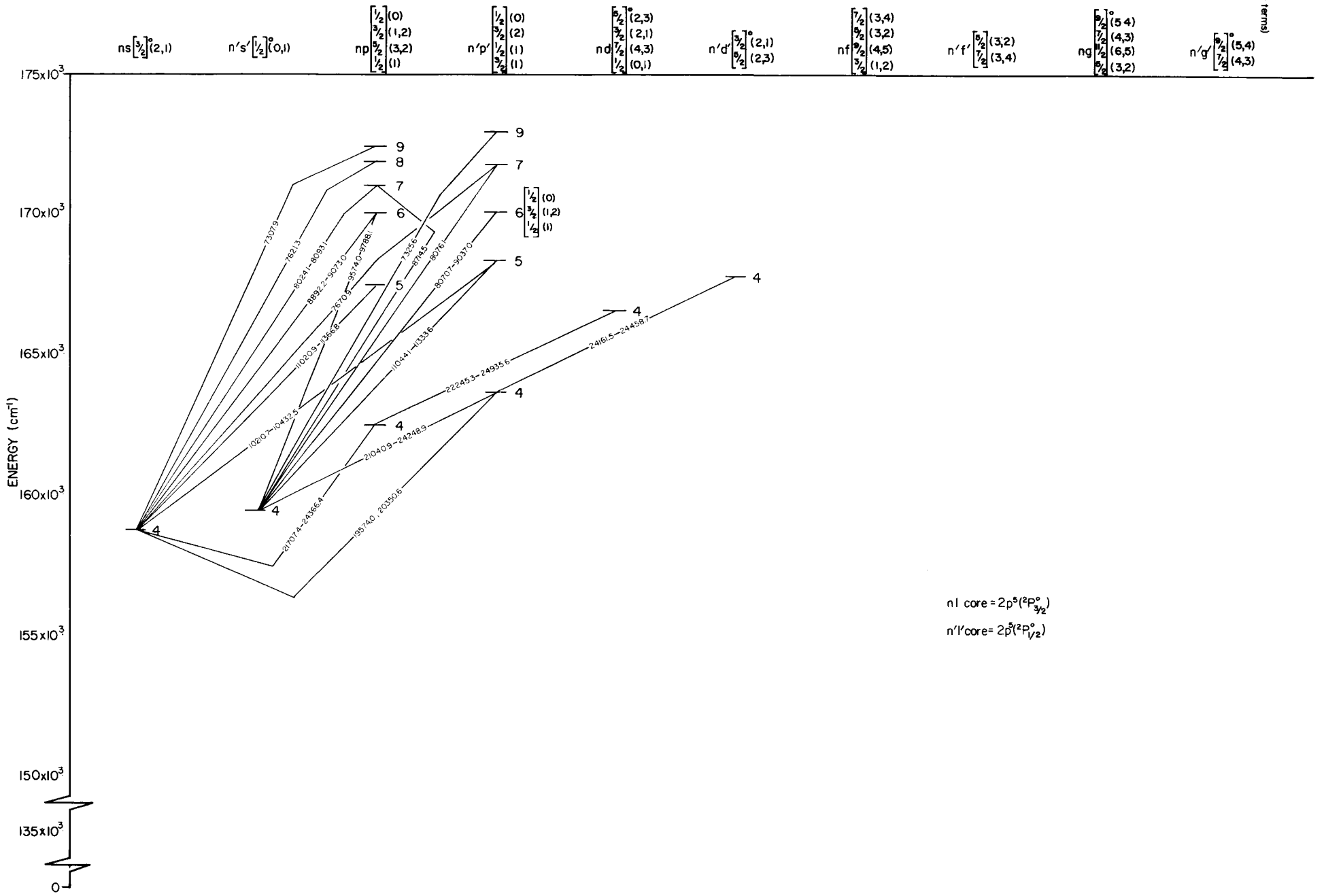
Ne I ENERGY LEVELS (10 electrons, Z=10)

Configuration: $1s^2\,2s^2\,2p^5(^2P^o)\,nl$



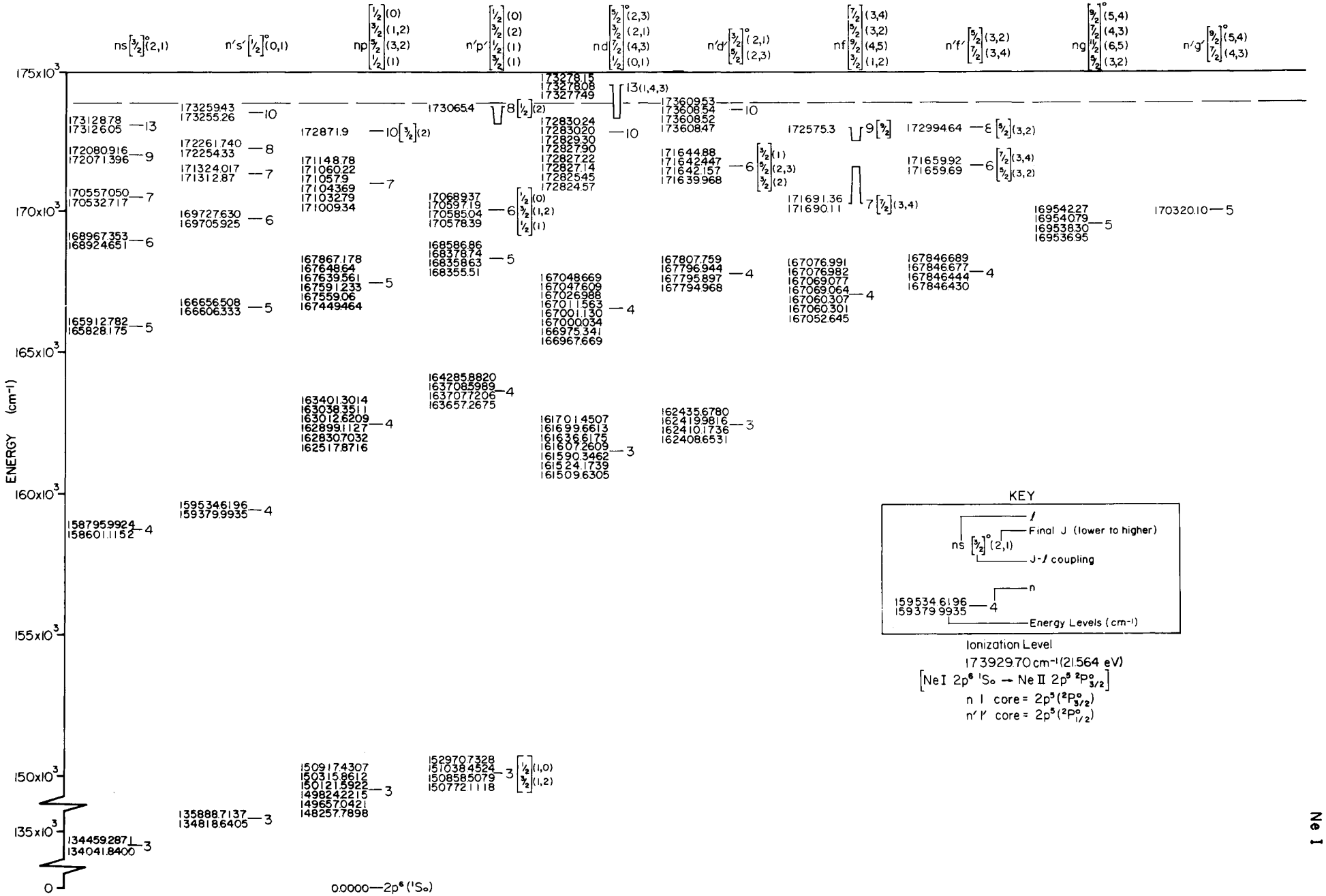
Ne I GROTRIAN DIAGRAM (10 electrons, Z = 10)

(Configuration: $1s^2 2p^2 2p^5(^2P^\circ)nl$, n = 4 to higher terms)

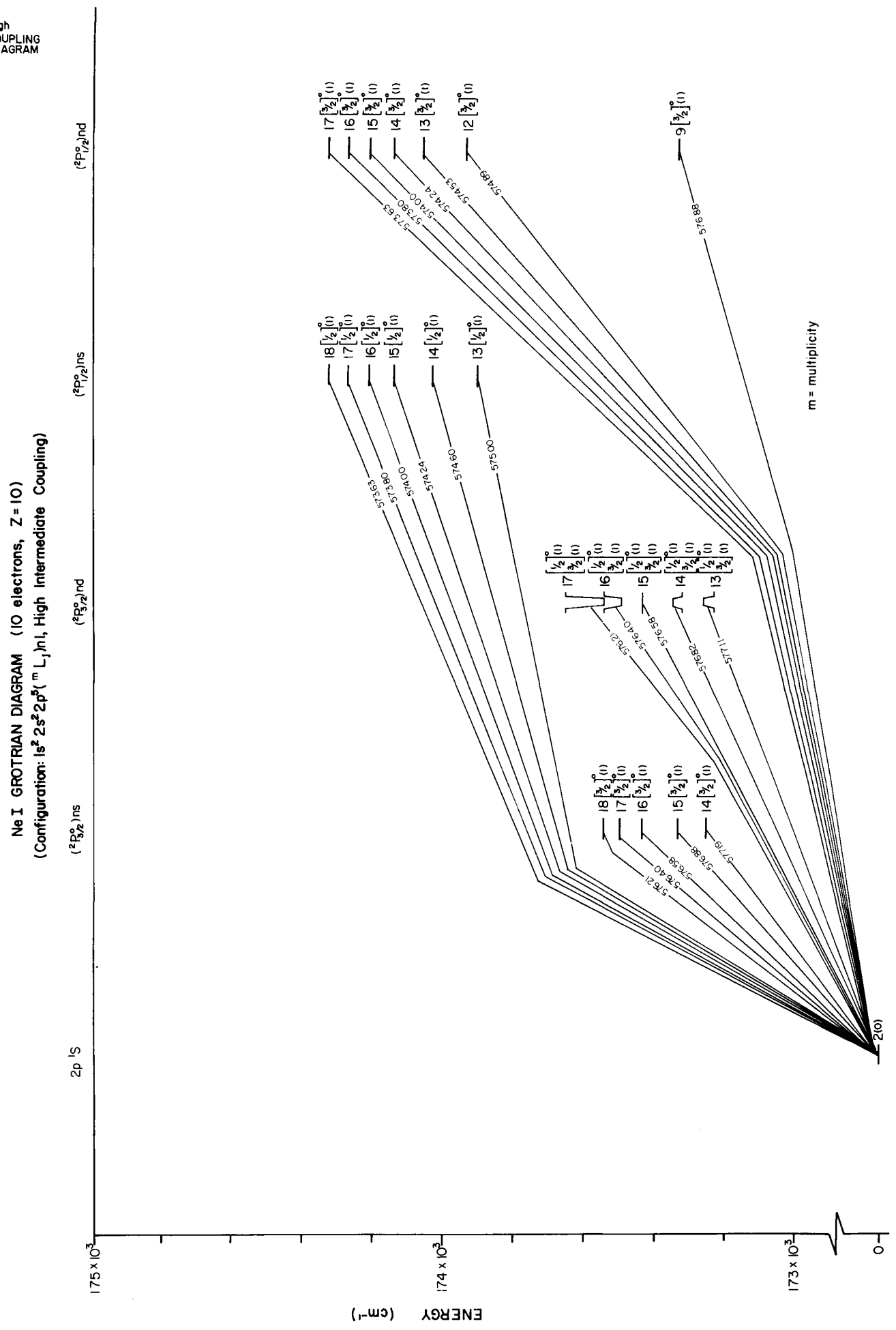


Ne I ENERGY LEVELS (10 electrons, Z=10)

Configuration: $1s^2\,2s^2\,2p^5(^2P^o)\,nl$

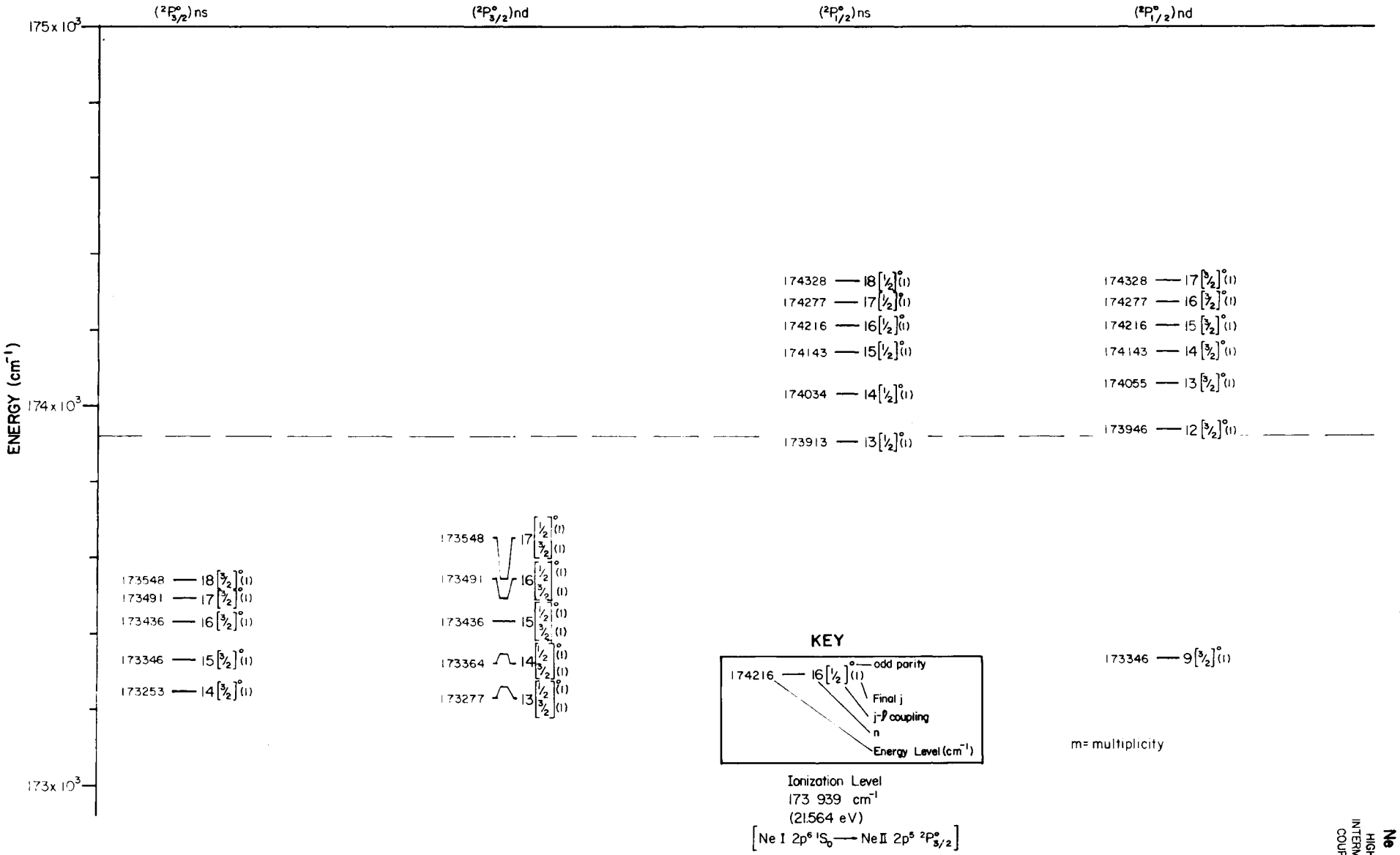


Ne I
$2p^6\ ^1S_0$ to High
TERMEDIATE COUPLING
GROTRIAN DIAGRAM

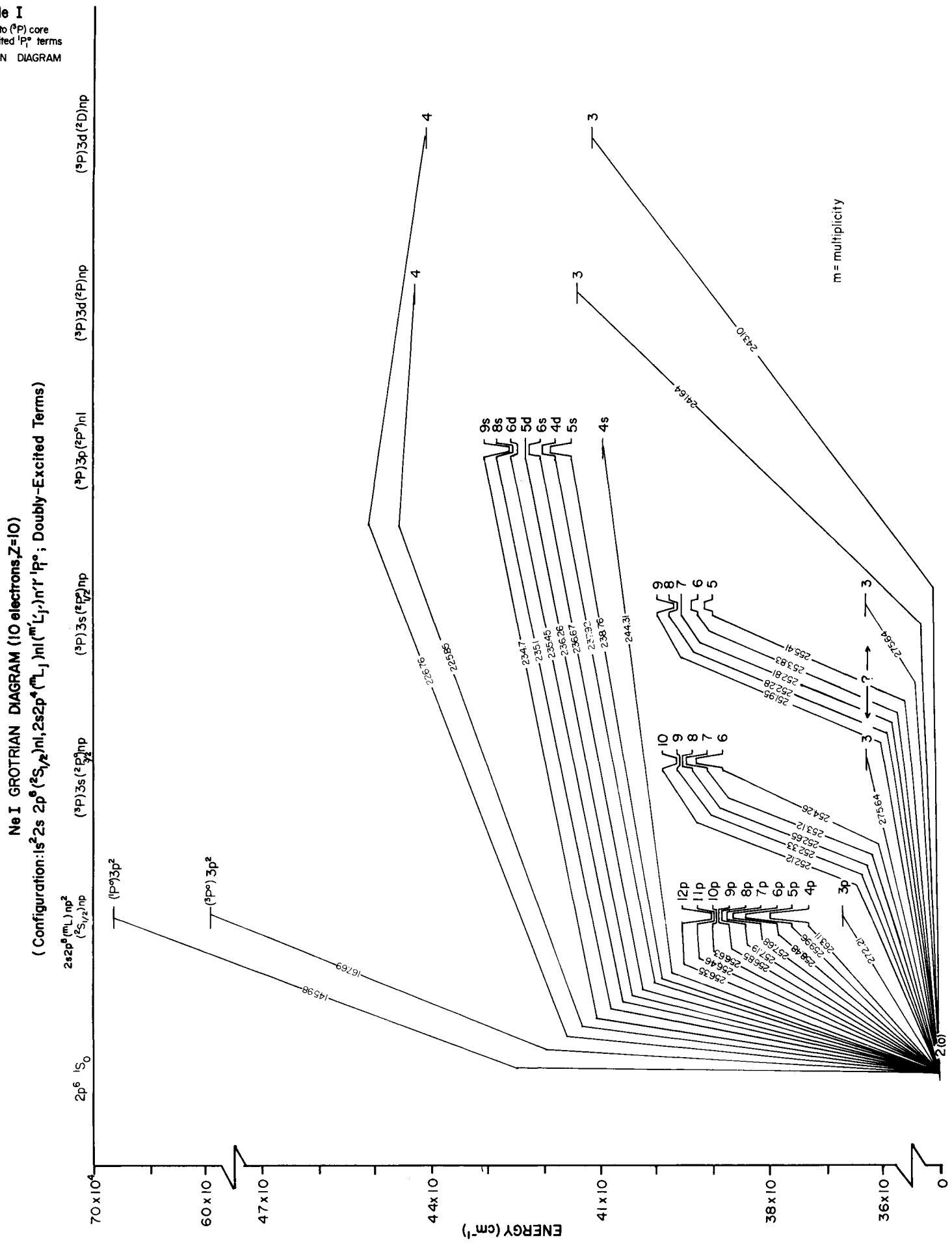


Ne I ENERGY LEVELS (10 electrons, Z = 10)

(Configuration: $1s^2 2s^2 2p^5 (^m L_j) nl$, High Intermediate Coupling)

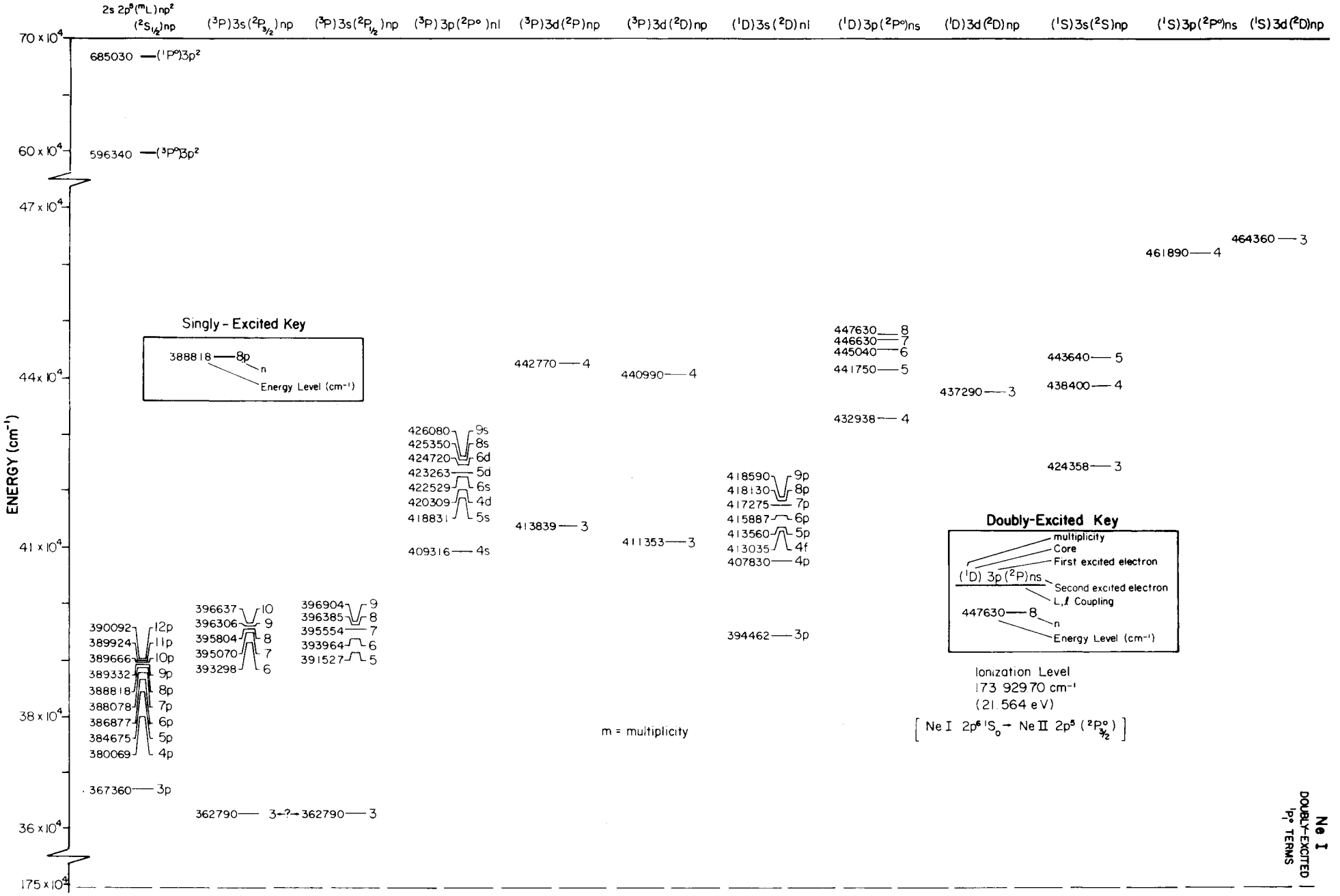


Ne I
HIGH INTERMEDIATE COUPLING


Ne I
2p⁶ ¹S₀ to (³P) core
doubly-excited ¹P₁° terms
GROTRIAN DIAGRAM
Ne I GROTRIAN DIAGRAM (10 electrons, Z=10)
(Configuration: 1s²2s 2p⁶(²S₁/₂)nl, 2s2p⁴(ᵐL_J)nl(ᵐ'L'_J')n'l' ¹P₁°; Doubly-Excited Terms)
2s2p⁶(ᵐL_J)np²
(²S₁/₂)np
(³P)3s(²P°₁/₂)np
(³P)3s(²P°₃/₂)np
(³P)3p(²P°)nl
(³P)3d(²P)np
(³P)3d(²D)np
2p⁶ ¹S₀
(¹P°)3p²
(³P°) 3p²
m = multiplicity
ENERGY (cm⁻¹)
70 x 10⁴
60 x 10
47 x 10
44 x 10
41 x 10
38 x 10
36 x 10
0

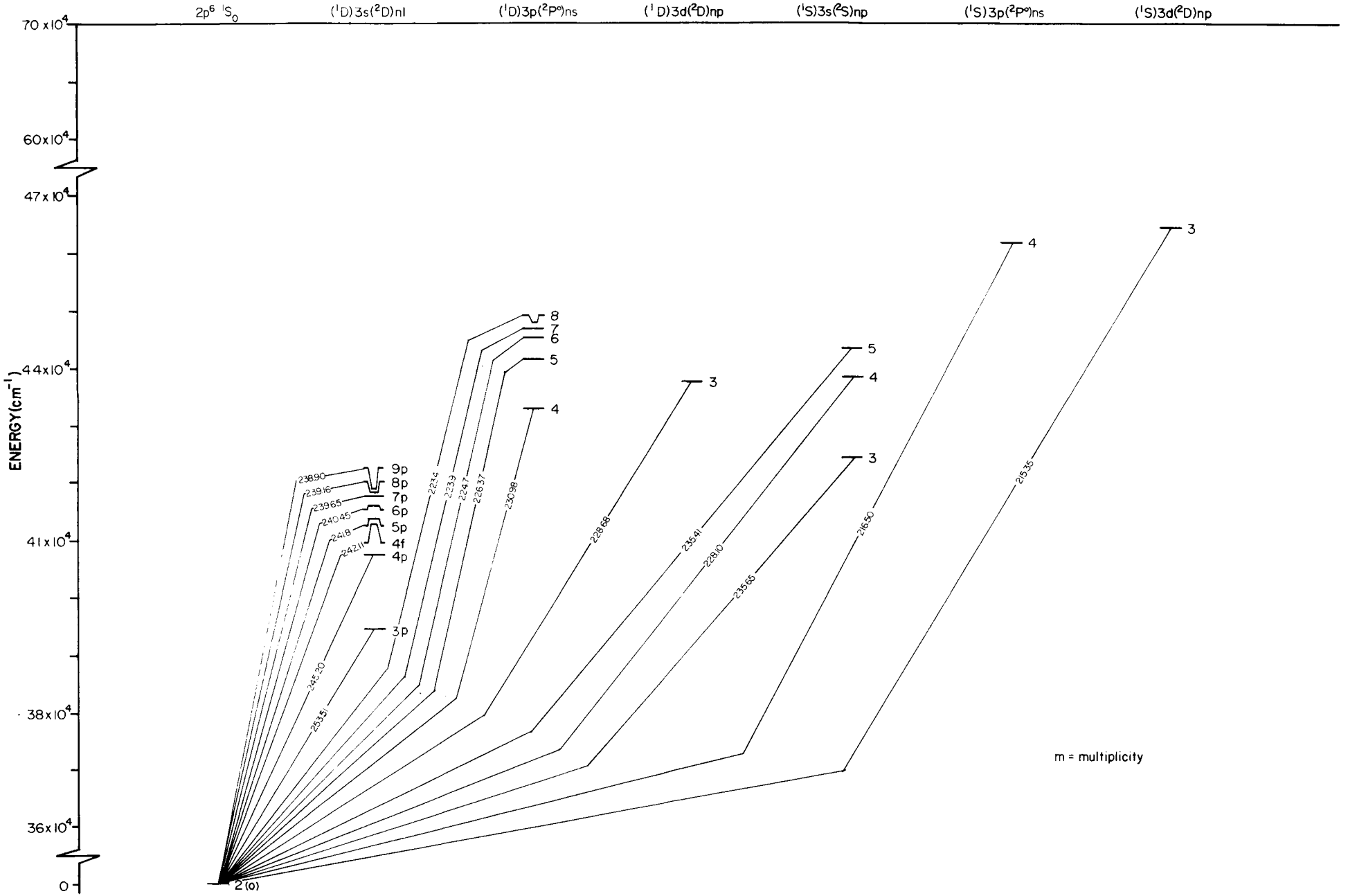
Ne I ENERGY LEVELS (10 electrons, Z=10)

(Configuration: $1s^2 2s\ 2p^6(^2S_{1/2})nl, 2s2p^4(^mL_J)nl(^{m'}L'_{J'})n'l'\ ^1P^o_1$; Doubly-Excited Terms)



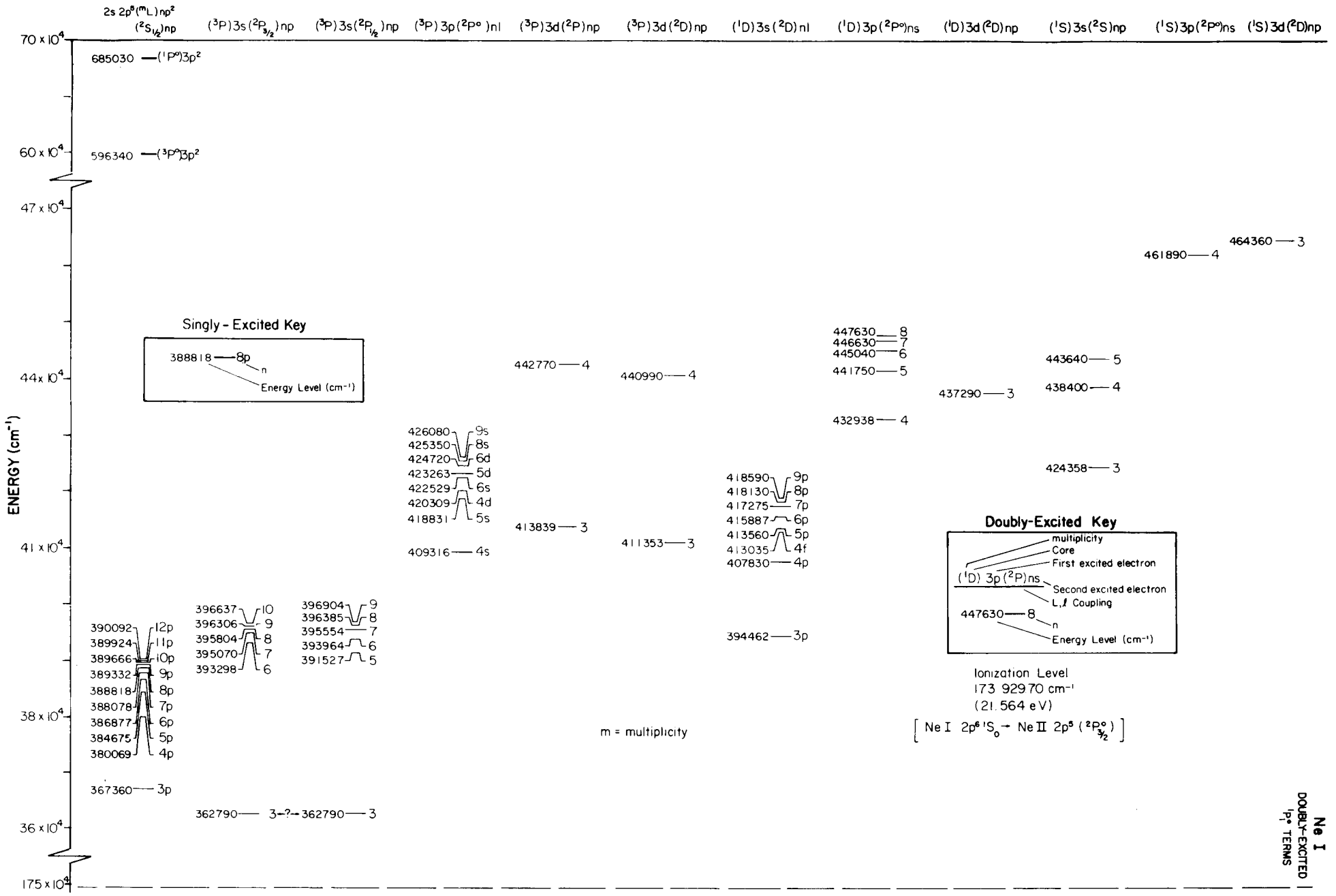
Ne I
DOUBLY-EXCITED
$^1P^o_1$ TERMS

Ne I GROTRIAN DIAGRAM (10 electrons, Z=10)
(Configuration: $1s^2\,2s\,2p^6({}^2S_{1/2})nl, 2s2p^4({}^mL_j)nl({}^{m'}L'_{j'})n'l'\,{}^1P^o_1$; Doubly-Excited Terms)

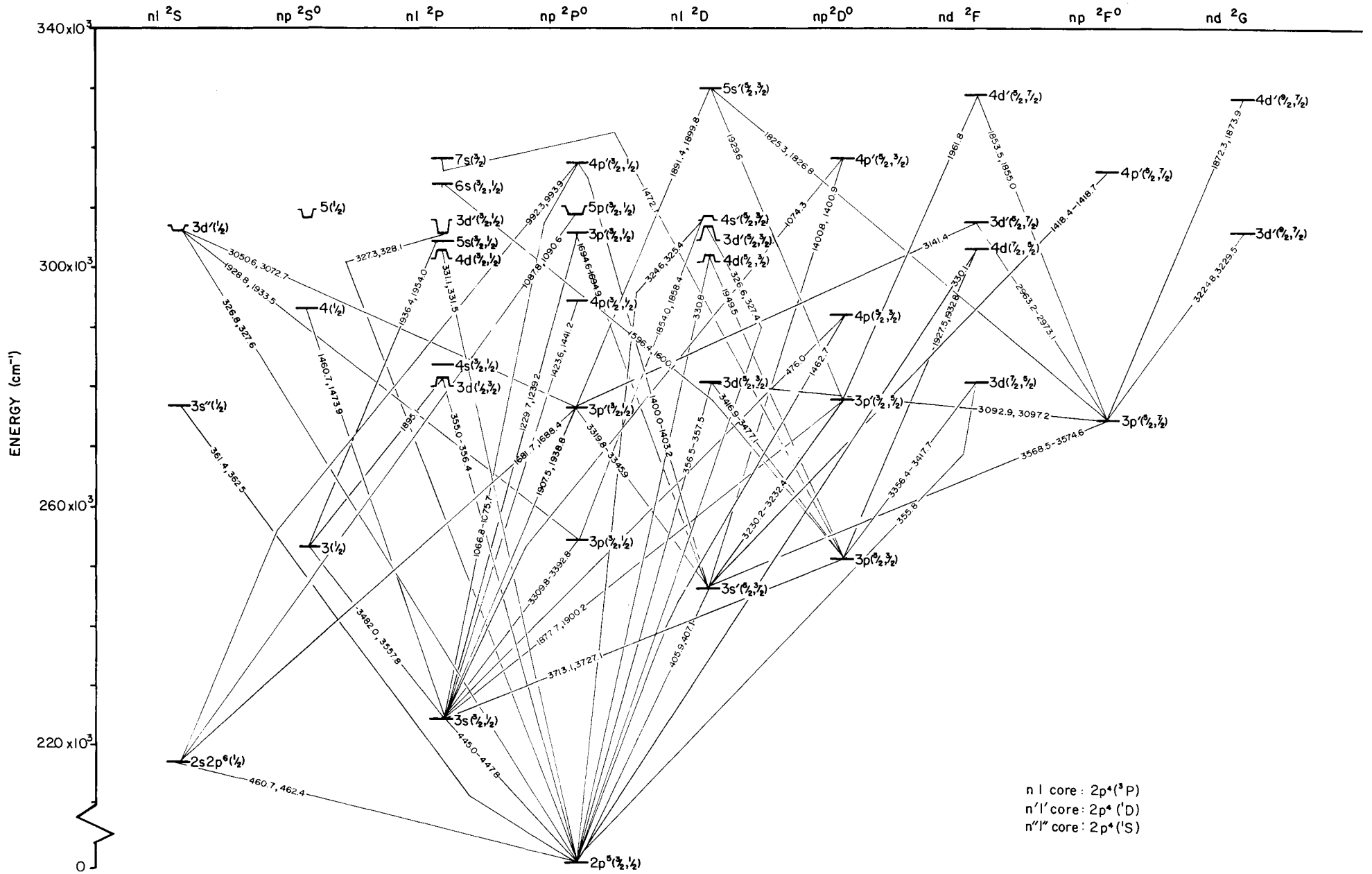


Ne I ENERGY LEVELS (10 electrons, Z=10)

(Configuration: $1s^2 2s\ 2p^6(^2S_{1/2})nl, 2s2p^4(^mL_J)nl(^{m'}L'_{J'})n'l'\ ^1P^o_1$; Doubly-Excited Terms)

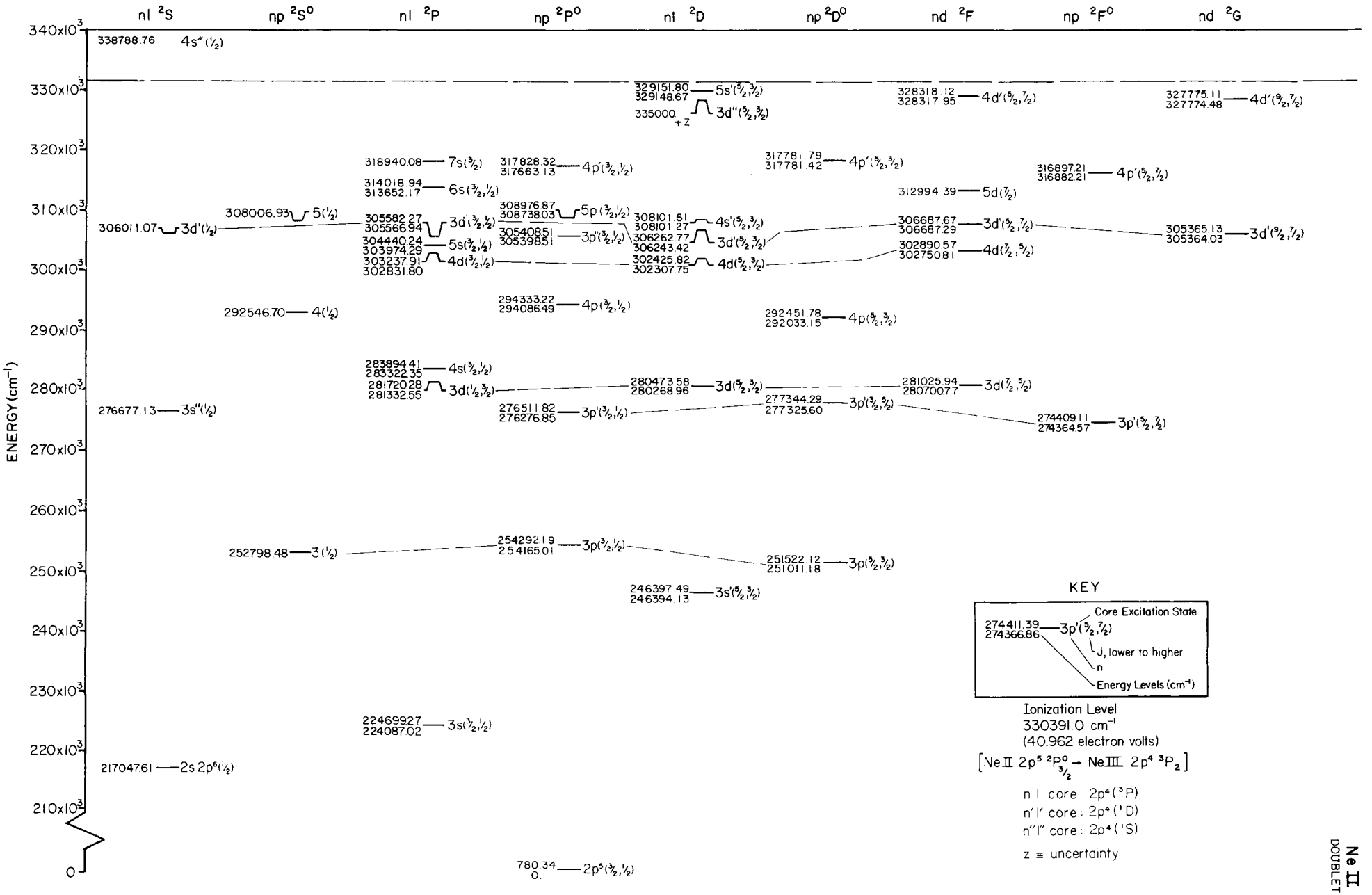


Ne II GROTRIAN DIAGRAM (9 electrons, Z=10)
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Doublet System)



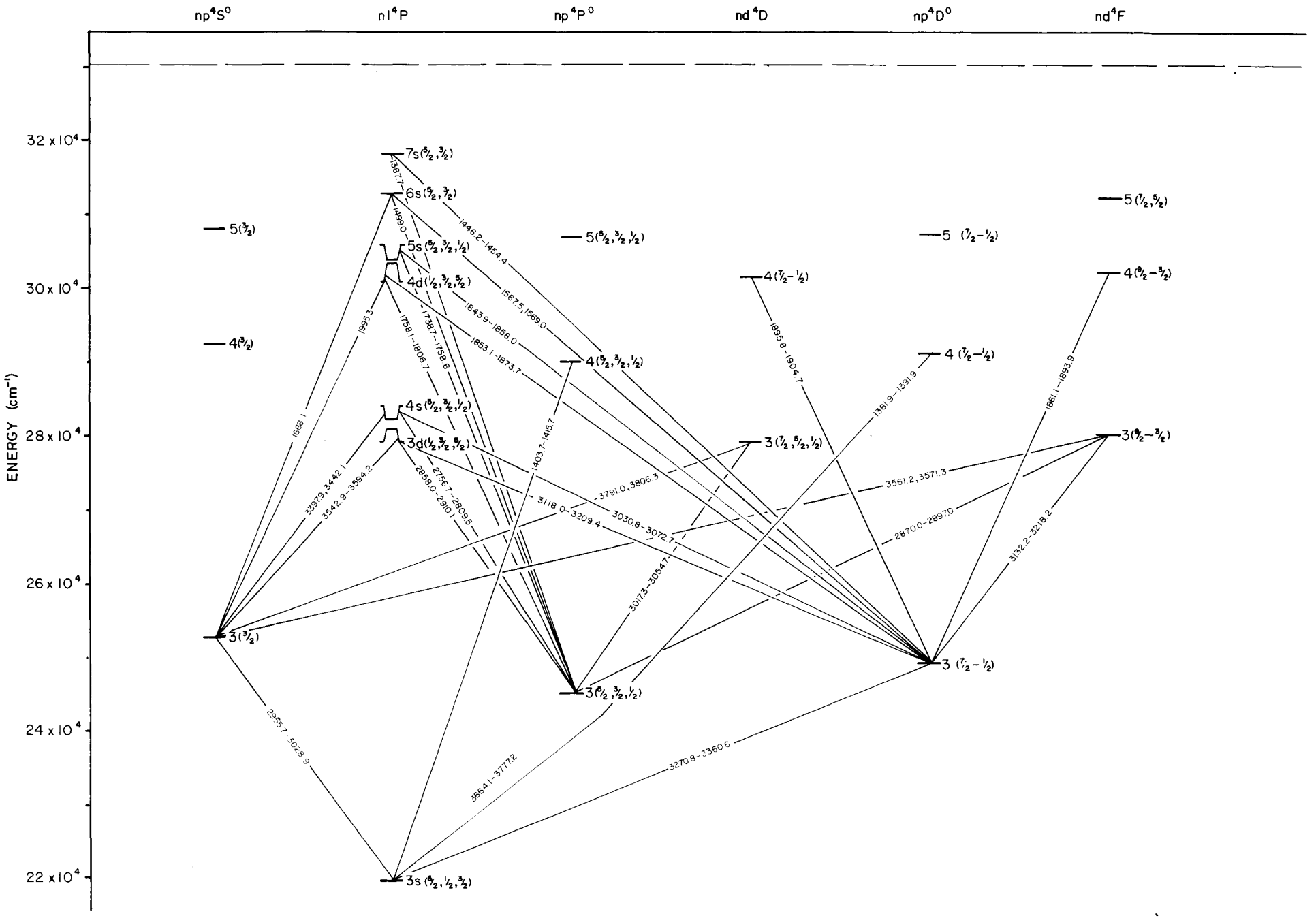
Ne II ENERGY LEVELS (9 electrons, Z=10)

(F I sequence, Configuration: $1s^2\,2s^2\,2p^4\,nl$, Doublet System)



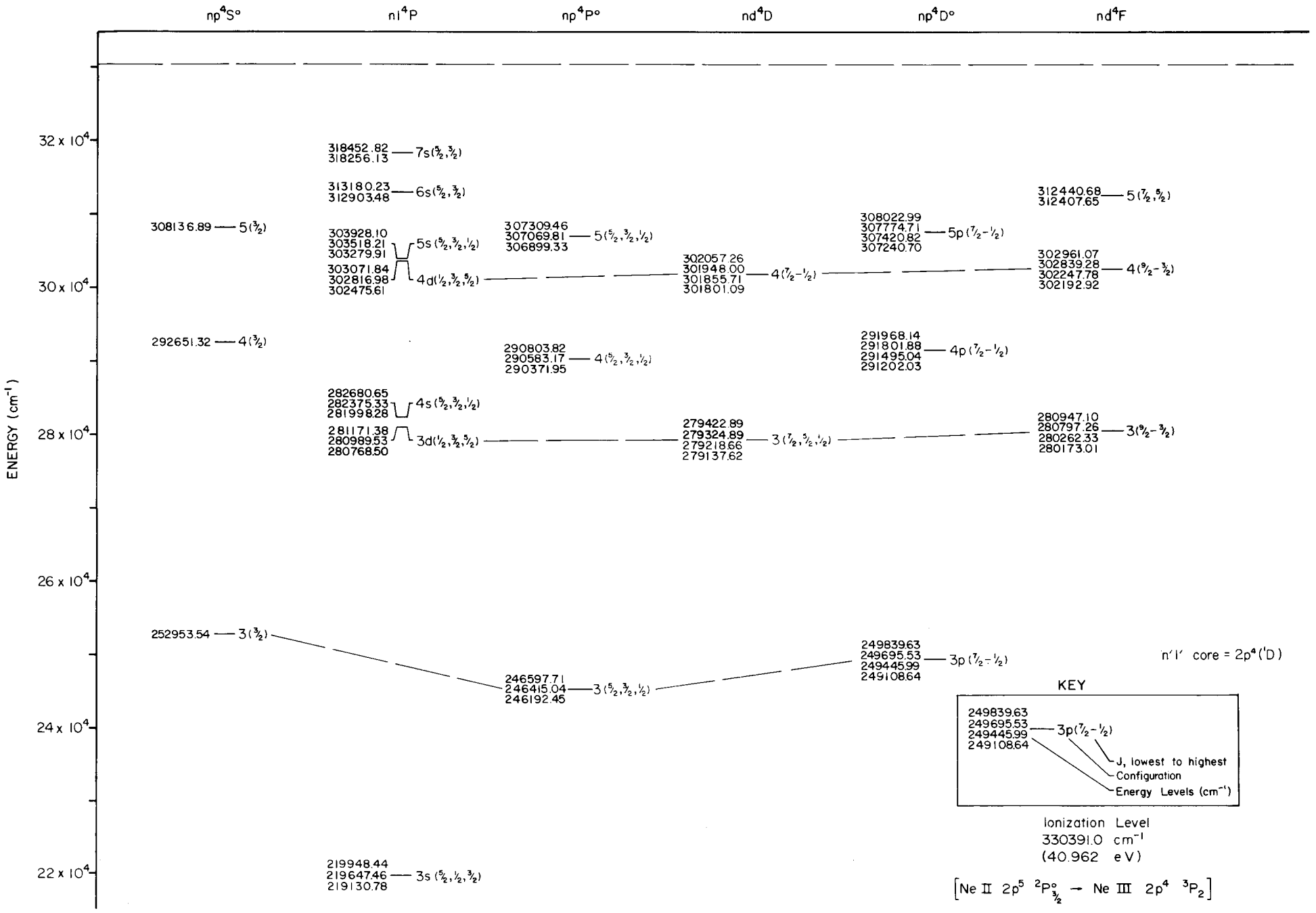
Ne II GROTRIAN DIAGRAM (9 electrons, Z = 10)

(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)



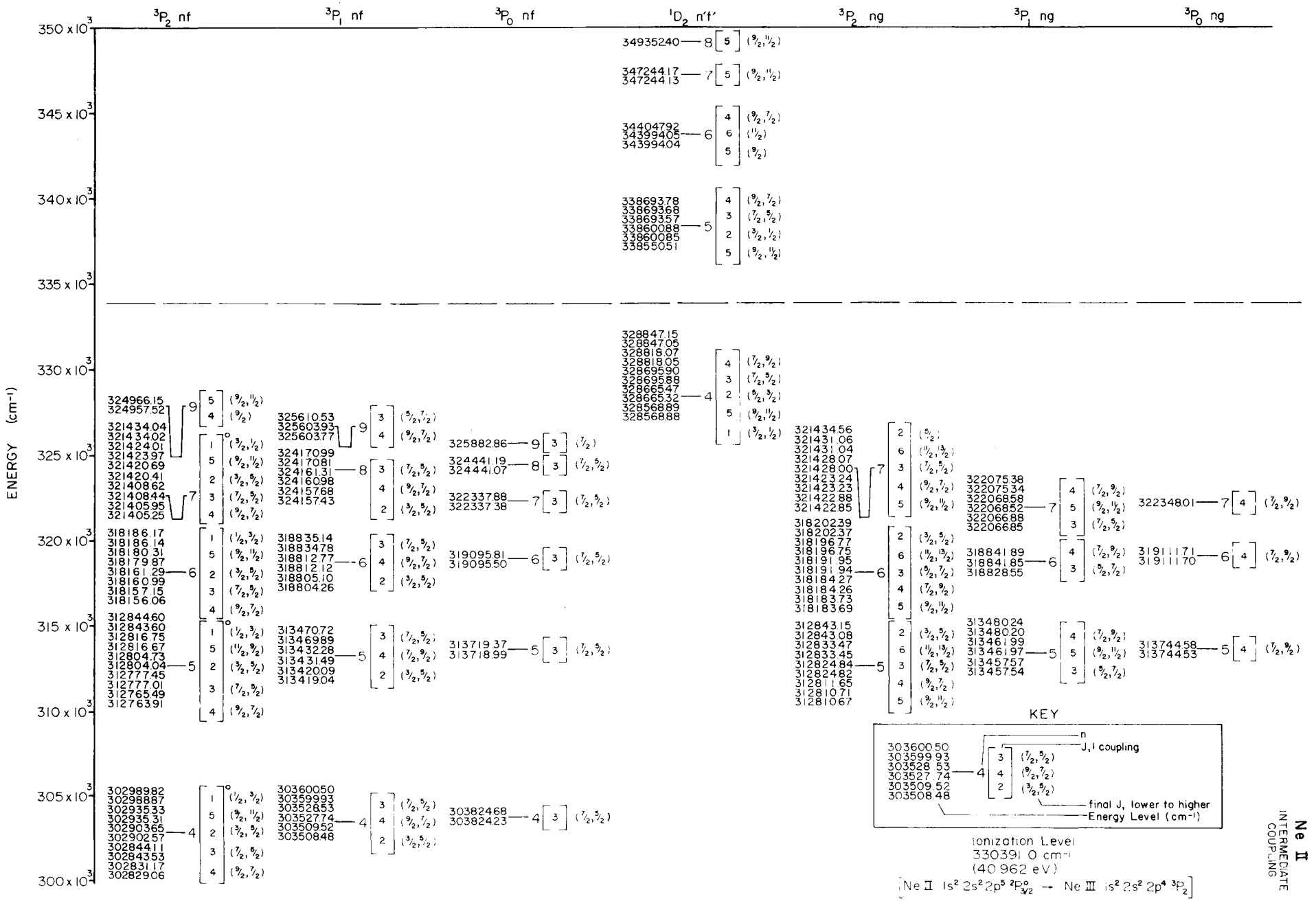
Ne II ENERGY LEVELS (9 electrons, Z = 10)

(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)

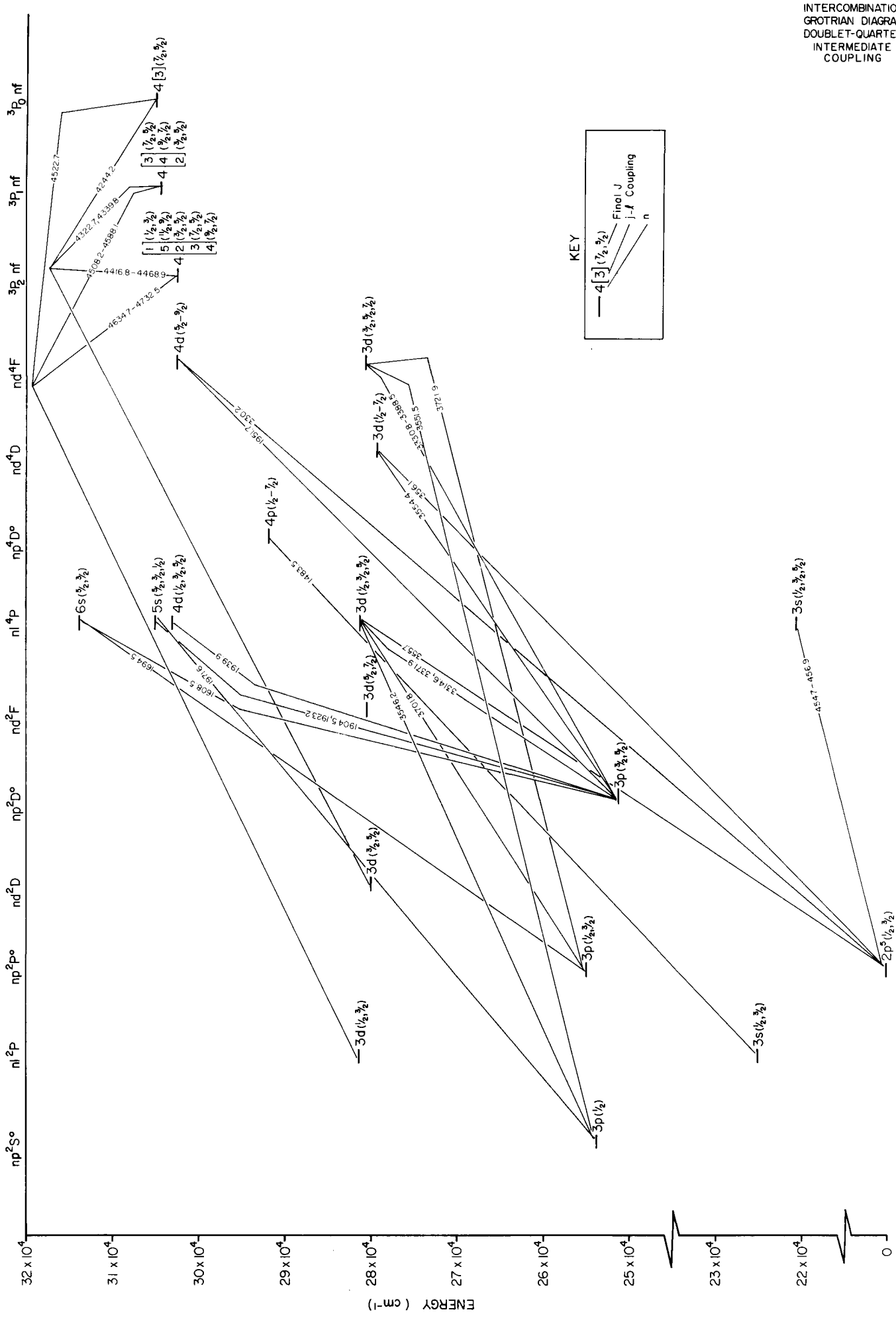


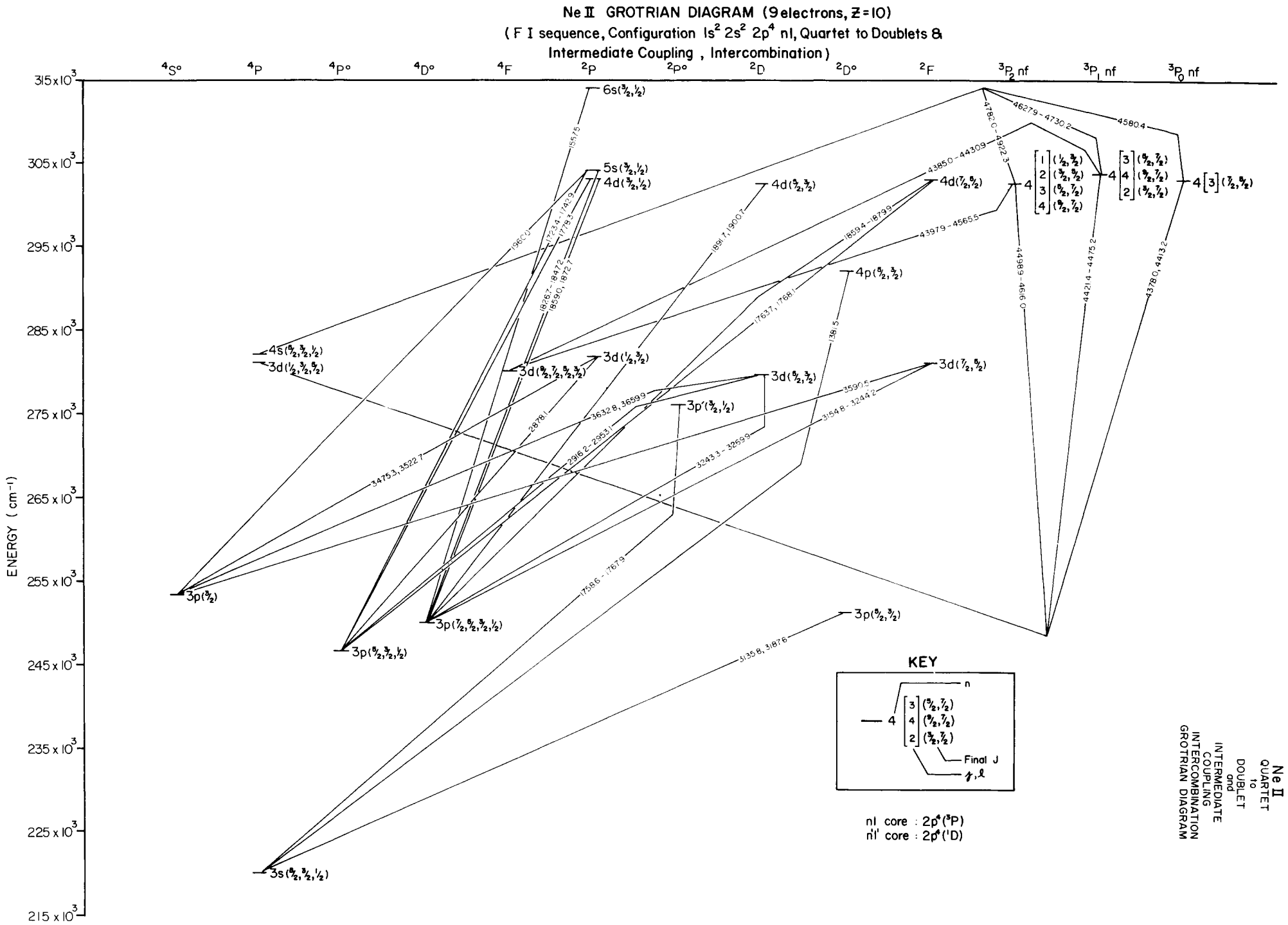
Ne II INTERMEDIATE COUPLING (9 electrons, Z=10)

F I sequence, Configuration $1s^2\,2s^2\,2p^4\,(^3P)\,nl$, $1s^2\,2s^2\,2p^4\,(^1D)\,n'l'\,[J,l](J)$

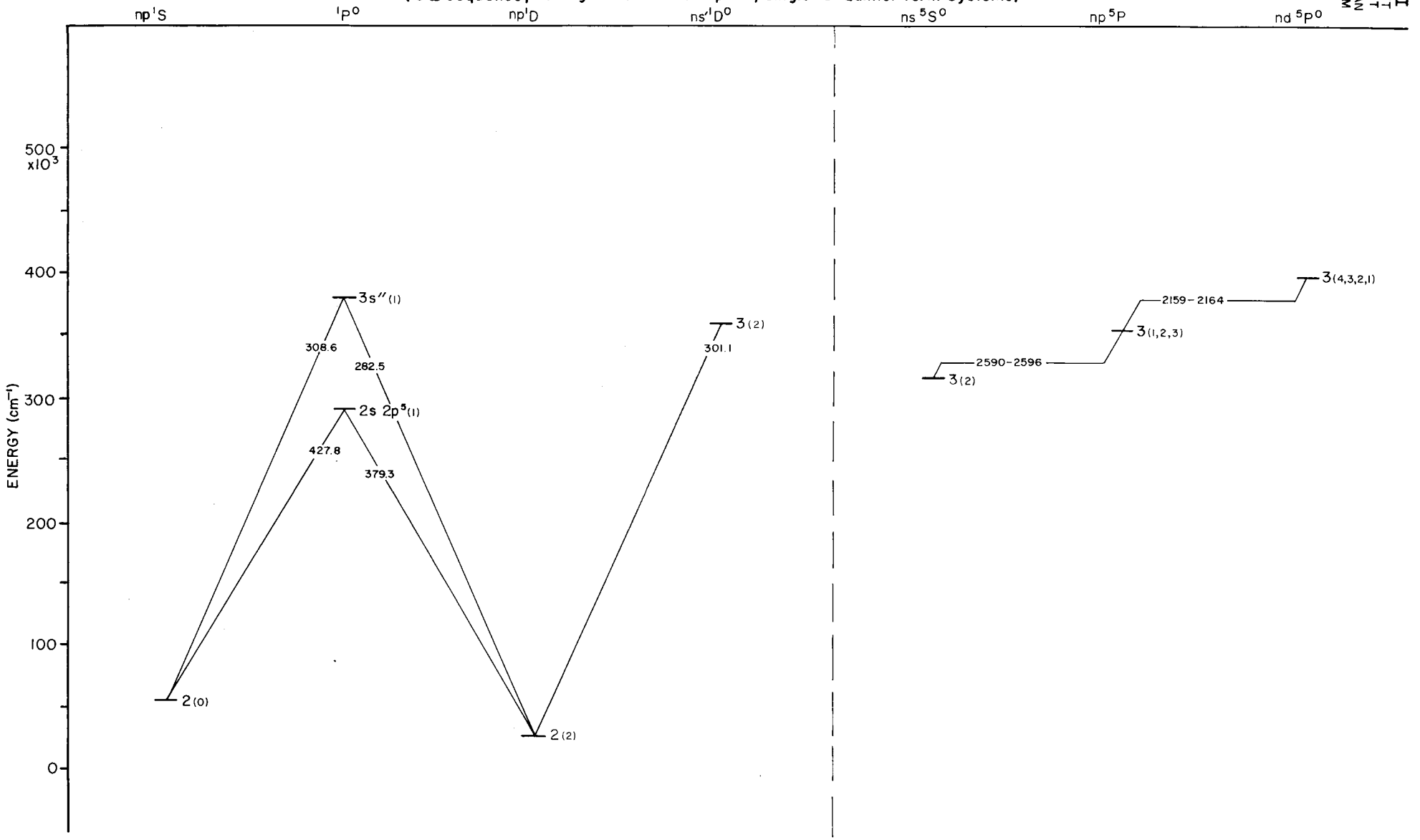


Ne II INTERCOMBINATION GROTRIAN DIAGRAM (9 electrons, Z=10)
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Doublet to Quartet, Intermediate Coupling Systems)



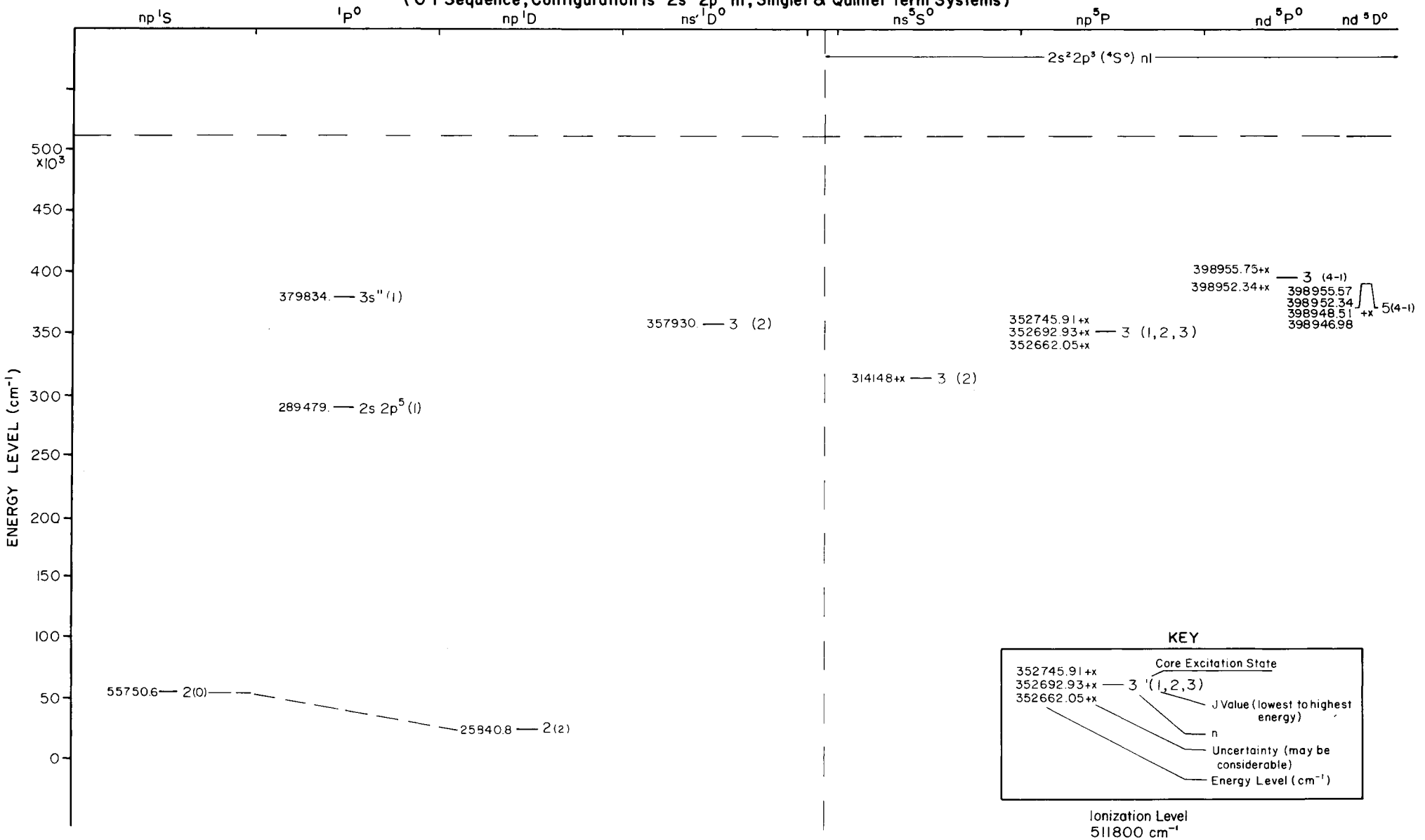

Ne II GROTRIAN DIAGRAM (9 electrons, Z=10)
(F I sequence, Configuration 1s² 2s² 2p⁴ nl, Quartet to Doublets &
Intermediate Coupling , Intercombination)
ENERGY (cm⁻¹)
KEY
nl core : 2p⁴(³P)
n'l' core : 2p⁴(¹D)
Ne II
QUARTET
to
DOUBLET
and
INTERMEDIATE
COUPLING
INTERCOMBINATION
GROTRIAN DIAGRAM

Ne III GROTRIAN DIAGRAM(8 electrons, Z=10)
(O I sequence, Configuration: $1s^2\ 2s^2\ 2p^3\ nl$, Singlet & Quintet Term Systems)



Ne III ENERGY LEVEL (8 electrons Z=10)

(O I Sequence, Configuration $1s^2 2s^2 2p^3 nl$, Singlet & Quintet Term Systems)

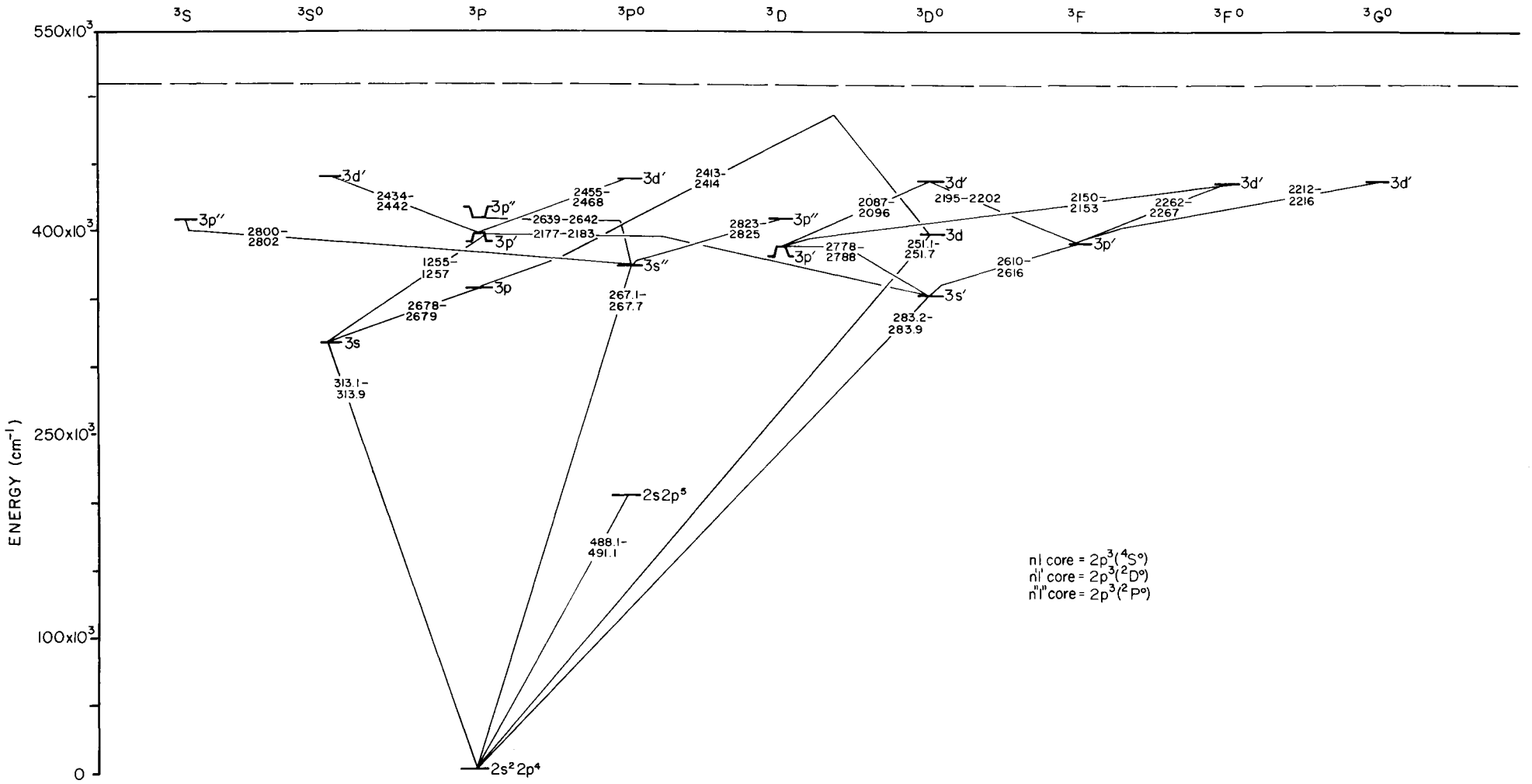


Ionization Level
511800 cm⁻¹
(63.45 electron volts)

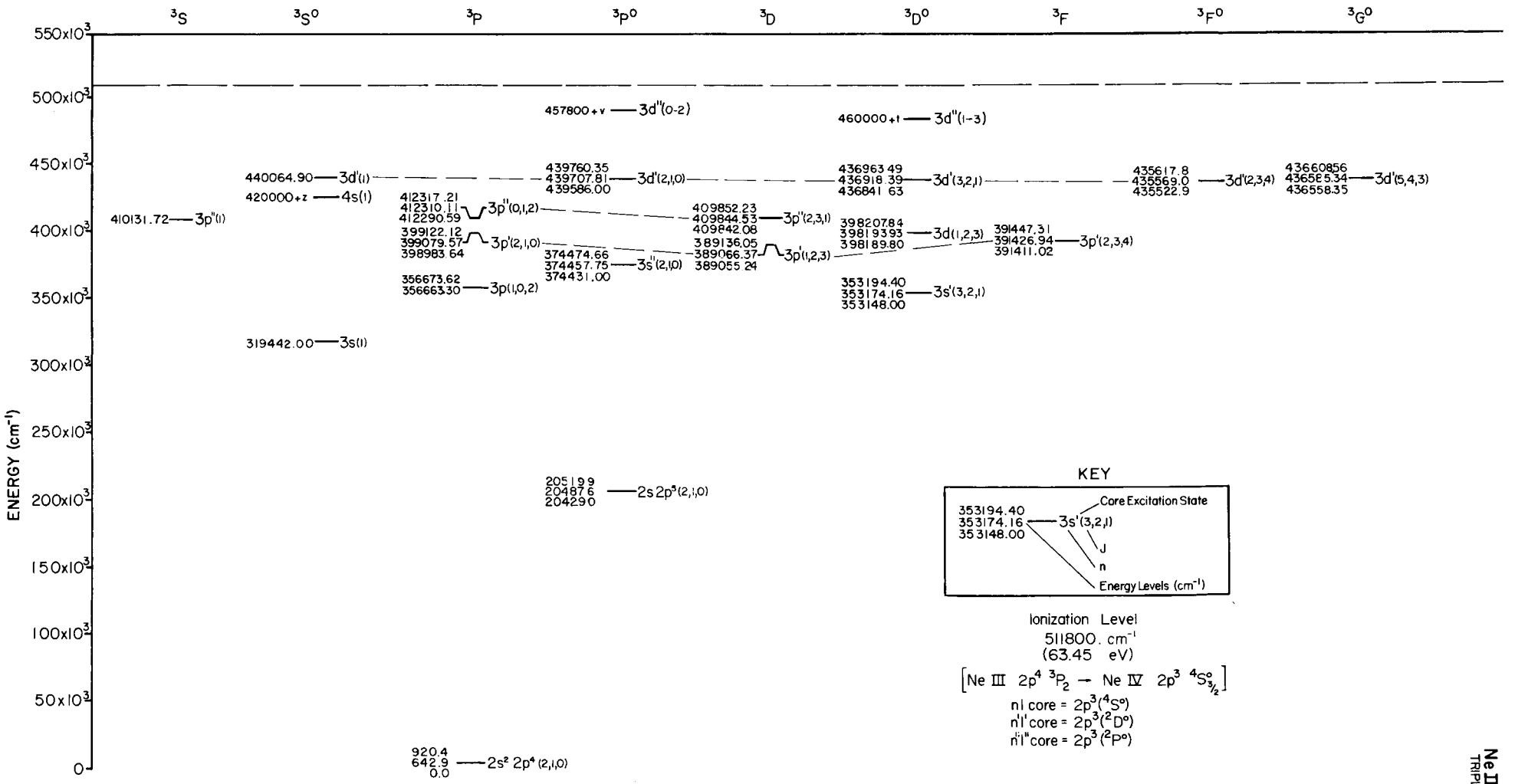
[Ne III $2p^4\ ^3P_2 \longrightarrow$ Ne IV $2p^3\ ^4S^o_{3/2}$]

n'l' core = $2s^2 2p^3 (^2D^o)$
n''l'' core = $2s^2 2p^3 (^2P^o)$

Ne III GROTRIAN DIAGRAM (8 electrons, Z = 10)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)



Ne III ENERGY LEVELS (8 electrons, Z=10)
(OI sequence, Configuration: $1s^2\ 2s^2\ 2p^3\ nl$, Triplet System)

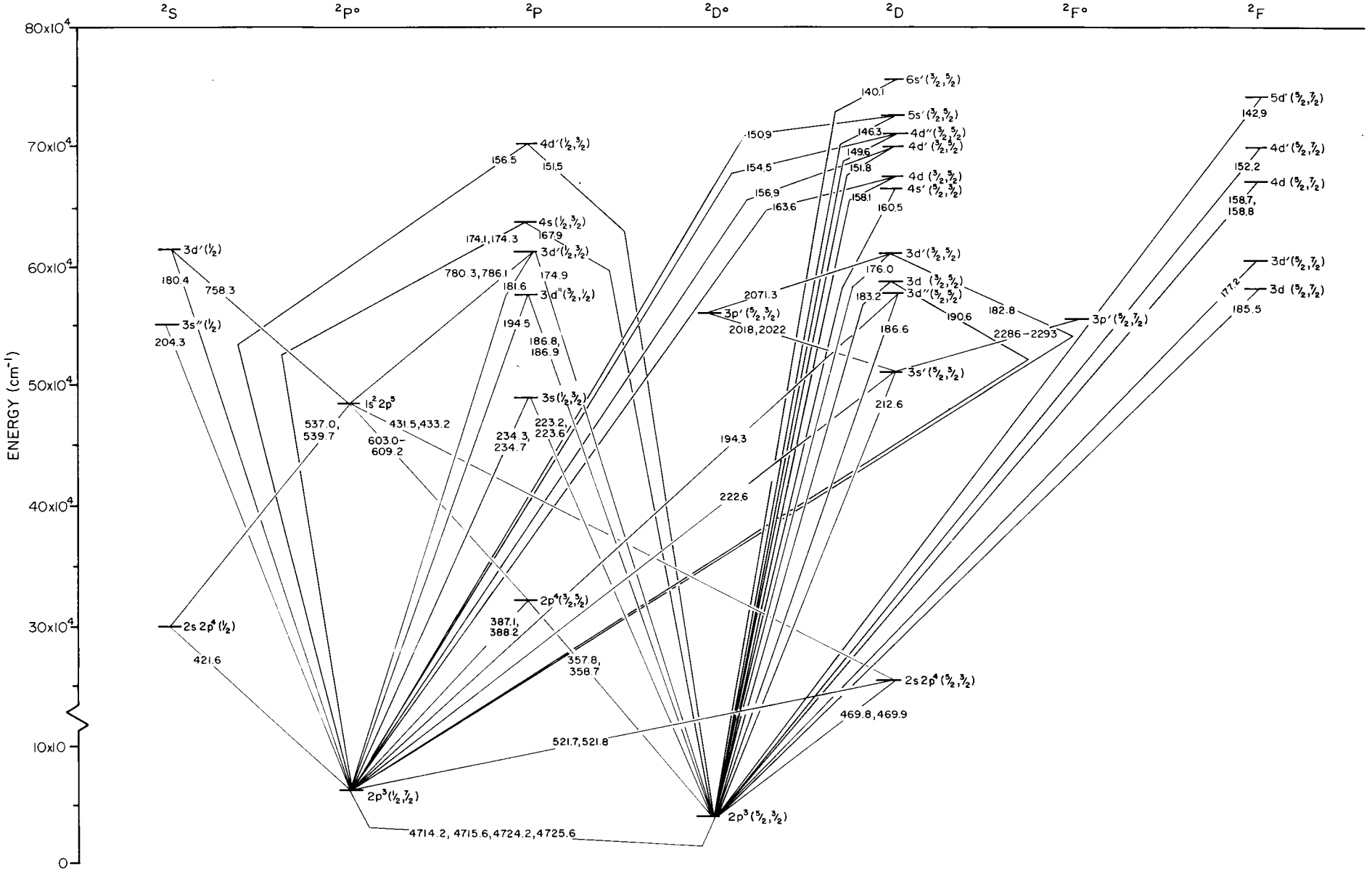


Ionization Level
511800. cm^{-1}
(63.45 eV)

[Ne III $2p^4\ ^3P_2$ → Ne IV $2p^3\ ^4S^o_{3/2}$]

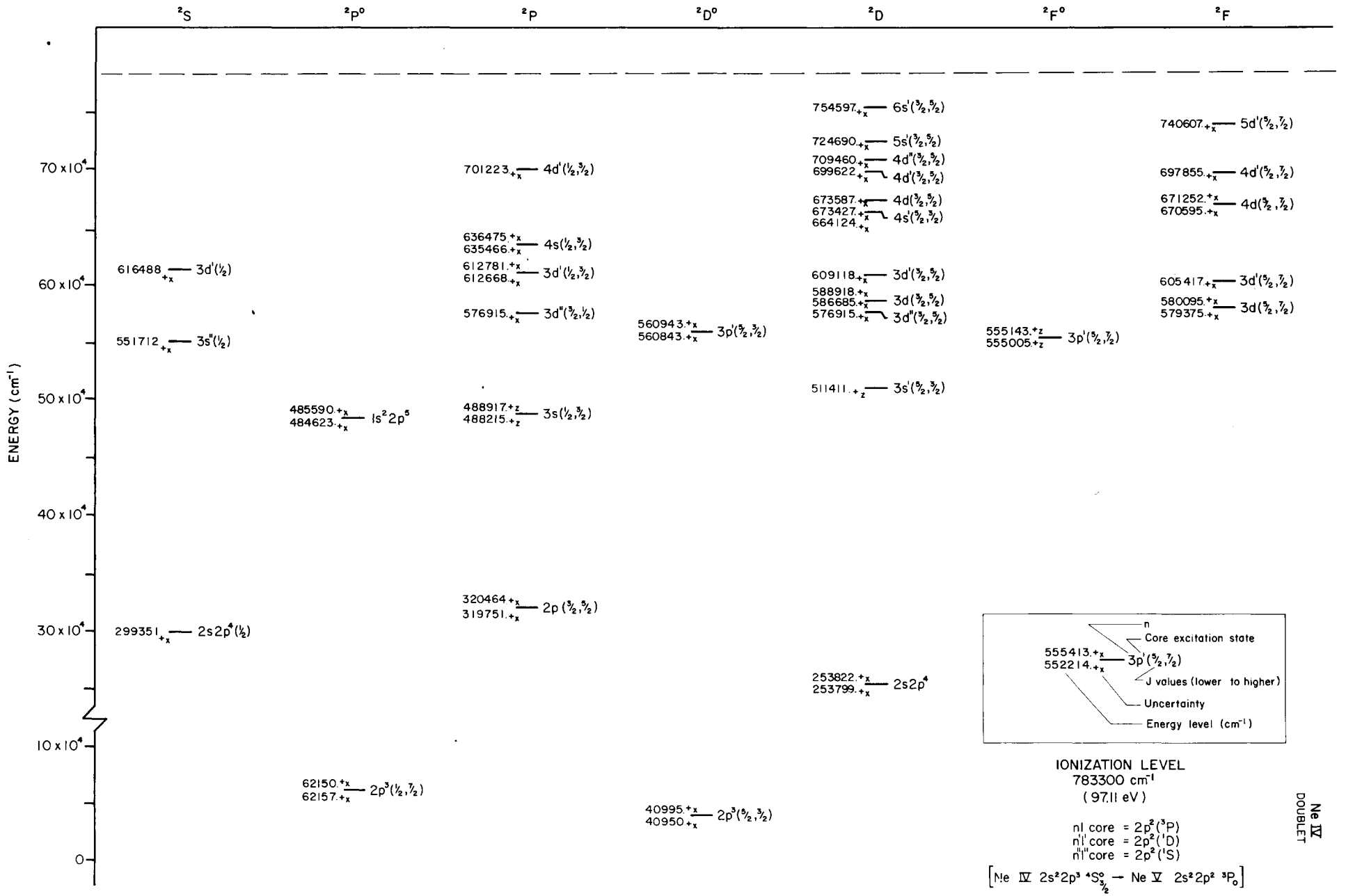
nl core = $2p^3(^4S^o)$
n'l' core = $2p^3(^2D^o)$
n''l'' core = $2p^3(^2P^o)$

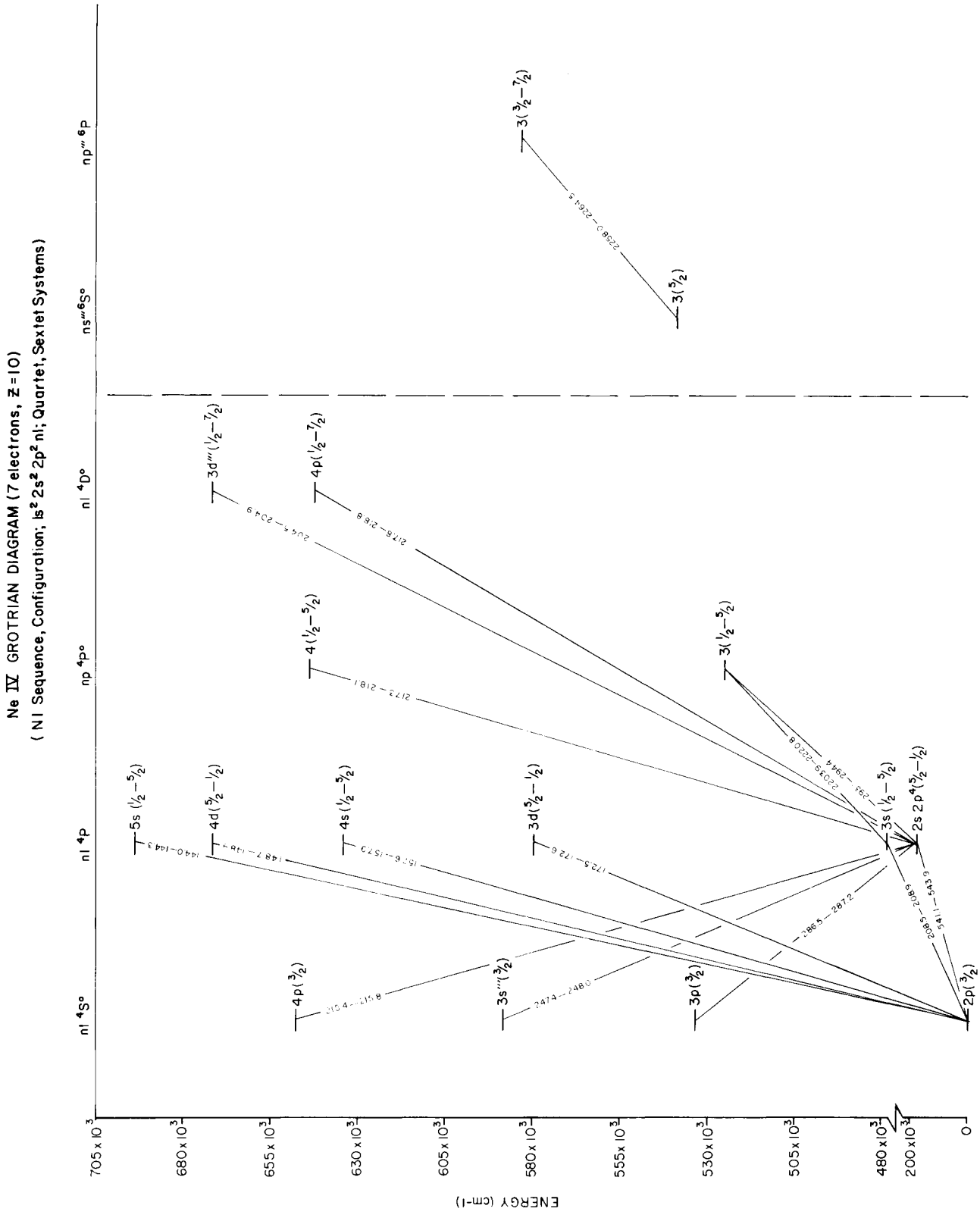
Ne IV GROTRIAN DIAGRAM (7 electrons, Z=10)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



Ne IV ENERGY LEVELS (7 electrons, Z=10)

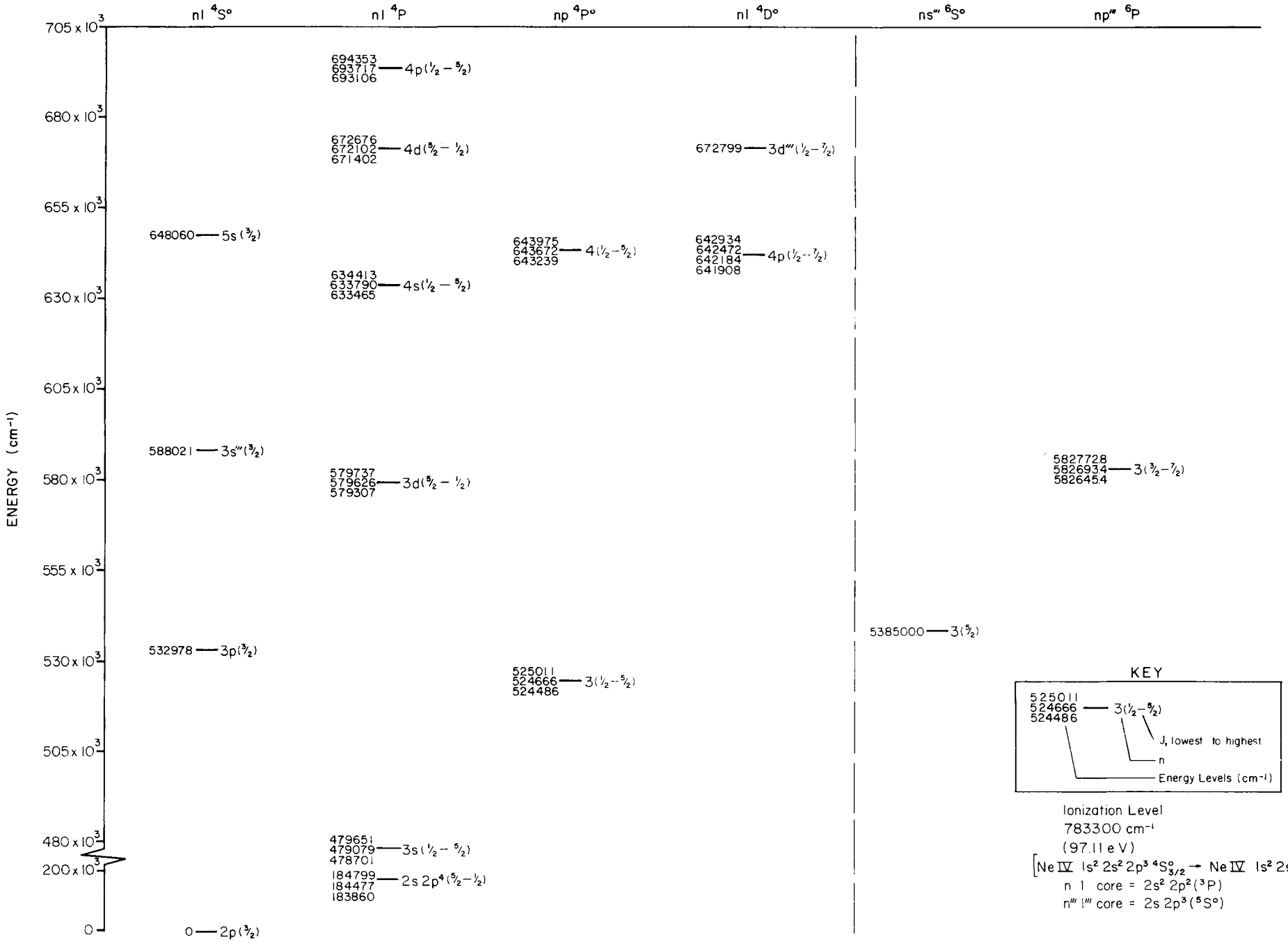
(N I Sequence, Configuration : $1s^2 2s^2 2p^2 nl$, Doublet Term System)




Ne IV GROTRIAN DIAGRAM (7 electrons, Z=10)
(N I Sequence, Configuration; 1s² 2s² 2p² nl; Quartet, Sextet Systems)
nl ⁴S°
nl ⁴P
np ⁴P°
nl ⁴D°
ns'''⁶S°
np'''⁶P
ENERGY (cm-1)
705 x 10³
680 x 10³
655 x 10³
630 x 10³
605 x 10³
580 x 10³
555 x 10³
530 x 10³
505 x 10³
480 x 10³
200 x 10³
0
5s (1/2 – 5/2)
4d(5/2 – 1/2)
4s(1/2 – 5/2)
3d(5/2 – 1/2)
4p(3/2)
3s'''(3/2)
3p(3/2)
2p(3/2)
3s(1/2 – 5/2)
2s 2p⁴(5/2 – 1/2)
3d'''(1/2 – 7/2)
4p(1/2 – 7/2)
4(1/2 – 5/2)
3(1/2 – 5/2)
3(3/2 – 7/2)
3(5/2)
1440 – 1443
1487 – 1496
1515 – 1573
1725 – 1726
2048 – 2089
2545 – 2611
2865 – 2872
2039 – 2220.8
2044 – 2044
2174 – 2181
2174 – 2268
2268.3 – 2264.5

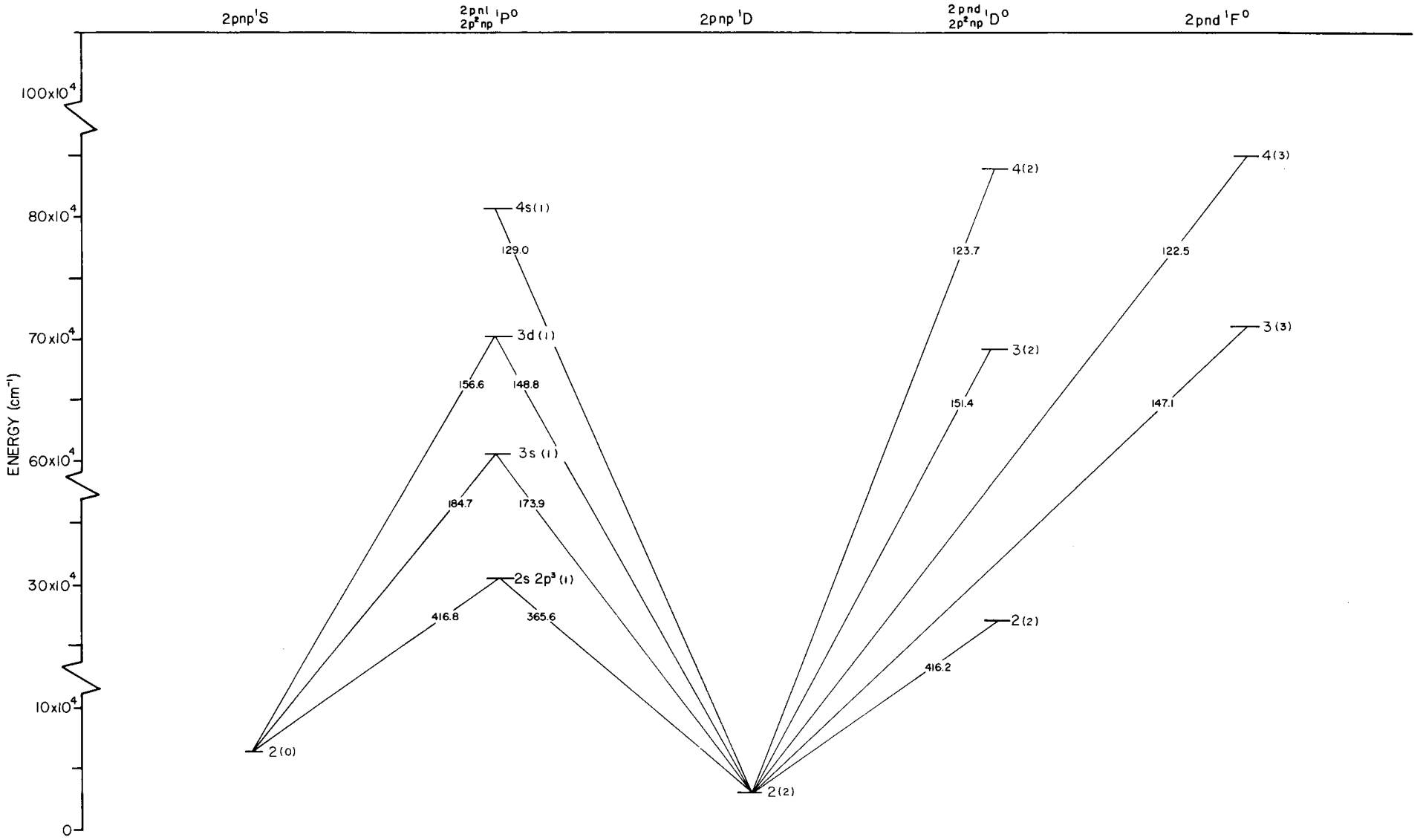
Ne IV ENERGY LEVELS (7 electrons, Z = 10)

(NI sequence, Configuration; $1s^2\,2s^2\,2p^2\,nl$; Quartet, Sextet Systems)



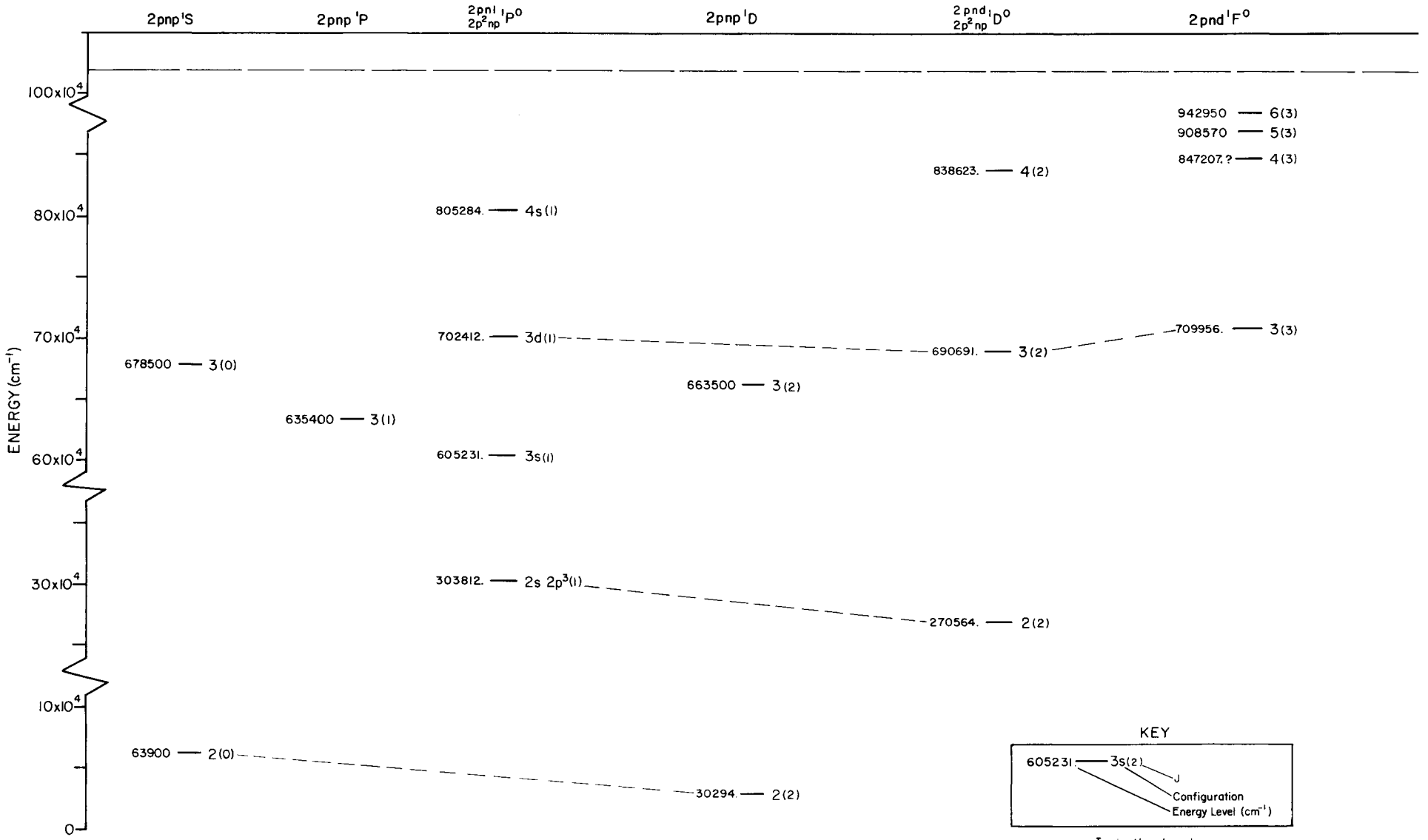
Ne IV
QUARTET
SEXTET

Ne V GROTRIAN DIAGRAM(6 electrons, Z=10)
(C I sequence, Configuration: $1s^2\,2s^2\,2pnl$ and $1s^2\,2s2p^2\,nl$ Singlet Systems)



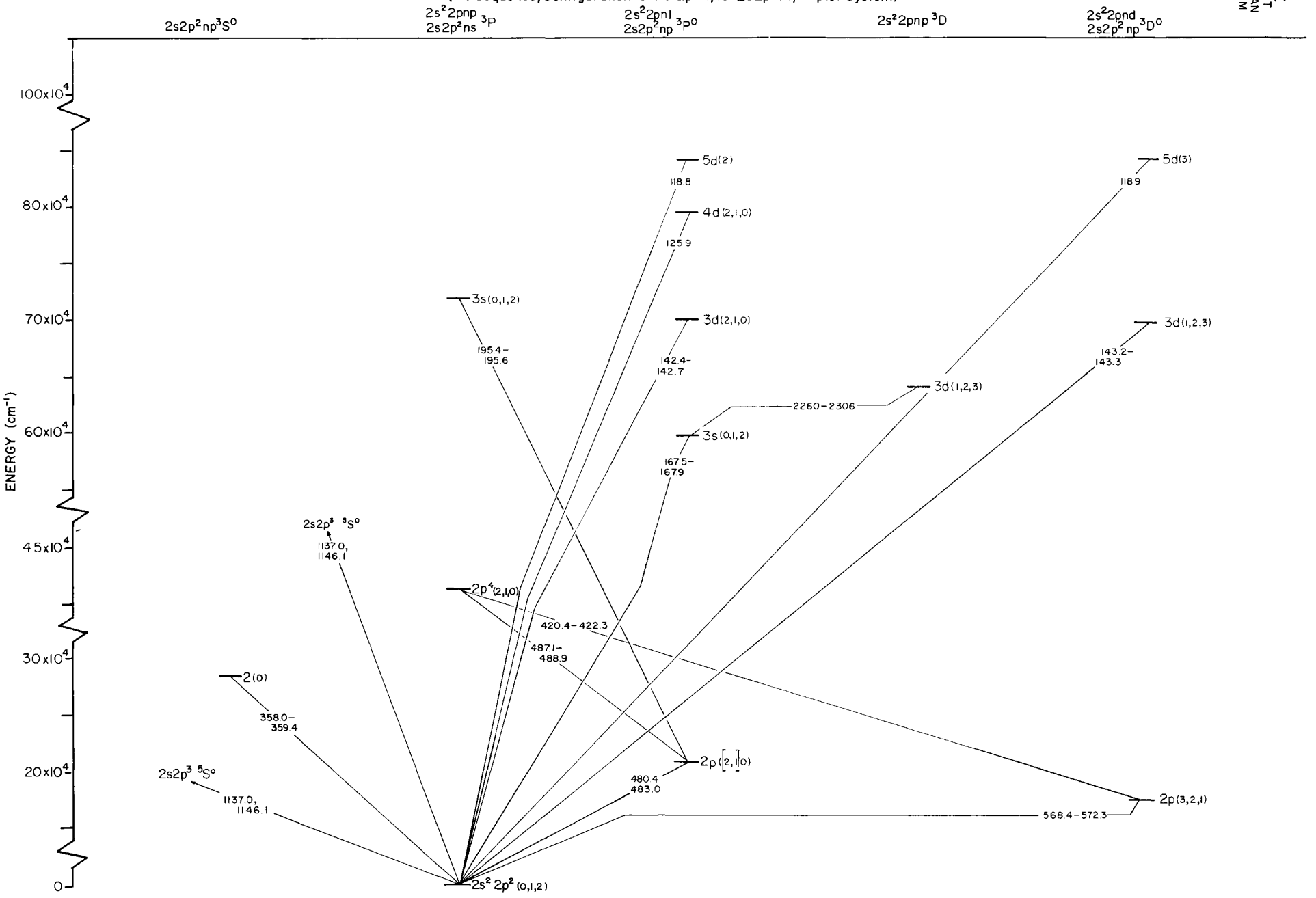
Ne V ENERGY LEVELS (6 electrons, Z = 10)

(CI sequence, Configuration: $1s^2\,2s^2\,2pnl$ and $1s^2\,2s\,2p^2\,nl$ Singlet System)

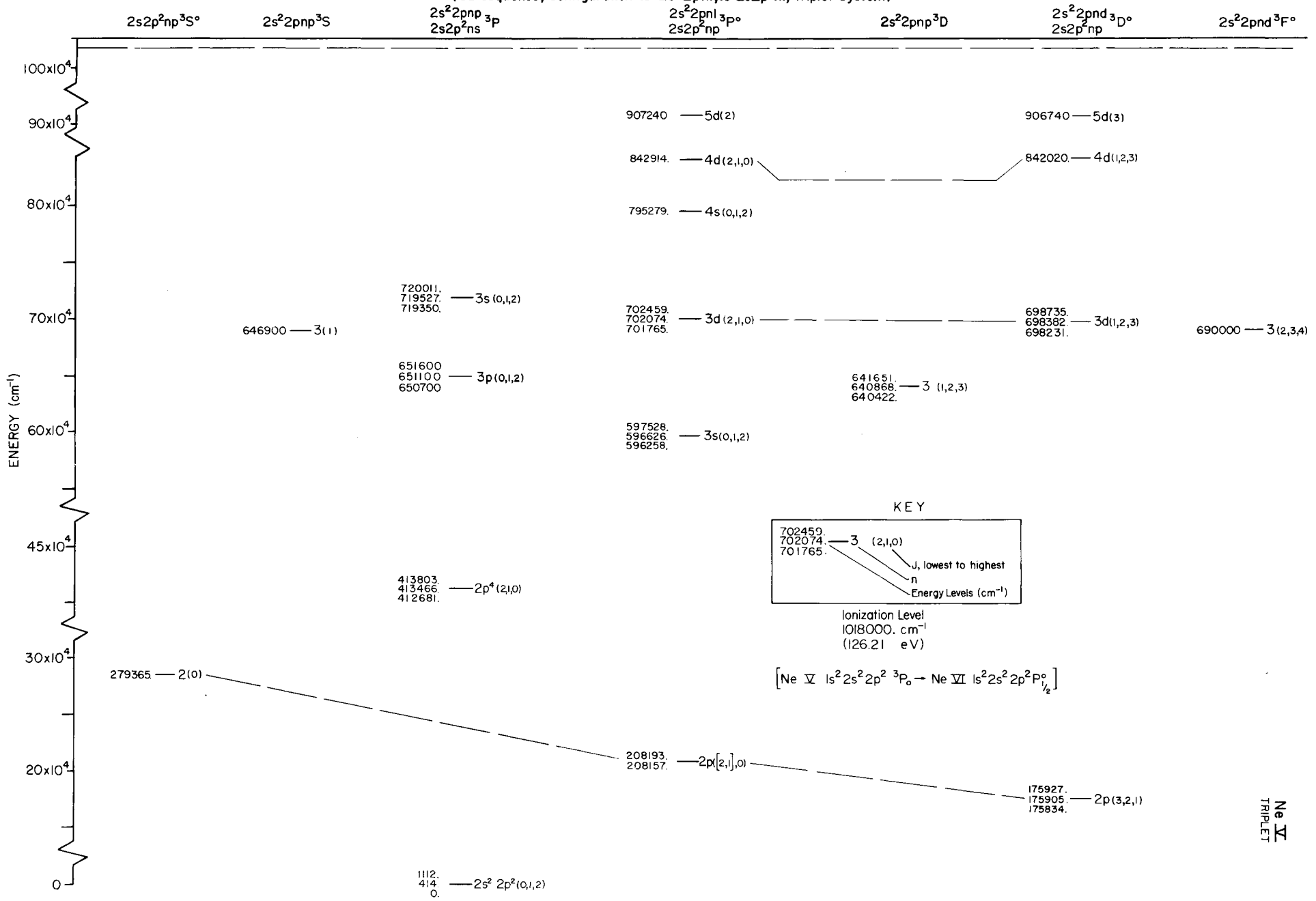


Ionization Level
1018000 cm⁻¹
(126.21 eV)
[Ne V $2s^2 2p^2\ ^3P_0 \rightarrow$ Ne VI $2s^2 2p\ ^2P^o_{1/2}$]

Ne V GROTRIAN DIAGRAM (6 electrons, Z = 10)
(CI sequence, Configuration: $1s^2 2s^2 2p\,nl$, $1s^2 2s 2p^2 nl$, Triplet System)

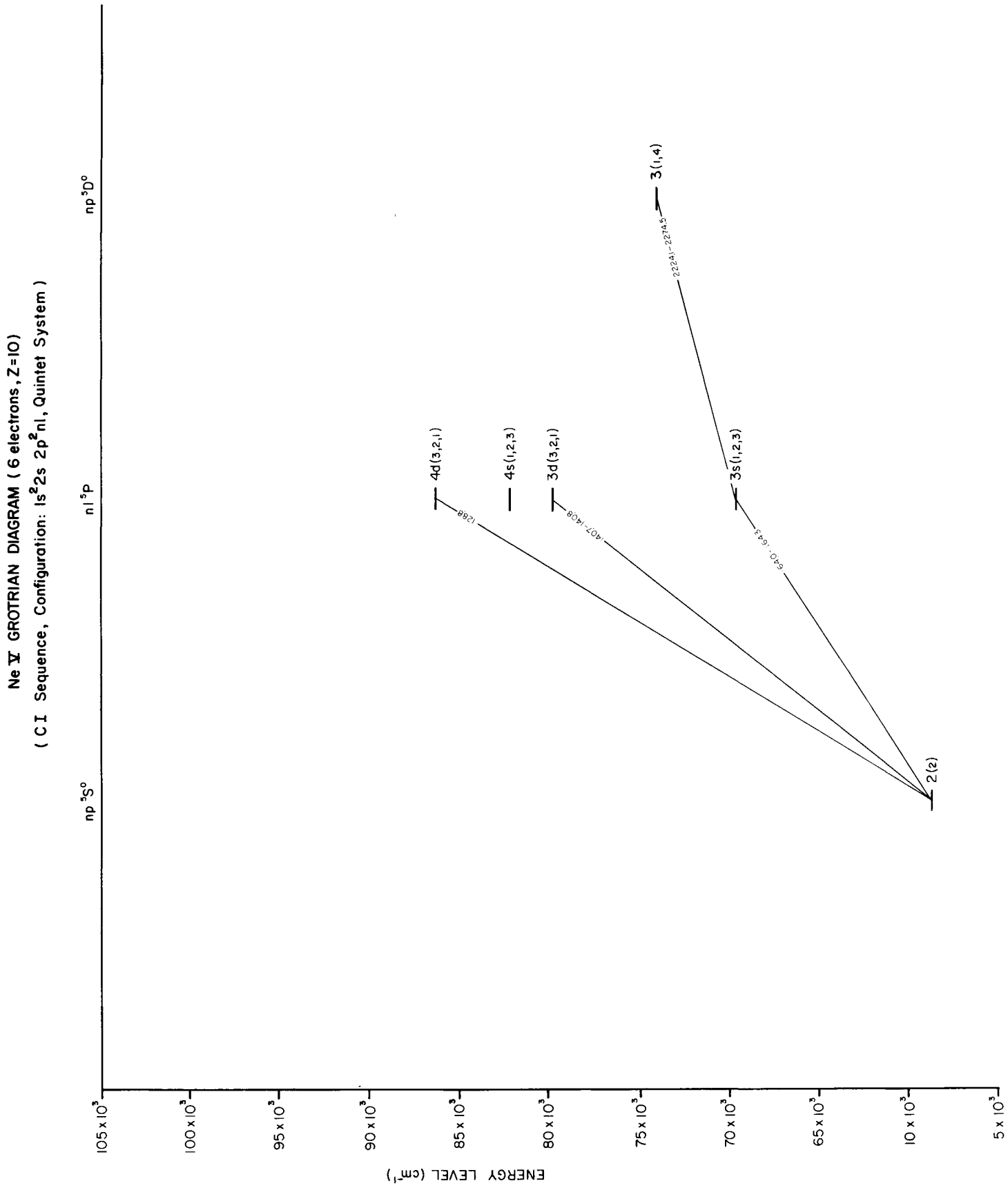


Ne V ENERGY LEVELS (6 electrons, Z = 10)
(CI sequence, Configuration: $1s^2 2s^2 2pnl$, $1s^2 2s2p^2 nl$, Triplet System)



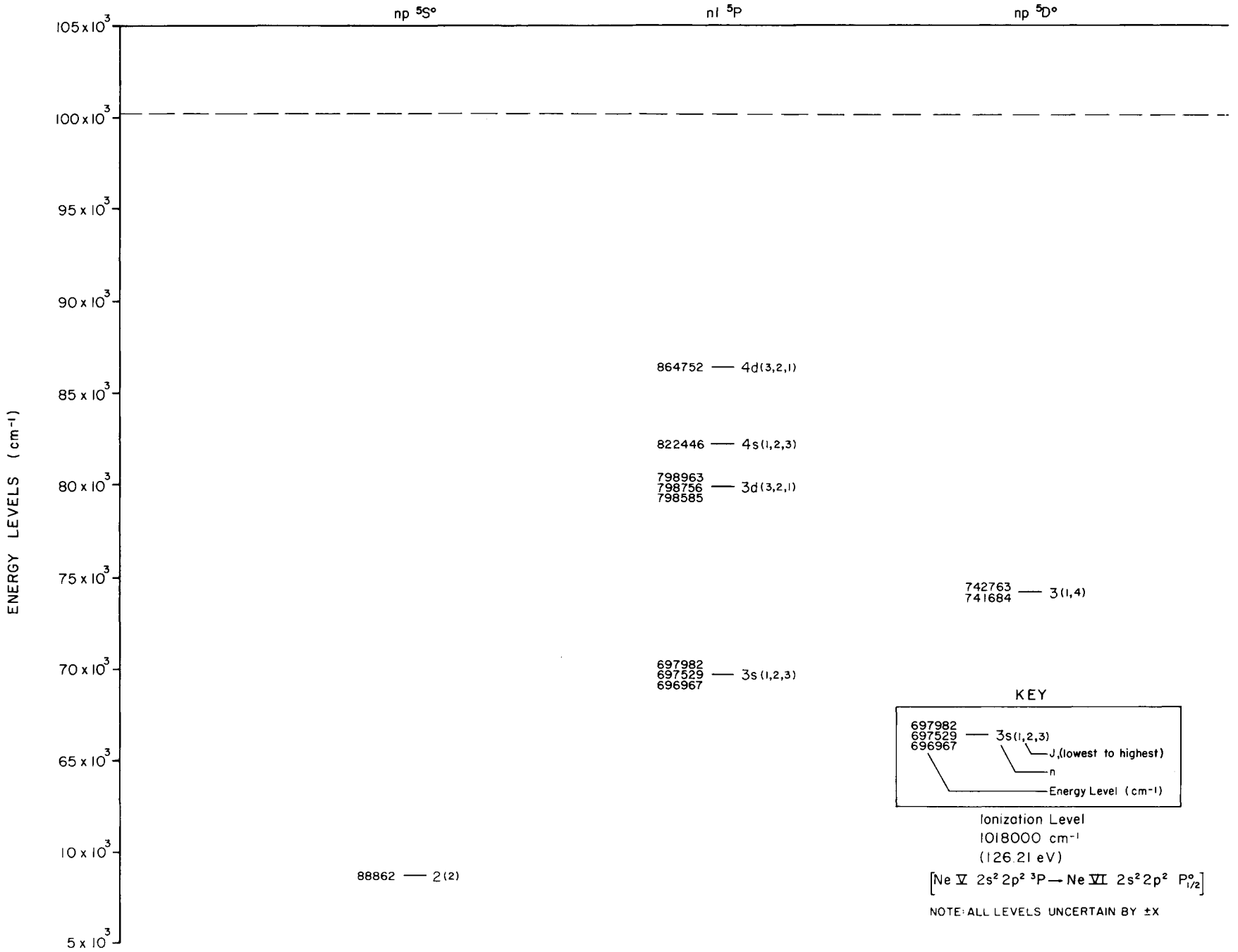
Ne V
TRIPLET

Ne V
QUINTET
GROTRIAN
DIAGRAM

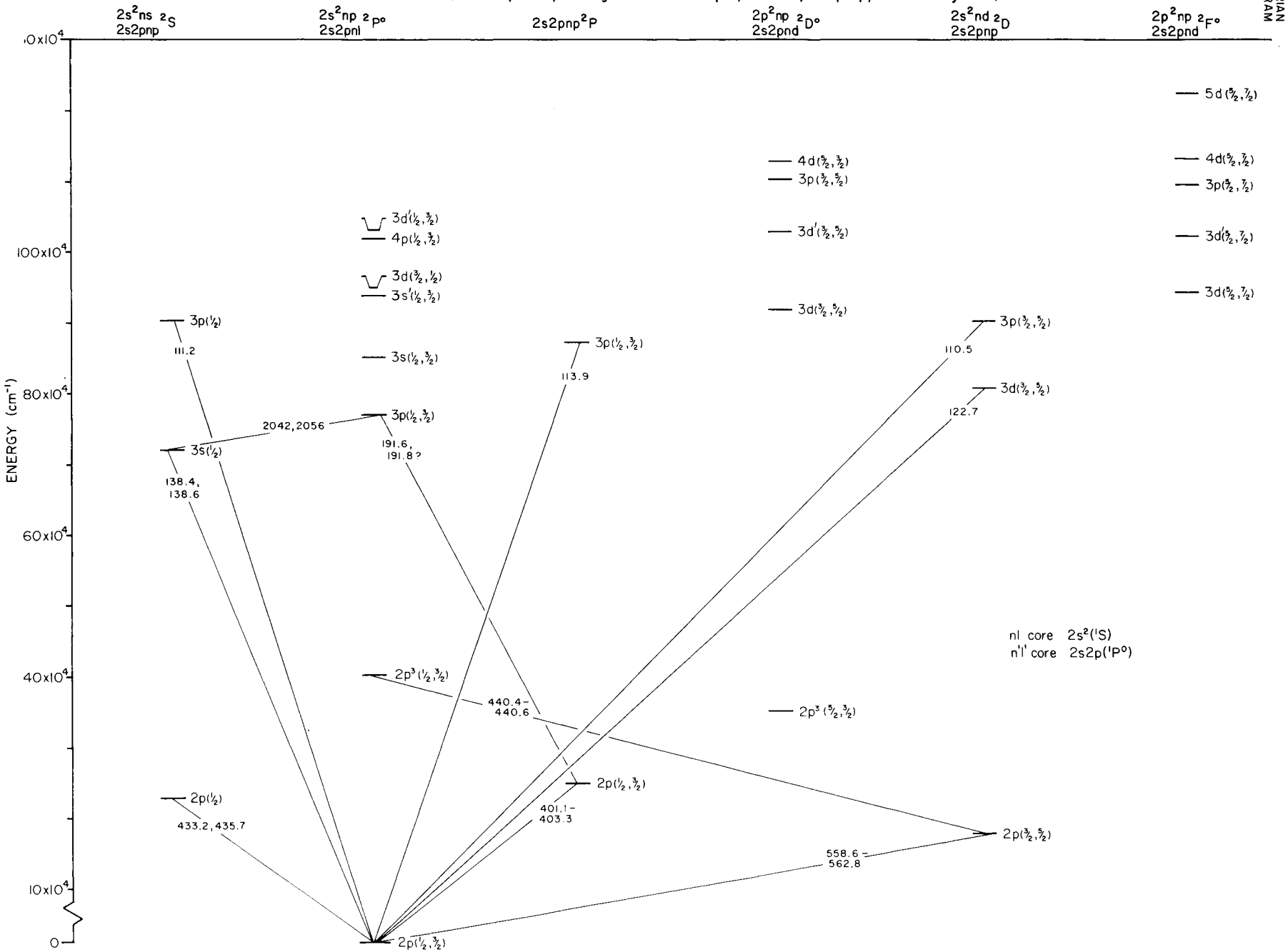


Ne V ENERGY LEVEL (6 electrons, Z=10)

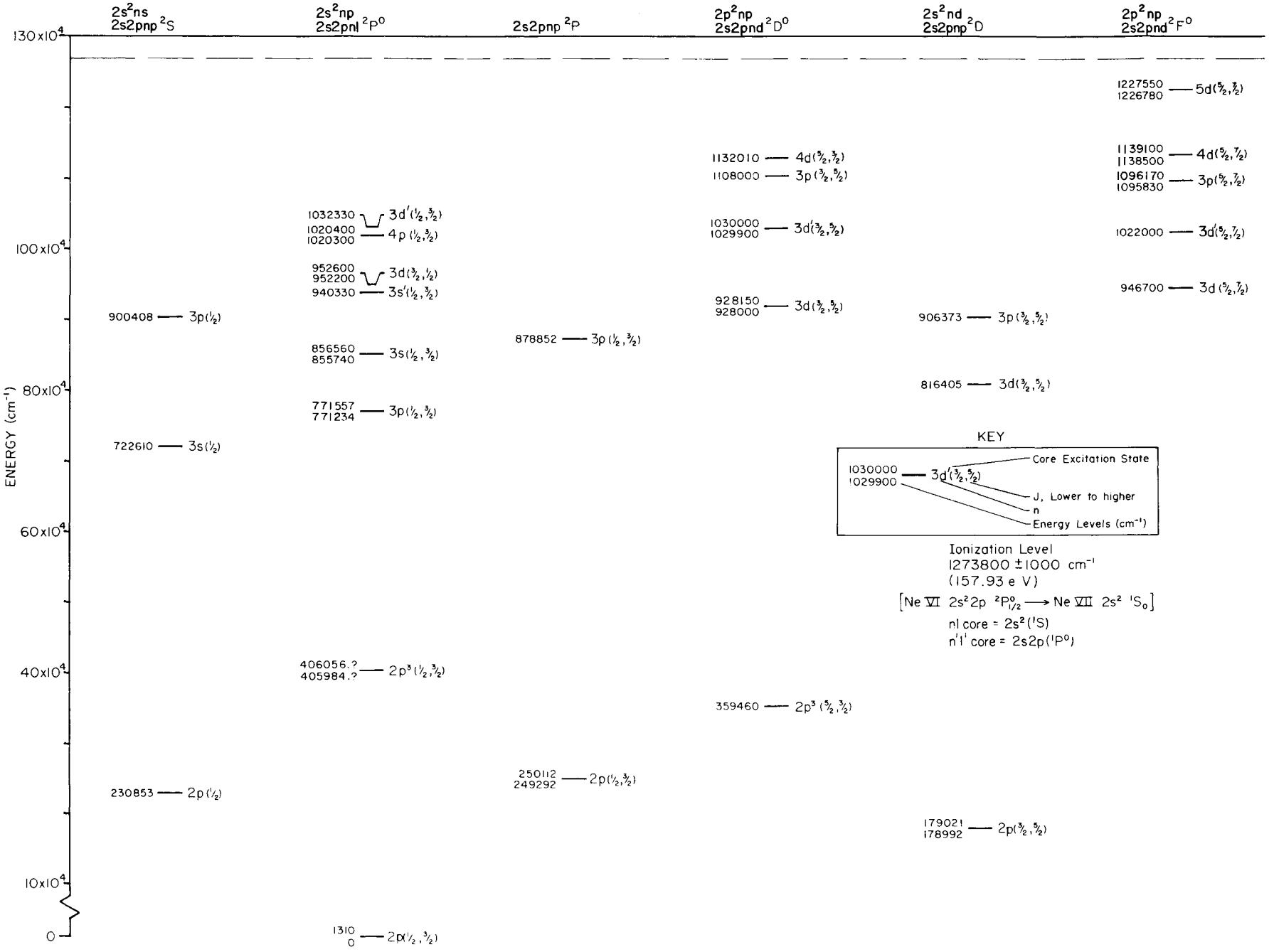
(C I sequence, Configuration: $1s^2\,2s\,2p^2\,nl$, Quintet System)



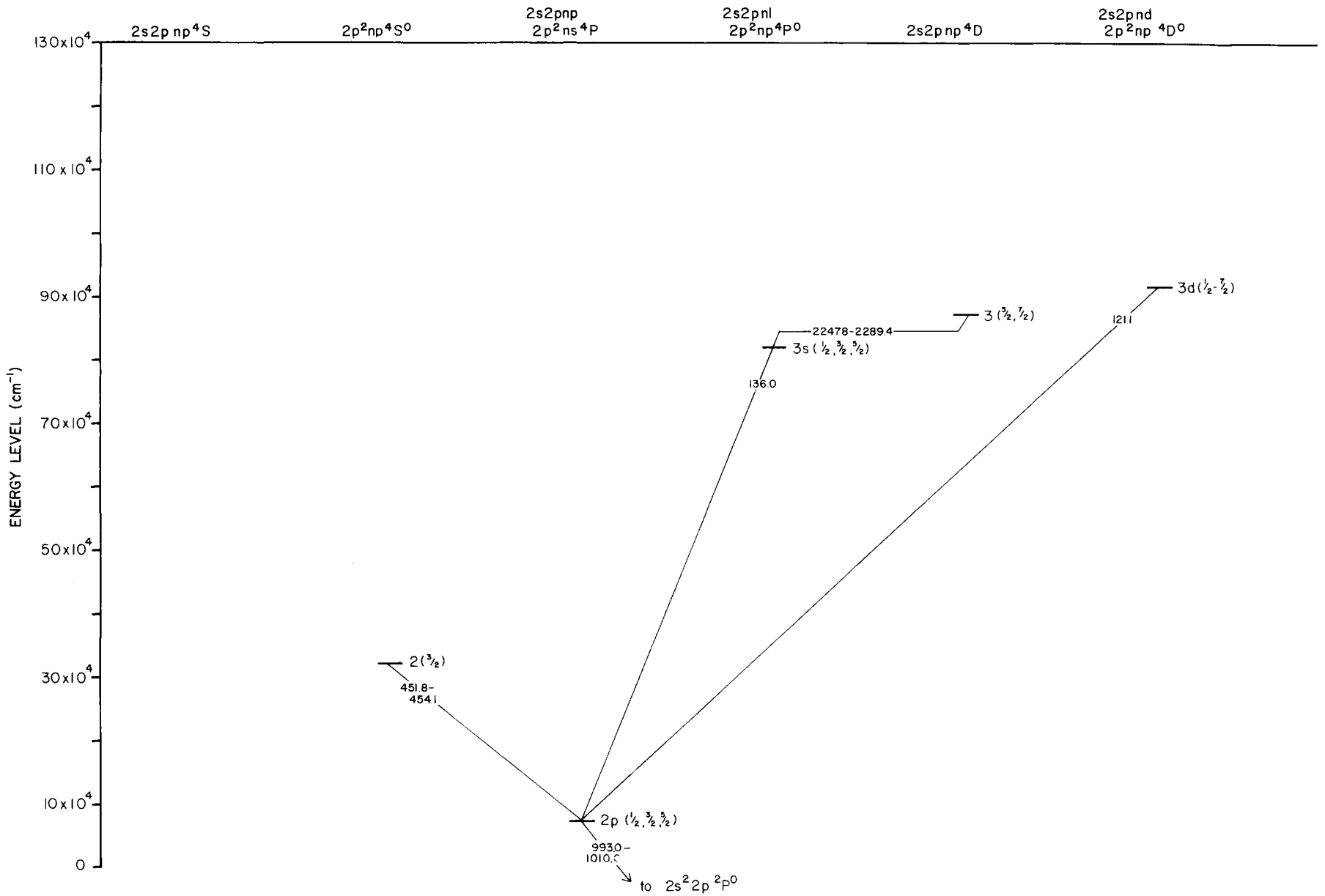
Ne VI GROTRIAN DIAGRAM (5 electrons, Z = 10)
(B I sequence, Configuration: $1s^2 2s2pnl$, $1s^2 2s^2 nl$, $1s^2 2p^2 np$, Doublet System)



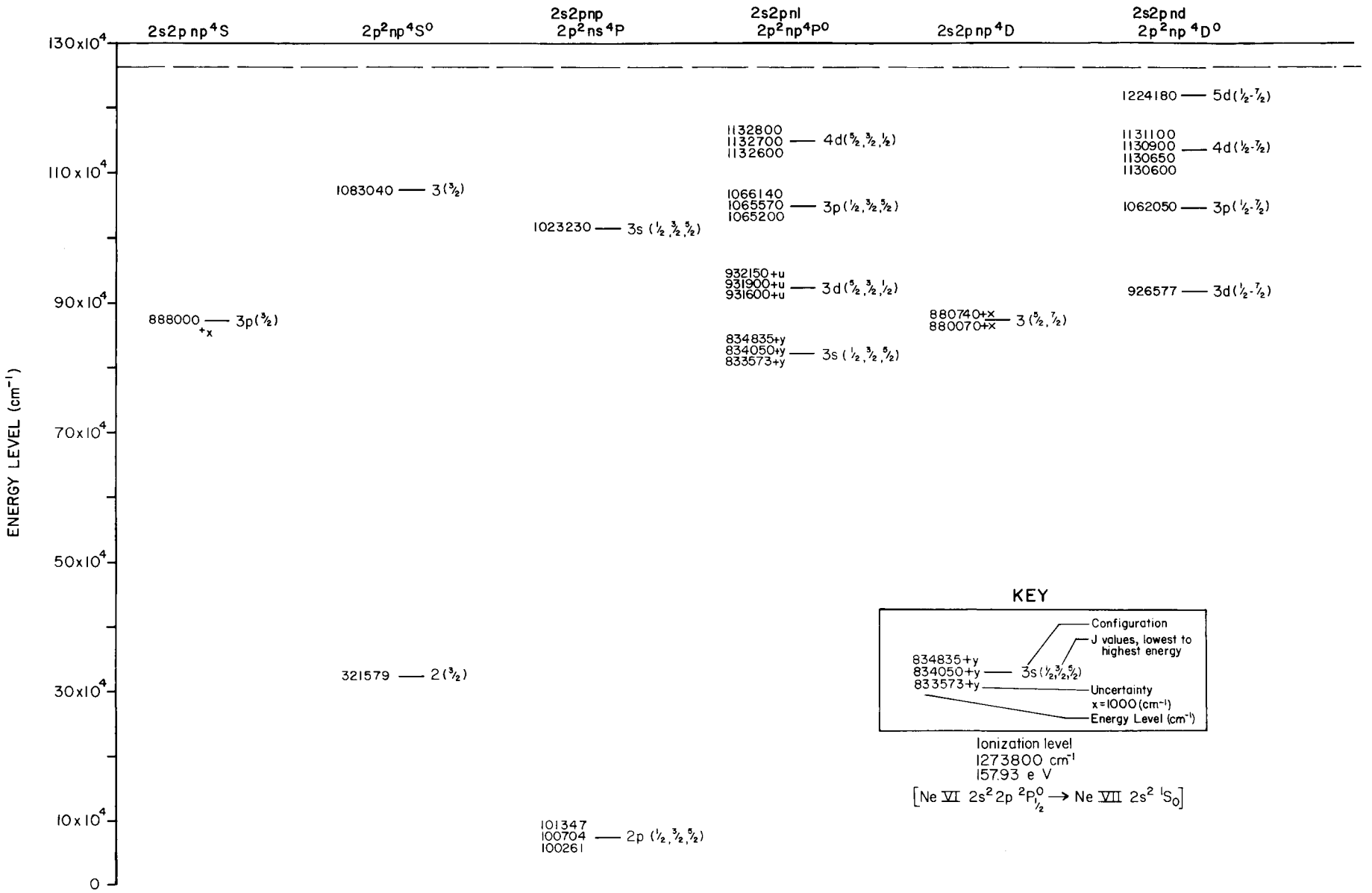
Ne VI ENERGY LEVELS (5 electrons, Z = 10)
(B I sequence, Configuration: $1s^2 2s2pnl$, $1s^2 2s^2 nl$, $1s^2 2p^2 np$, Doublet System)

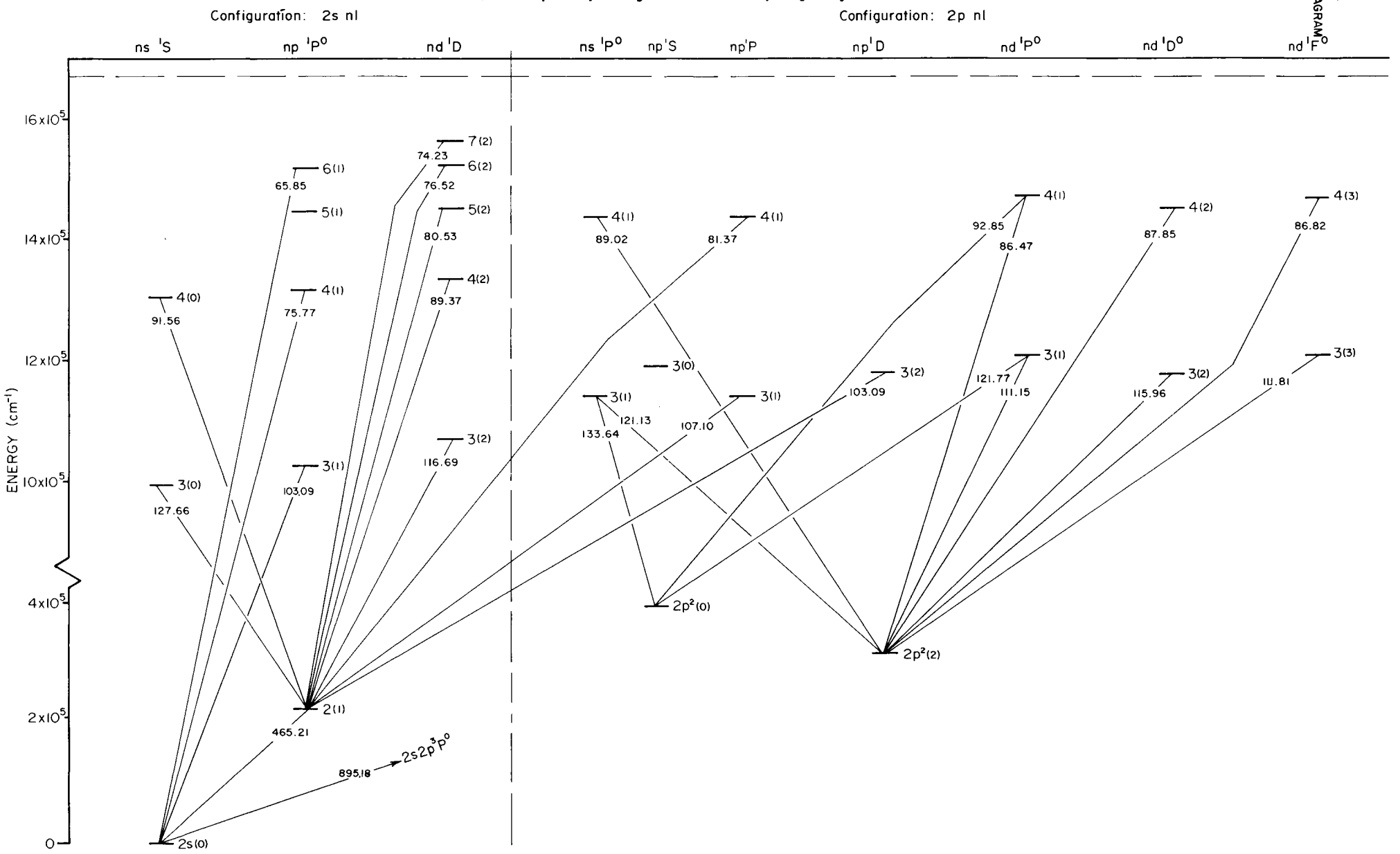


Ne VI GROTRIAN DIAGRAM (5 electrons, Z=10)
(B I Sequence Configurations: $1s^2 2s2p(^3P^o)nl$, $1s^2 2p^2(^3P)nl$, Quartet System)

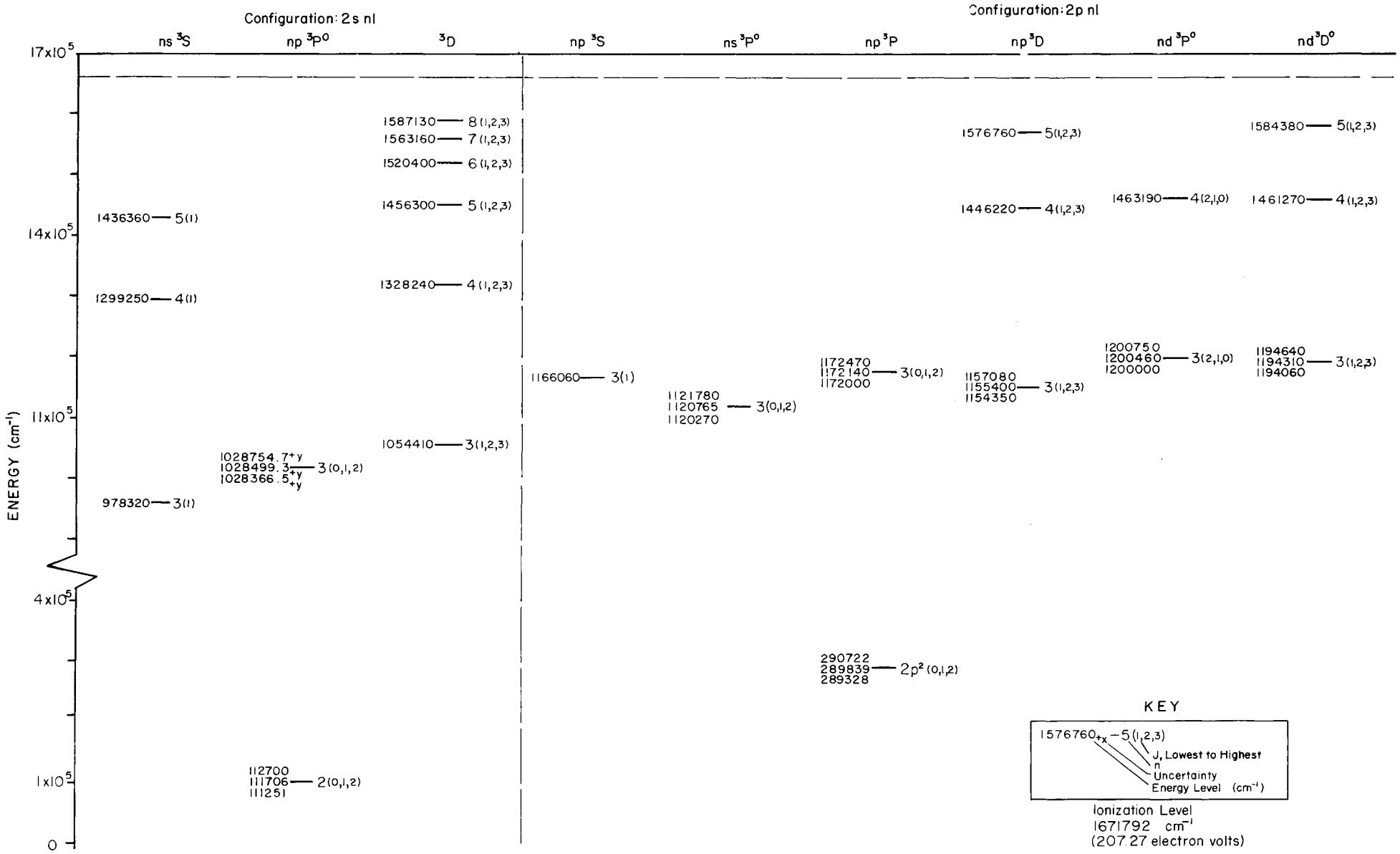


Ne VI ENERGY LEVELS (5 electrons, Z=10)
(B I Sequence Configurations: $1s^2 2s2p(^3P^o)nl$, $1s^2 2p^2(^3P)nl$, Quartet System)

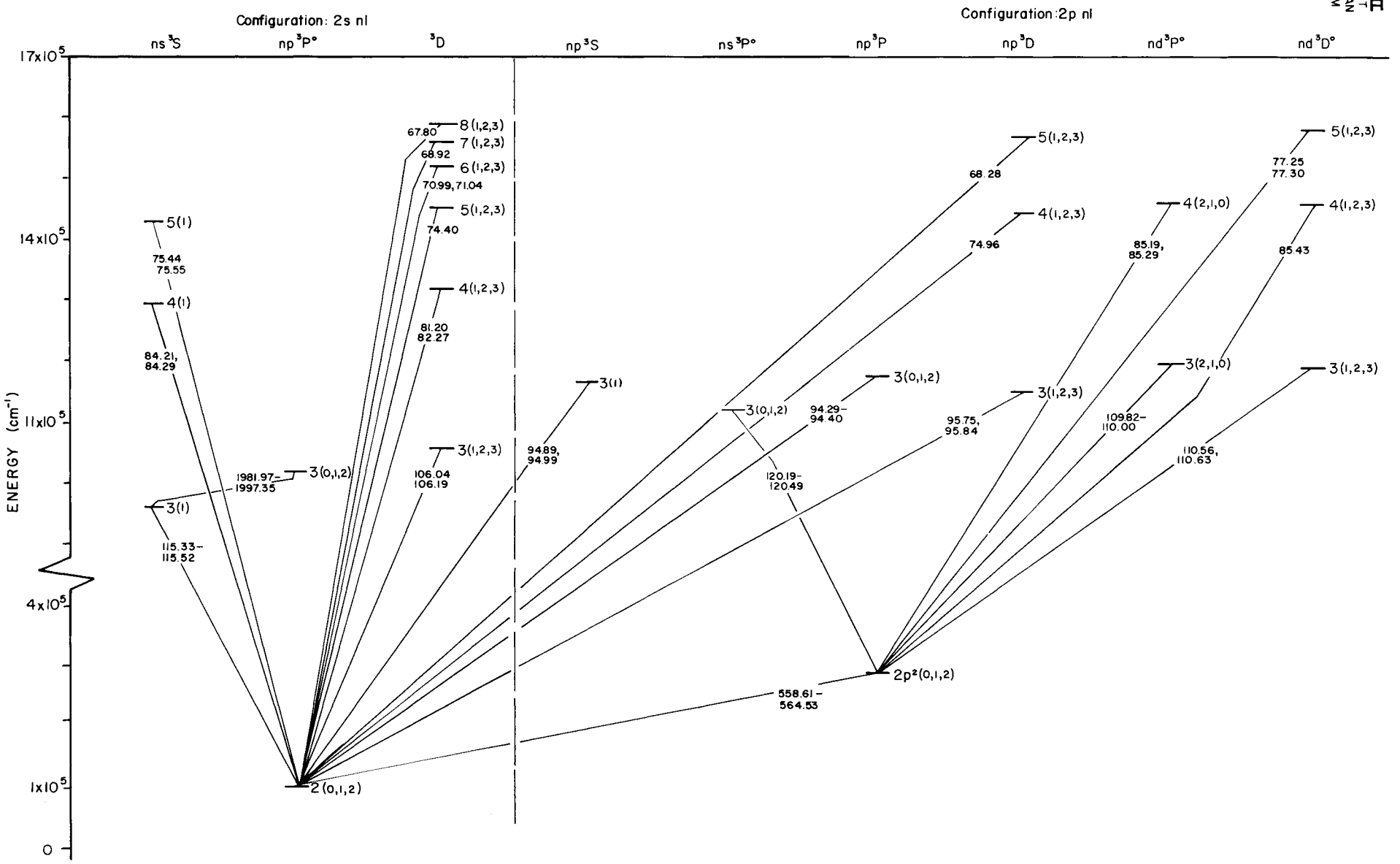



Ne VII GROTRIAN DIAGRAM (4 electrons, Z=10)
(Be I sequence, Configuration: $1s^2 nl\ n'l'$, Singlet System)
Configuration: 2s nl
Configuration: 2p nl
ns ^1S
np $^1P^o$
nd ^1D
ns $^1P^o$
np ^1S
np ^1P
np ^1D
nd $^1P^o$
nd $^1D^o$
nd $^1F^o$
ENERGY (cm^{-1})
16x10^5
14x10^5
12x10^5
10x10^5
4x10^5
2x10^5
0
2s(0)
2(1)
465.21
895.18
$2s2p^3P^o$
4(0)
91.56
3(0)
127.66
6(1)
65.85
5(1)
4(1)
75.77
3(1)
103.09
7(2)
74.23
6(2)
76.52
5(2)
80.53
4(2)
89.37
3(2)
116.69
4(1)
89.02
3(1)
133.64
121.13
3(0)
4(1)
81.37
3(1)
107.10
$2p^2(0)$
3(2)
103.09
$2p^2(2)$
4(1)
92.85
86.47
3(1)
121.77
111.15
4(2)
87.85
3(2)
115.96
4(3)
86.82
3(3)
111.81

Ne VII ENERGY LEVELS (4 electrons, Z=10)
(Be I sequence, Configuration: $1s^2\ nl\ n'l'$, Triplet System)

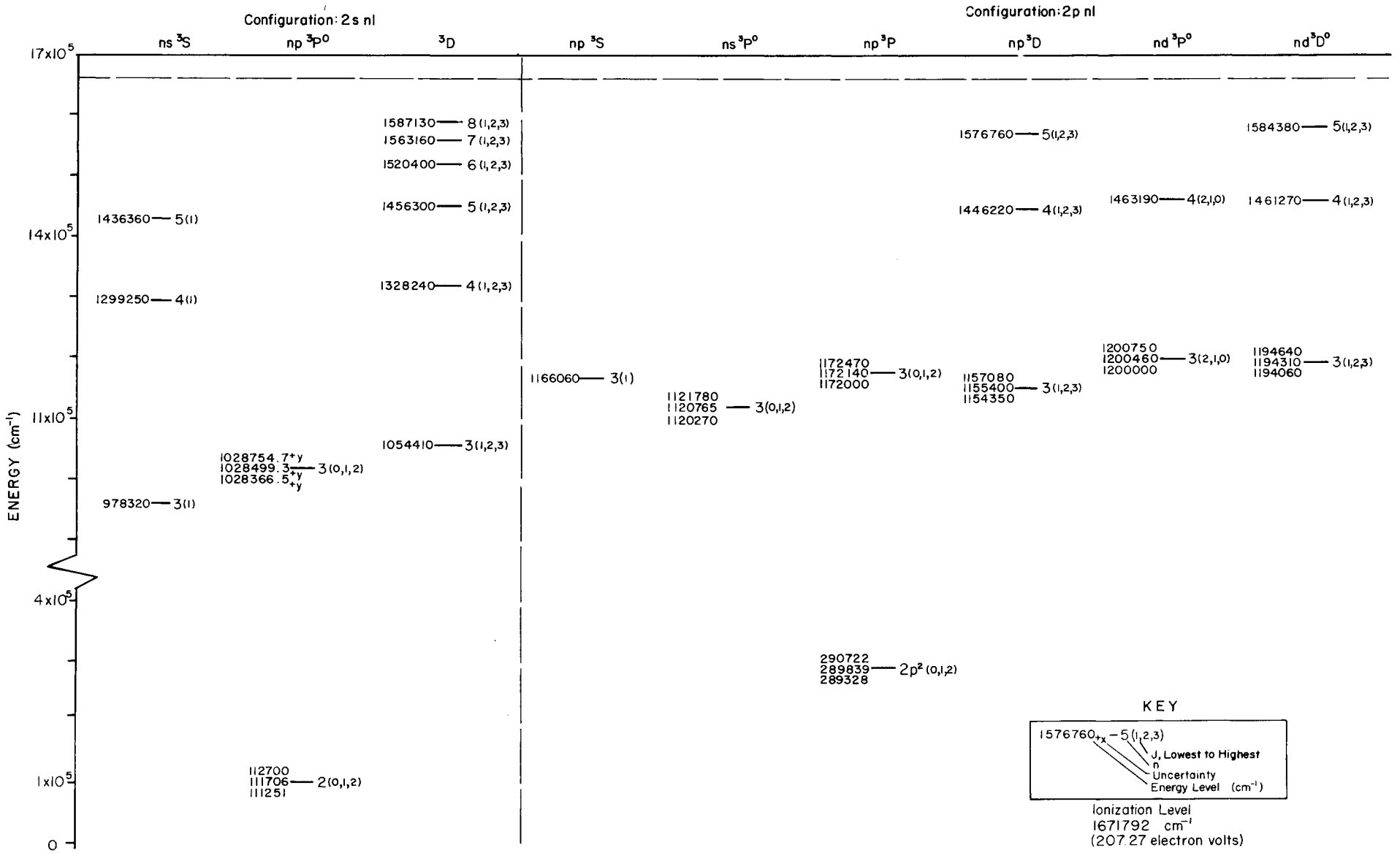


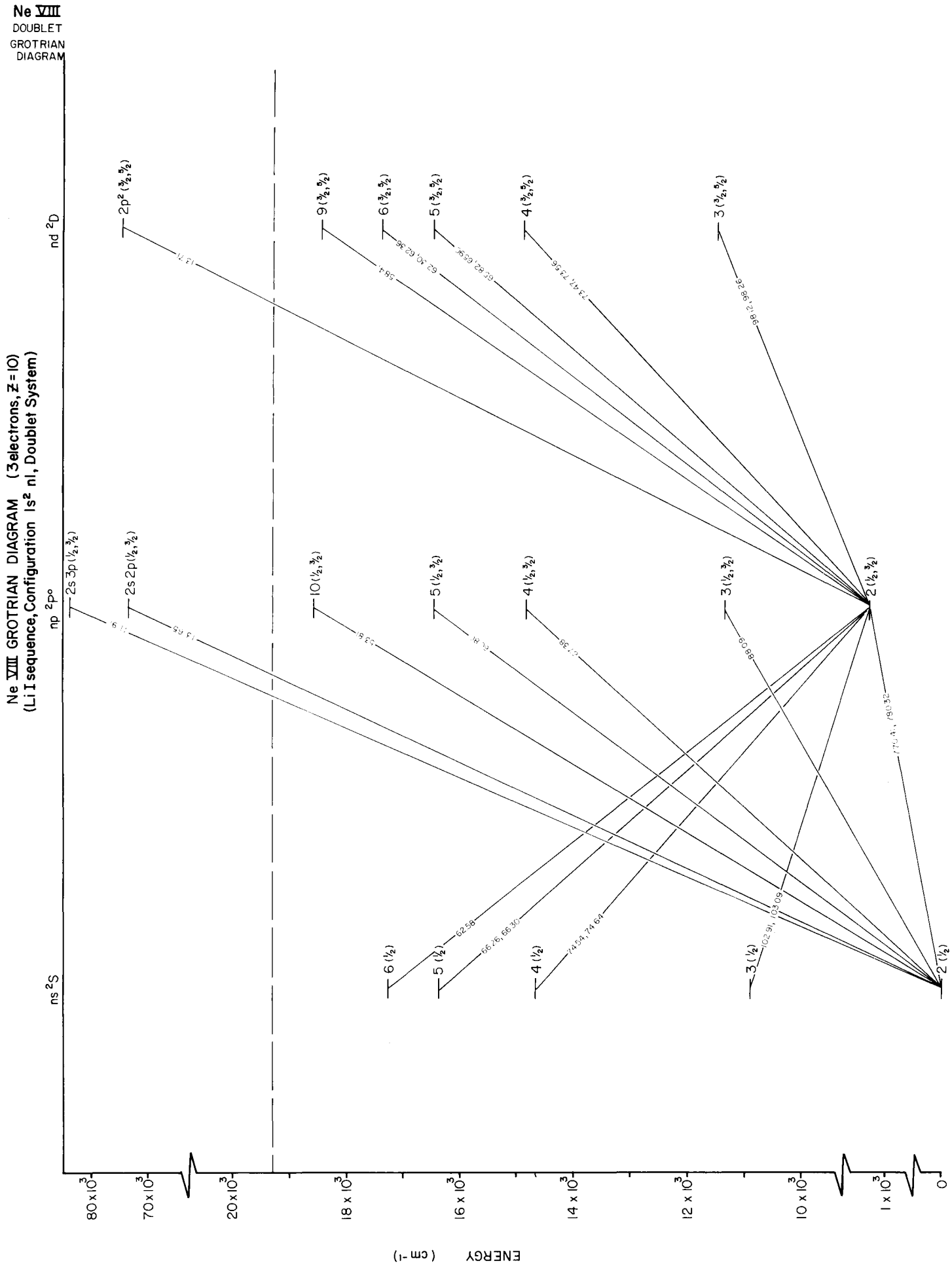
Ne VII GROTRIAN DIAGRAM (4 electrons, Z=10)
(BeI sequence, Configuration: $1s^2\,nl\,n'l'$, Triplet System)



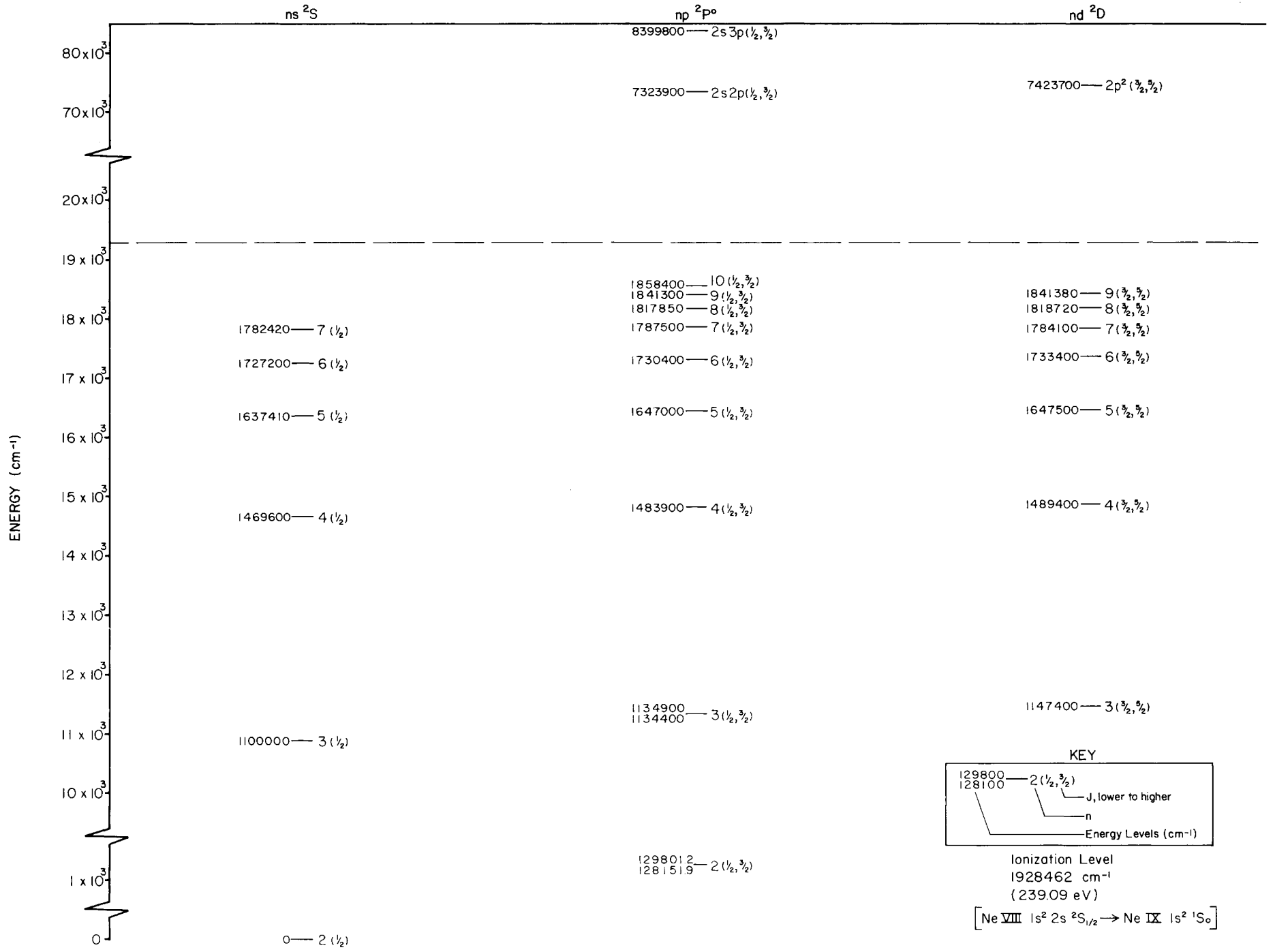
Ne VII TRIPLET GROTRIAN DIAGRAM

Ne VII ENERGY LEVELS (4 electrons, Z=10)
(Be I sequence, Configuration: $1s^2\ nl\,n'l'$, Triplet System)



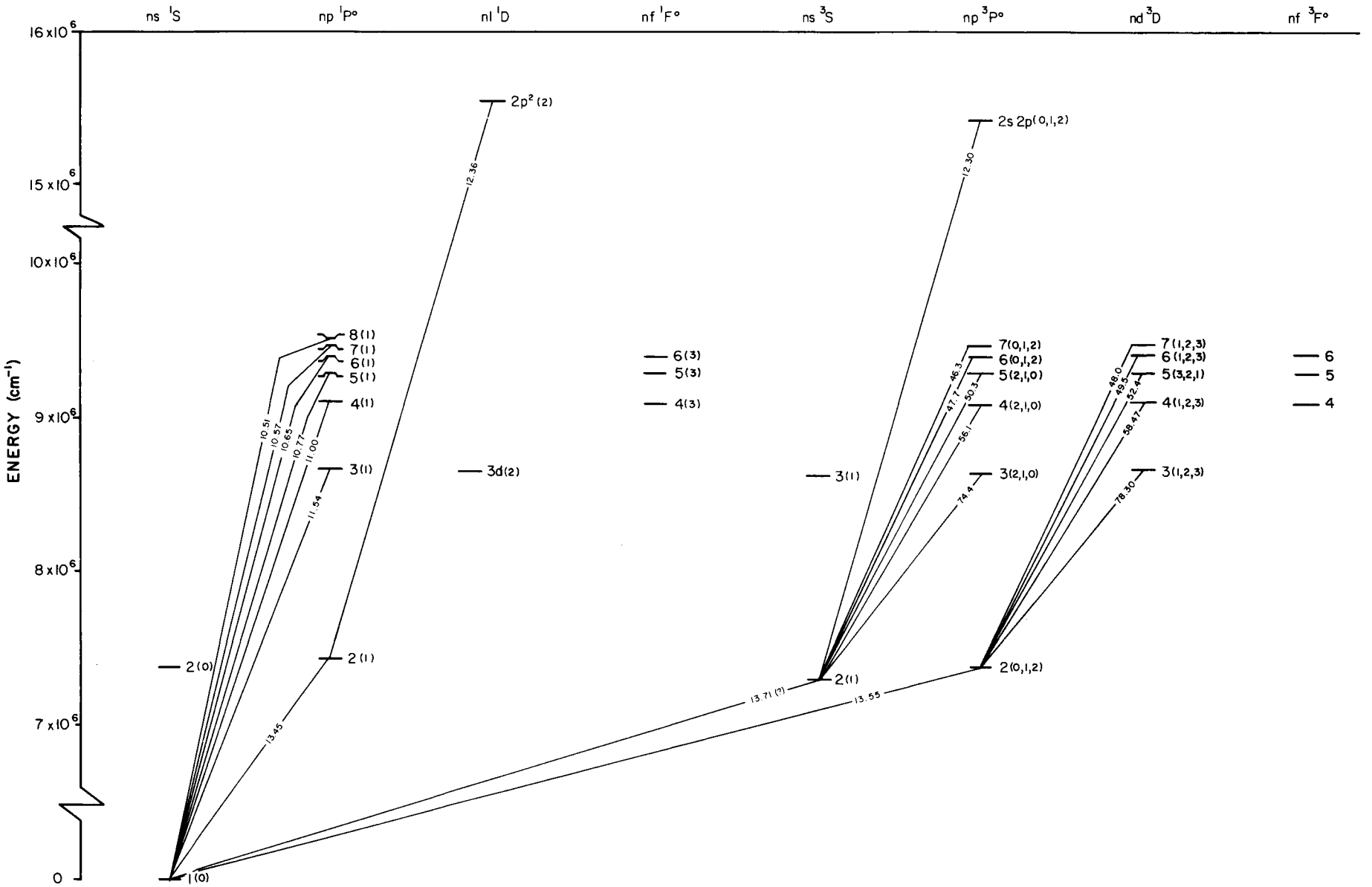

Ne VIII
DOUBLET
GROTRIAN
DIAGRAM
Ne VIII GROTRIAN DIAGRAM (3electrons, Z=10)
(Li I sequence, Configuration 1s² nl, Doublet System)
ns ²S
np ²P°
nd ²D
2p² (3/2,5/2)
2s 3p (1/2,3/2)
2s 2p (1/2,3/2)
9 (3/2,5/2)
6 (3/2,5/2)
5 (3/2,5/2)
4 (3/2,5/2)
3 (3/2,5/2)
10 (1/2,3/2)
5 (1/2,3/2)
4 (1/2,3/2)
3 (1/2,3/2)
2 (1/2,3/2)
6 (1/2)
5 (1/2)
4 (1/2)
3 (1/2)
2 (1/2)
13.71
58.41
62.30, 62.36
65.82, 65.92
73.41, 73.56
98.12, 98.26
13.9
13.66
33.81
60.81
67.38
89.09
62.58
66.26, 66.30
74.54, 74.64
102.91, 103.09
80 x 10³
70 x 10³
20 x 10³
18 x 10³
16 x 10³
14 x 10³
12 x 10³
10 x 10³
1 x 10³
0
ENERGY (cm⁻¹)

Ne VIII ENERGY LEVELS (3 electrons, Z=10)
(Li I sequence, Configuration $1s^2$ nl, Doublet System)



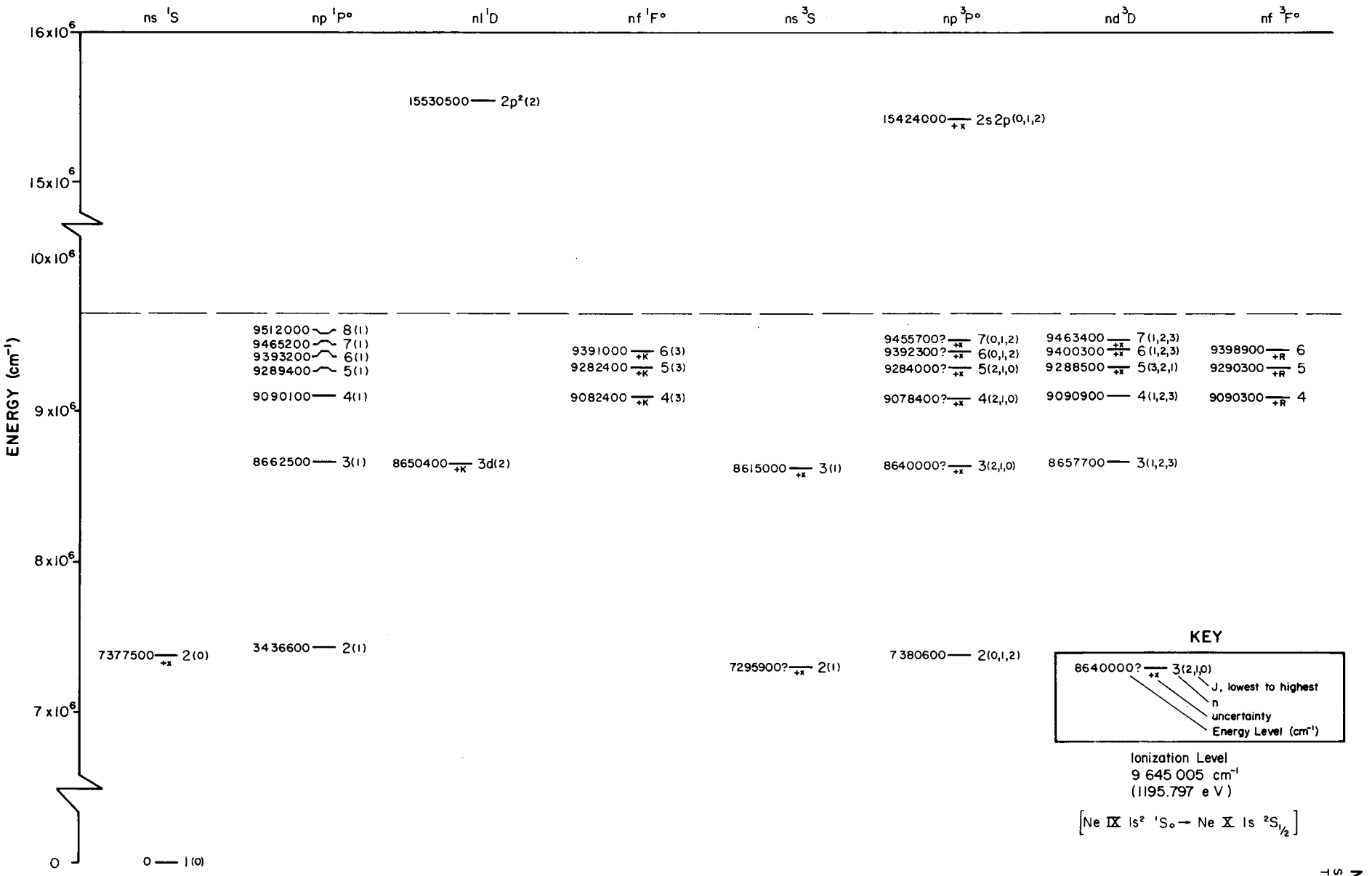
Ne IX GROTRIAN DIAGRAM (2 electrons, Z=10)

(He I sequence, Configuration: 1s nl, Singlet & Triplet Systems)

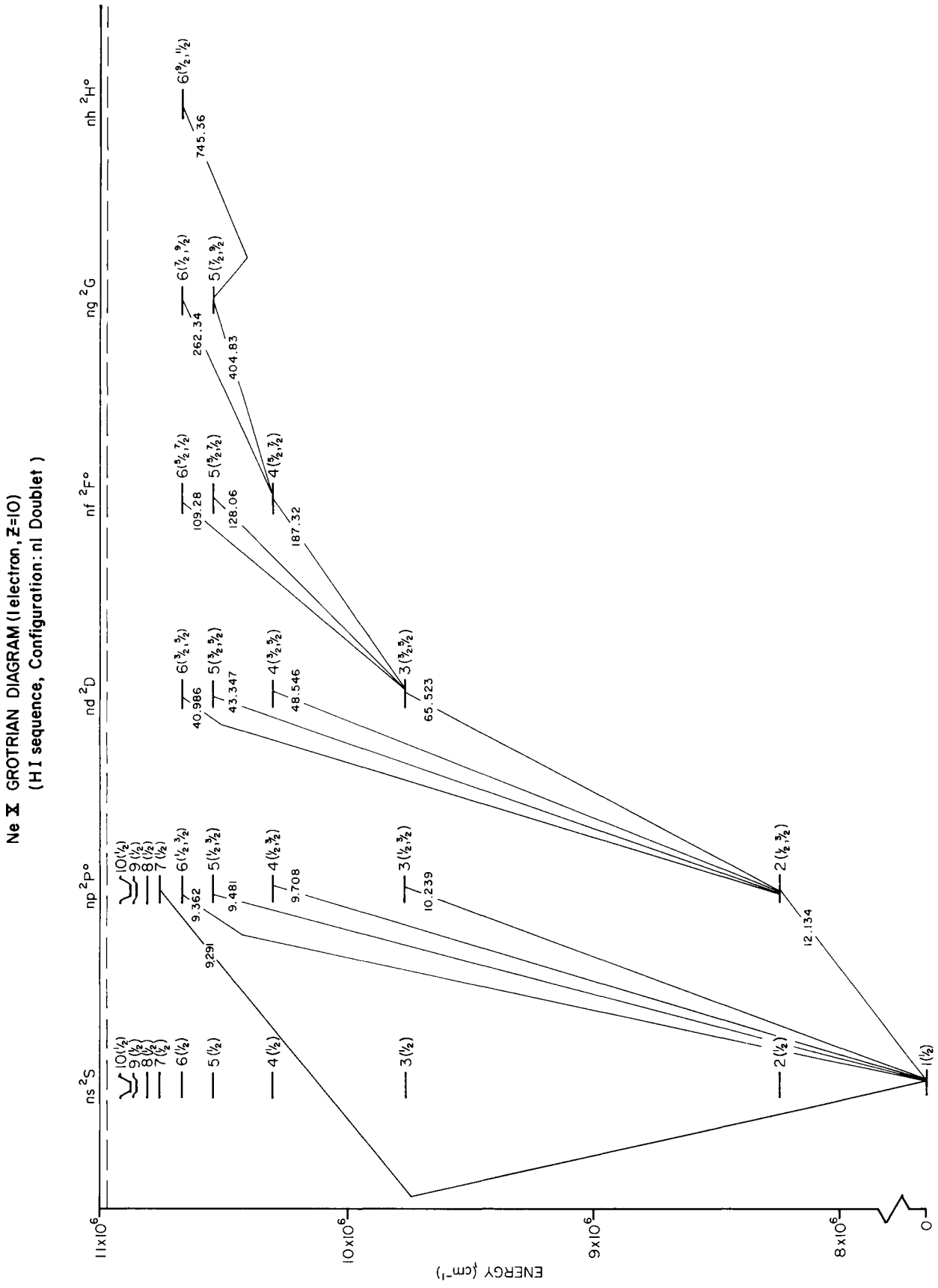


Ne IX ENERGY LEVELS (2 electrons, Z=10)

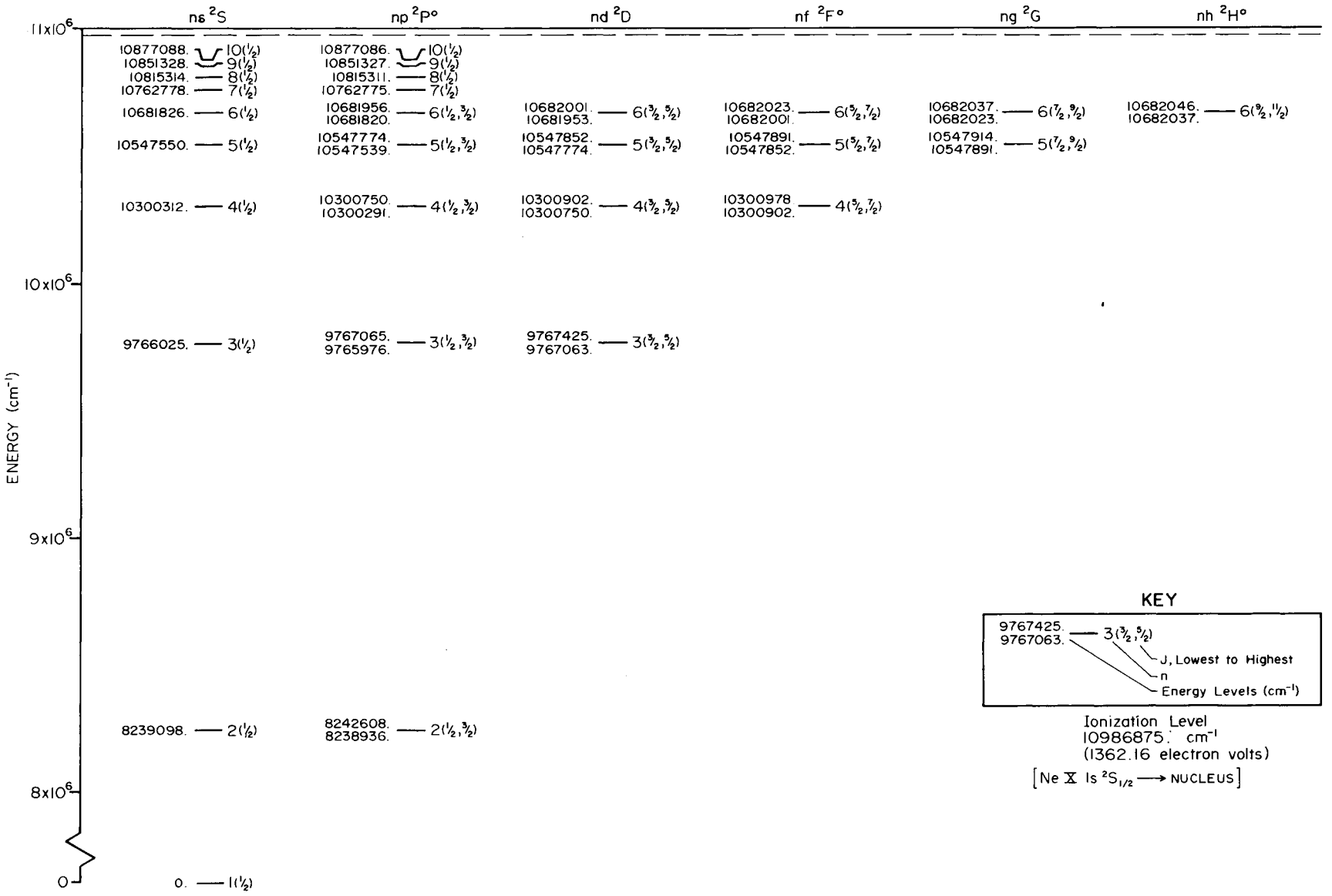
(He I sequence, Configuration: 1s nl, Singlet & Triplet Systems)



Ne X
GROTRIAN DIAGRAM
DOUBLET



Ne X ENERGY LEVELS (1 electron, Z = 10)
(H I sequence, Configuration: nl, Doublet)



Ne I $Z = 10$ 10 electrons

O. Andrade, M. Gallardo, and K. Bockasten, Appl. Phys. Letters **11**, 99 (1967).

Authors give a table of lines observed in noble-gas lasers.

K. Codling, R.P. Madden, and D.L. Ederer, Phys. Rev. **155**, 26 (1967).

Authors give a line table of resonance lines in the absorption spectrum in the range 80–570 Å.

K.G. Ericsson and L.R. Lidholt, IEEE J. Qu. Electronics **3**, 94 (1967).

Authors give wavelengths of superradiant transitions, observed and calculated.

W.L. Faust, R.A. McFarlane, C.K.N. Patel, and C.G.B. Garrett, Phys. Rev. **133A**, 1476 (1964).

Authors give a line table, a term table, and a partial Grotrian diagram based on observations in the region 20 000–350 000 Å.

C.J. Humphreys, E. Paul, Jr., R.D. Cowan, and K.L. Andrew, J. Opt. Soc. Amer. **57**, 855 (1967).

Authors give a line table and an energy level array from observations in the region 39 000–40 160 Å.

U. Litzén, Ark. Fys. **38**, 317 (1968).

Author gives a line table based on observations and an energy level table of values observed and calculated.

Not all levels are shown, but the most energetic in each column is given. The coupling scheme is taken from C.E. Moore, *Atomic Energy Levels*, N.B.S. Circular 467, Vol. 1 (1965). All spectral lines have been shown, but at the expense of dividing the Grotrian Diagram into eight parts. The information for high intermediate coupling and doubly-excited terms comes from Codling, Madden, and Ederer. Note that the origin of λ 275.64 Å is uncertain; two possible parent terms are shown, linked by a question mark. The designation, including the *j*-values, at a given level is either shown explicitly or, if not shown, is the same as that at the column heading.

Ne II $Z = 10$ 9 electrons

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give a table of lines observed and calculated in ion gas lasers.

K.G. Ericsson and L.R. Lidholt, IEEE J. Qu. Electronics **3**, 94 (1967).

Authors give wavelengths of superradiant transitions, observed and calculated.

U. Fink, S. Bashkin, and W.S. Bickel, J. Quant. Spectrosc. Radiat. Transfer **10**, 1241 (1970).

Authors give a line table of calculated and observed values in the region 3195–4515 Å.

J.E. Hansen and W. Persson, Physica Scripta **8**, 197 (1973).

Authors give $2p^4\,ns$ and $2p^4\,nd$ configurations in F I and Ne II.

K.W. Meissner, R.D. Van Veld, and P.G. Wilkinson, J. Opt. Soc. Amer. **48**, 1001 (1958).

Authors give line tables in the vacuum ultraviolet region.

W. Persson and L. Minnhagen, Ark. Fys. **37**, 273 (1967).

Authors give line tables, energy level tables, and a partial energy level diagram for lines observed in the region 10 200–2500 Å.

For intermediate-coupling terms, please see W. Persson, Physica Scripta **3**, 133 (1971).

Ne III $Z = 10$ 8 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives wavelengths from nebular observations.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give a line table from observations and calculations for ion gas lasers.

U. Fink, S. Bashkin, and W.S. Bickel, J. Quant. Spectrosc. Radiat. Transfer **10**, 1241 (1970).

Authors give a line table of calculated and observed values in the region 2590–2785 Å.

Ne IV $Z = 10$ 7 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line table of values predicted and observed in nebulae.

W.B. Bridges and A.N. Chester, IEEE J. Qu. Electronics **1**, 66 (1965).

Authors give a line table from observations and calculations for ion gas lasers.

Ne V $Z = 10$ 6 electrons

I.S. Bowen, Ap. J. **121**, 306 (1955).

Author gives wavelengths from nebular observations.

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line table based on laboratory and nebular observations.

Ne VI $Z = 10$ 5 electrons

L.J. Shamey, J. Opt. Soc. Amer. **61**, 942 (1971).

Author gives a line table and a table of calculated energy levels.

Ne VII $Z = 10$ 4 electrons

L.L. House and G.A. Sawyer, Ap. J. **139**, 775 (1964).

Authors give a line table of lines observed in the region 128–75 Å.

Ne VIII $Z = 10$ 3 electrons

L.L. House and G.A. Sawyer, Ap. J. **139**, 775 (1964).

Authors give a line table for lines observed in the region 60–104 Å.

Ne IX $Z = 10$ 2 electrons

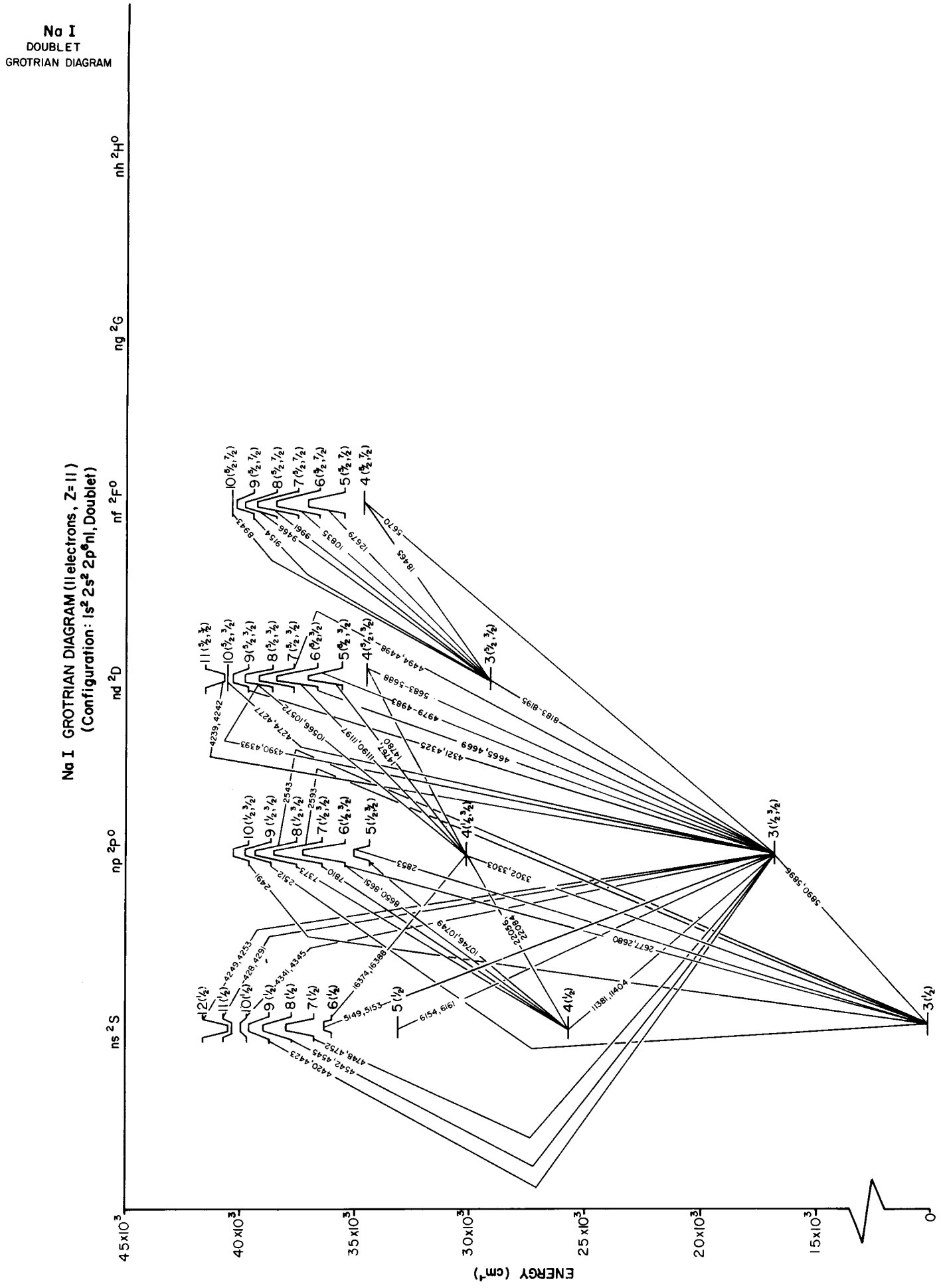
E. Holøien and J. Midtdal, J. Phys. B: Atom. Molec. Phys. **4**, 1243 (1971).

Authors calculate nonrelativistically energies for the He I isoelectronic sequence.

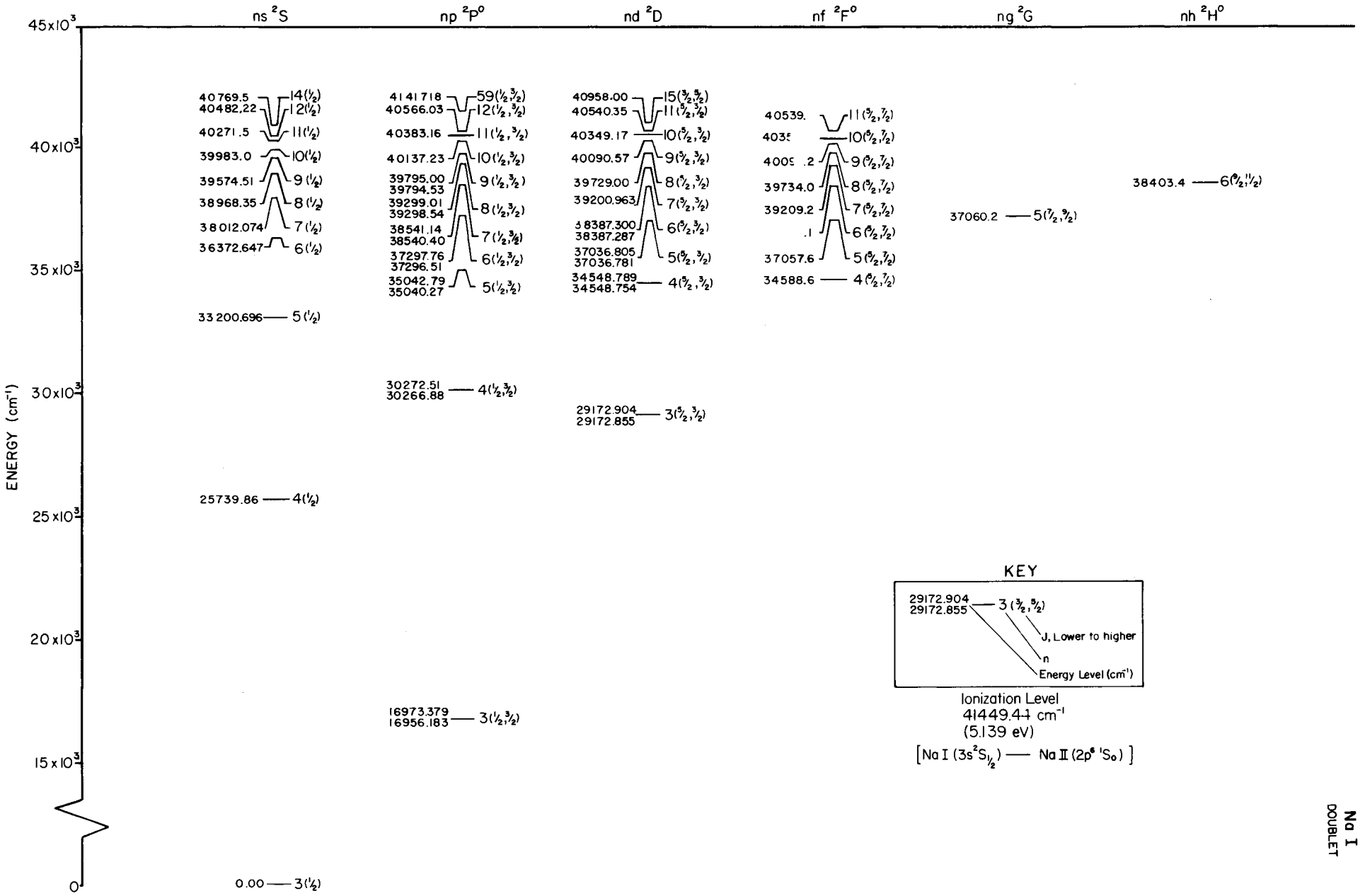
Ne X $Z = 10$ 1 electron

Please see the general references.

Sodium (Na)

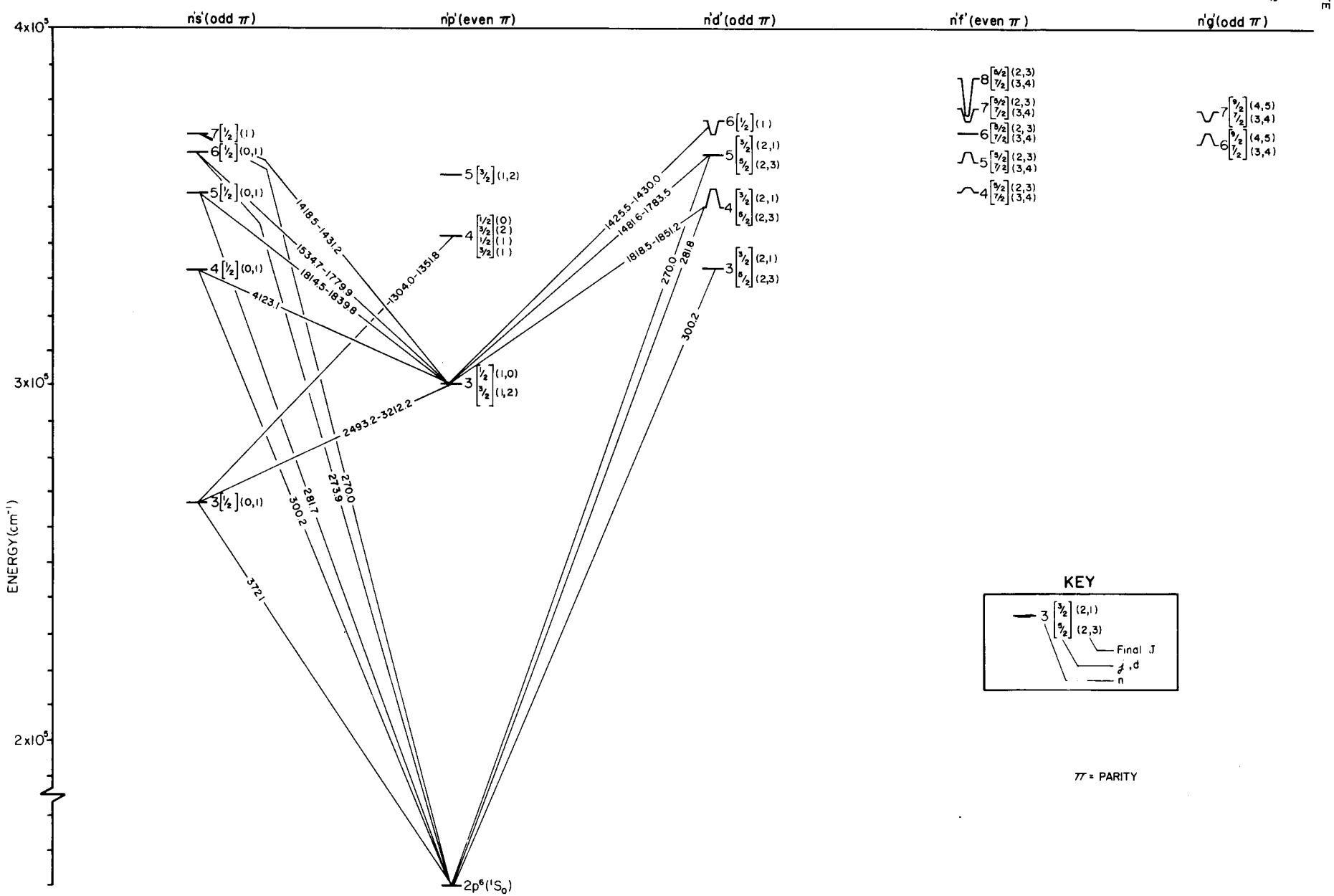

Na I
DOUBLET
GROTRIAN DIAGRAM
Na I GROTRIAN DIAGRAM (11 electrons, Z=11)
(Configuration: 1s² 2s² 2p⁶nl, Doublet)
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
ENERGY (cm⁻¹)
45x10³
40x10³
35x10³
30x10³
25x10³
20x10³
15x10³
0

Na I ENERGY LEVELS (11 electrons, Z = 11)
(Configuration: $1s^2\ 2s^2\ 2p^6\ nl$, Doublet)



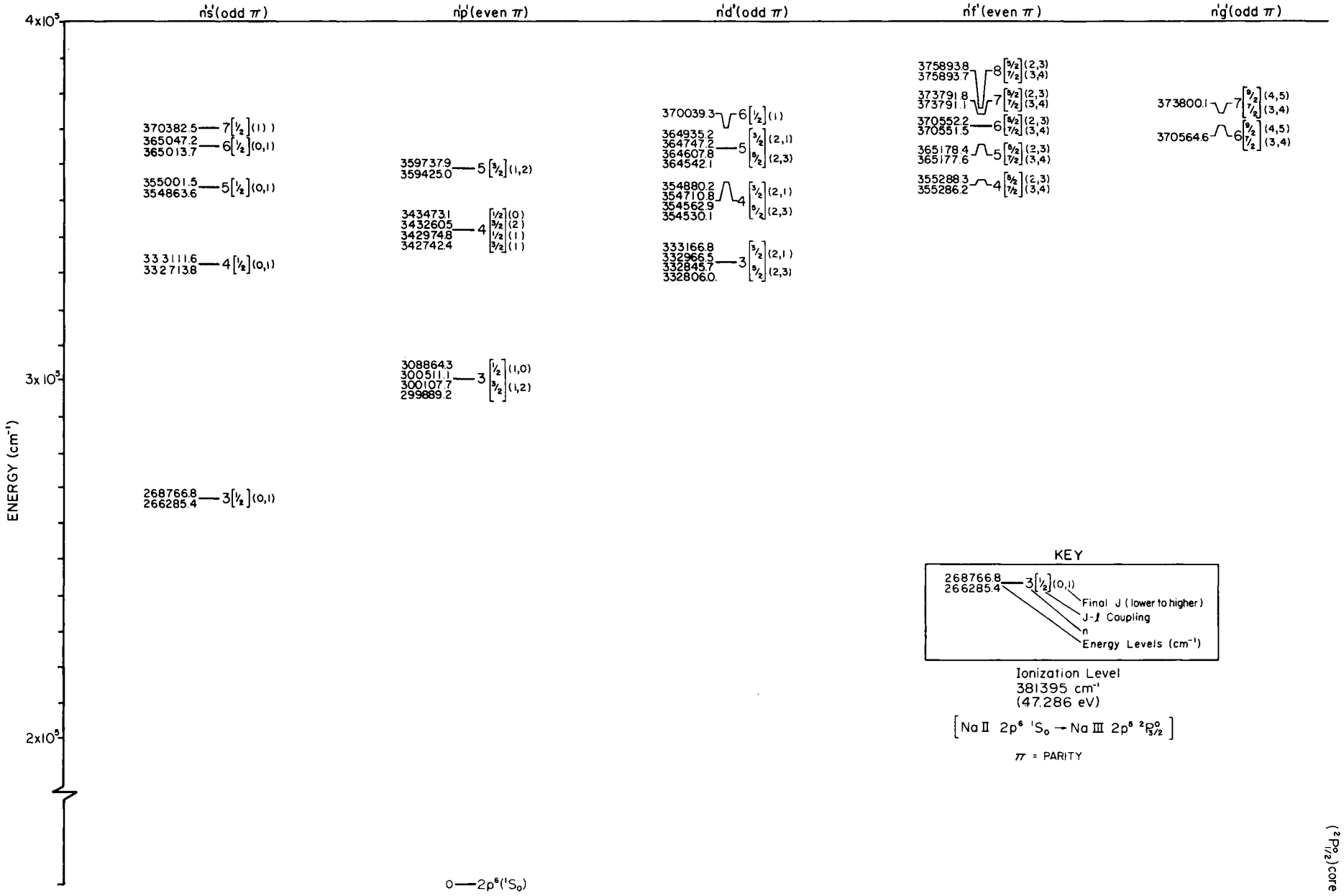
Na II
INTERMEDIATE COUPLING GROTRIAN DIAGRAM ($^2P^o_{1/2}$) core

Na II GROTRIAN DIAGRAM (10 electrons, Z=11)
(Ne I sequence, Configuration: $1s^2\ 2s^2\ 2p^5(^2P^o_{1/2})nl$, Intermediate Coupling)



Na II ENERGY LEVELS (10 electrons, Z = 11)

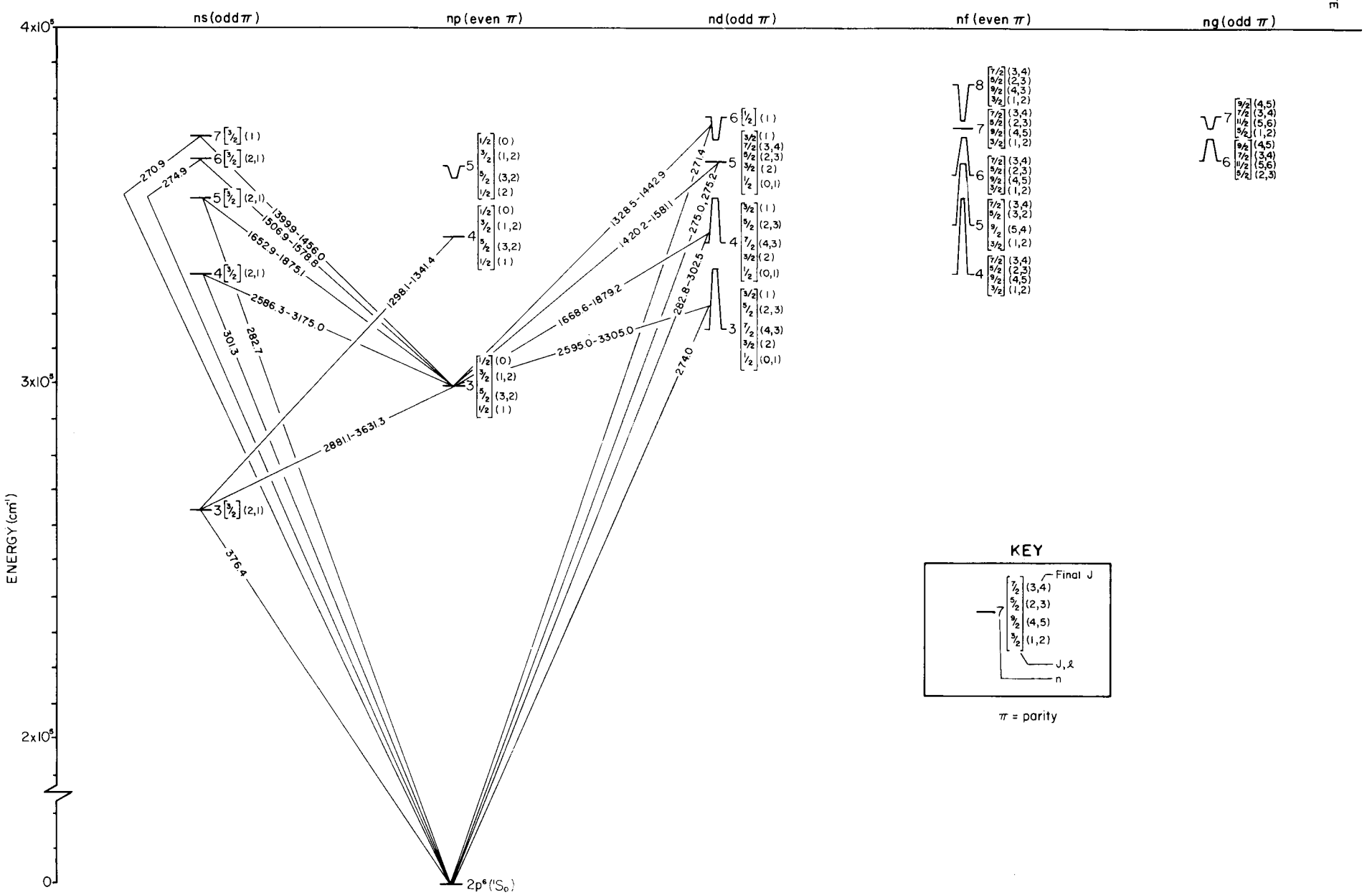
(Ne I sequence, Configuration: $1s^2\,2s^2\,2p^6(^2P^o_{1/2})\,nl$, Intermediate Coupling)



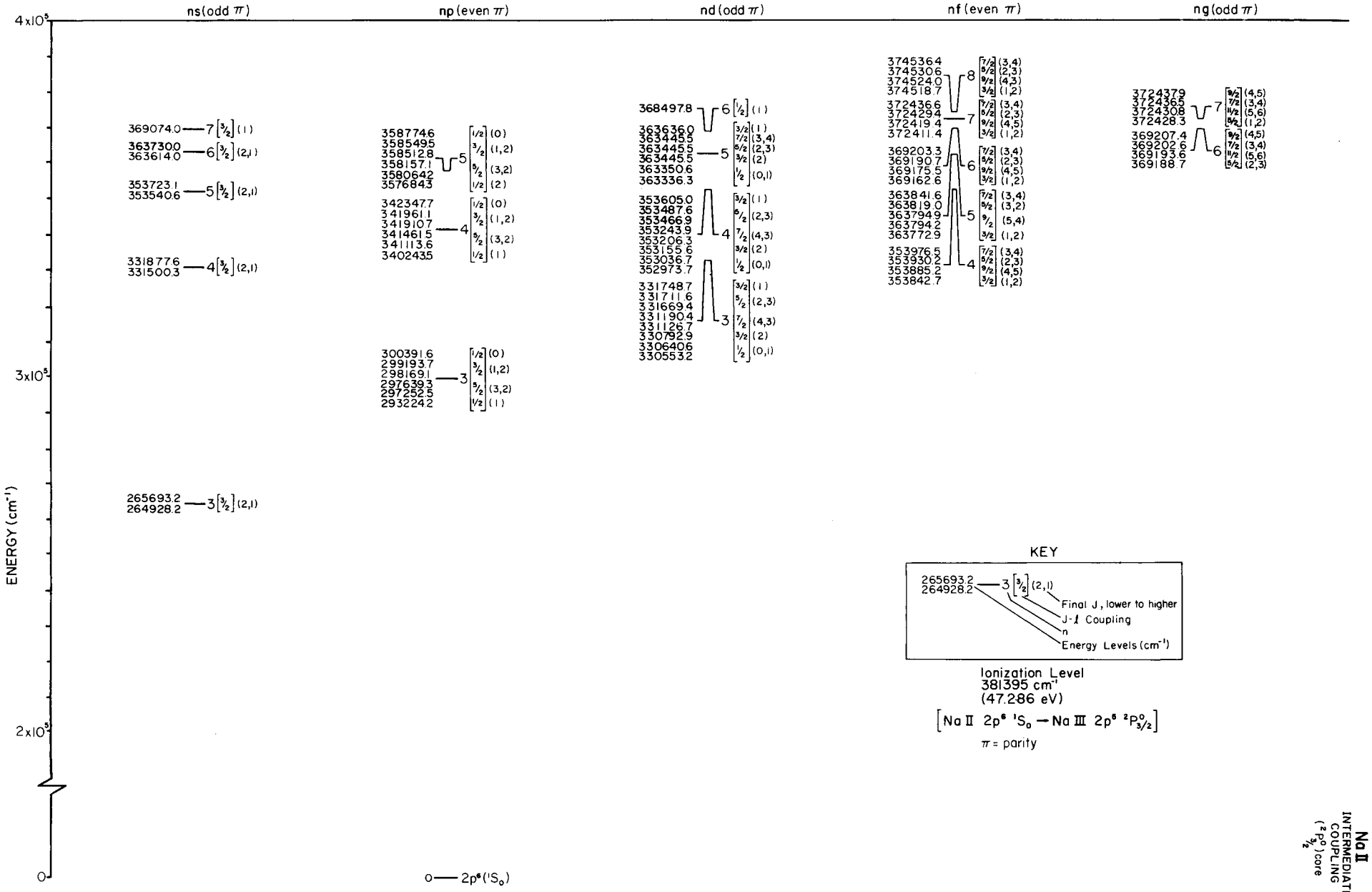
Na II
INTERMEDIATE COUPLING
($^2P^o_{1/2}$) core

Na II
INTERMEDIATE COUPLING GROTRIAN DIAGRAM
($^2P^o_{3/2}$) core

Na II GROTRIAN DIAGRAM (10 electrons, Z=11)
(Ne I sequence, Configuration: $1s^2 2s^2 2p^5 (^2P^o_{3/2})$ nl, Intermediate Coupling)



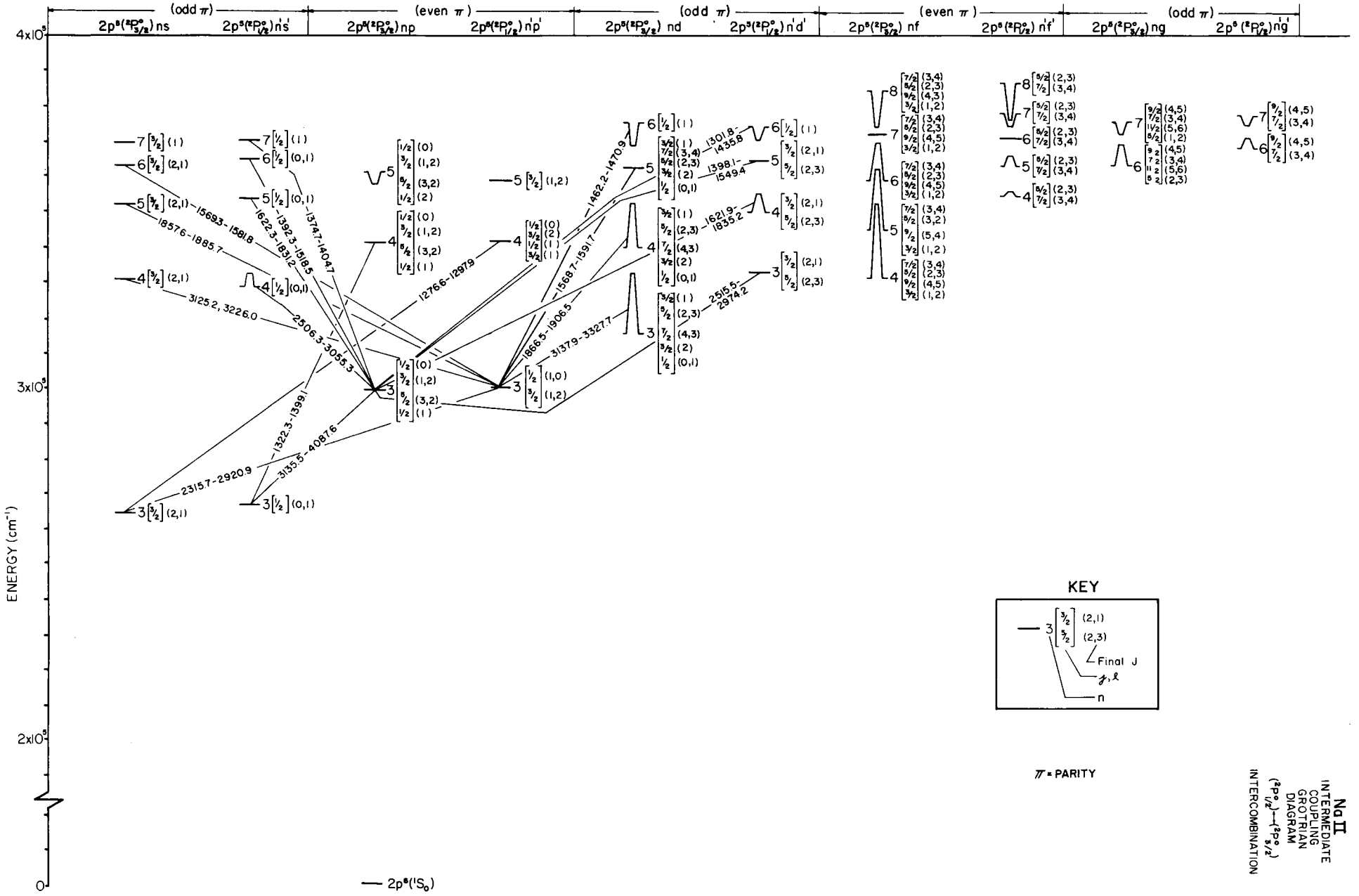
Na II ENERGY LEVELS (10 electrons, Z=11)
(Ne I sequence, Configuration: $1s^2 2s^2 2p^6 (^2P^o_{3/2})$ nl, Intermediate Coupling)



Na II
INTERMEDIATE COUPLING
$(^2P^o_{3/2})$ core

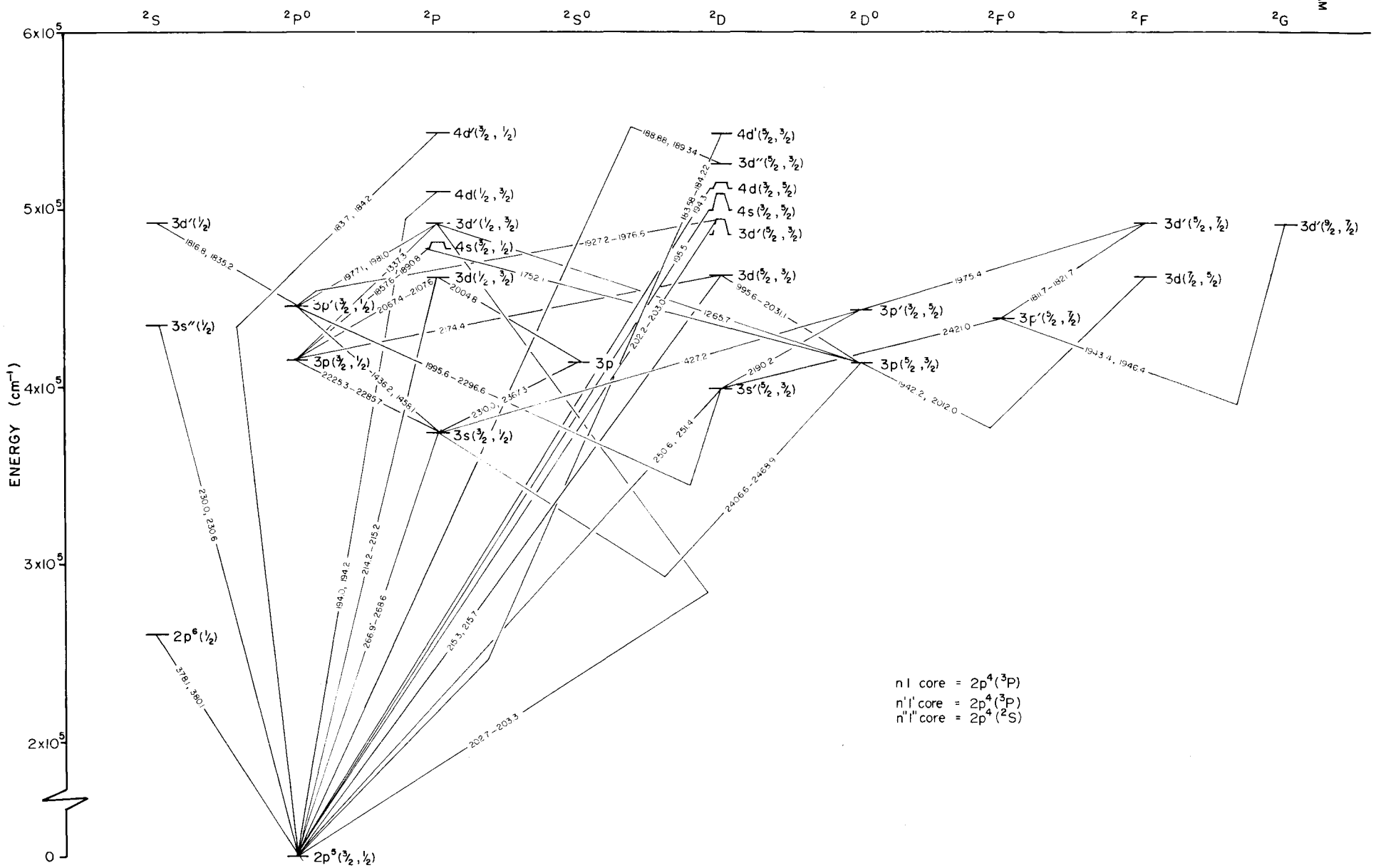
Na II GROTRIAN DIAGRAM (10 electrons, Z=11)

(Ne I sequence, Configuration: $1s^2 2s^2 2p^5 nl$, Intermediate Coupling), Intercombinations: $(^2P^o_{1/2})$ core to $(^2P^o_{3/2})$ core



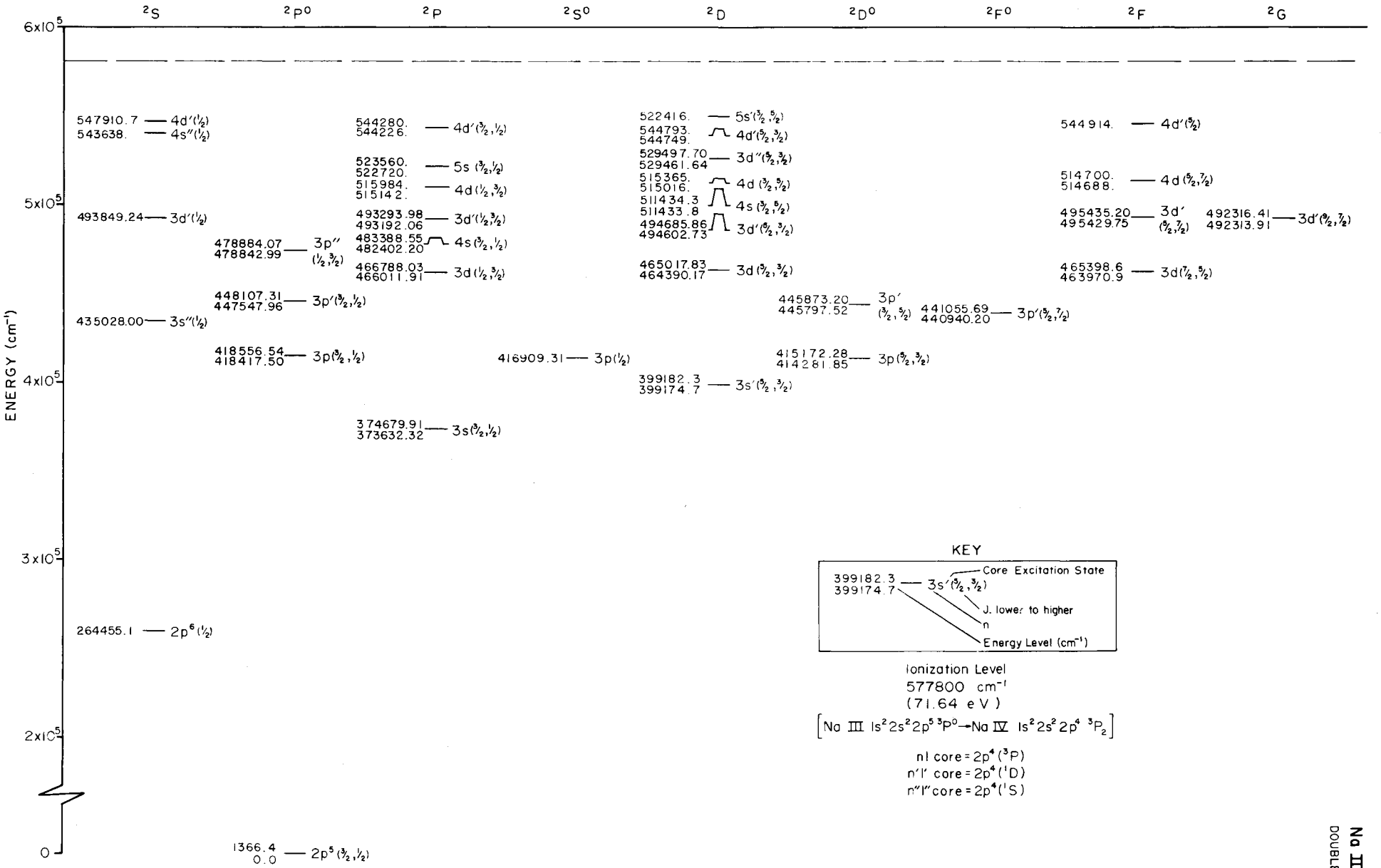
Na II INTERMEDIATE COUPLING GROTRIAN DIAGRAM $(^2P^o_{1/2})$—$(^2P^o_{3/2})$ INTERCOMBINATION

Na III GROTRIAN DIAGRAM (9 electrons, Z = 11)
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Doublet System)

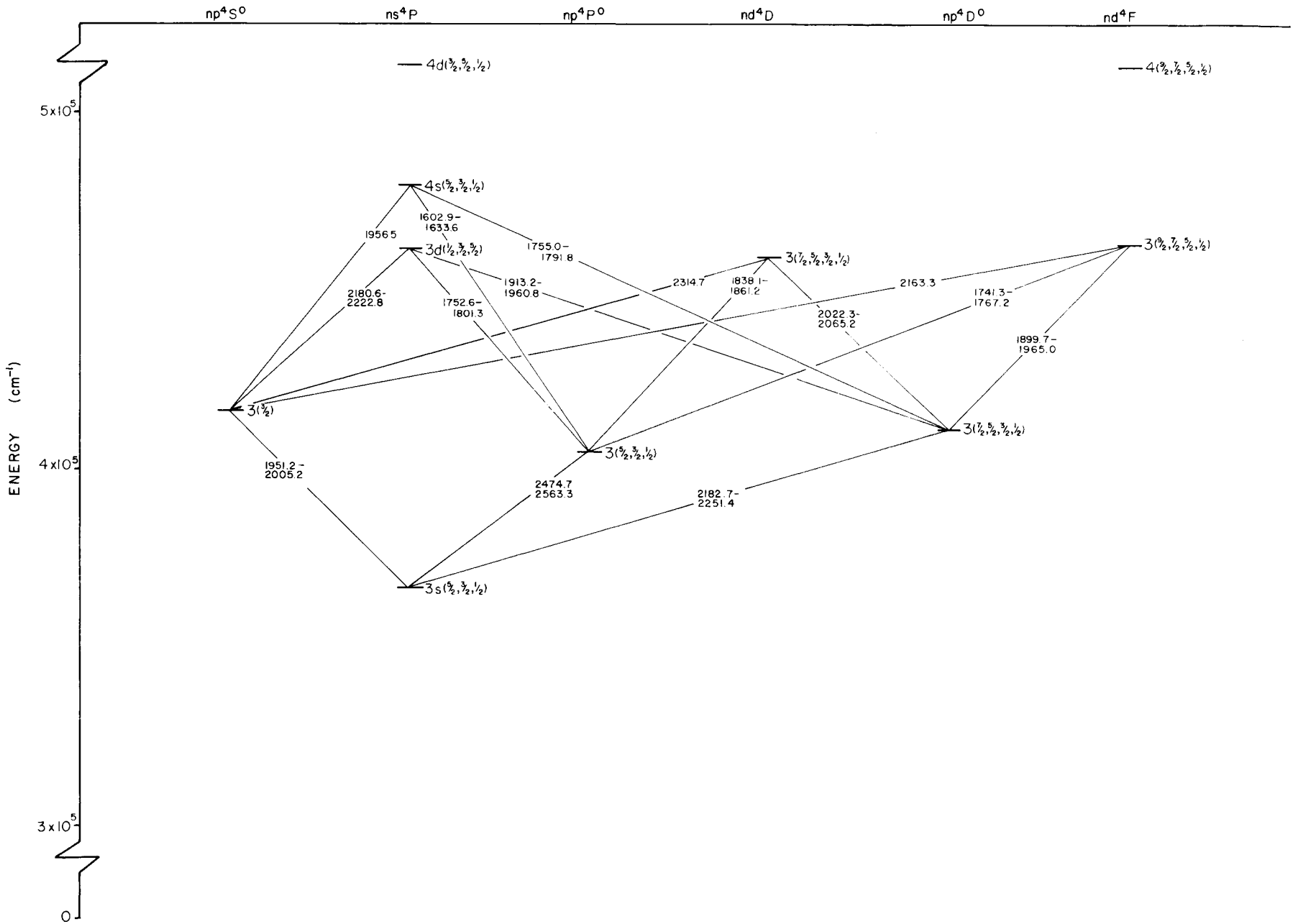


Na III ENERGY LEVELS (9 electrons, Z = 11)

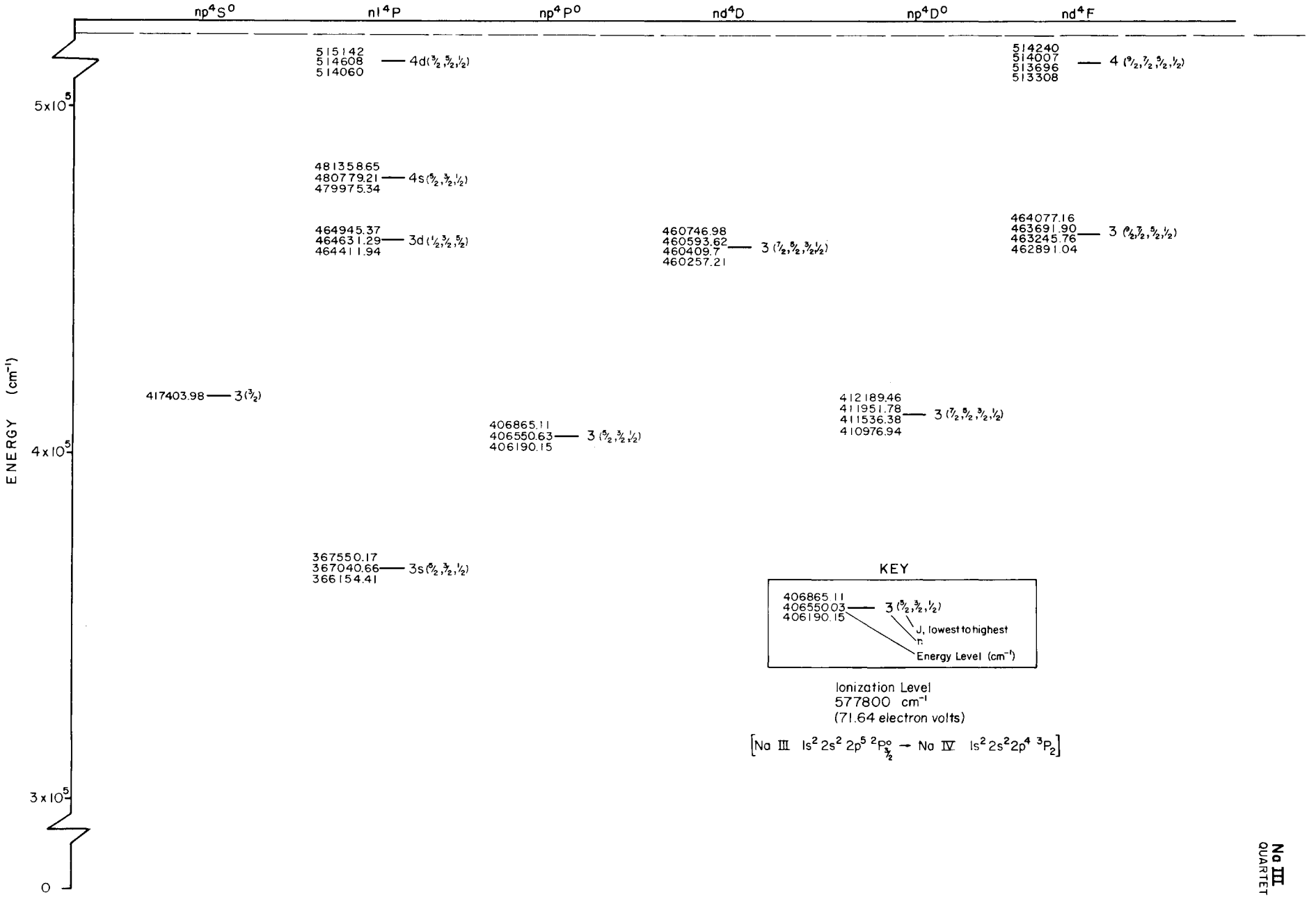
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Doublet System)



Na III GROTRIAN DIAGRAM (9 electrons, Z= 11)
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)



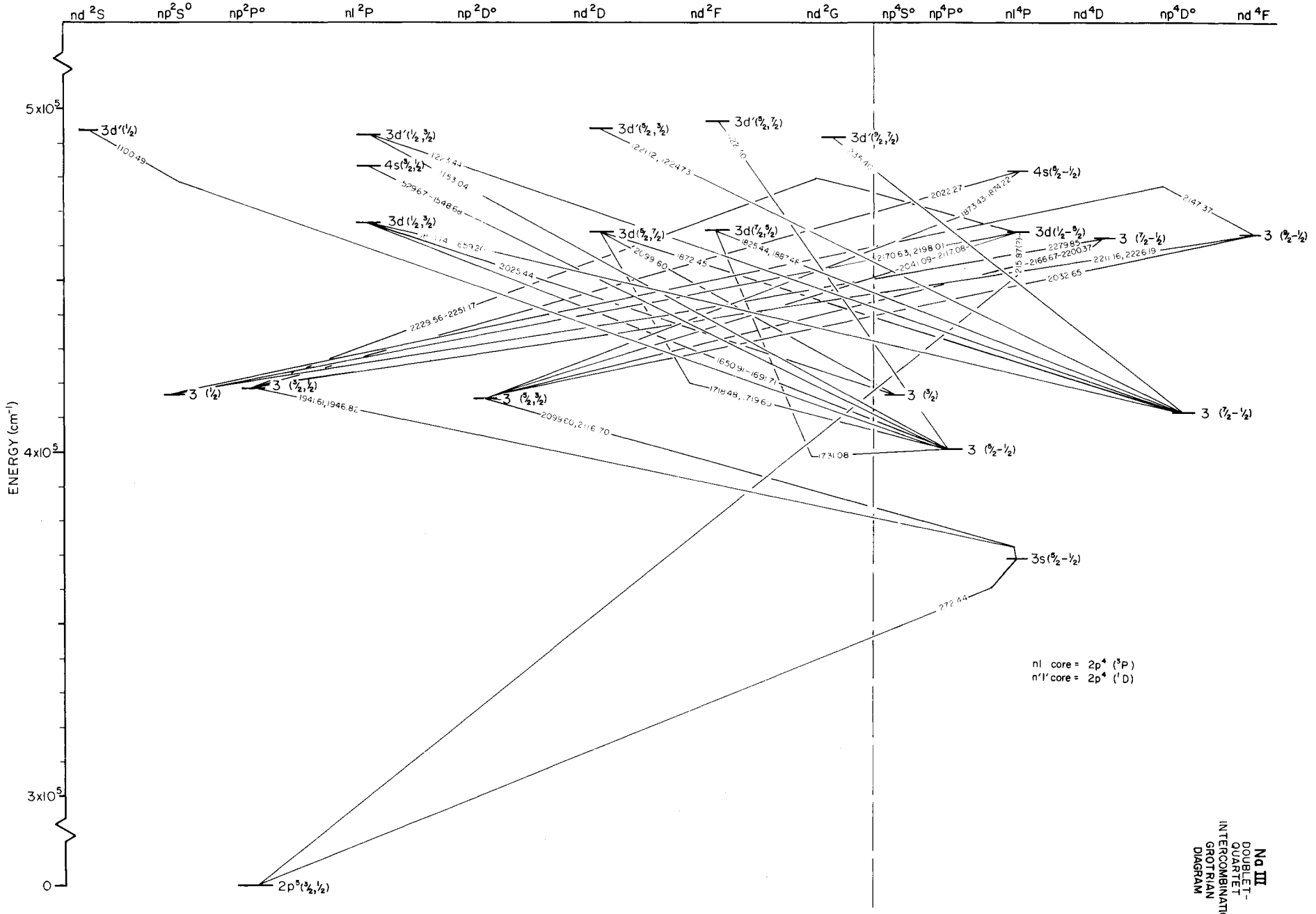
Na III ENERGY LEVELS (9 electrons, Z = 11)
(F I sequence, Configuration: $1s^2 2s^2 2p^4 nl$, Quartet System)



Ionization Level
577800 cm^{-1}
(71.64 electron volts)

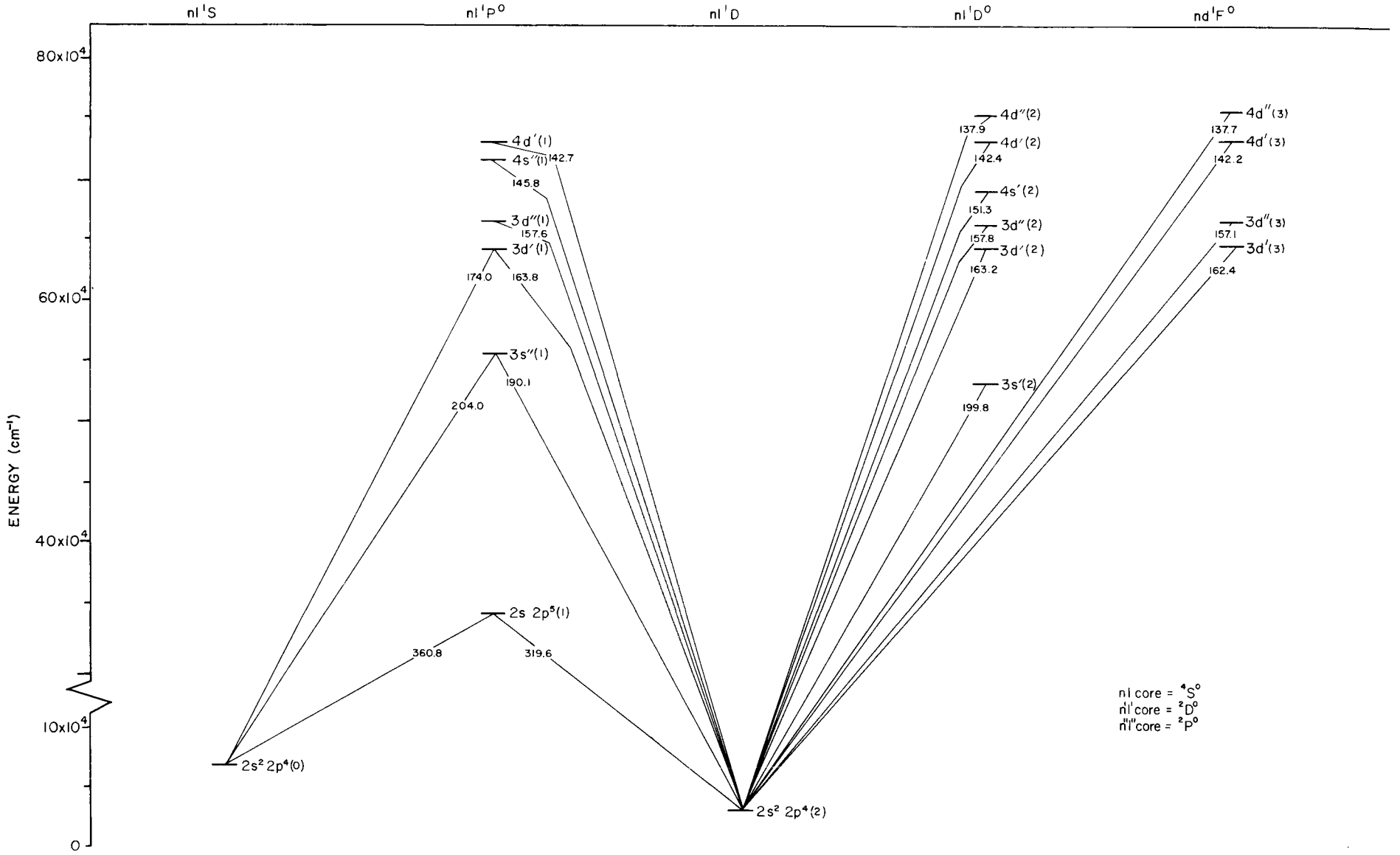
$[\text{Na III } 1s^2 2s^2 2p^5\ {}^2P^o_{3/2} \rightarrow \text{Na IV } 1s^2 2s^2 2p^4\ {}^3P_2]$

Na III INTERCOMBINATION GROTRIAN DIAGRAM (9 electrons, Z = 11)
(F I sequence, Configuration: $1s^2 2s^2 2p^4$ nl, Doublet-Quartet System)

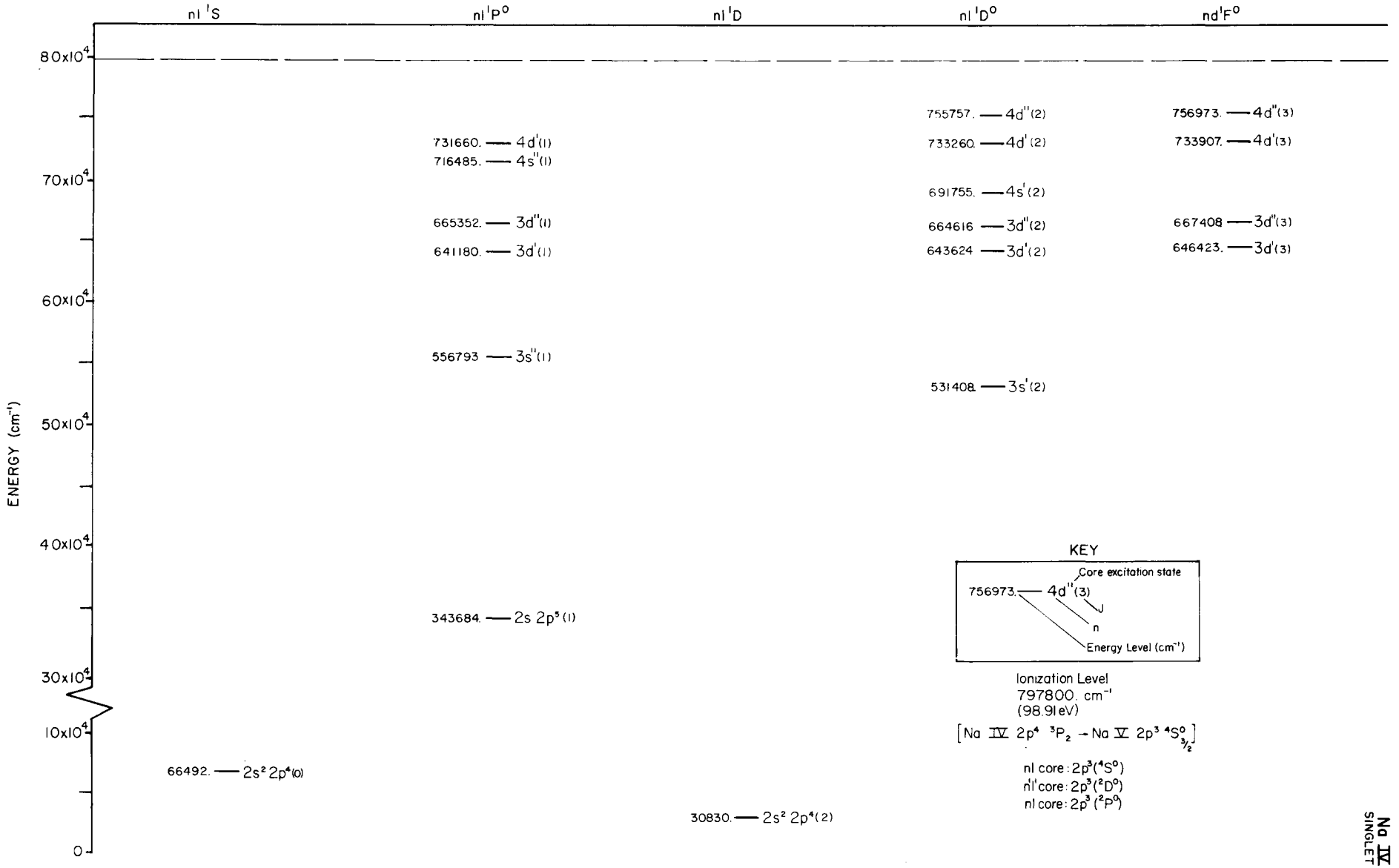


Na III
DOUBLET-
QUARTET
INTERCOMBINATION
GROTRIAN
DIAGRAM

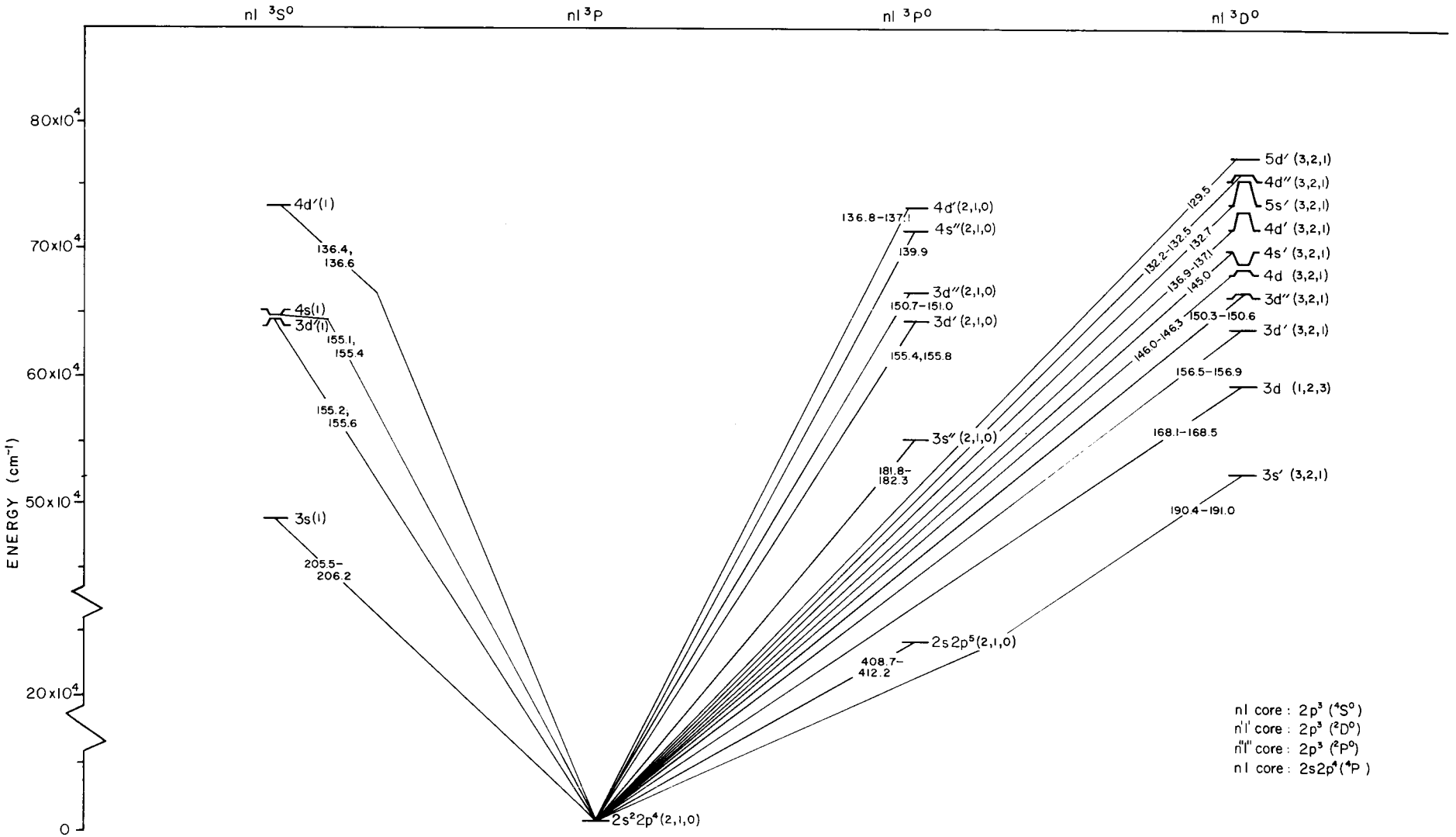
Na IV GROTRIAN DIAGRAM (8 electrons, Z = 11)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Singlet System)



Na IV ENERGY LEVELS (8 electrons, Z = 11)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Singlet System)

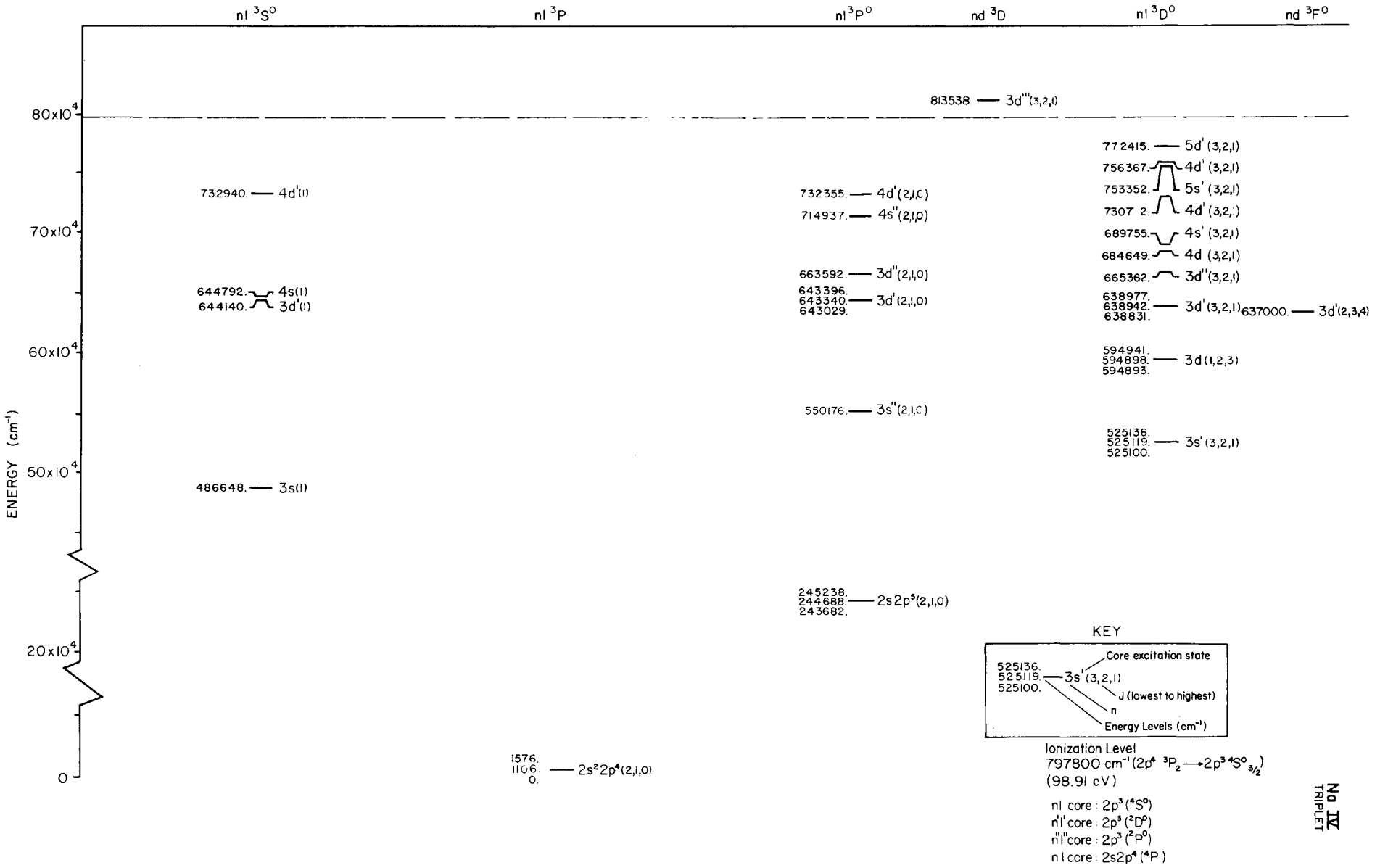


Na IV GROTRIAN DIAGRAM (8 electrons, Z=11)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)



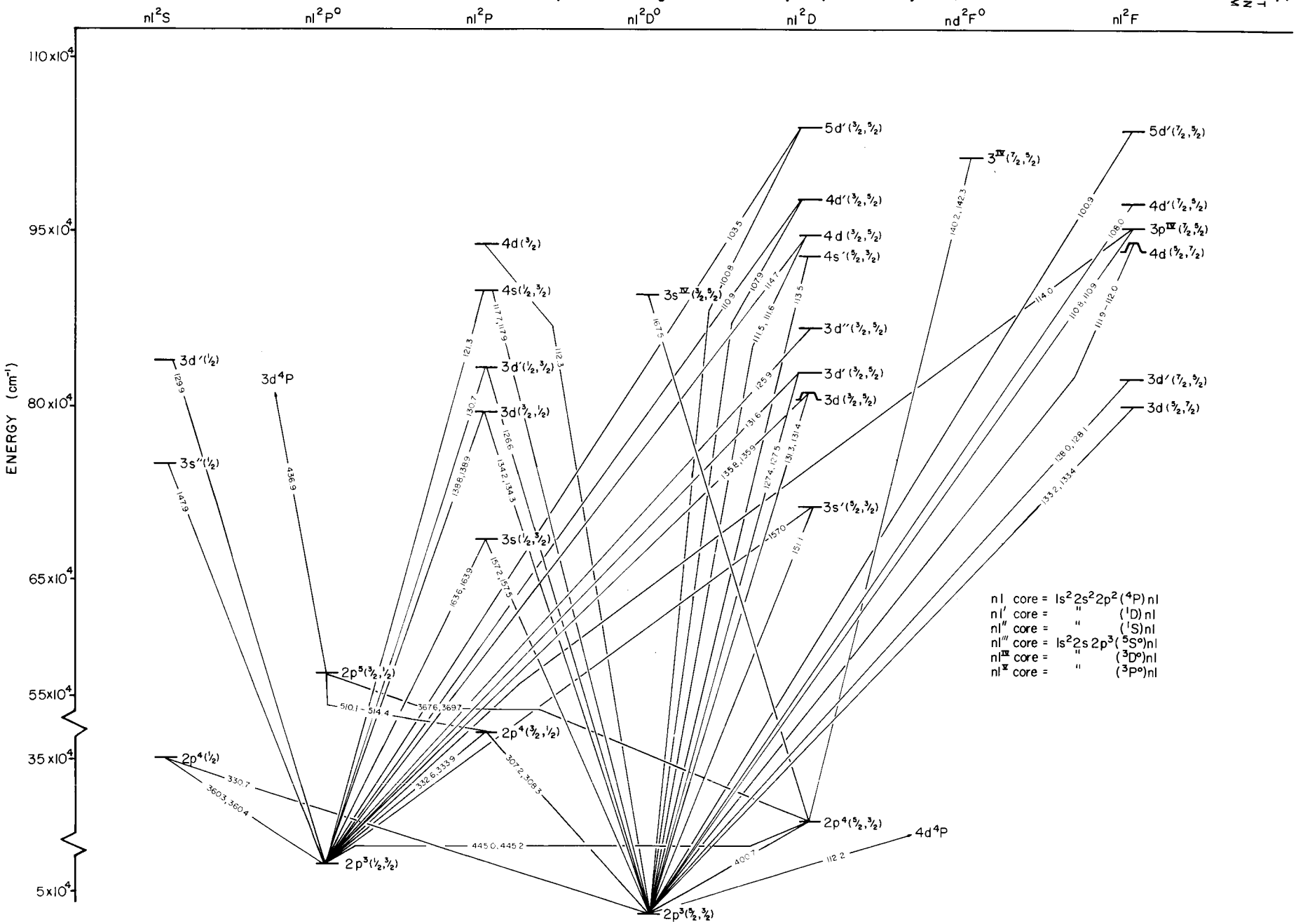
Na IV ENERGY LEVELS (8 electrons, Z=11)

(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)

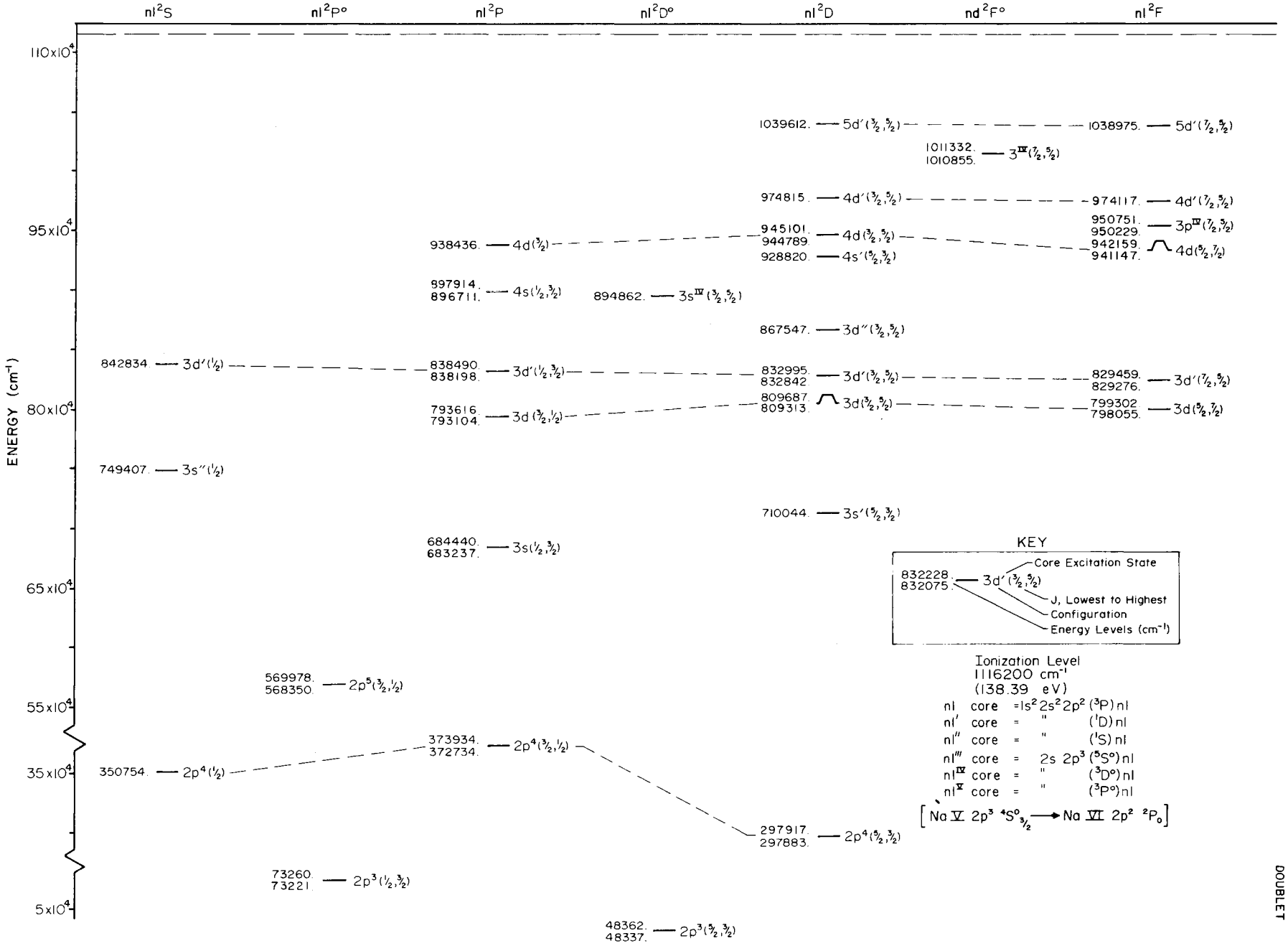


Na IV
TRIPLET

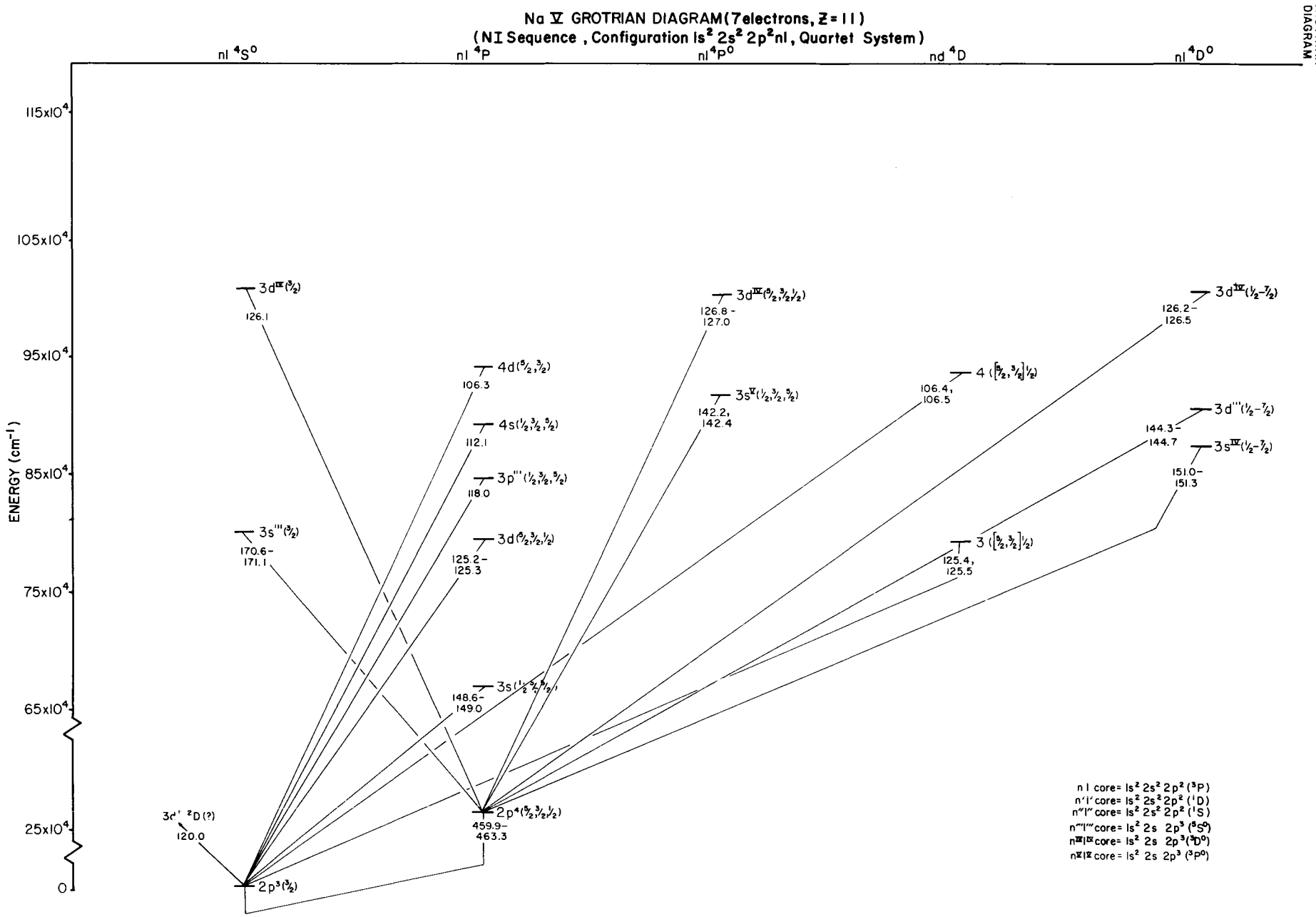
Na V GROTRIAN DIAGRAM (7 electrons, Z=11)
(N I sequence. Configuration: $1s^2 2s^2 2p^2$ nl, Doublet System)



Na V ENERGY LEVELS (7 electrons, Z = 11)
(N I sequence, Configuration: $1s^2 2s^2 2p^2$ nl, Doublet System)

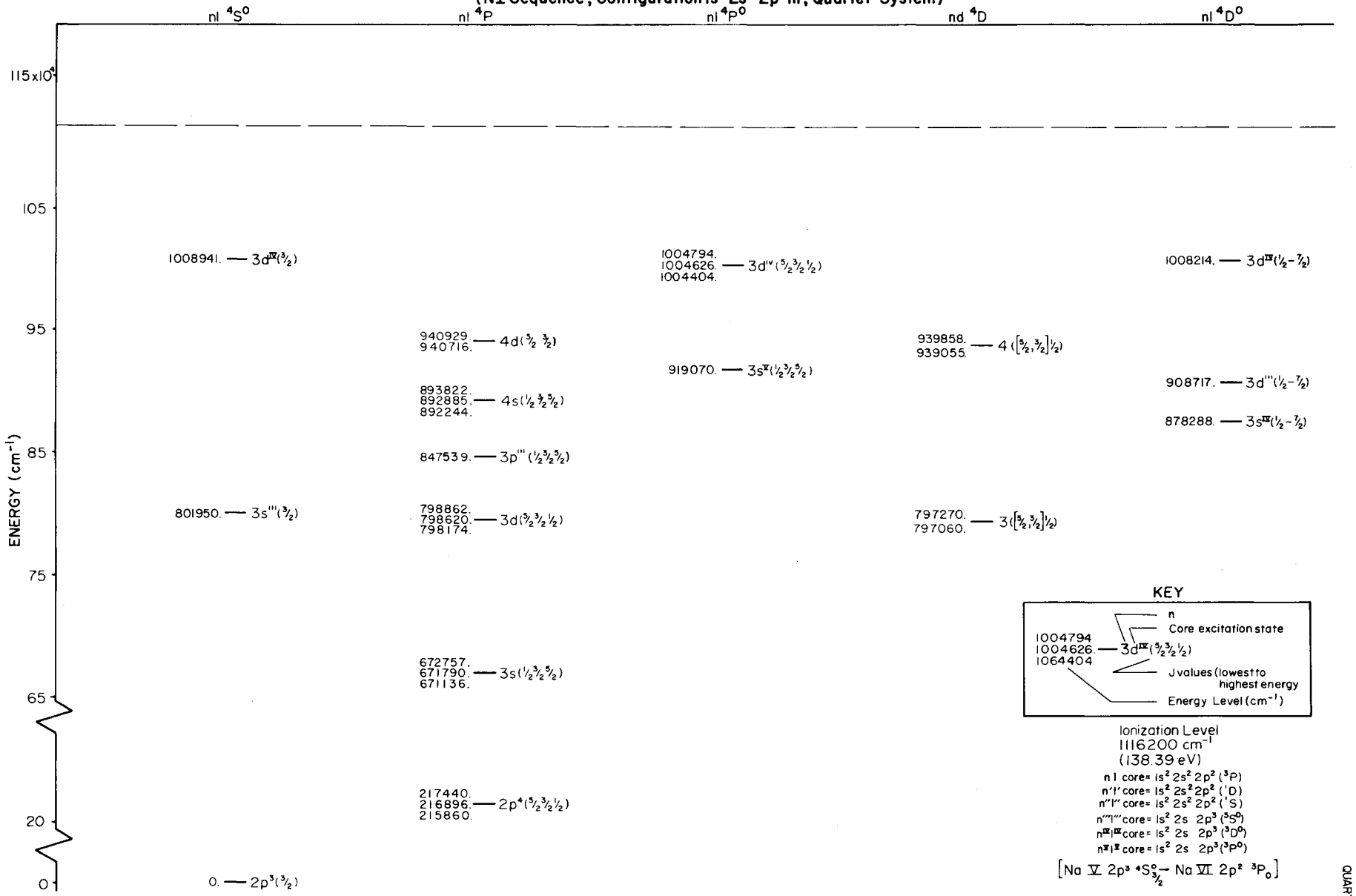


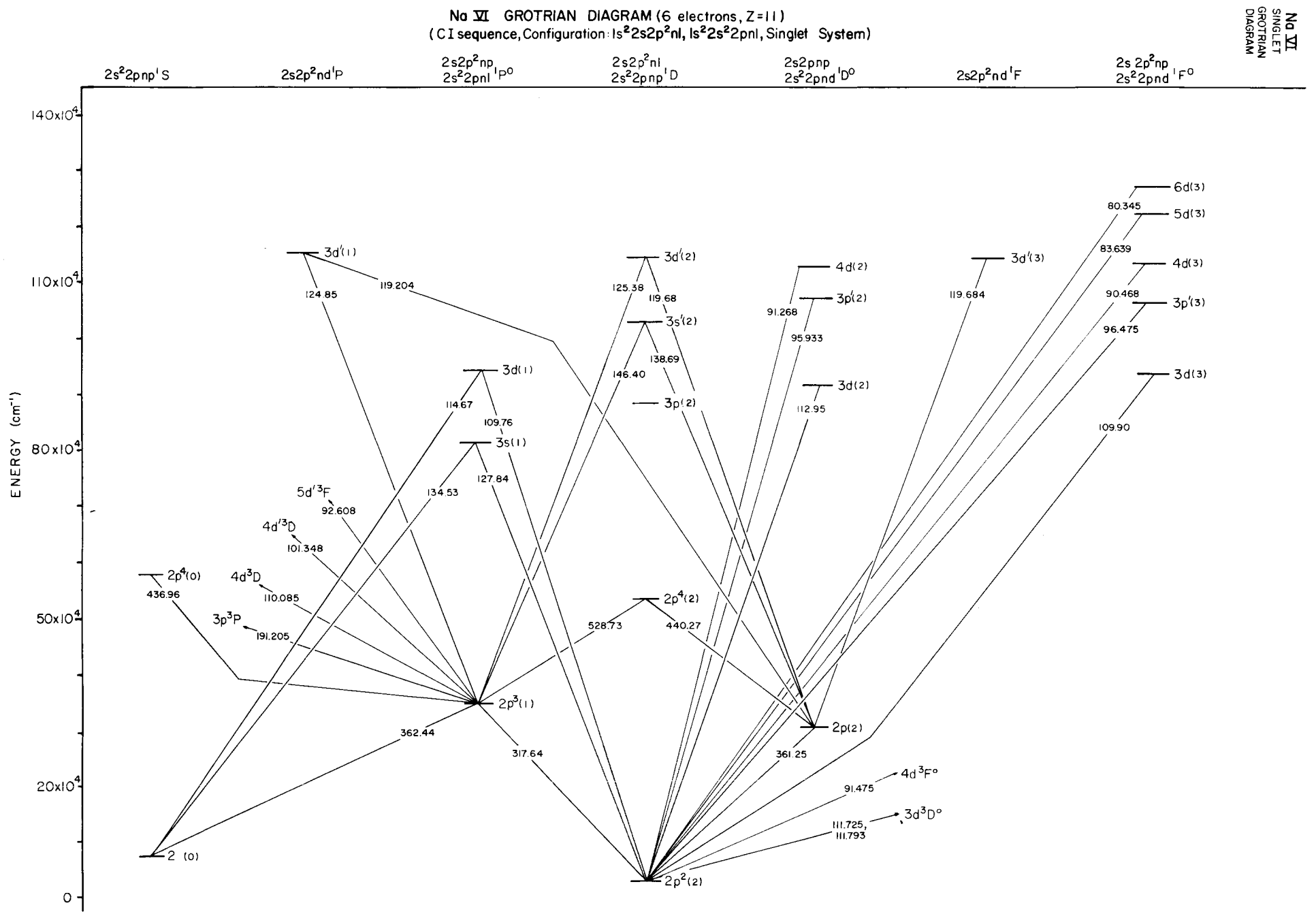
Na V DOUBLET


Na V GROTRIAN DIAGRAM (7 electrons, Z = 11)
(NI Sequence, Configuration 1s² 2s² 2p²nl, Quartet System)
nl ⁴S⁰
nl ⁴P
nl ⁴P⁰
nd ⁴D
nl ⁴D⁰
ENERGY (cm⁻¹)
115x10⁴
105x10⁴
95x10⁴
85x10⁴
75x10⁴
65x10⁴
25x10⁴
0
3d^IV(3/2)
126.1
4d(3/2,3/2)
106.3
4s(1/2,3/2,5/2)
112.1
3p'''(1/2,3/2,5/2)
118.0
3d(3/2,3/2,1/2)
125.2-
125.3
3s'''(3/2)
170.6-
171.1
3s(1/2,3/2,5/2)
148.6-
149.0
3d'' ²D(?)
120.0
2p³(3/2)
2p⁴(3/2,3/2,1/2)
459.9-
463.3
3d^IV(3/2,3/2,1/2)
126.8-
127.0
3s^V(1/2,3/2,5/2)
142.2,
142.4
4([3/2,3/2]1/2)
106.4,
106.5
3([3/2,3/2]1/2)
125.4,
125.5
3d^IV(1/2-7/2)
126.2-
126.5
3d'''(1/2-7/2)
144.3-
144.7
3s^IV(1/2-7/2)
151.0-
151.3
n l core = 1s² 2s² 2p² (³P)
n'l' core = 1s² 2s² 2p² (¹D)
n''l'' core = 1s² 2s² 2p² (¹S)
n'''l''' core = 1s² 2s 2p³ (⁵S⁰)
n^IV l^IV core = 1s² 2s 2p³ (³D⁰)
n^V l^V core = 1s² 2s 2p³ (³P⁰)

Na V ENERGY LEVELS (7 electrons, Z=11)

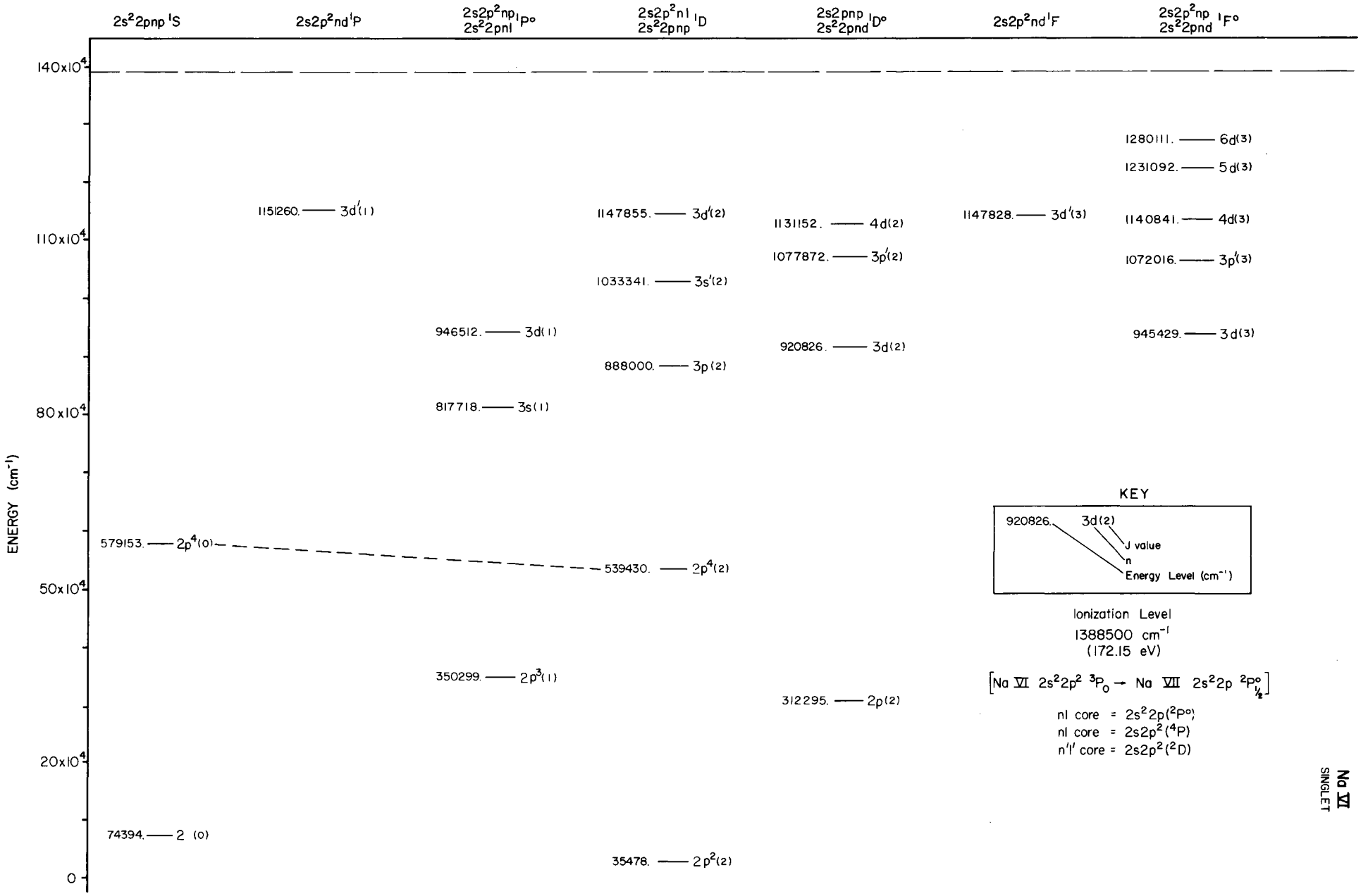
(NI Sequence, Configuration $1s^2 2s^2 2p^2 nl$, Quartet System)

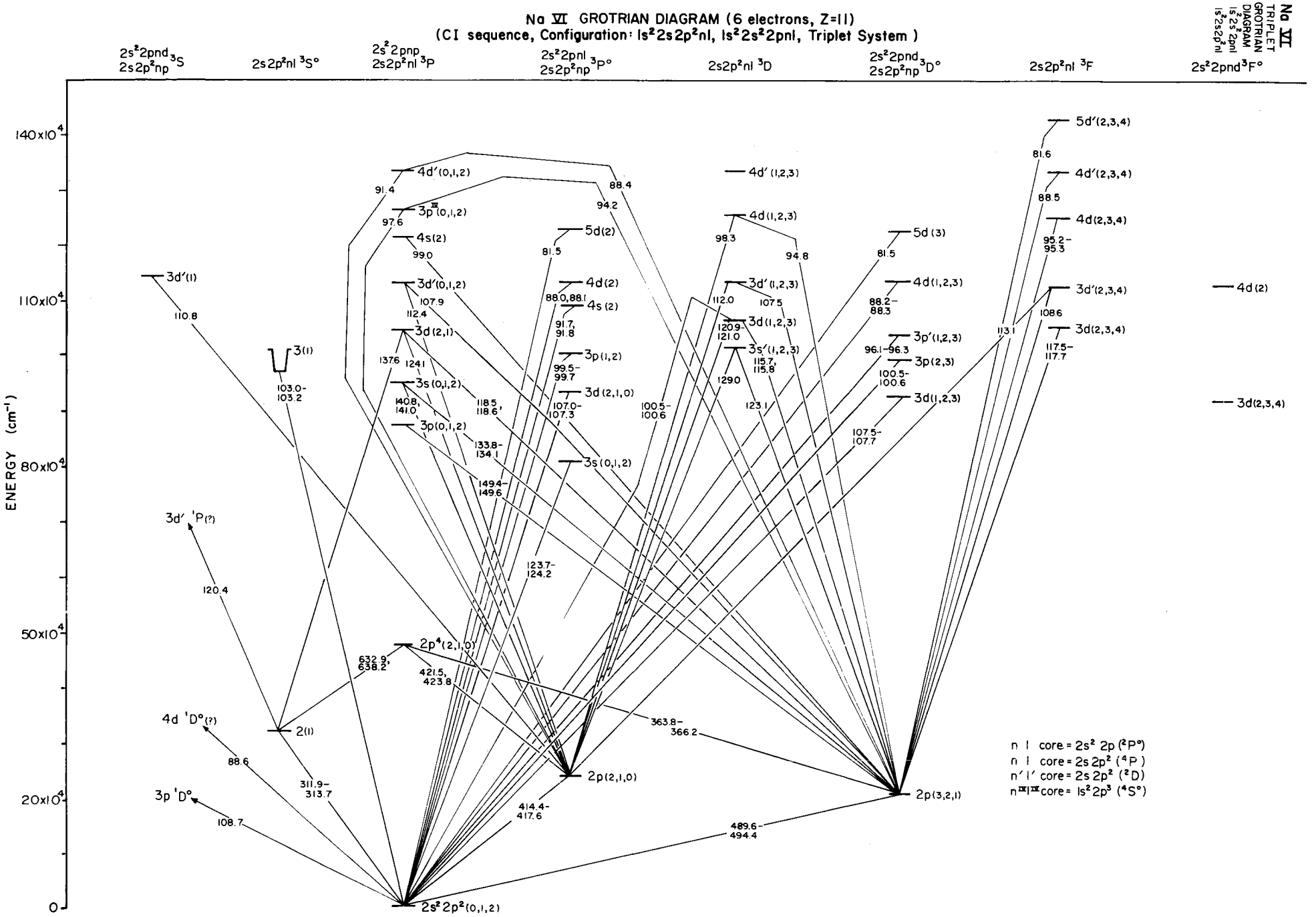



Na VI GROTRIAN DIAGRAM (6 electrons, Z=11)
(C I sequence, Configuration: 1s²2s2p²nl, 1s²2s²2pnl, Singlet System)
2s²2pnp ¹S
2s2p²nd ¹P
2s2p²np 2s²2pnl ¹P°
2s2p²nl 2s²2pnp ¹D
2s2pnp 2s²2pnd ¹D°
2s2p²nd ¹F
2s 2p²np 2s²2pnd ¹F°
ENERGY (cm⁻¹)
140x10⁴
110x10⁴
80x10⁴
50x10⁴
20x10⁴
0
3d'(1)
3d(1)
3s(1)
5d'³F
4d'³D
4d³D
3p³P
2p⁴(0)
2 (0)
2p³(1)
3d'(2)
3s'(2)
3p(2)
2p⁴(2)
2p²(2)
4d(2)
3p'(2)
3d(2)
2p(2)
3d'(3)
6d(3)
5d(3)
4d(3)
3p'(3)
3d(3)
4d³F°
3d³D°
124.85
119.204
114.67
109.76
134.53
127.84
92.608
101.348
110.085
191.205
436.96
362.44
317.64
125.38
119.68
138.69
146.40
528.73
440.27
91.268
95.933
112.95
361.25
119.684
80.345
83.639
90.468
96.475
109.90
91.475
111.725,
111.793

Na VI ENERGY LEVELS (6 electrons, Z = 11)

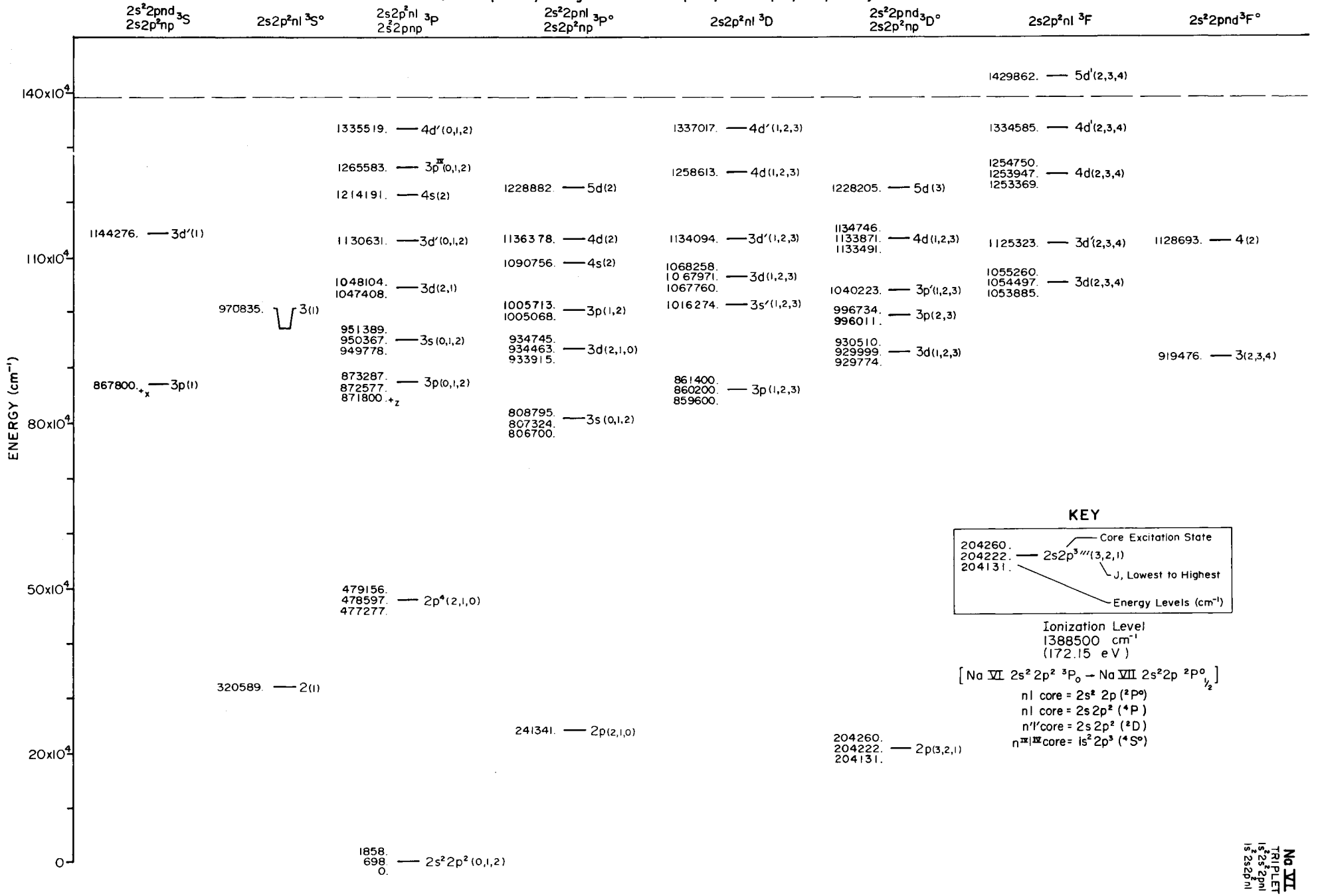
(CI sequence, Configuration: $1s^2 2s2p^2 nl$, $1s^2 2s^2 2pnl$, Singlet System)



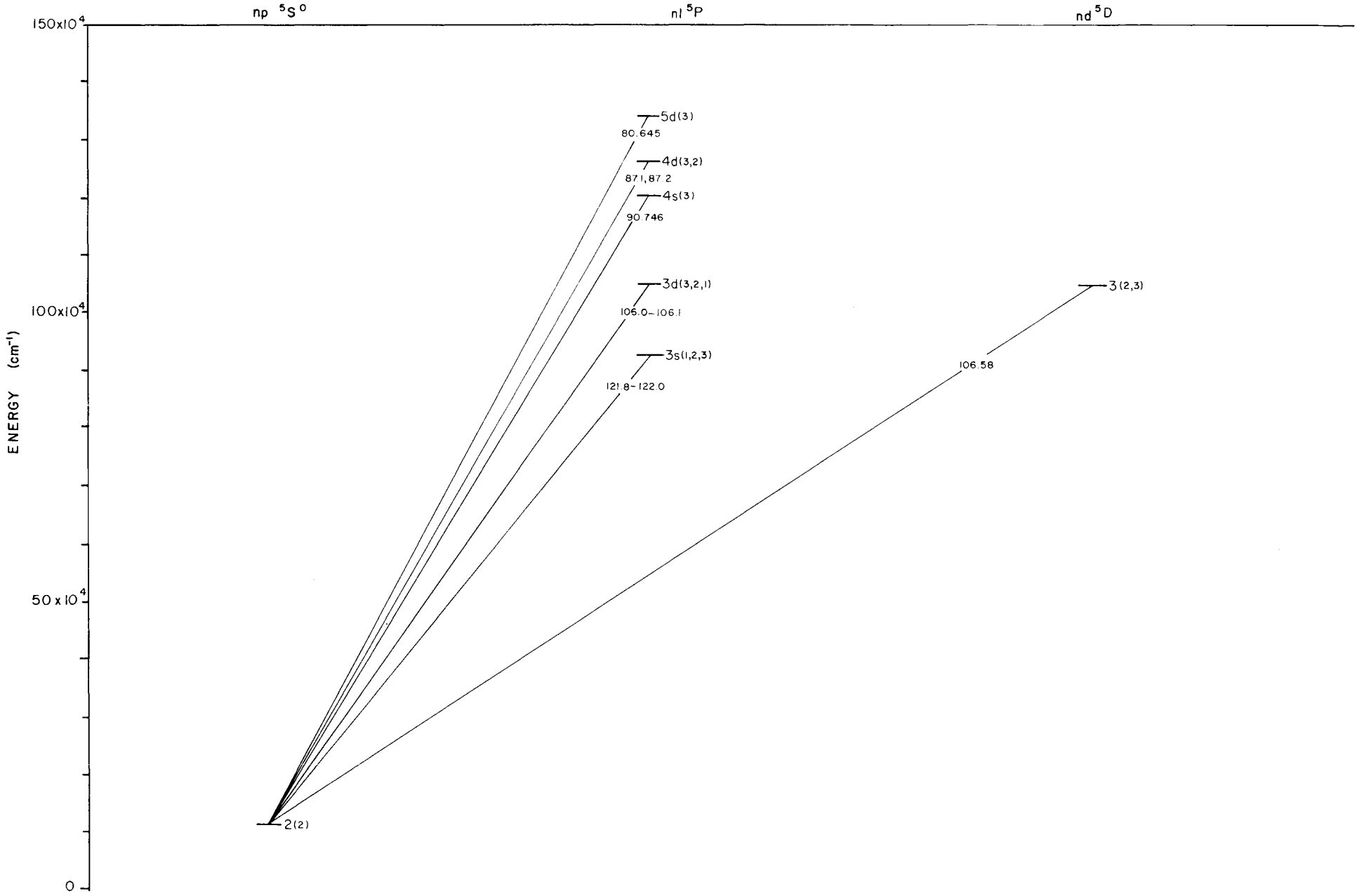

Na VI GROTRIAN DIAGRAM (6 electrons, Z=11)
(CI sequence, Configuration: $1s^2 2s 2p^2 nl$, $1s^2 2s^2 2pnl$, Triplet System)
Na VI TRIPLET GROTRIAN DIAGRAM
$1s^2 2s^2 2pnl$
$1s^2 2s 2p^3 nl$
$2s^2 2pnd\ ^3S$
$2s 2p^2 np$
$2s 2p^2 nl\ ^3S°$
$2s^2 2pnp$
$2s 2p^2 nl\ ^3P$
$2s^2 2pnl$
$2s 2p^2 np\ ^3P°$
$2s 2p^2 nl\ ^3D$
$2s^2 2pnd$
$2s 2p^2 np\ ^3D°$
$2s 2p^2 nl\ ^3F$
$2s^2 2pnd\ ^3F°$
ENERGY (cm^{-1})
140x10^4
110x10^4
80x10^4
50x10^4
20x10^4
0
$2s^2 2p^2(0,1,2)$
$2p(2,1,0)$
$2p(3,2,1)$
$2p^4(2,1,0)$
$3p\ ^1D°$
$4d\ ^1D°(?)$
$3d'\ ^1P(?)$
$3d'(1)$
3(1)
2(1)
$3p^{IV}(0,1,2)$
4s(2)
$3d'(0,1,2)$
3d(2,1)
3s(0,1,2)
3p(0,1,2)
$4d'(0,1,2)$
5d(2)
4d(2)
4s(2)
3p(1,2)
3d(2,1,0)
3s(0,1,2)
$4d'(1,2,3)$
4d(1,2,3)
$3d'(1,2,3)$
3d(1,2,3)
$3s'(1,2,3)$
5d(3)
4d(1,2,3)
3p'(1,2,3)
3p(2,3)
3d(1,2,3)
$5d'(2,3,4)$
$4d'(2,3,4)$
4d(2,3,4)
$3d'(2,3,4)$
3d(2,3,4)
4d(2)
3d(2,3,4)
110.8
103.0-103.2
91.4
97.6
99.0
107.9
112.4
137.6
124.1
140.8, 141.0
118.5, 118.6
133.8-134.1
149.4-149.6
88.4
94.2
81.5
88.0, 88.1
91.7, 91.8
99.5-99.7
107.0-107.3
123.7-124.2
100.5-100.6
98.3
94.8
112.0
107.5
120.9-121.0
129.0
115.7, 115.8
123.1
81.5
88.2-88.3
96.1-96.3
100.5-100.6
107.5-107.7
81.6
88.5
95.2-95.3
108.6
113.1
117.5-117.7
120.4
88.6
108.7
311.9-313.7
632.9, 638.2
421.5, 423.8
363.8-366.2
414.4-417.6
489.6-494.4
n l core = $2s^2 2p\ (^2P°)$
n l core = $2s 2p^2\ (^4P)$
n' l' core = $2s 2p^2\ (^2D)$
$n^{IV} l^{IV}$ core = $1s^2 2p^3\ (^4S°)$

Na VI ENERGY LEVELS (6 electrons, Z=11)

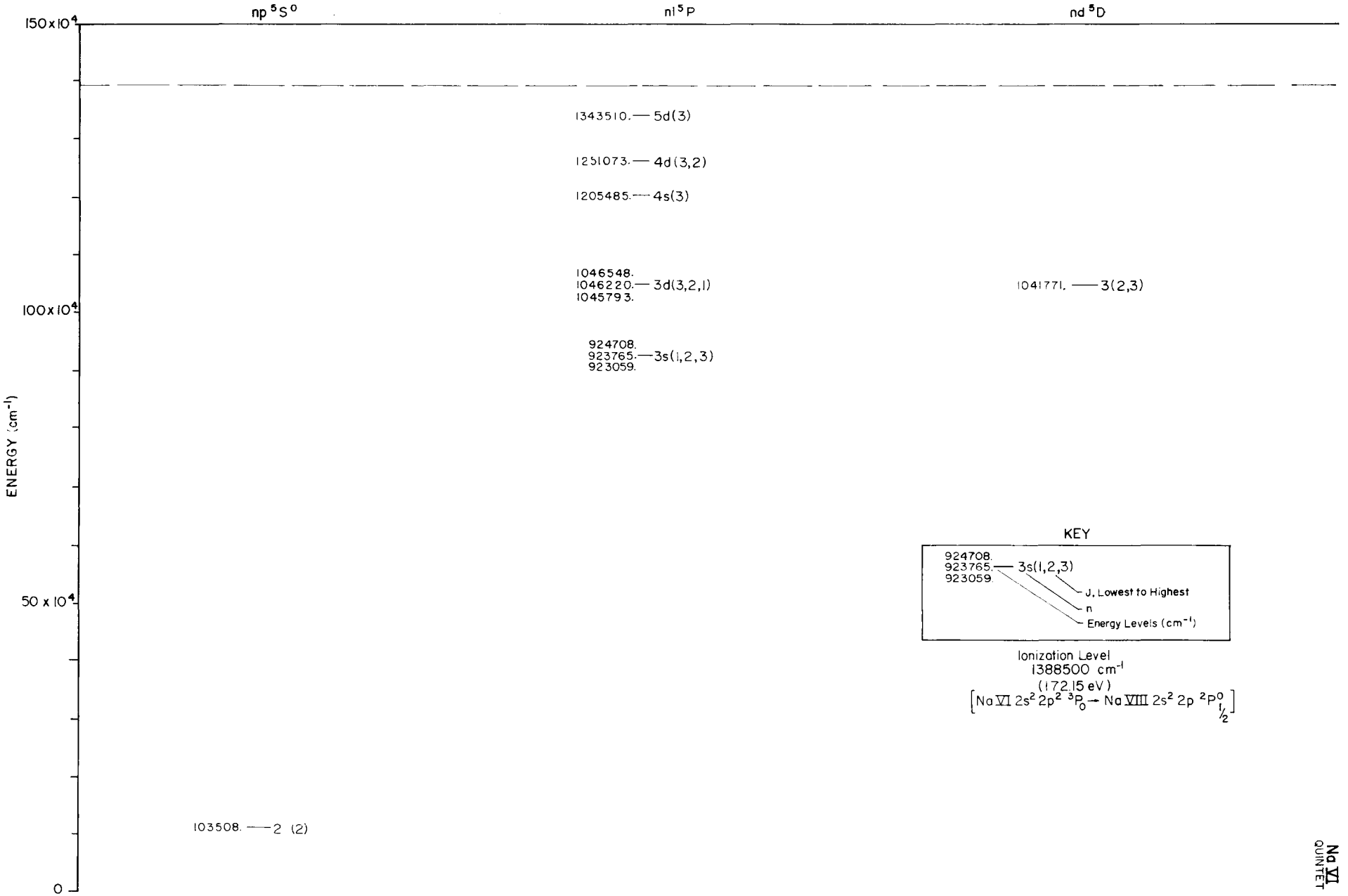
(CI sequence, Configuration: $1s^2 2s 2p^2 nl$, $1s^2 2s^2 2pnl$, Triplet System)



Na VI GROTRIAN DIAGRAM (6 electrons, Z=11)
(C I sequence, Configuration: $1s^2\ 2s\ 2p^2\ nl$, Quintet System)

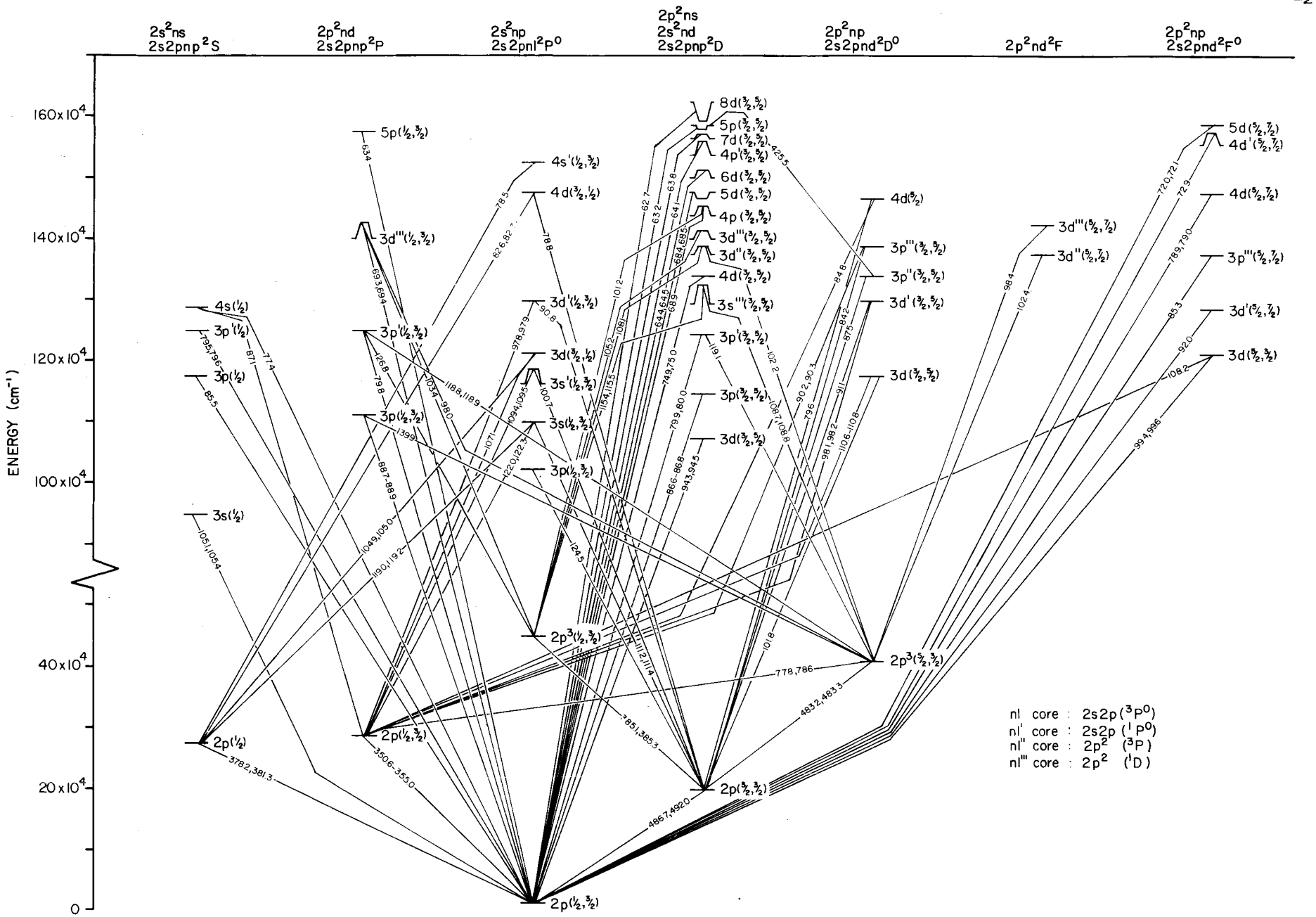


Na VI ENERGY LEVELS (6 electrons, Z = 11)
(C I Sequence, Configuration: $1s^2\,2s\,2p^2\,nl$, Quintet System)



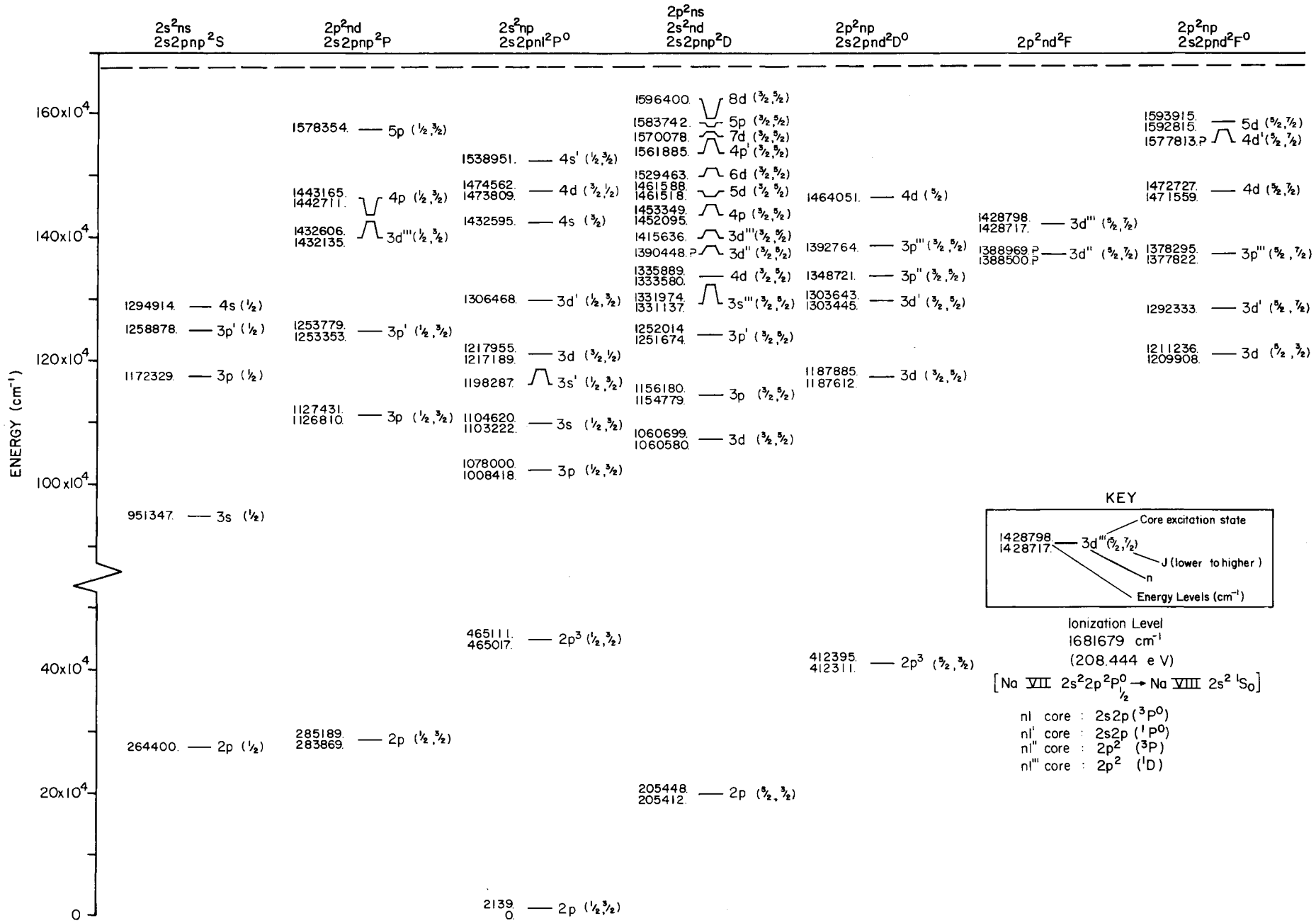
Na VII GROTRIAN DIAGRAM (5 electrons, Z=11)

(B I sequence, Configuration: $1s^2 nl\, n'l'\, n''l''$, Doublet System)

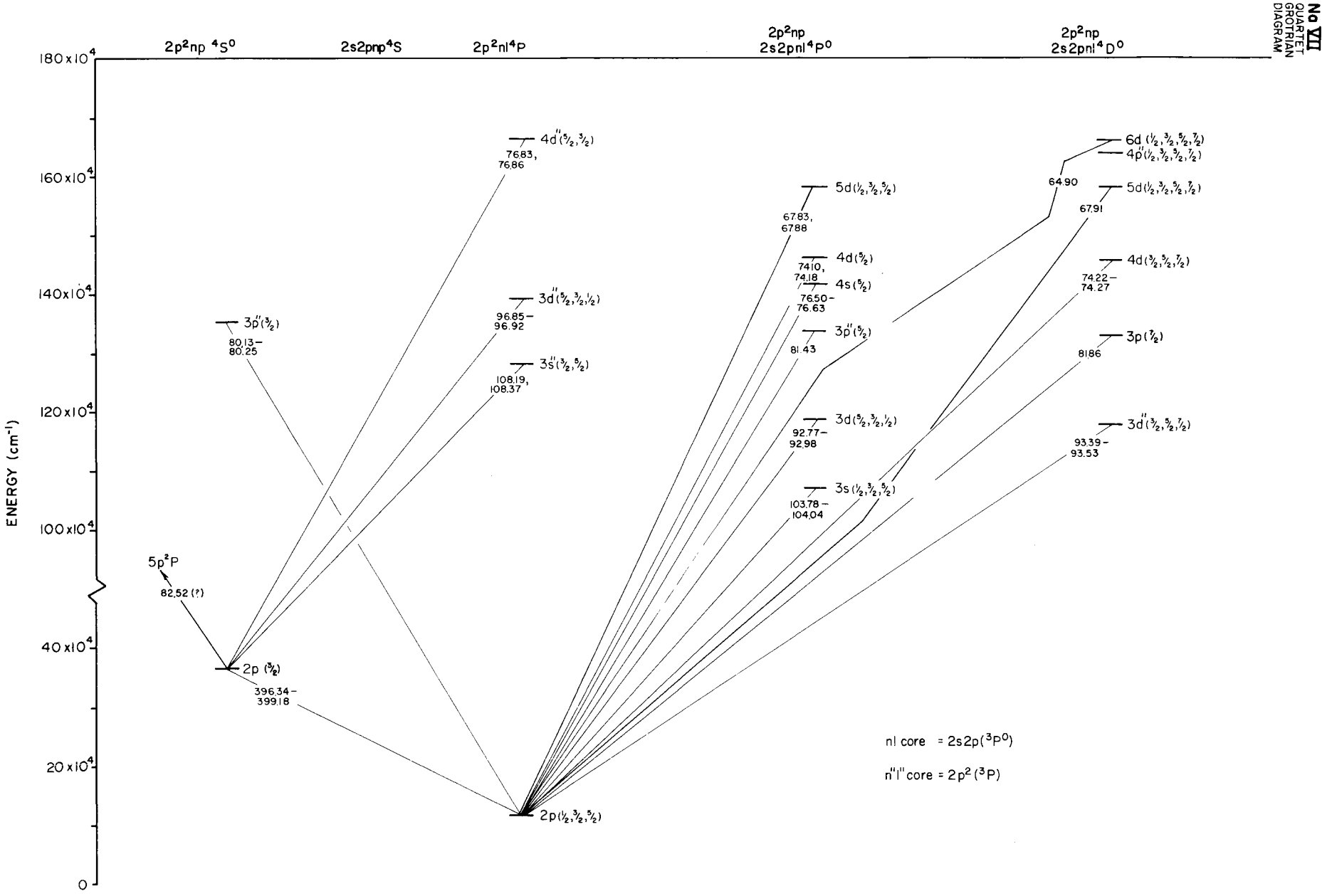


Na VII ENERGY LEVELS (5 electrons, Z=11)

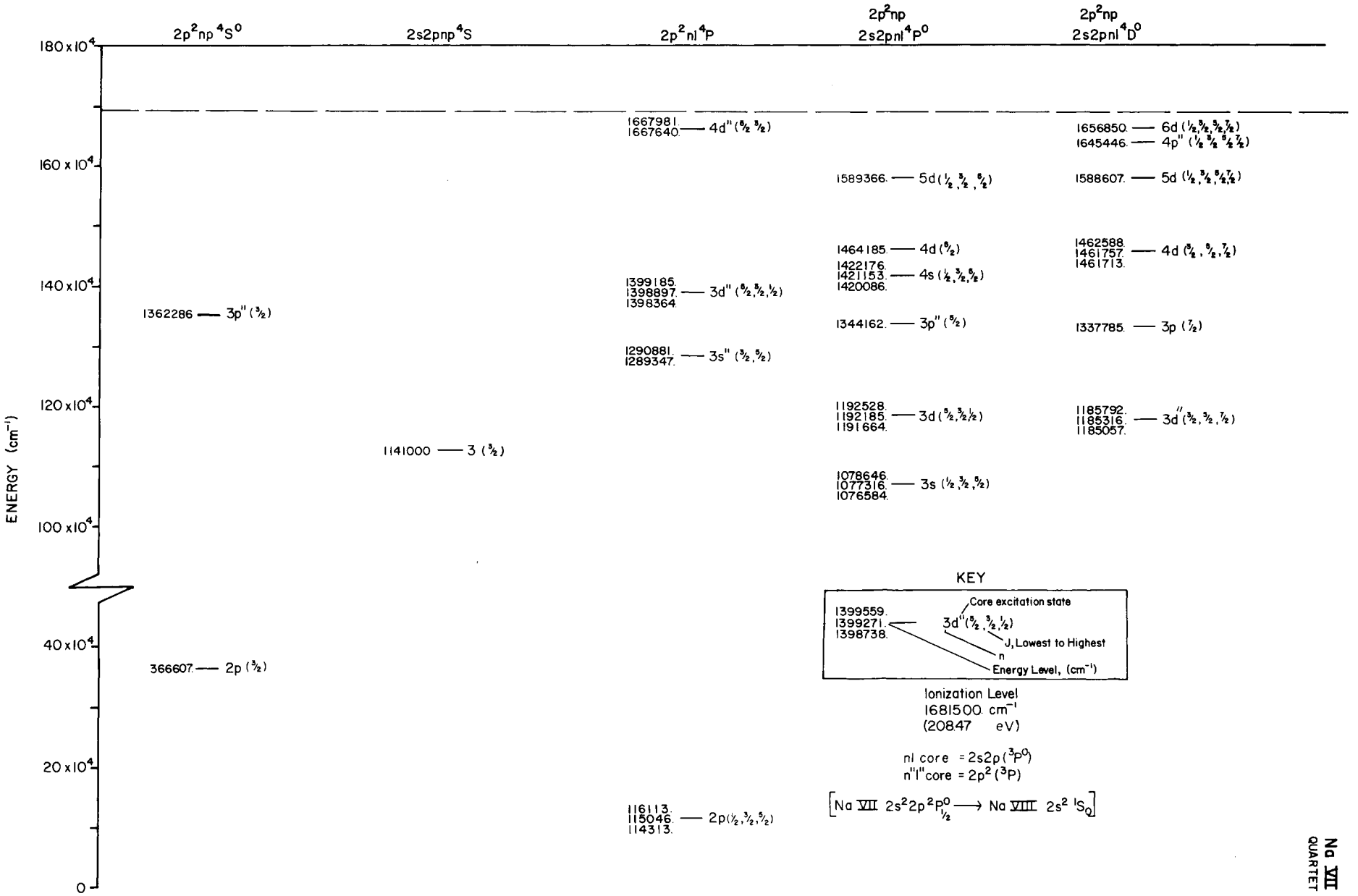
(B I sequence, Configuration: $1s^2nl\,n'l'n''l''$, Doublet System)



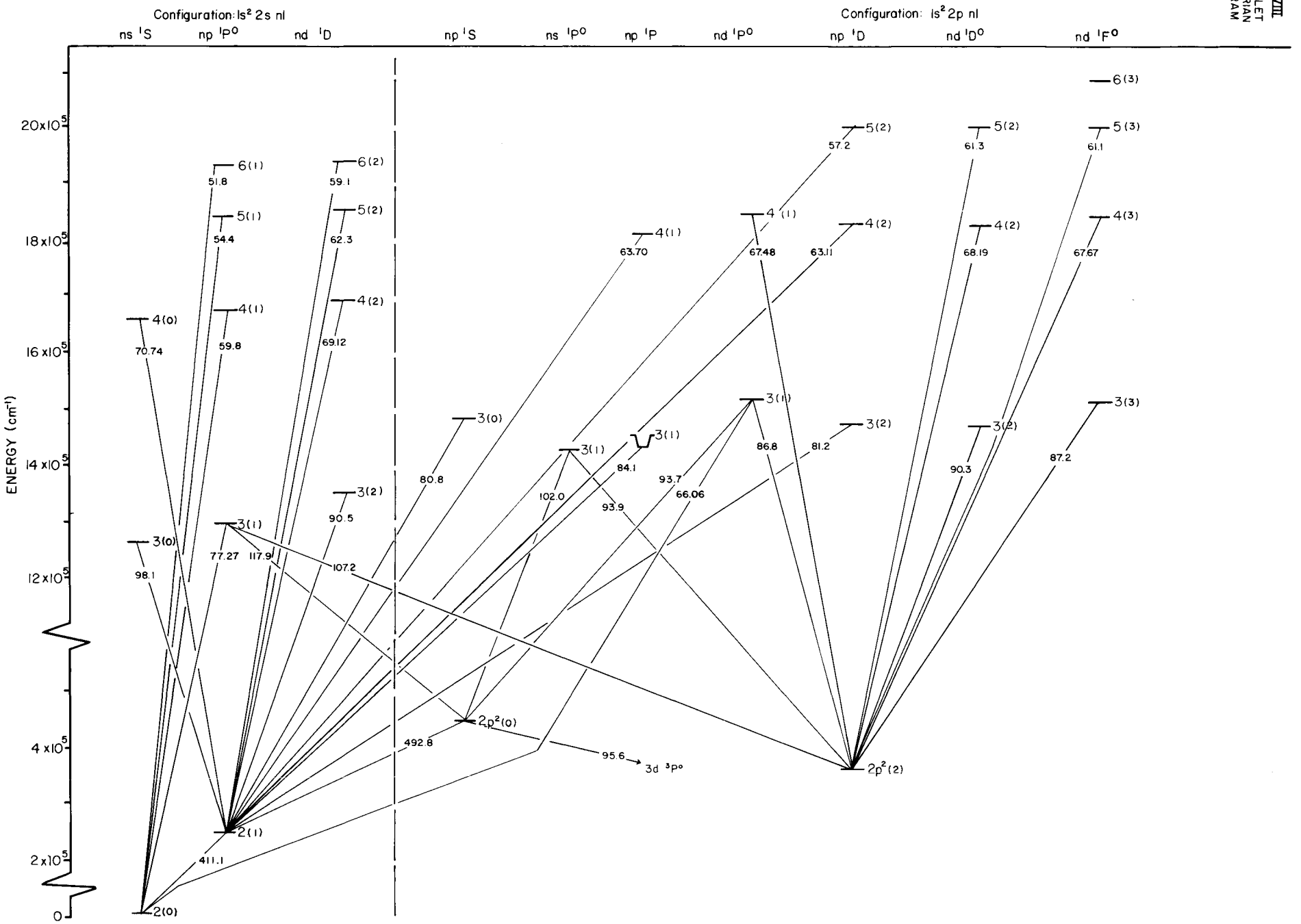
Na VII GROTRIAN DIAGRAM (5 electrons Z=11)
(B I sequence Configurations: $1s^2 2s2pnl$, $1s^2 2p^2 nl$, Quartet System)



Na VII ENERGY LEVELS (5 electrons, Z=11)
(B I sequence, Configurations: $1s^2 2s2pnl$, $1s^2 2p^2nl$, Quartet System)

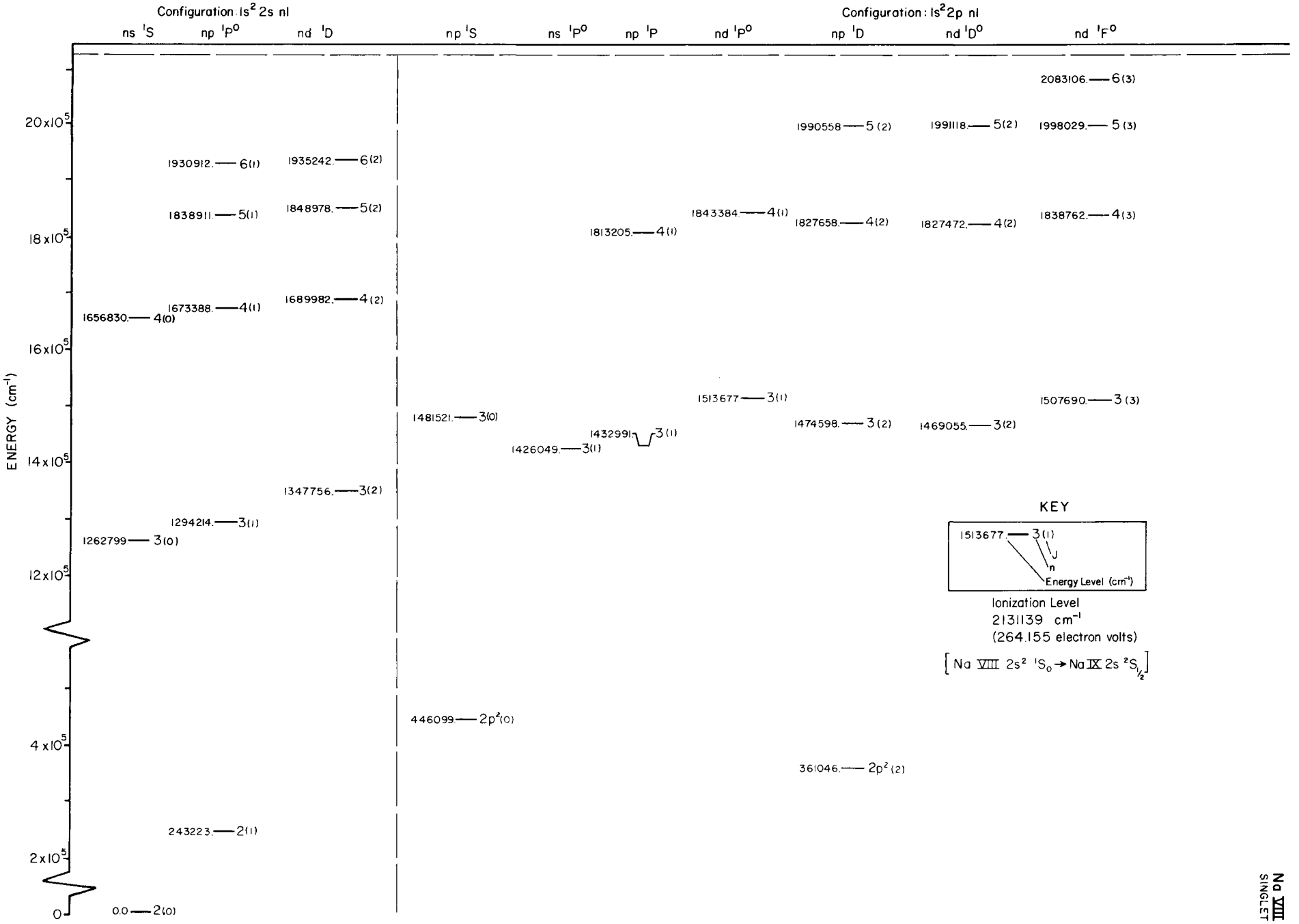


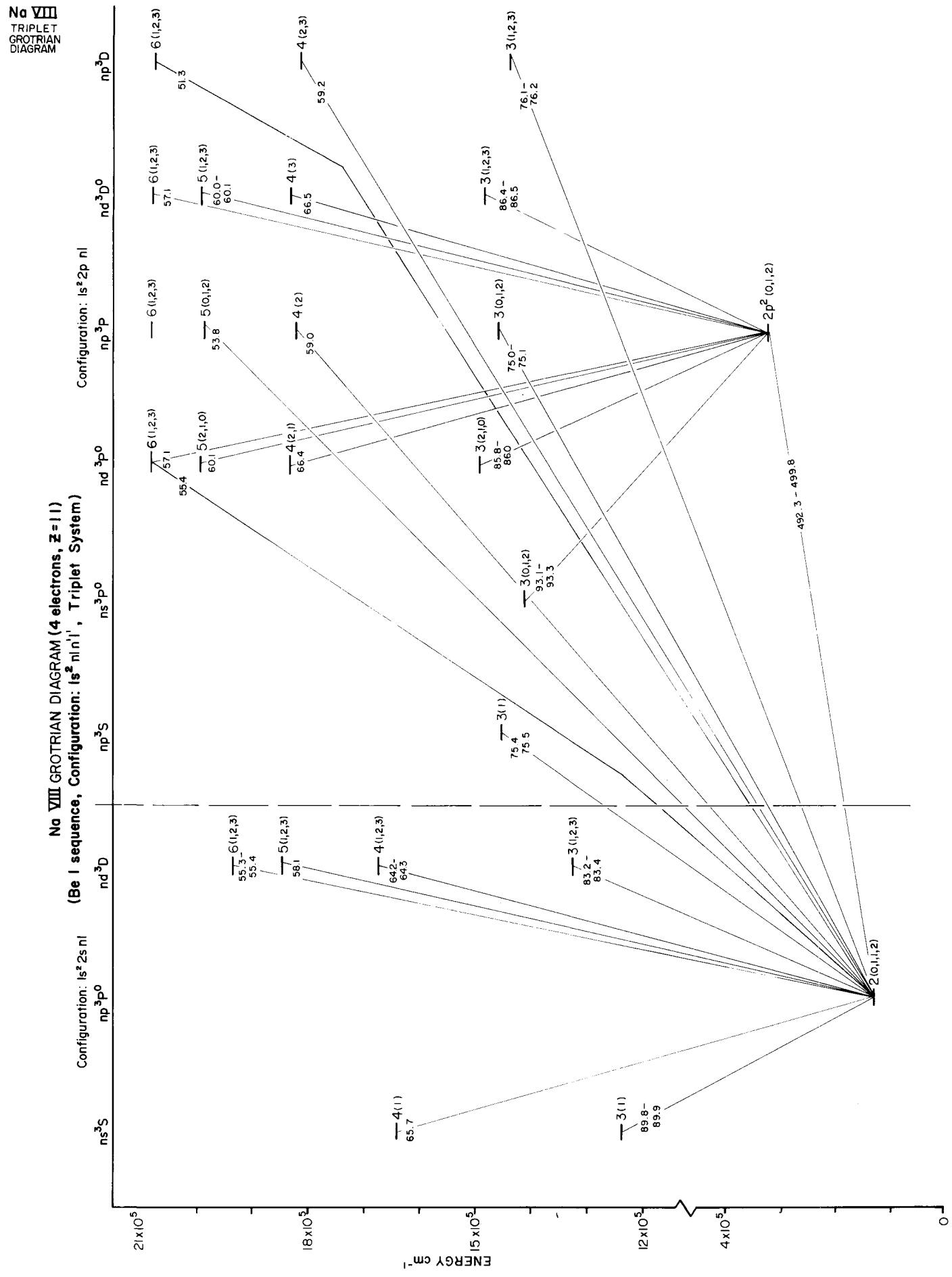
Na VIII GROTRIAN DIAGRAM (4 electrons, Z=11)
(Be I sequence, Configuration: $1s^2 nl\, n'l'$, Singlet System)



Na VIII ENERGY LEVELS (4 electrons, Z = 11)

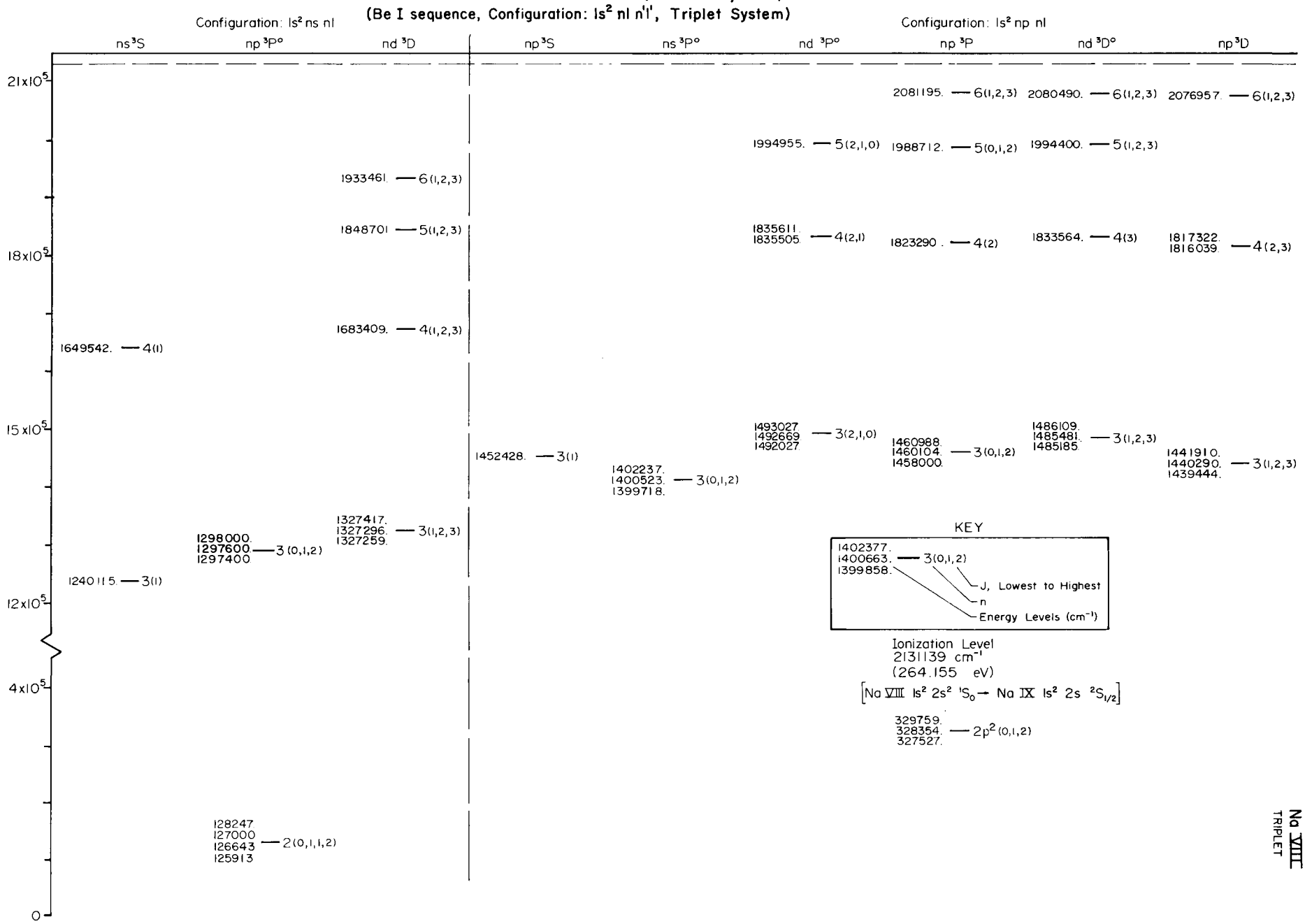
(Be I sequence, Configuration: $1s^2 nl\, n'l'$, Singlet System)



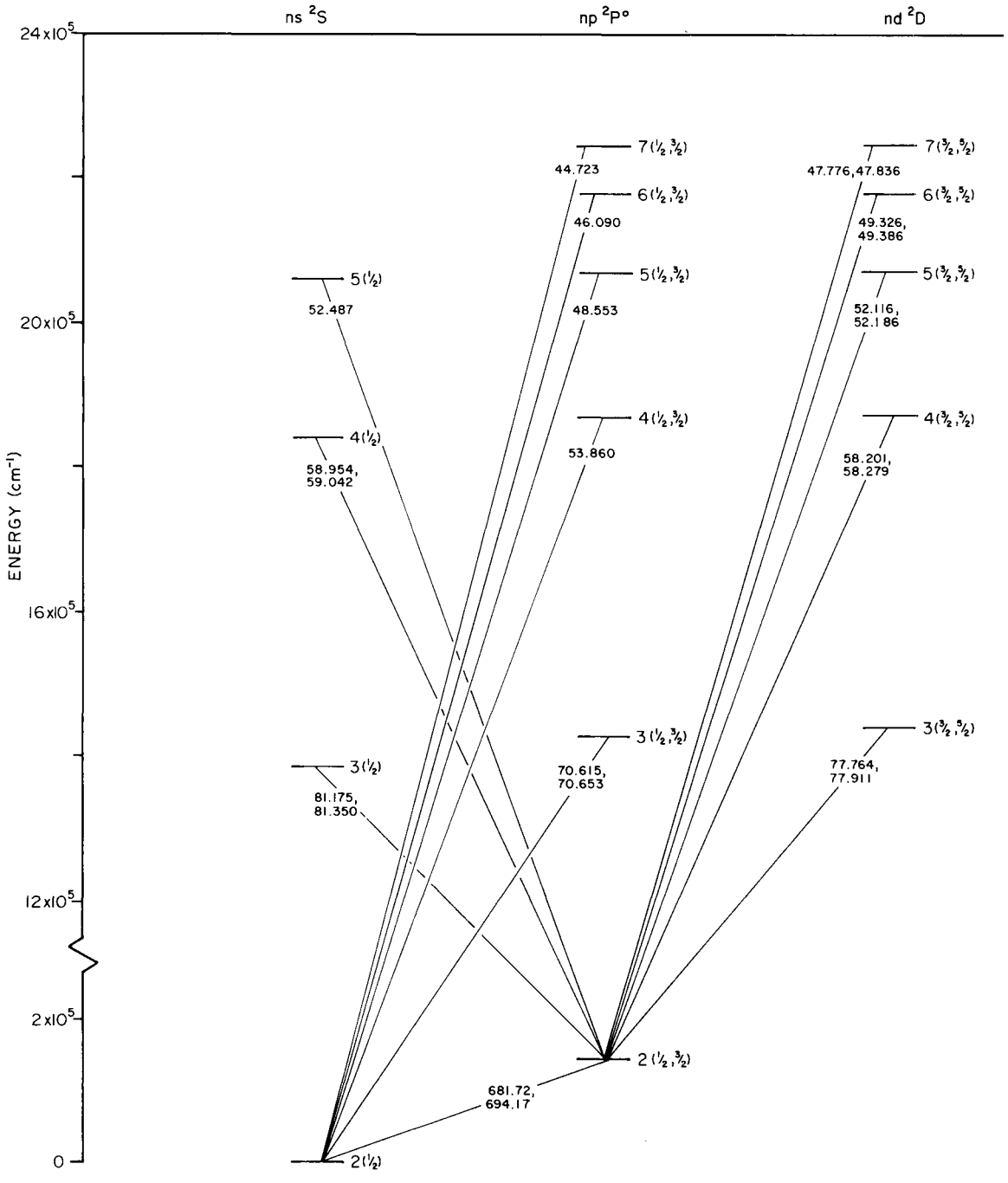

Na VIII
TRIPLET
GROTRIAN
DIAGRAM
Na VIII GROTRIAN DIAGRAM (4 electrons, Z=11)
(Be I sequence, Configuration: 1s² nl n'l', Triplet System)
Configuration: 1s²2s nl
Configuration: 1s²2p nl
ns³S
np³P°
nd³D
ns³P°
np³S
nd³P°
np³P
nd³D°
np³D
ENERGY cm⁻¹
21x10⁵
18x10⁵
15x10⁵
12x10⁵
4x10⁵
0
2p² (0,1,2)
2(0,1,1,2)
492.3 - 499.8

Na VIII ENERGY LEVELS (4 electrons, Z = 11)

(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Triplet System)

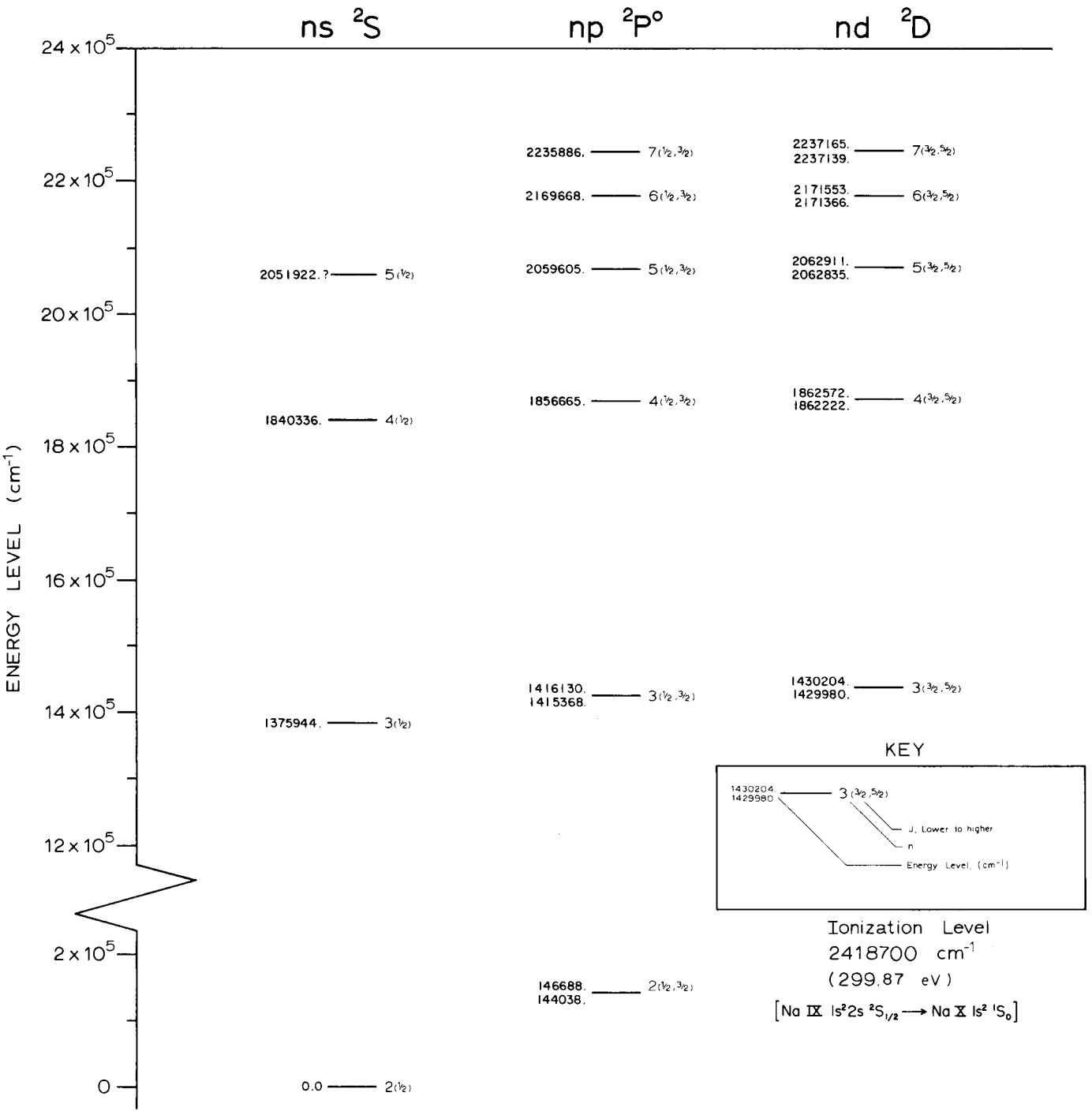


Na IX GROTRIAN DIAGRAM (3 electrons, Z = 11)
(Li I sequence, Configuration: $1s^2\,nl$)

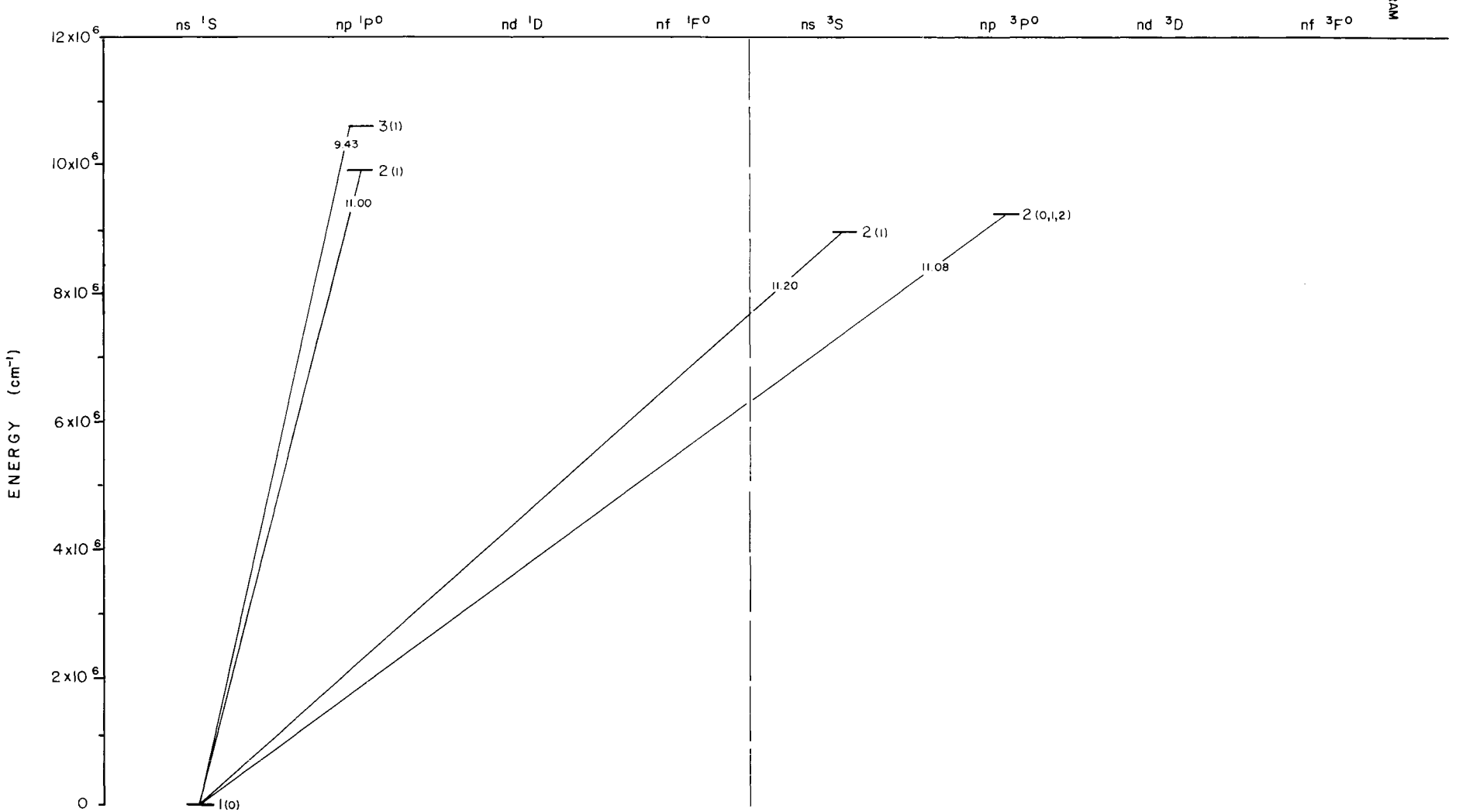


Na IX ENERGY LEVELS (3 electrons, Z = 11)

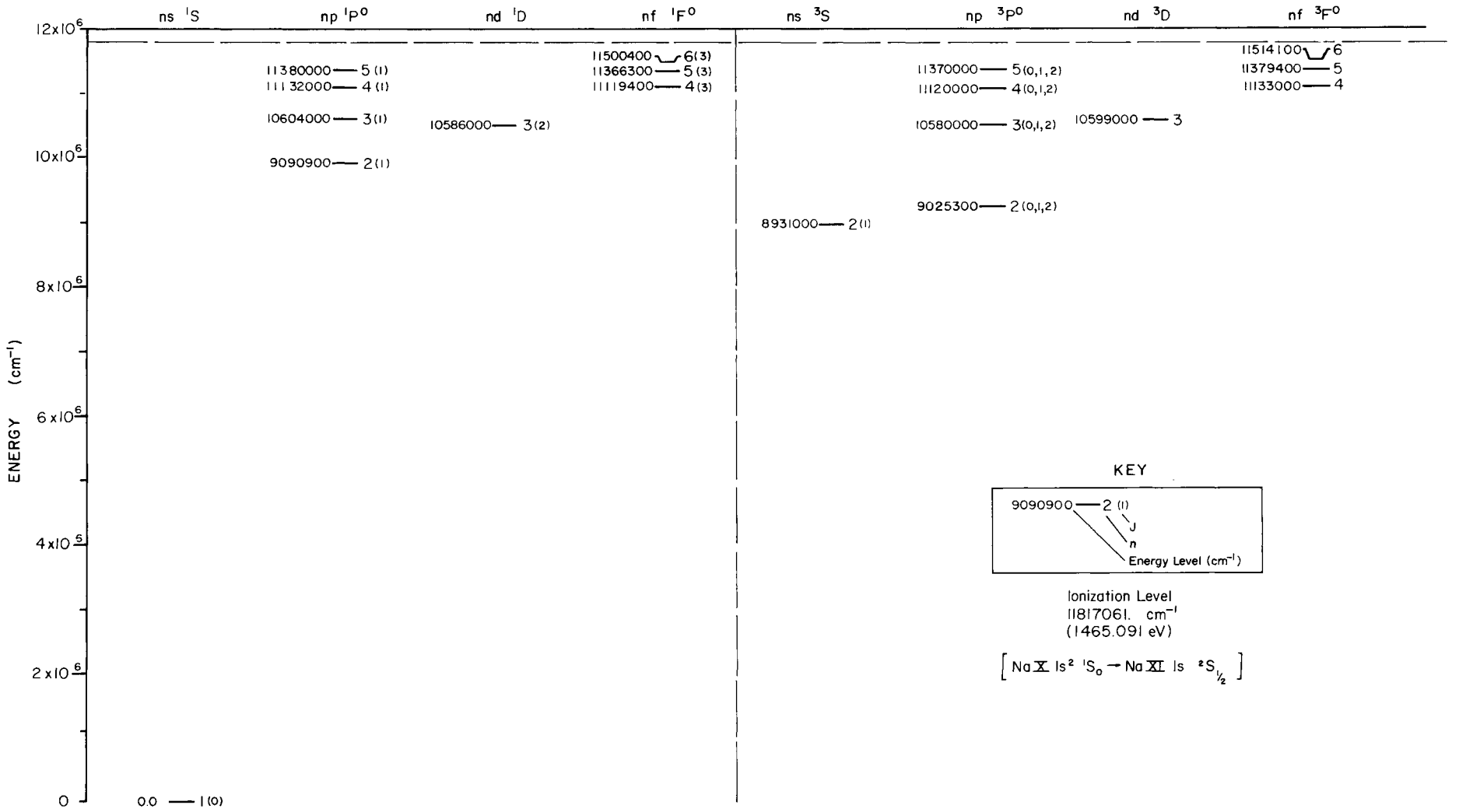
(Li I sequence, Configuration : $1s^2$ nl)

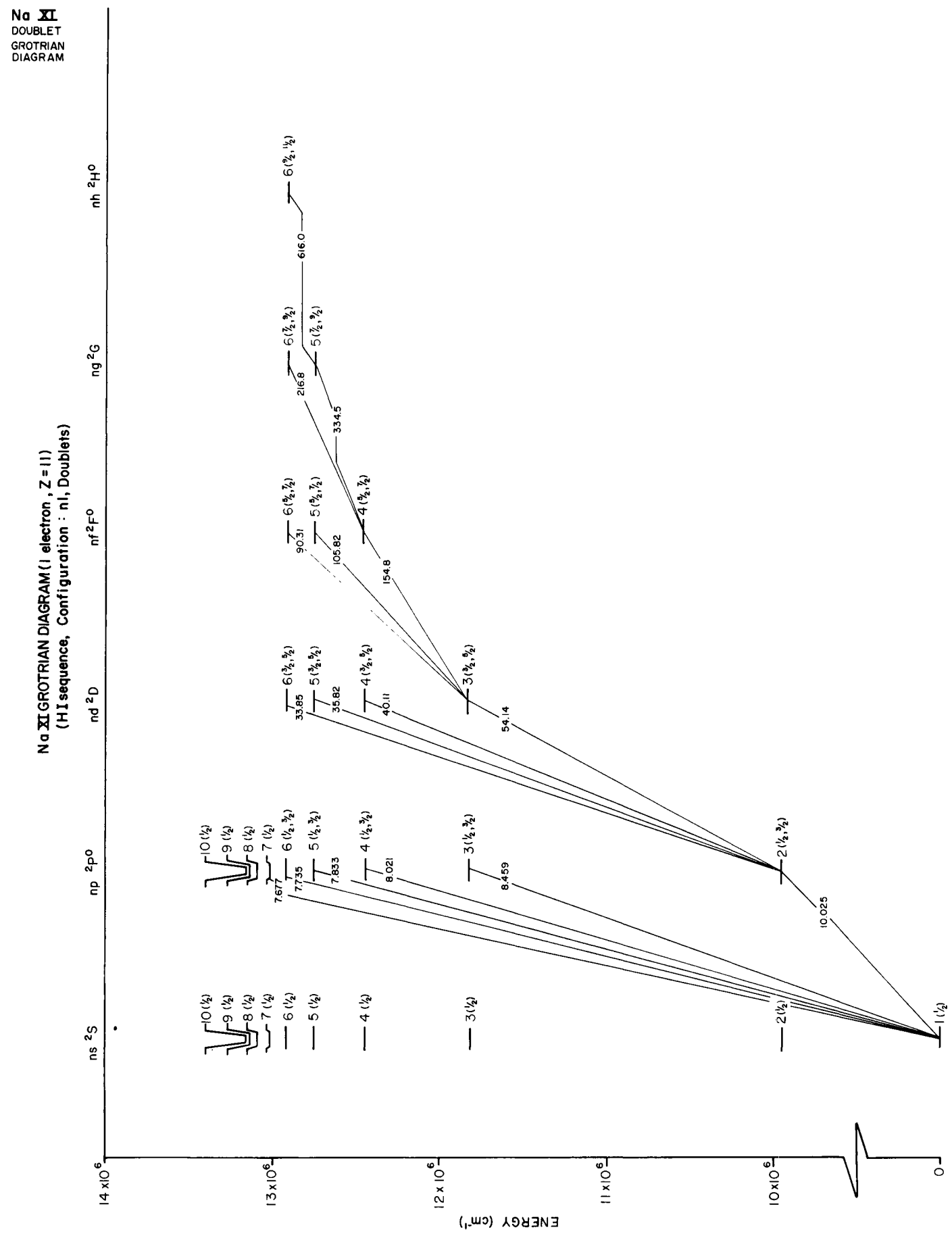


Na XI GROTRIAN DIAGRAM (2 electrons, Z = 11)
(He I sequence, Configuration: 1s nl, Singlet & Triplet System)

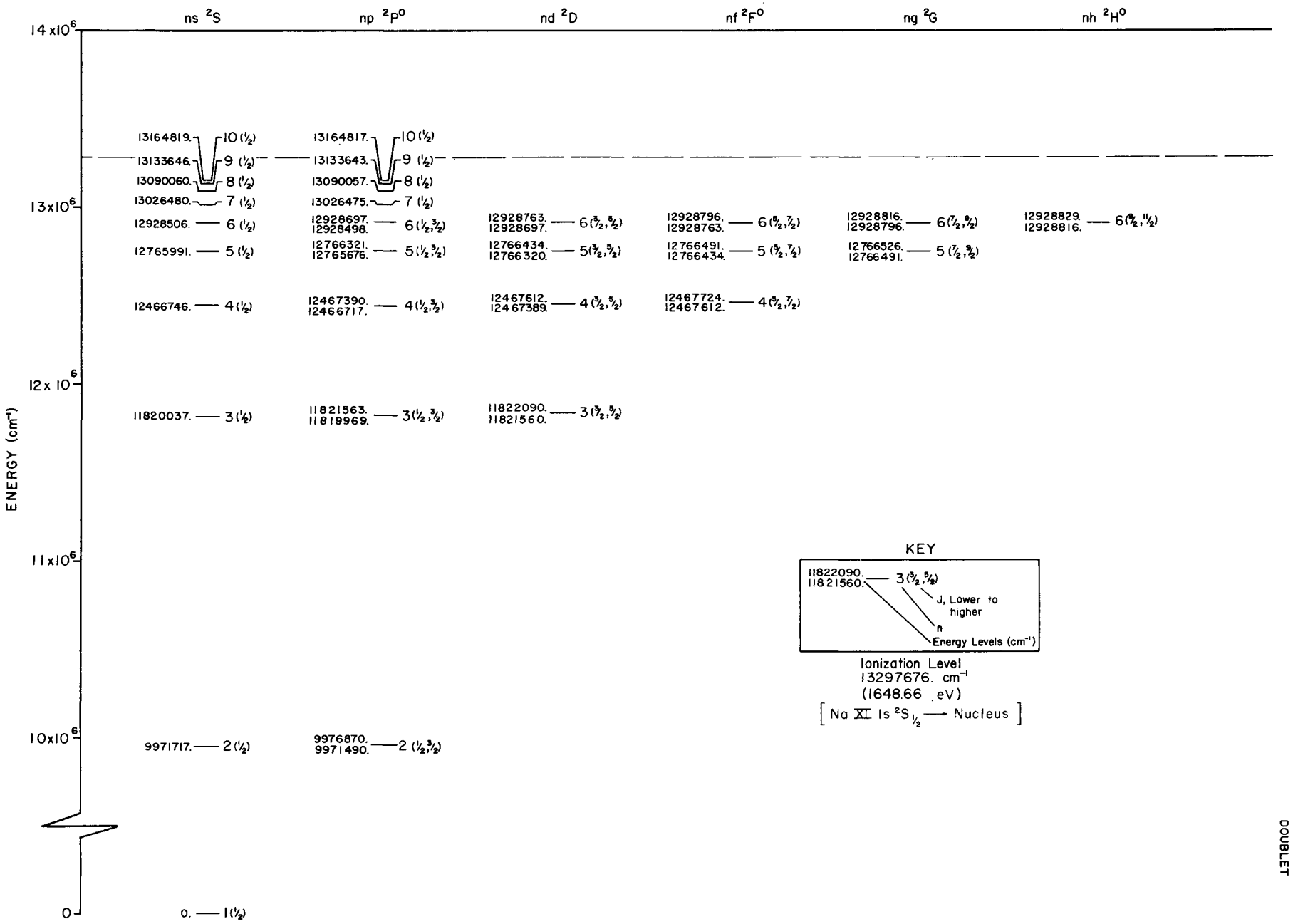


Na X ENERGY LEVELS (2 electrons, Z = 11)
(He I sequence, Configuration: 1s nl, Singlet & Triplet System)




Na XI
DOUBLET
GROTRIAN
DIAGRAM
Na XI GROTRIAN DIAGRAM (1 electron, Z = 11)
(H I sequence, Configuration : nl, Doublets)
ns ²S
np ²P⁰
nd ²D
nf ²F⁰
ng ²G
nh ²H⁰
ENERGY (cm⁻¹)
14 x10⁶
13 x10⁶
12 x10⁶
11 x10⁶
10 x10⁶
0
7.677
7.735
7.833
8.021
8.459
10.025
33.85
35.82
40.11
54.14
90.31
105.82
154.8
216.8
334.5
616.0

Na XI ENERGY LEVELS (1 electron, Z=11)
(HI sequence, Configuration: nl, Doublet System)



Na I $Z = 11$ 11 electrons

L. Johansson, Ark. Fys. **20**, 135 (1961).

Author gives a line table of lines observed in the region 2380–12 680 Å.

Na II $Z = 11$ 10 electrons

Please see the general references.
The intermediate-coupling designation is taken from Kelly's unpublished tabulation of energy levels. He quotes A.M. Crooker, unpublished data (1966).

Na III $Z = 11$ 9 electrons

Please see the general references.

Na IV $Z = 11$ 8 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular and laboratory observations.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Na V $Z = 11$ 7 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from laboratory observations.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Na VI $Z = 11$ 6 electrons

Please see the general references.

Na VII $Z = 11$ 5 electrons

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Please note that the following lines were omitted:

$2s^2\,2p\,{}^2P^\circ$	–	$2p^2\,({}^3P)\,3s\,{}^4P$	77.56 (?)
$2s\,2p^2\,{}^2D$	–	$4d\,{}^4D$	79.62 (?)
$2p^3\,{}^2P^\circ$	–	$4d\,{}^4P$	83.18 (?)
	–	$3d\,{}^4P$	107.09

Na VIII $Z = 11$ 4 electrons

Please see the general references.
Note that the following line was omitted: $2s^2\ ^1S$–$2s\,2p\ ^3P^\circ$: 789.6.

Na IX $Z = 11$ 3 electrons

Please see the general references.

Na X $Z = 11$ 2 electrons

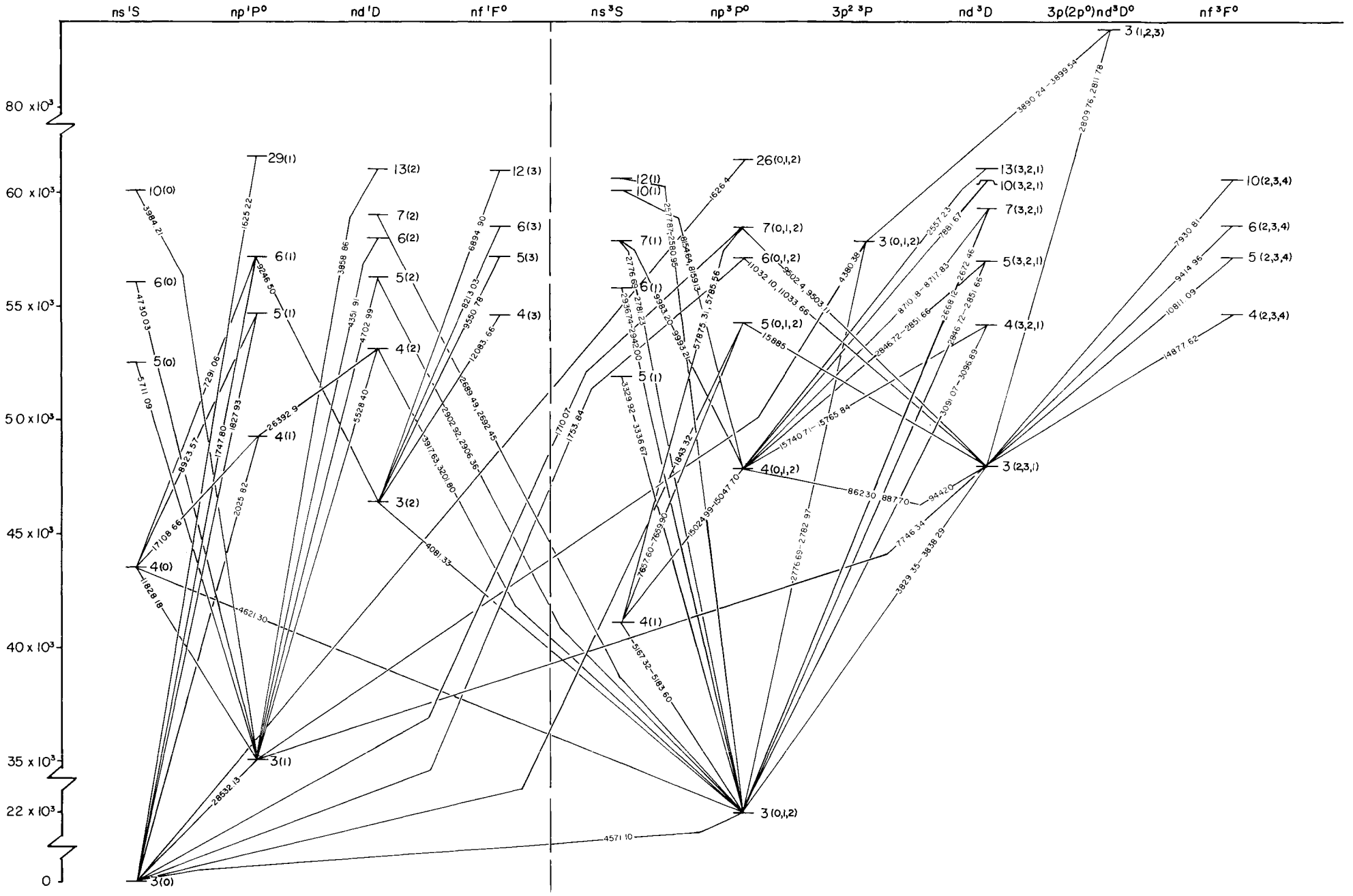
Please see the general references.

Na XI $Z = 11$ 1 electron

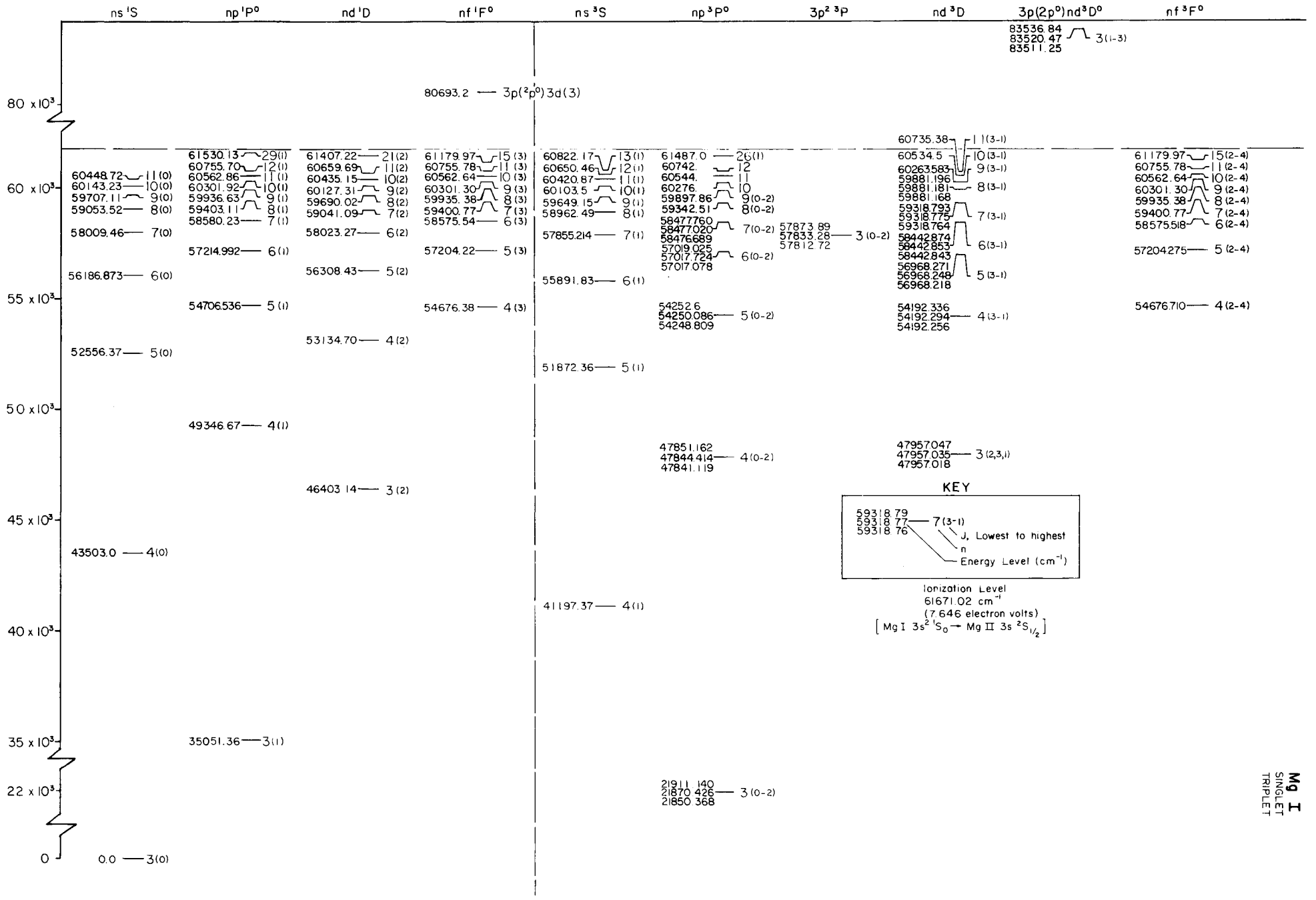
Please see the general references.

Magnesium (Mg)

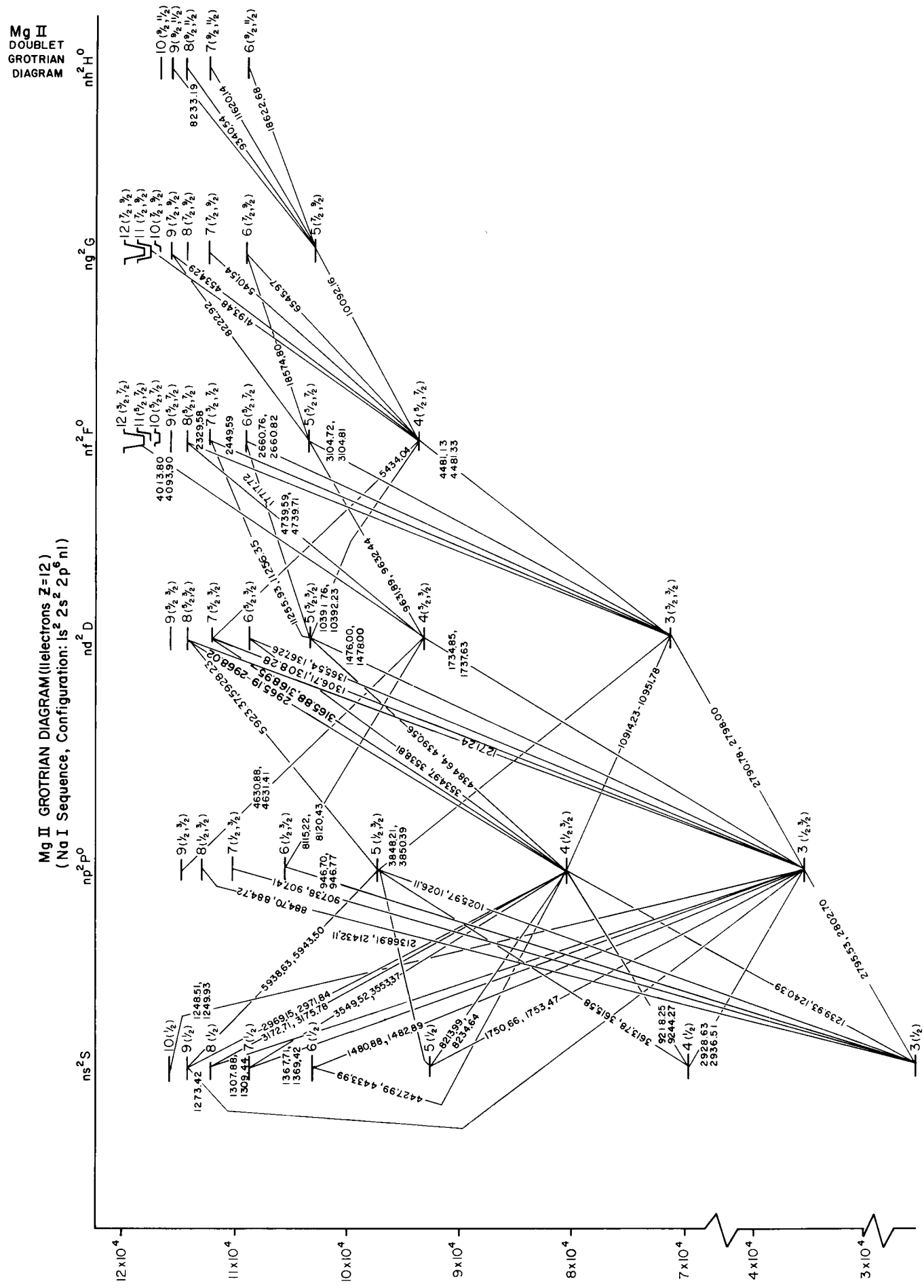
MgI GROTRIAN DIAGRAM (12 electrons, Z=12)
(Configuration: $1s^2 2s^2 2p^6 3snl$, Singlet and Triplet System)



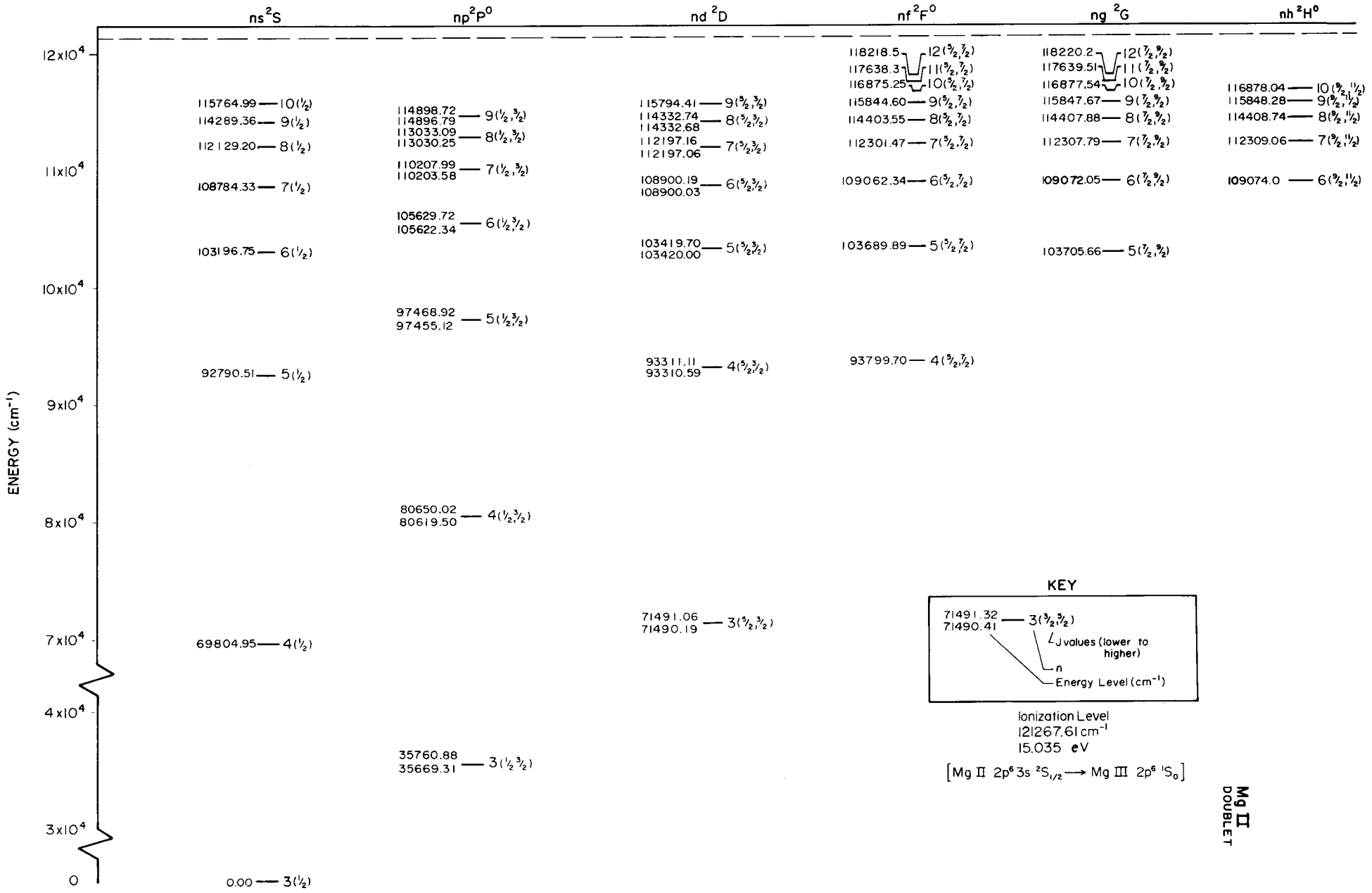
Mg I ENERGY LEVELS (12 electrons, Z=12)
(Configuration: $1s^2\,2s^2\,2p^6\,3snl$, Singlet and Triplet System)



Mg I
SINGLET
TRIPLET

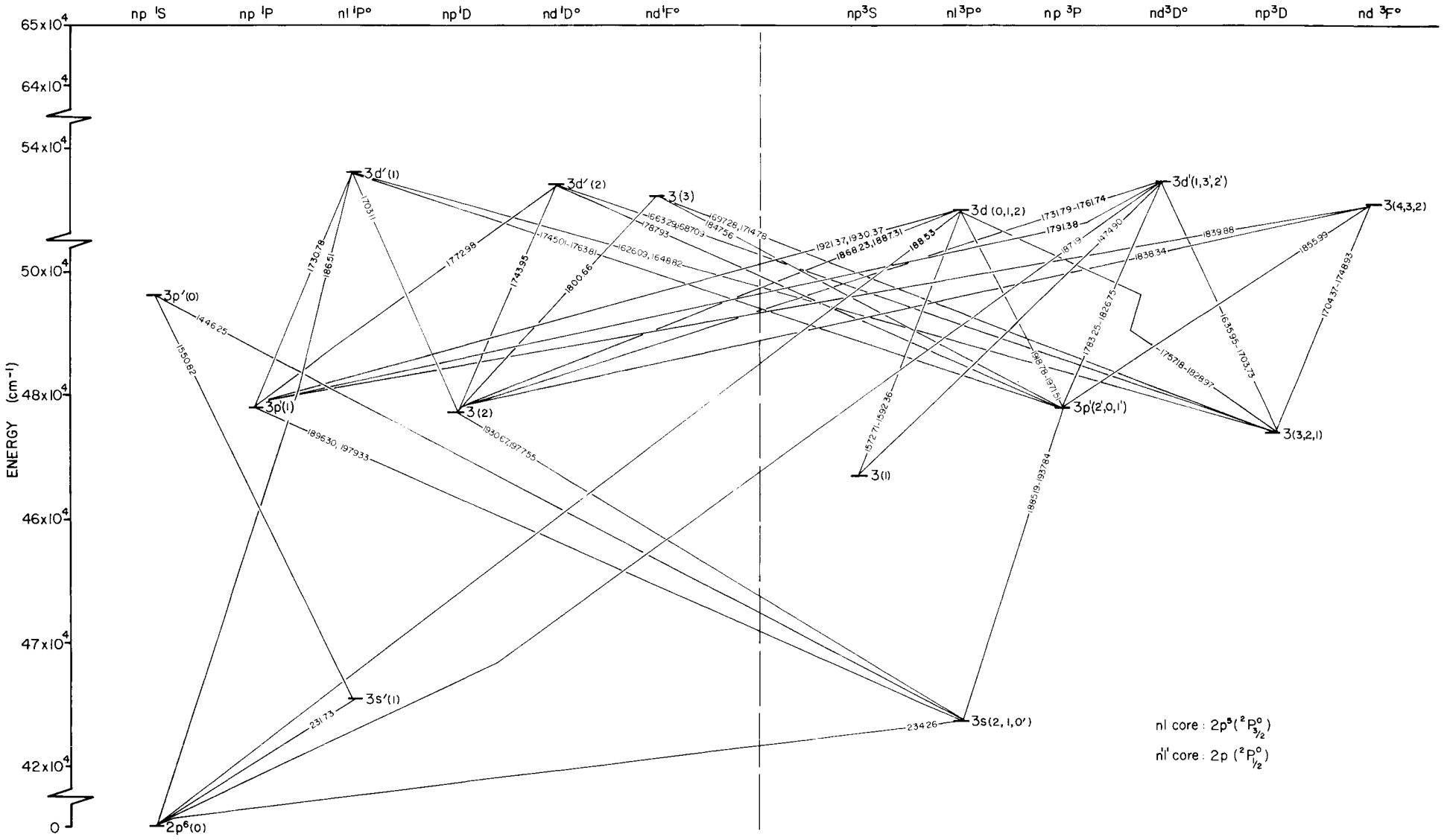

Mg II
DOUBLET
GROTRIAN
DIAGRAM
Mg II GROTRIAN DIAGRAM (11 electrons Z=12)
(Na I Sequence, Configuration: 1s² 2s² 2p⁶ nl)
ns²S
np²P°
nd²D
nf²F°
ng²G
nh²H°
12x10⁴
11x10⁴
10x10⁴
9x10⁴
8x10⁴
7x10⁴
4x10⁴
3x10⁴

Mg II ENERGY LEVELS (11 electrons, Z=12)
(Na I Sequence, Configuration: $1s^2\ 2s^2\ 2p^6\ nl$ Doublet)



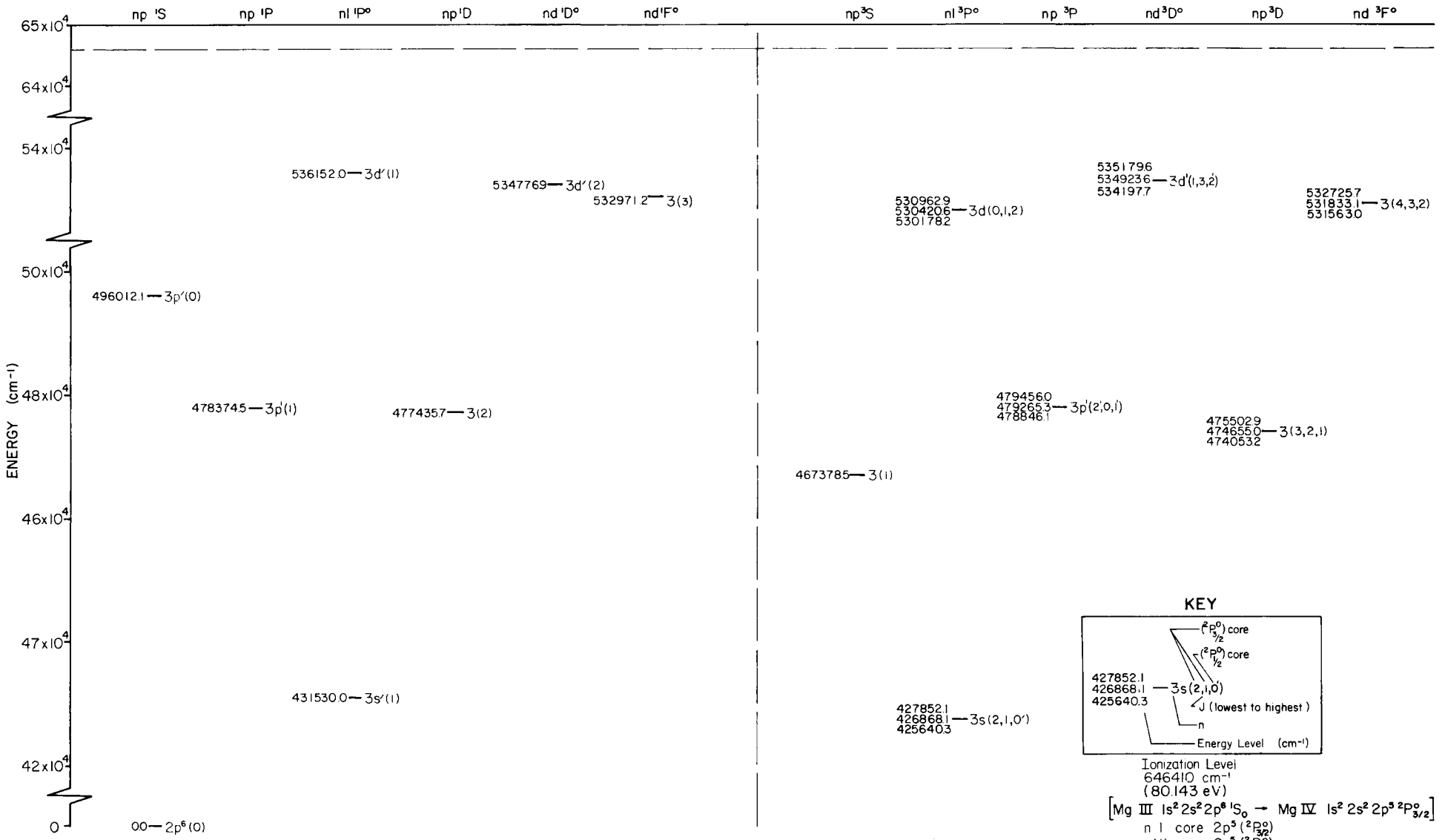
Mg III GROTRIAN DIAGRAM (10 electrons, Z=12)

(Ne I sequence, Configuration: $1s^2 2s^2 2p^5 nl$, Singlet & Triplet Terms)



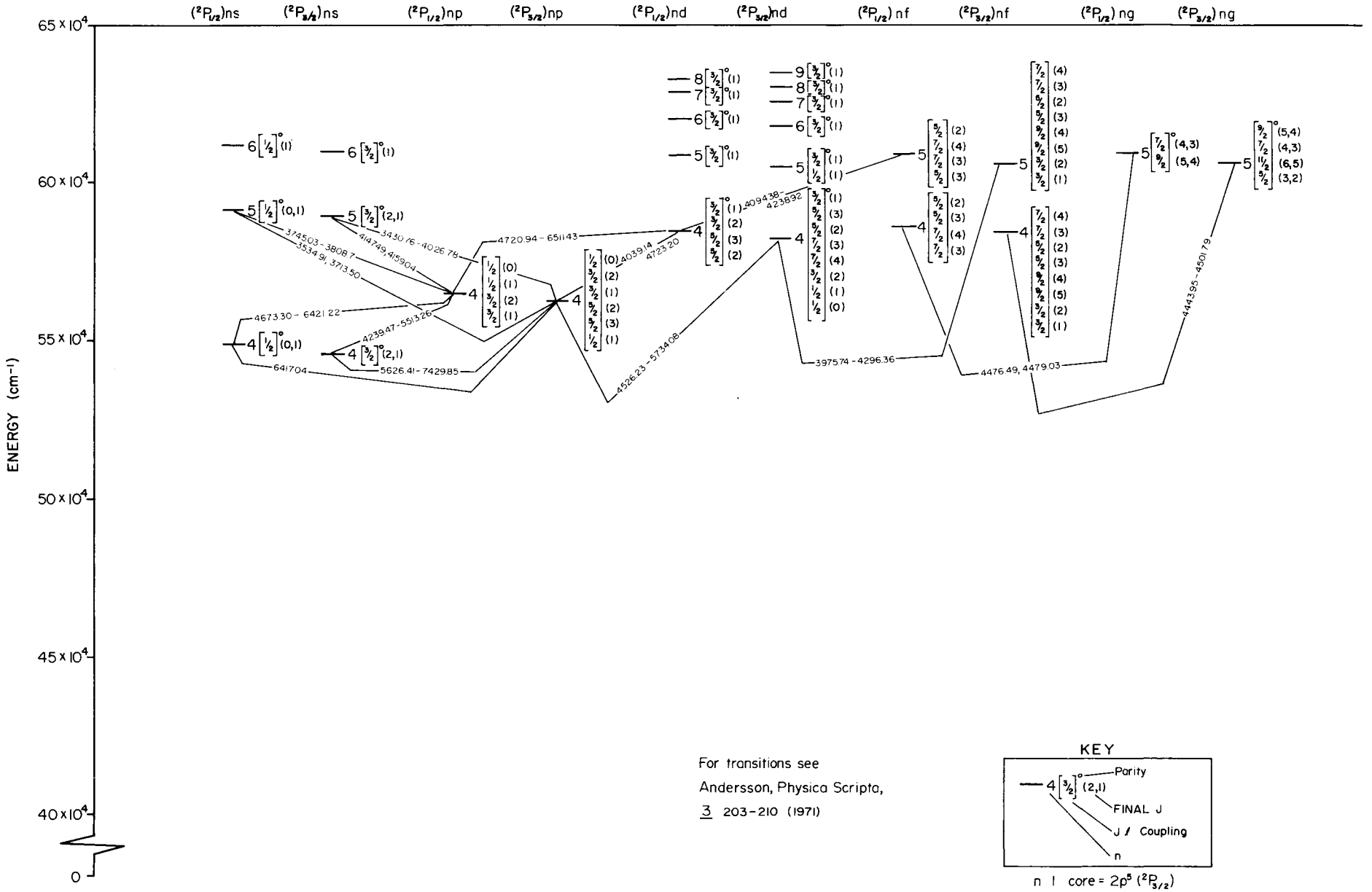
Mg III ENERGY LEVELS (10 electrons, Z = 12)

(Ne I sequence, Configuration: $1s^2 2s^2 2p^5 nl$, Singlet & Triplet Terms)



Mg III GROTRIAN DIAGRAM (10 electrons, Z = 12)

(Ne I sequence, Configuration: $1s^2\ 2s^2\ 2p^5\ nl$, Intermediate Coupling)



For transitions see
Andersson, Physica Scripta,
3 203-210 (1971)

KEY

$4\left[\frac{3}{2}\right]^{\circ}(2,1)$

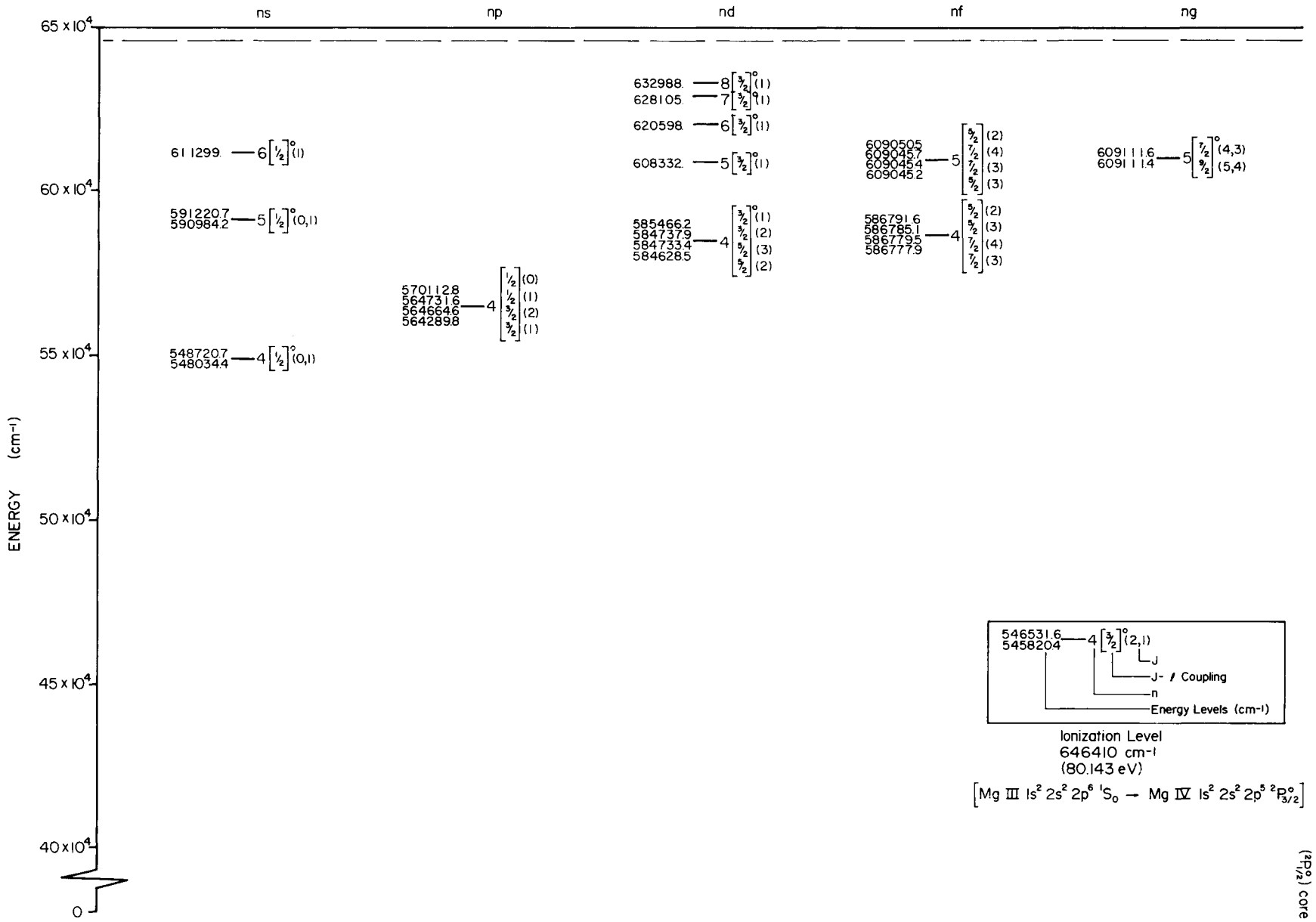
Parity
FINAL J
J / Coupling
n

n l core = $2p^5\ (^2P_{3/2})$

n′ l′ core = $2p^5\ (^2P_{1/2})$

Mg III ENERGY LEVELS (10 electrons, Z = 12)

(Ne I sequence, Intermediate Coupling, Configuration $1s^2 2s^2 2p^5 (^2P^o_{1/2}) n'l' [J, l]$ (J))



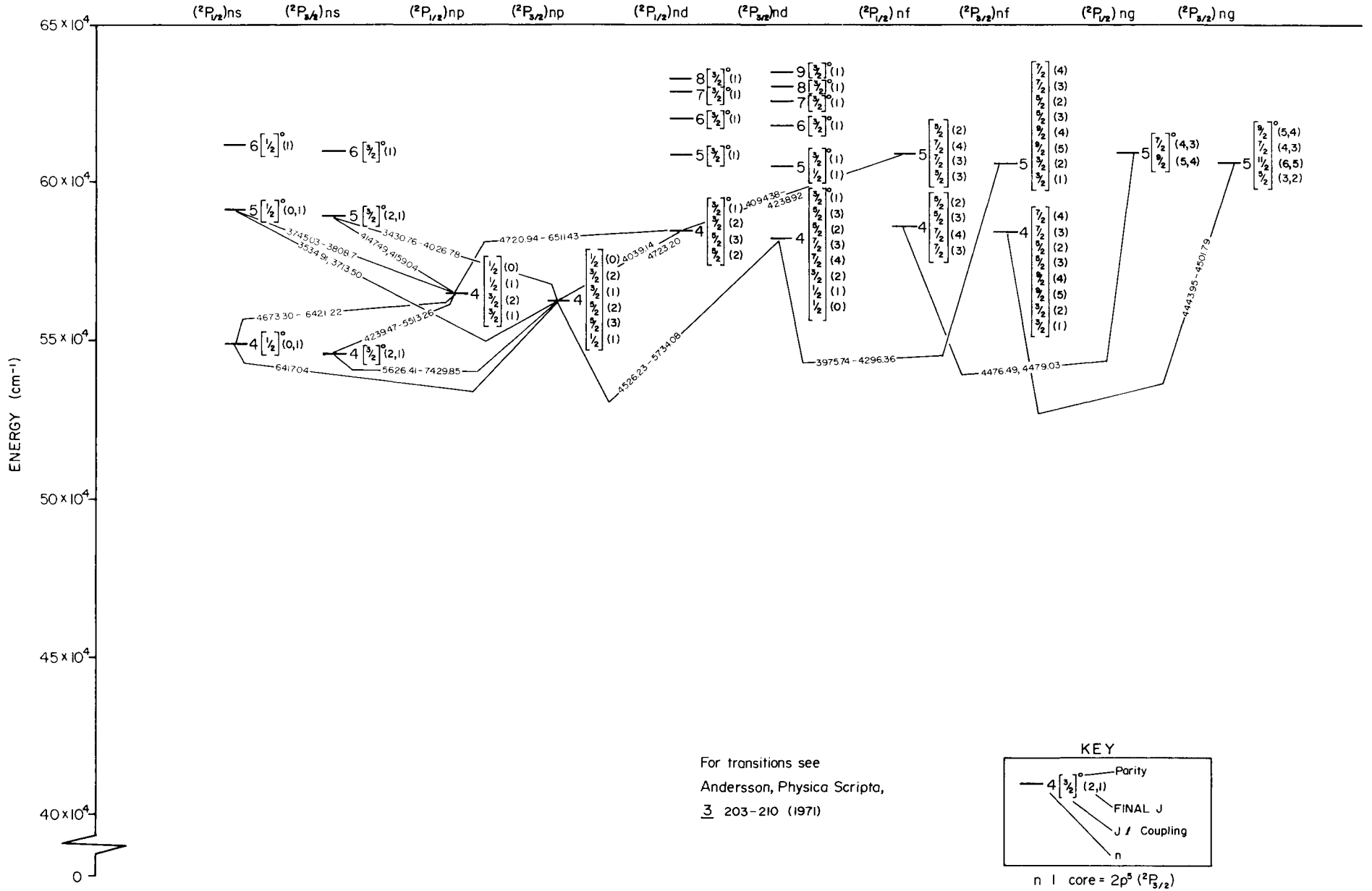
Ionization Level
646410 cm-1
(80.143 eV)

[Mg III $1s^2 2s^2 2p^6\ ^1S_0$ → Mg IV $1s^2 2s^2 2p^5\ ^2P^o_{3/2}$]

Mg III
INTERMEDIATE COUPLING
($^2P^o_{1/2}$) core

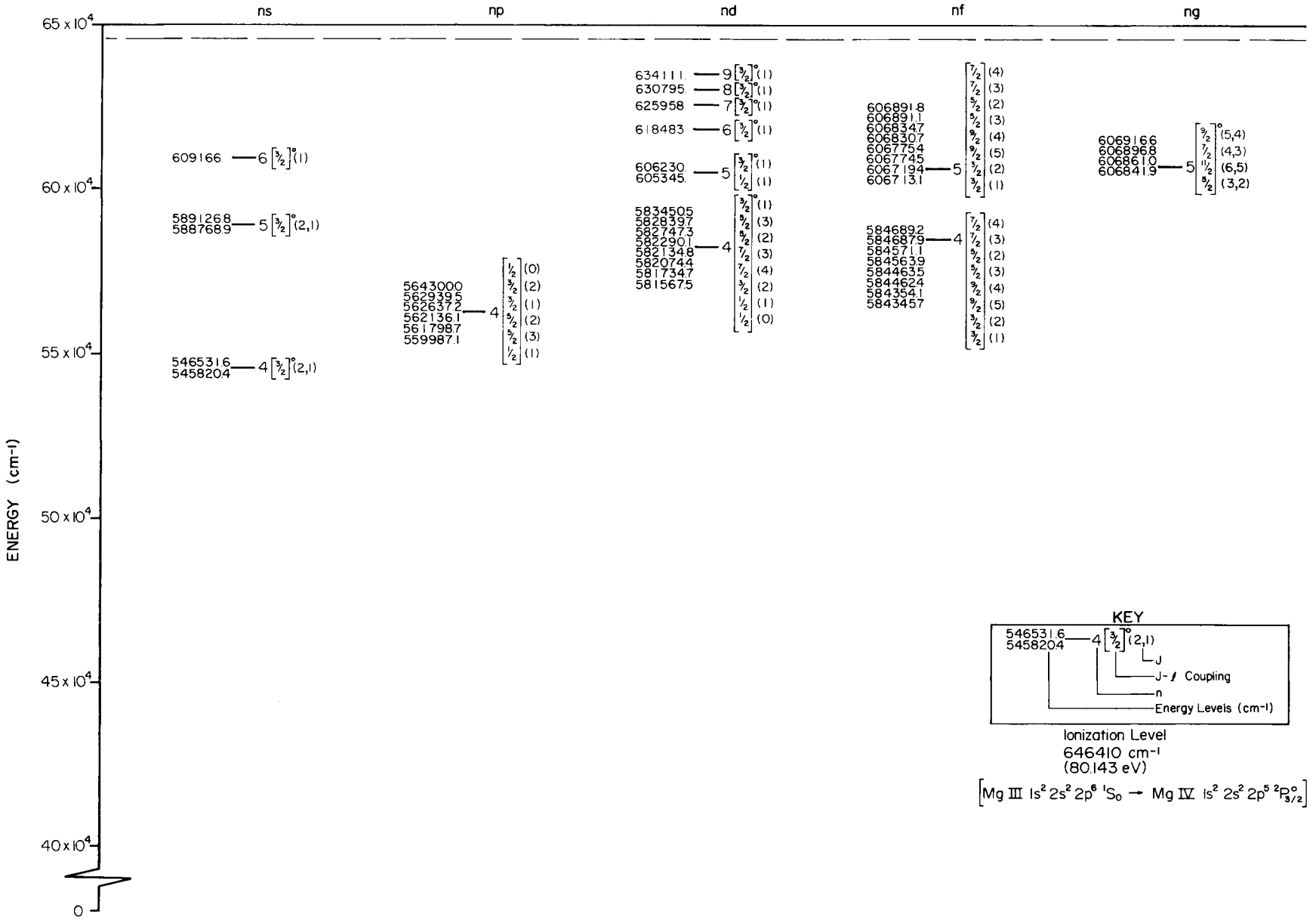
Mg III GROTRIAN DIAGRAM (10 electrons, Z = 12)

(Ne I sequence, Configuration: $1s^2\ 2s^2\ 2p^5\ nl$, Intermediate Coupling)



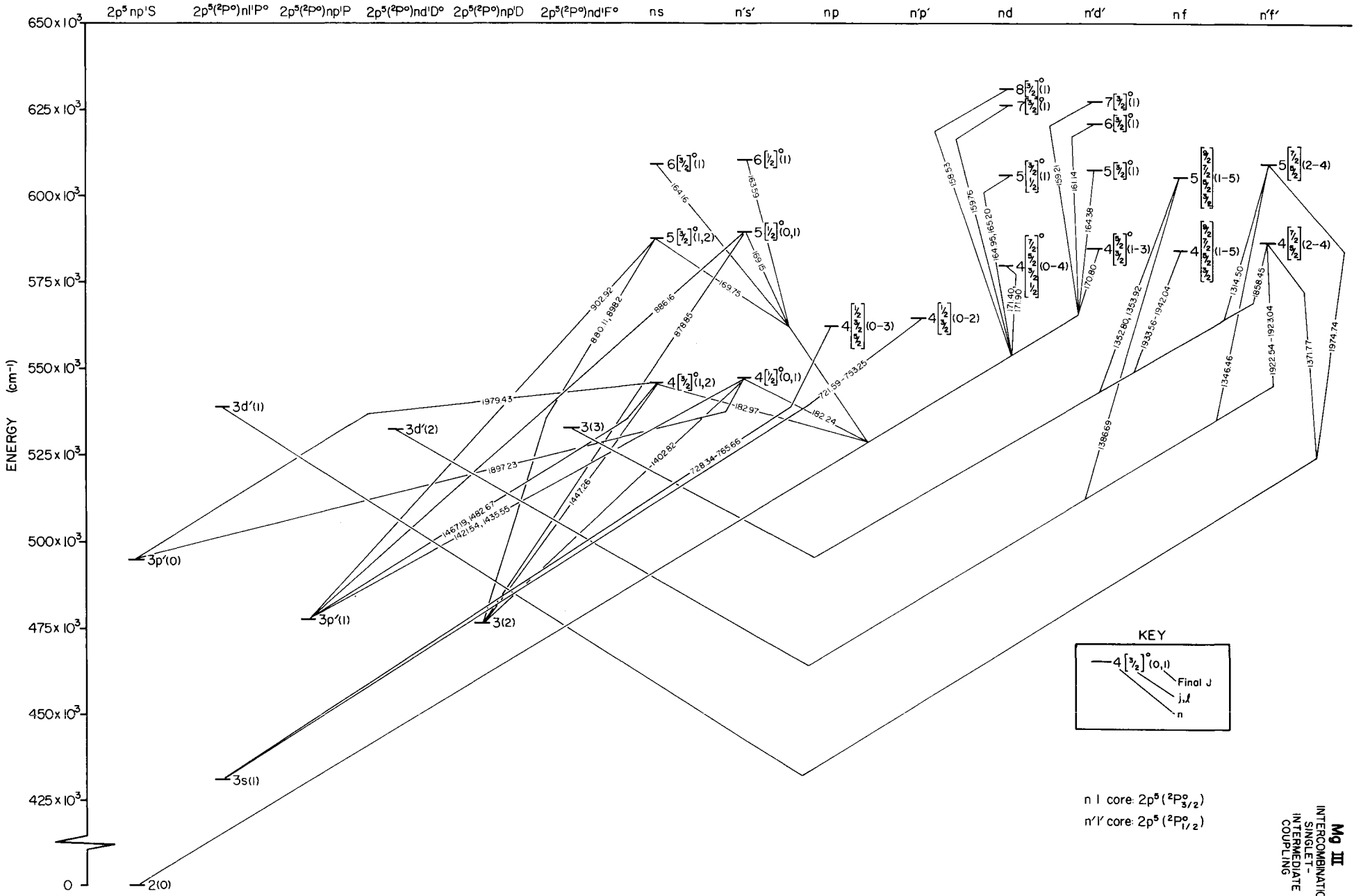
Mg III ENERGY LEVELS (10 electrons, Z=12)

(Ne I sequence, Intermediate Coupling, Configuration $1s^2 2s^2 2p^5 (^2P^o_{3/2}) n l [J, \ell] (J)$)



Mg III
INTERMEDIATE COUPLING
($^2P^o_{3/2}$) core

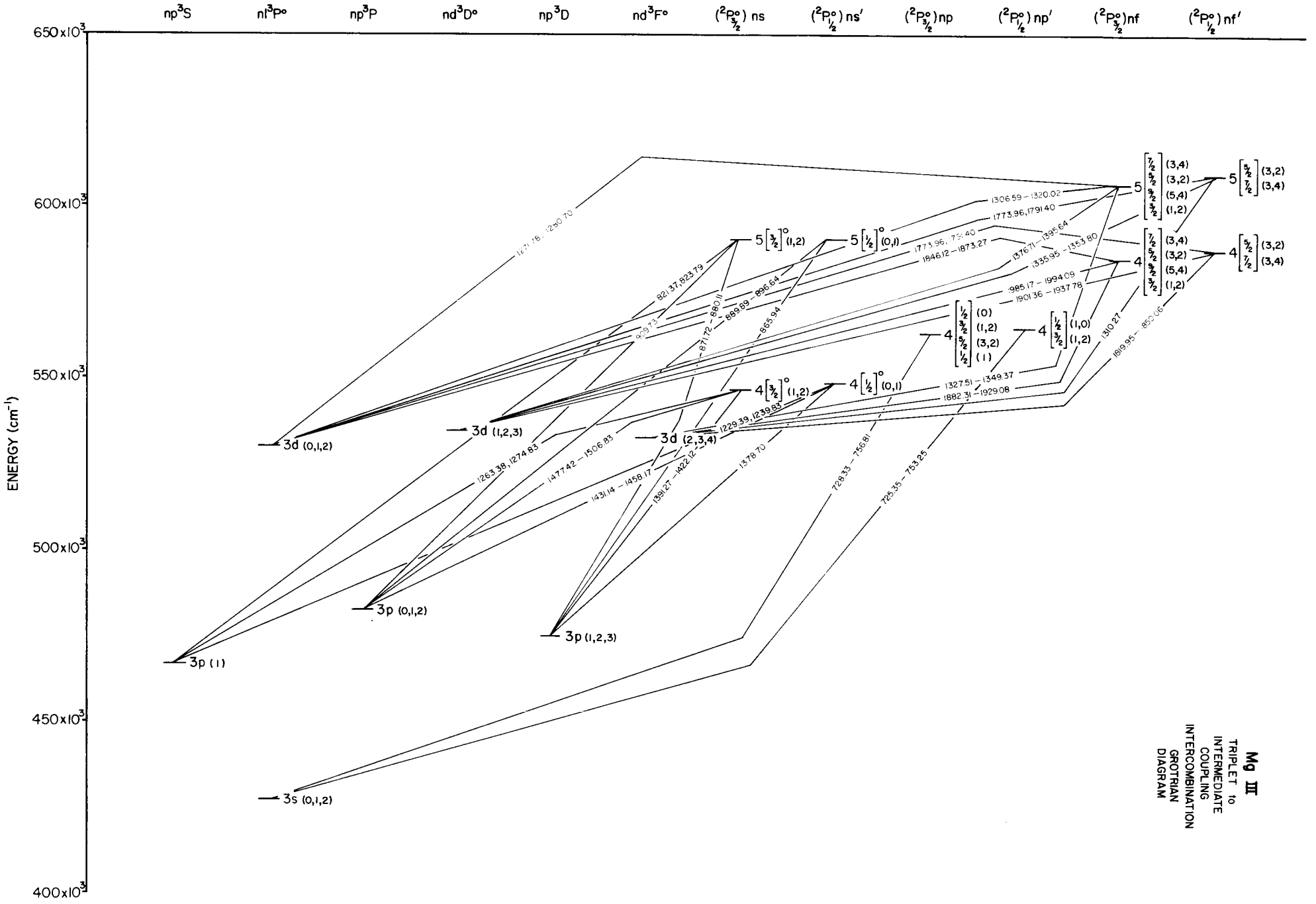
Mg III INTERCOMBINATION GROTRIAN DIAGRAM
(10 electrons Z=12)
(Ne I sequence, Intercombinations, Singlet to Intermediate Coupling)



Mg III
INTERCOMBINATION
SINGLET-
INTERMEDIATE
COUPLING

Mg III INTERCOMBINATION GROTRIAN DIAGRAM (10 electrons, Z = 12)

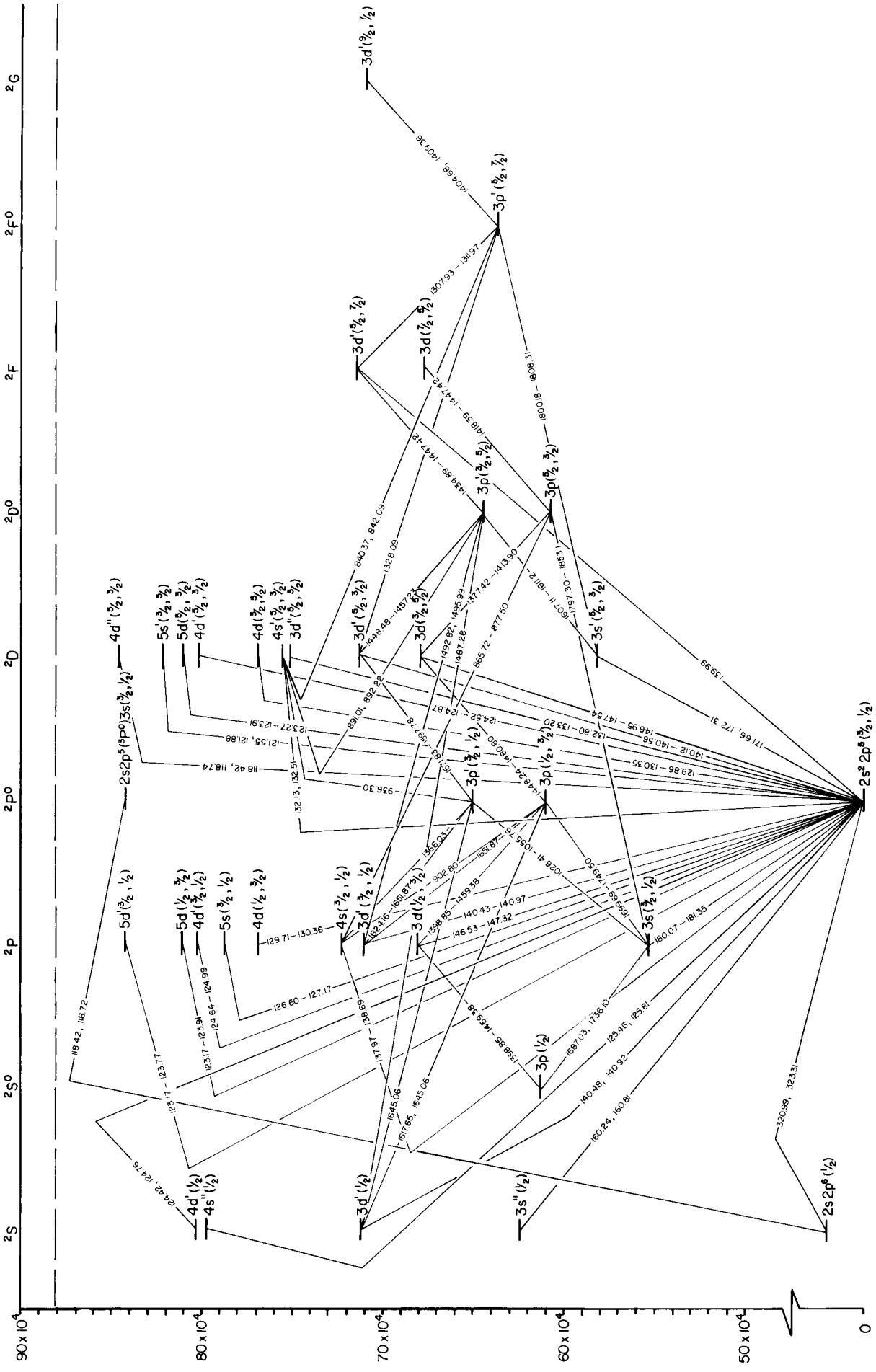
(Ne I sequence, Configuration: $1s^2 2s^2 2p^5\, nl\, {}^3L - 1s^2 2s^2 2p^5 ({}^2P^o) nl\, [j,l]\, (J)$, Triplet to Intermediate Coupling)



Mg III
TRIPLET to INTERMEDIATE COUPLING INTERCOMBINATION GROTRIAN DIAGRAM

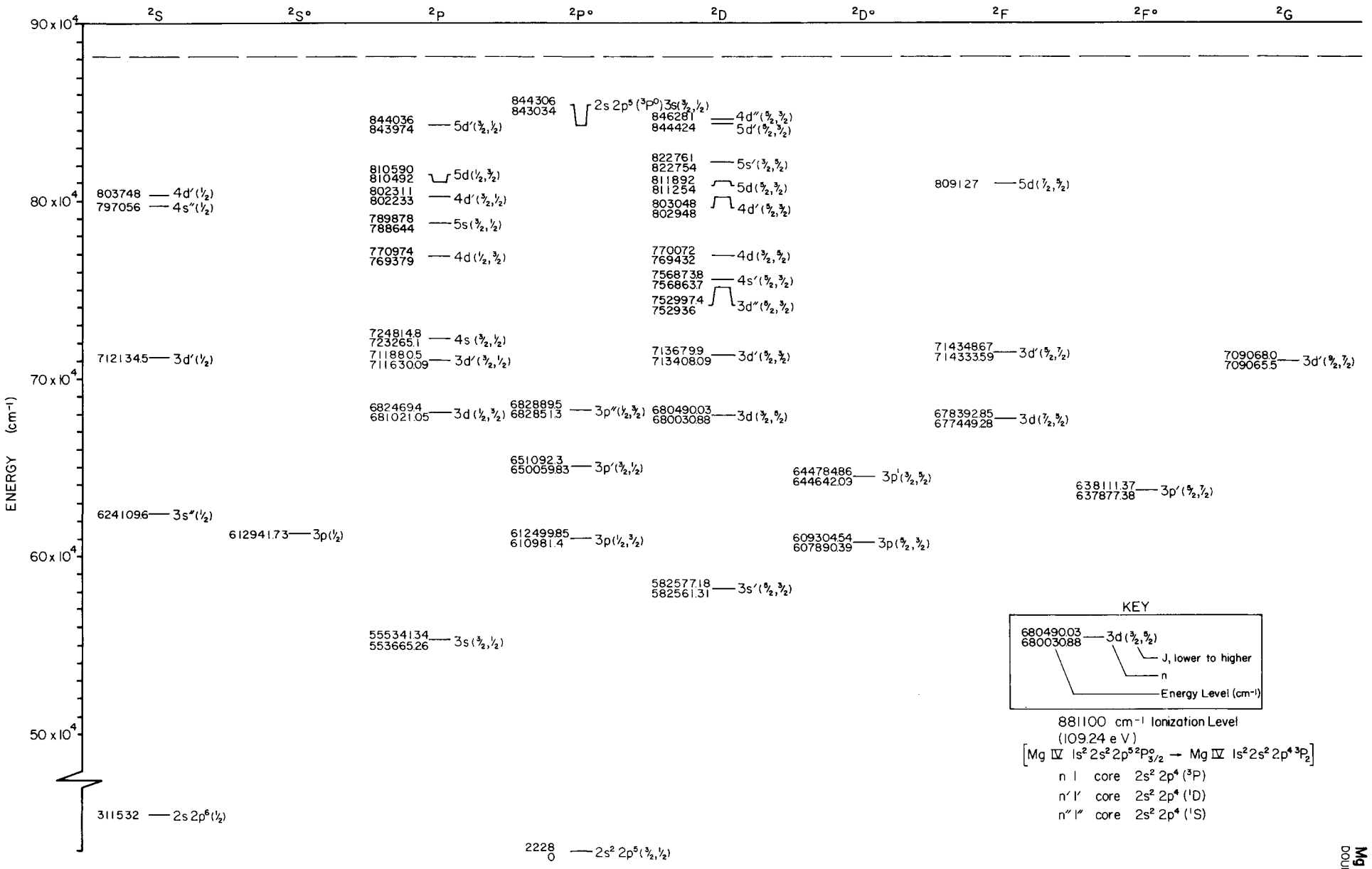
Mg IV
DOUBLET
GROTRIAN DIAGRAM

Mg IV GROTRIAN DIAGRAM (9 electrons, Z = 12)
(F I sequence, Configuration: $1s^2 2s^2 2p^6 nl$, Doublet System)

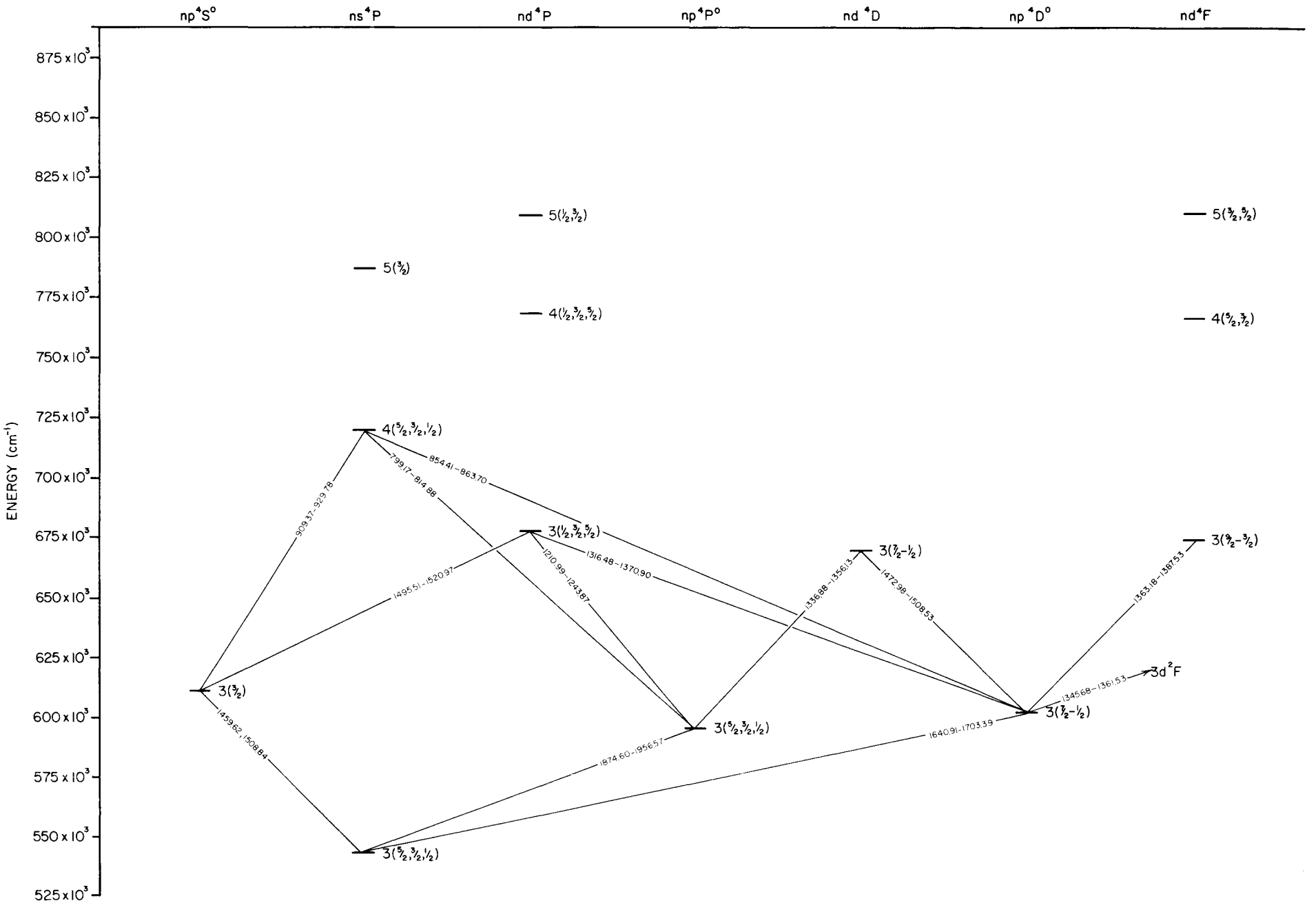


Mg IV ENERGY LEVEL (9 electrons, Z = 12)

(F I sequence, Configuration $1s^2 2s^2 2p^4 nl$, Doublet System)

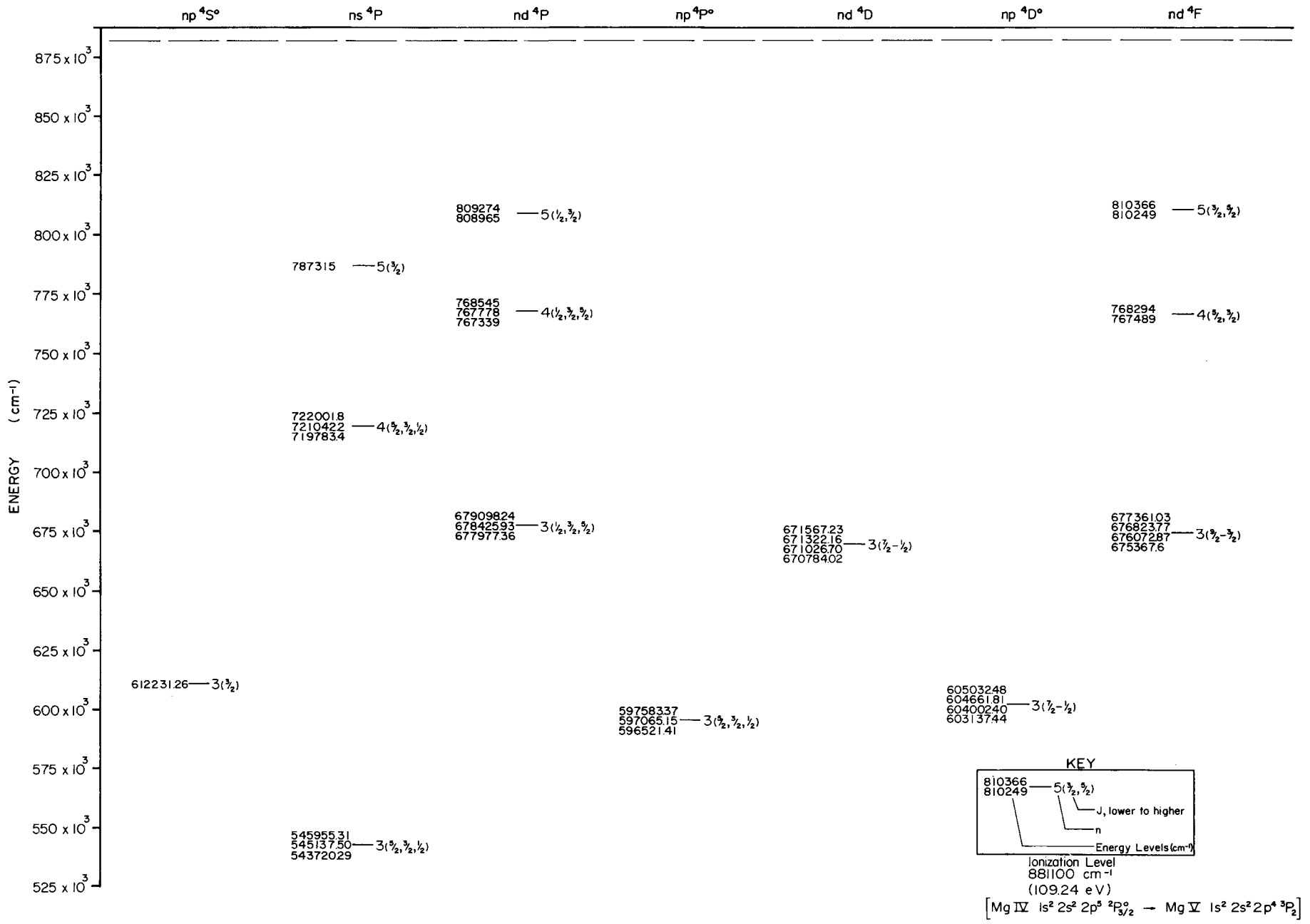


Mg IV GROTRIAN DIAGRAM (9 electrons, Z=12)
F I Sequence, Configuration $1s^2\ 2s^2\ 2p^4\ (^3P)\ nl$, Quartet System)

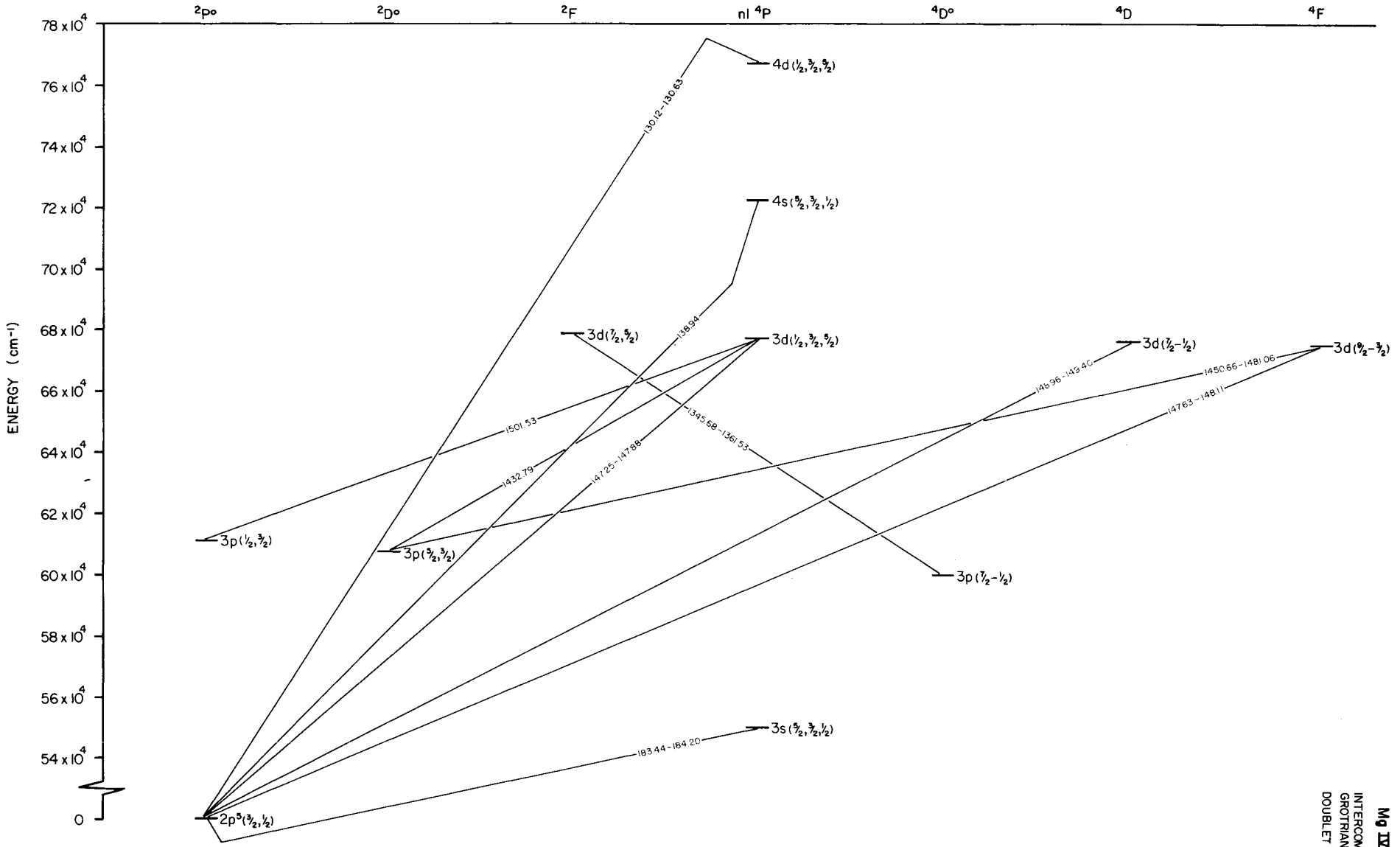


Mg IV ENERGY LEVELS (9 electrons, Z=12)

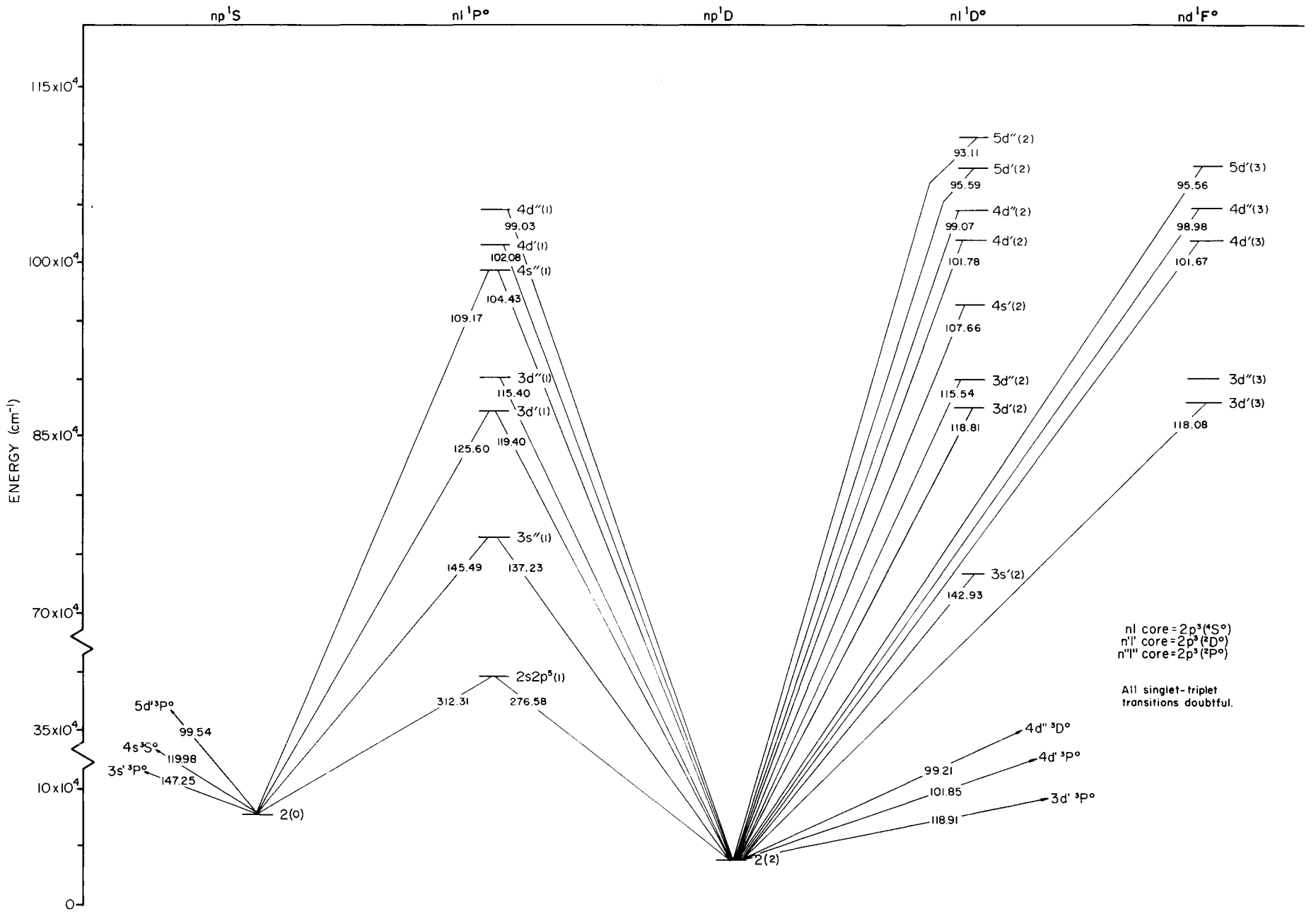
(F I sequence, Configuration $1s^2\,2s^2\,2p^4\,(^3P)\,nl$, Quartet System)



Mg IV INTERCOMBINATION GROTRIAN DIAGRAM (9 electrons, Z = 12)
F I sequence, Configuration: $2p^4(^3P)nl$, Doublet–Quartet System

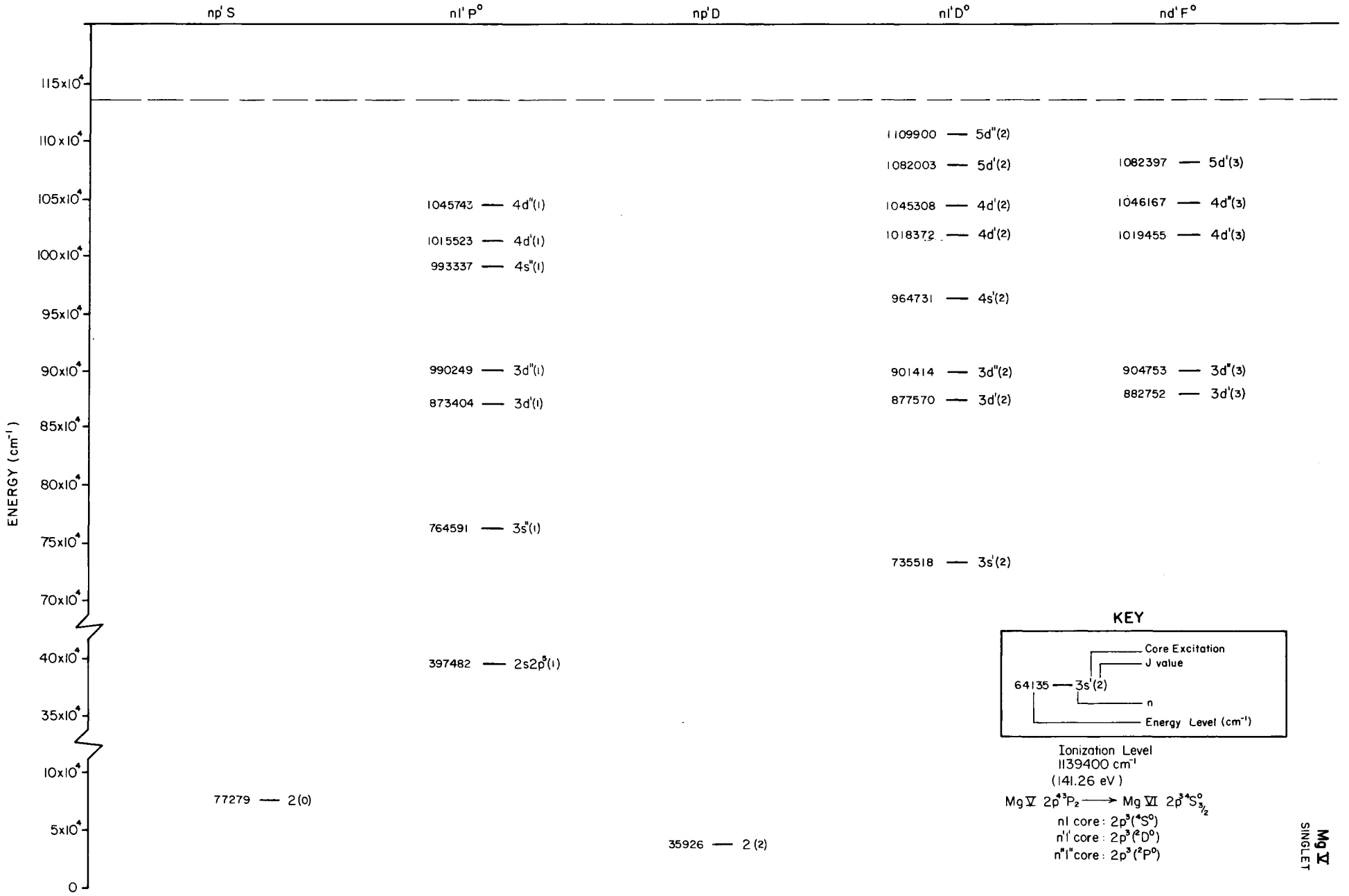


Mg V GROTRIAN DIAGRAM (8 electrons, Z=12)
(O I sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Singlet System)

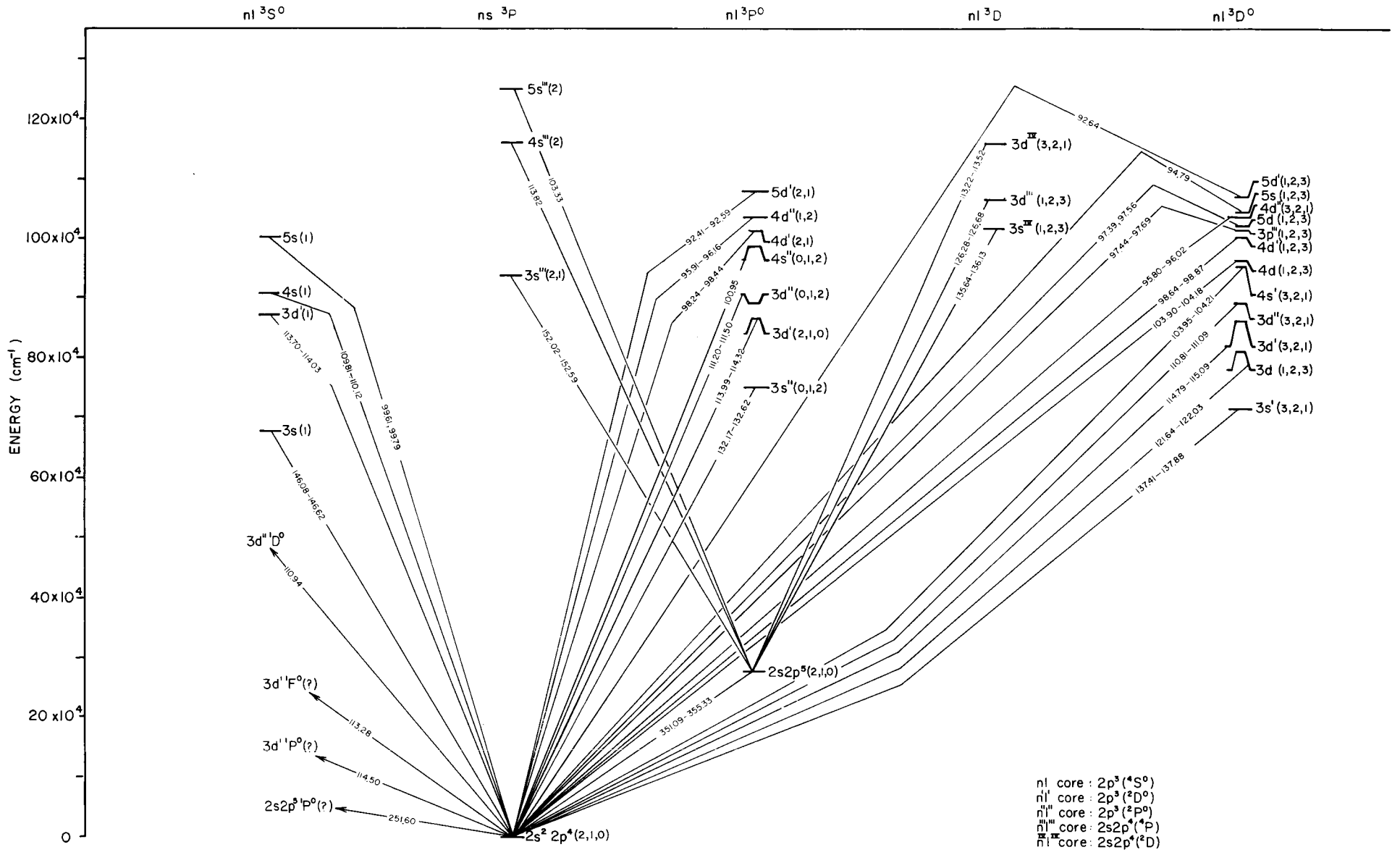


Mg V ENERGY LEVEL (8 electrons, Z=12)

(OI Sequence, Configuration $1s^2 2s^2 2p^3 nl$, Singlet Term System)

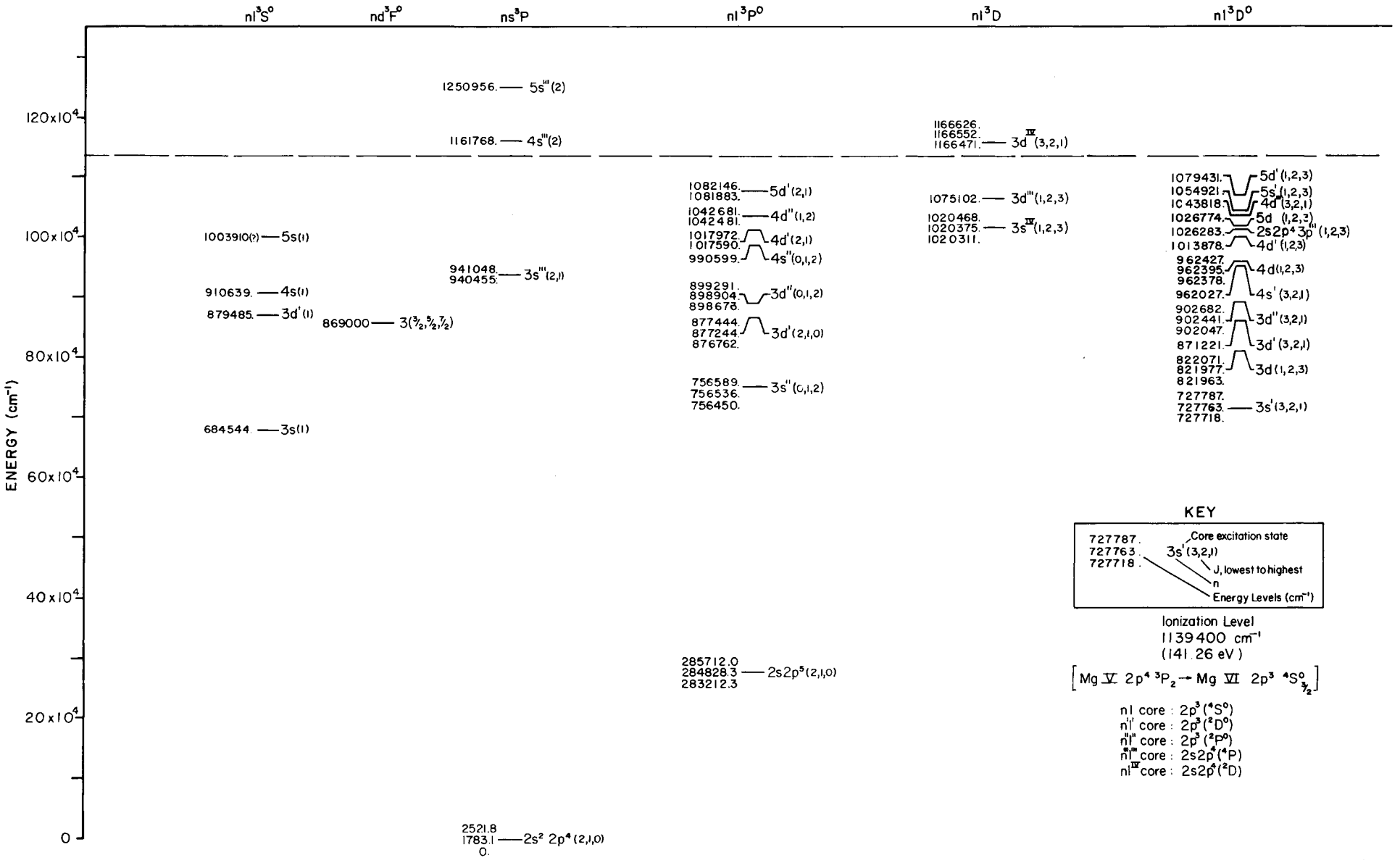


Mg V GROTRIAN DIAGRAM (8 electron, Z=12)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$ Triplet System)

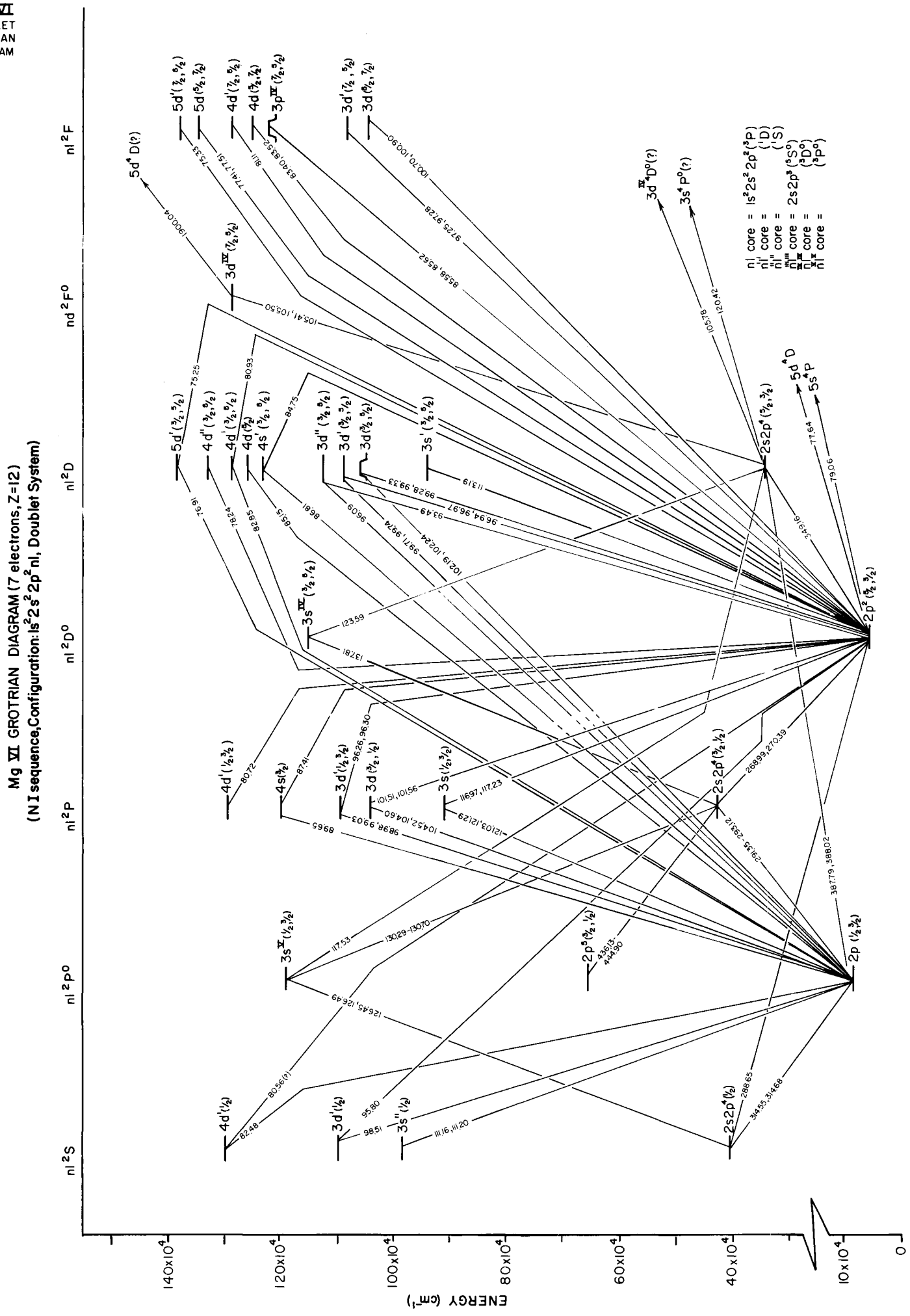


Mg V ENERGY LEVELS (8 electrons, Z=12)

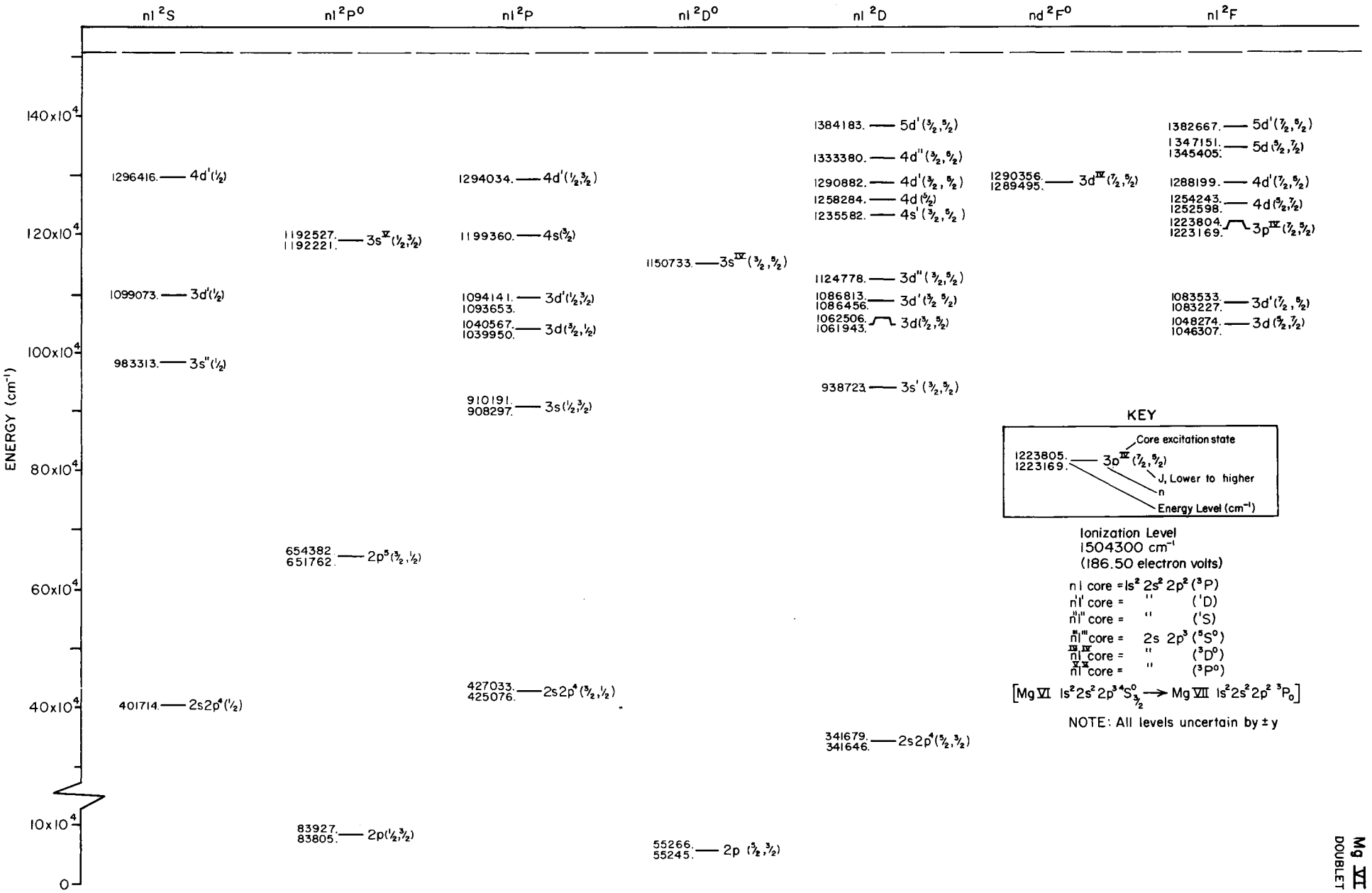
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)



Mg VI
DOUBLET
GROTRIAN
DIAGRAM

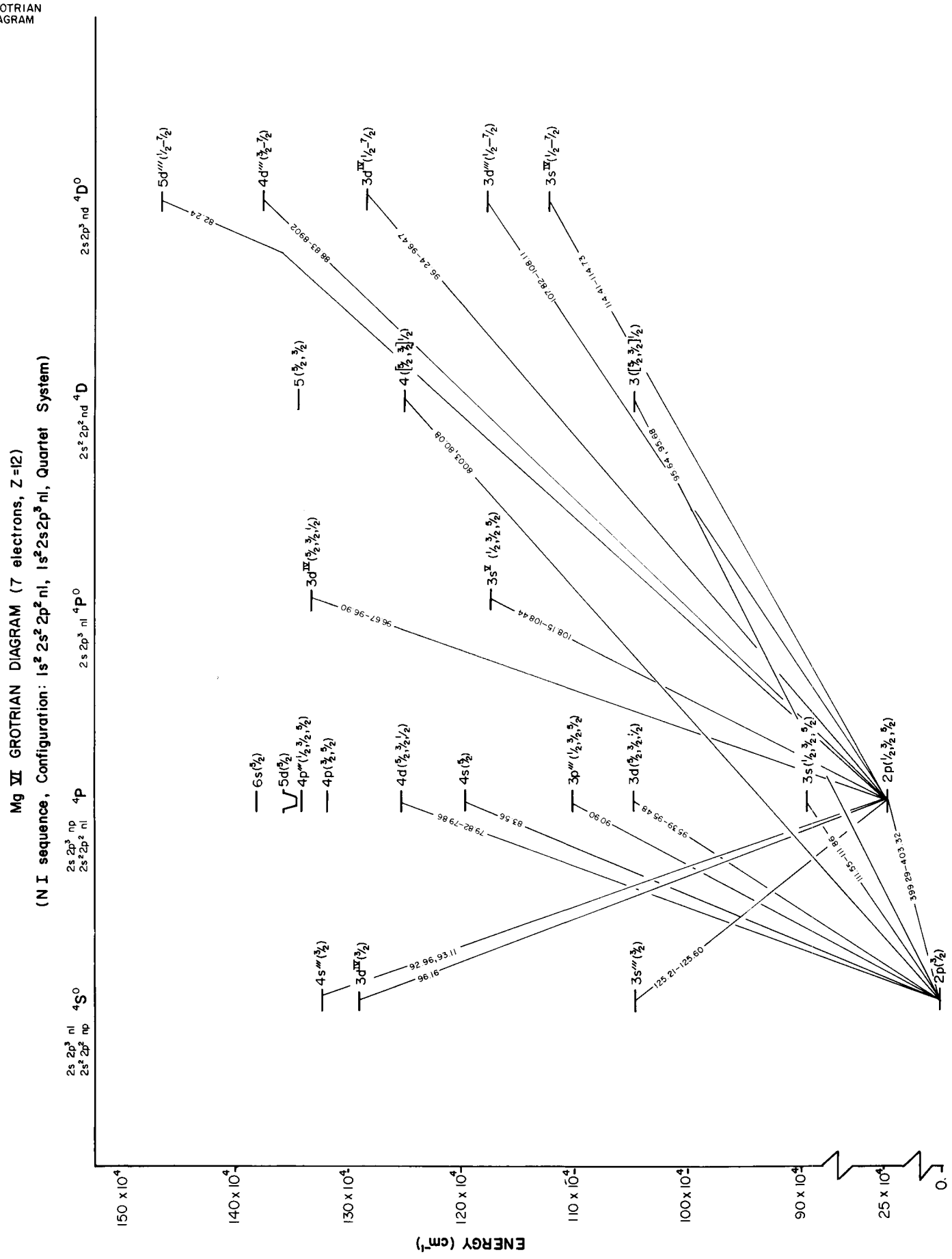


Mg VI ENERGY LEVELS (7 electrons, Z=12)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



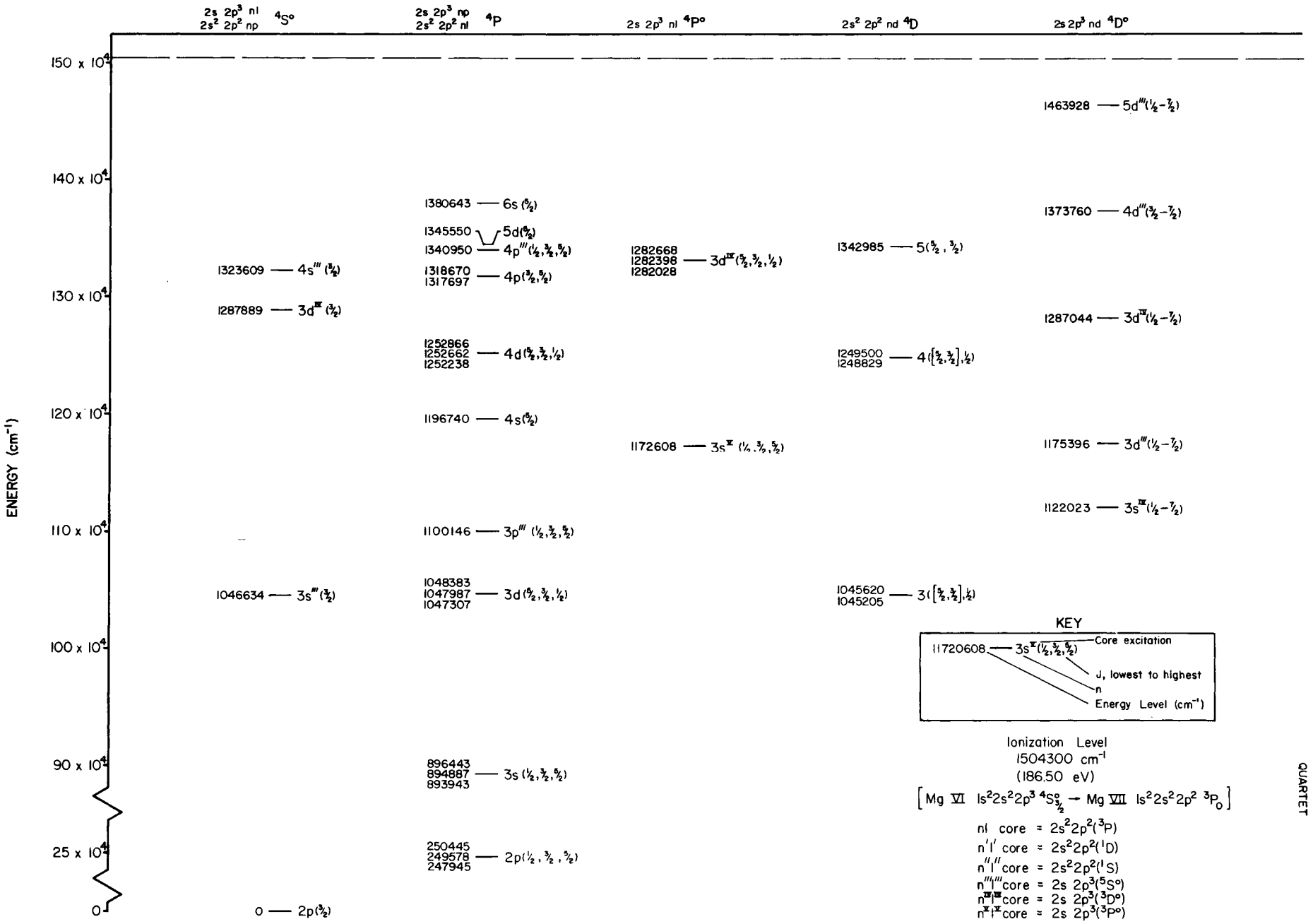
Mg VI

QUARTET
GROTRIAN
DIAGRAM



Mg VI ENERGY LEVELS (7 electrons, Z = 12)

(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, $1s^2 2s 2p^3 nl$, Quartet System)

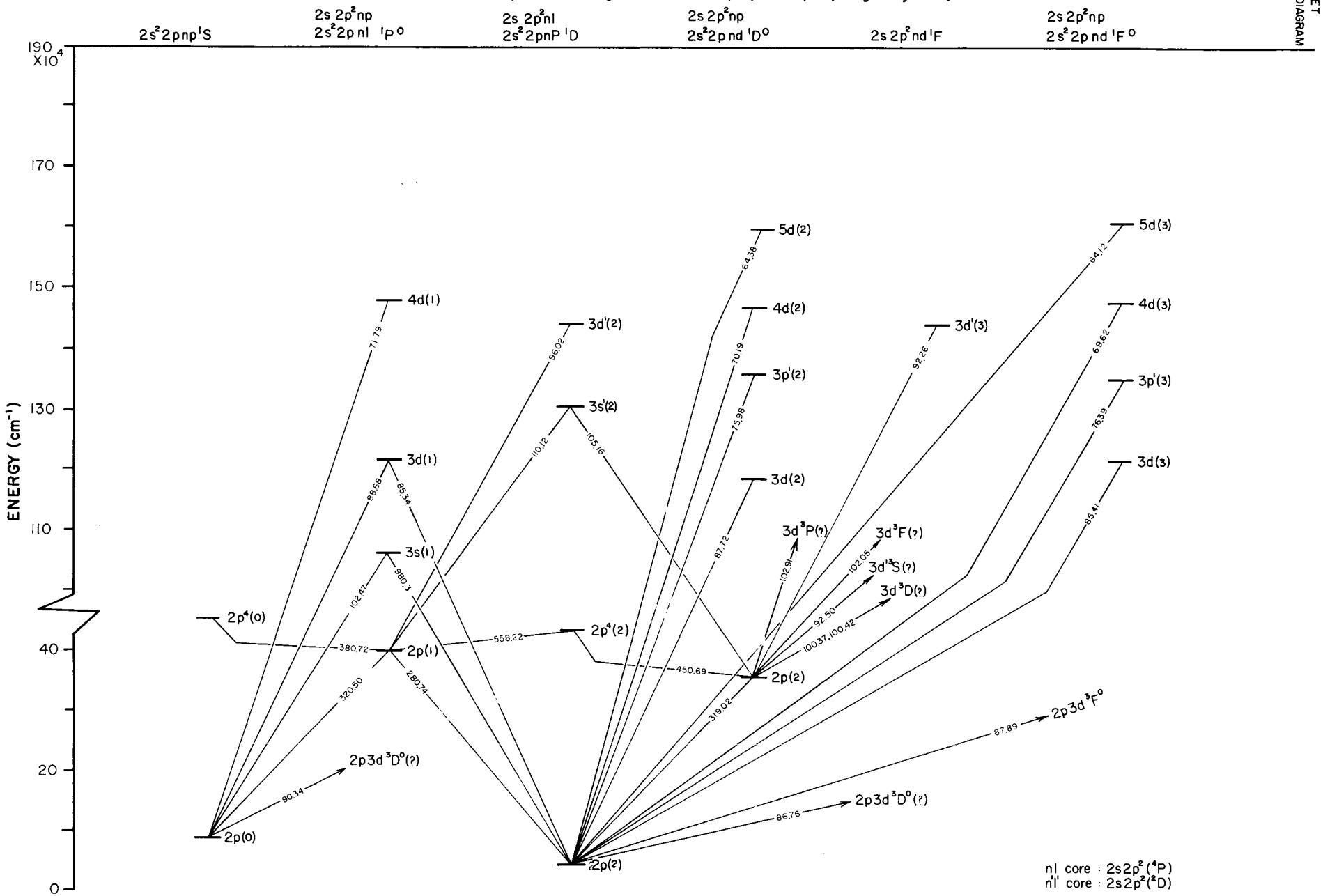


Ionization Level
1504300 cm⁻¹
(186.50 eV)

$[\text{Mg VI } 1s^2 2s^2 2p^3\ {}^4S^\circ_{3/2} \rightarrow \text{Mg VII } 1s^2 2s^2 2p^2\ {}^3P_0]$

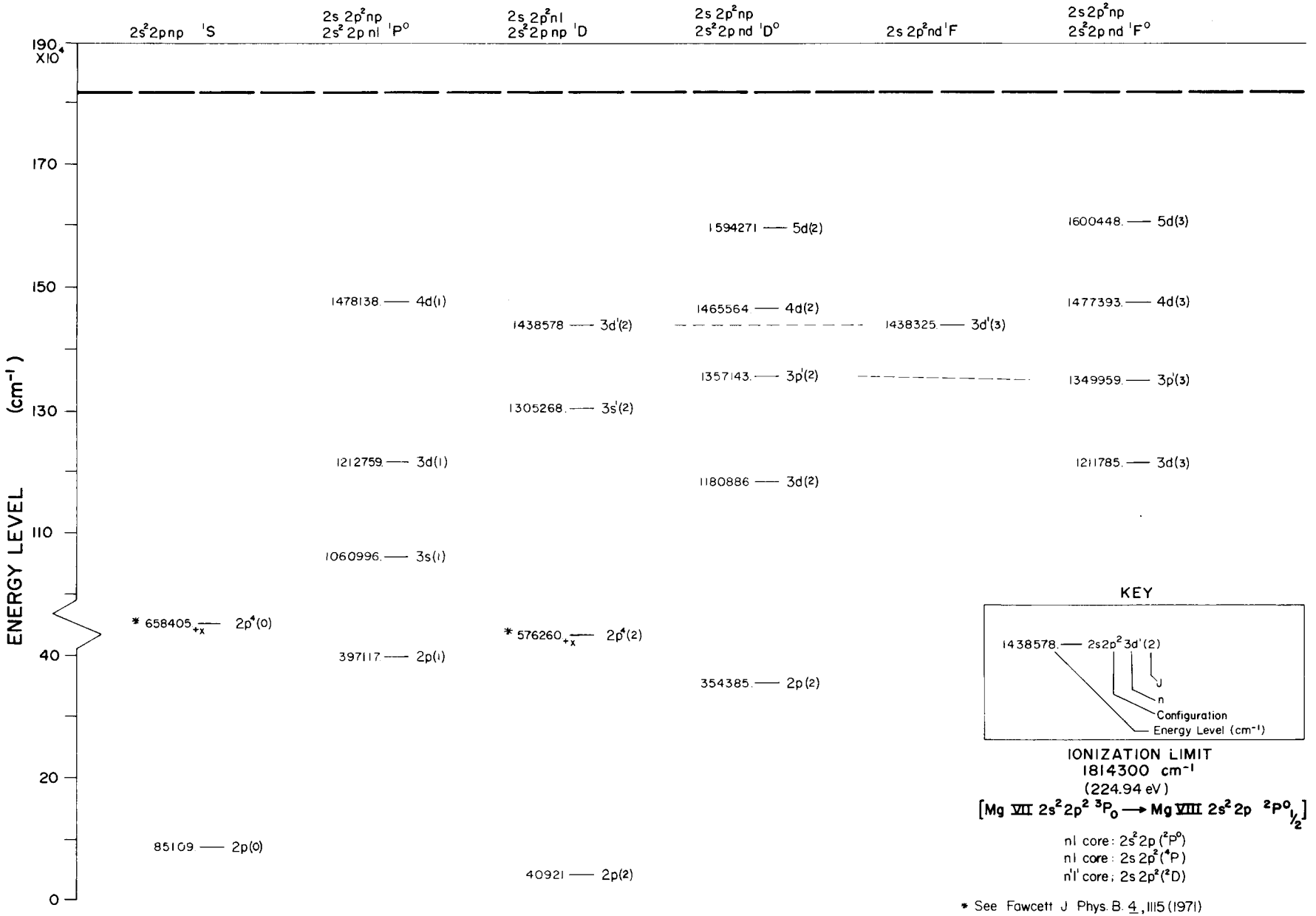
nl core = $2s^2 2p^2 ({}^3P)$
$n'l'$ core = $2s^2 2p^2 ({}^1D)$
$n''l''$ core = $2s^2 2p^2 ({}^1S)$
$n'''l'''$ core = $2s\ 2p^3 ({}^5S^\circ)$
$n^{IV}l^{IV}$ core = $2s\ 2p^3 ({}^3D^\circ)$
$n^{V}l^{V}$ core = $2s\ 2p^3 ({}^3P^\circ)$

Mg VII GROTRIAN DIAGRAM (6 electrons, Z=12)
(C I Sequence Configuration $1s^2 2s^2 2pnl$, $1s^2 2s 2p^2 nl$, Singlet System)



Mg VII ENERGY LEVELS (6 electrons, Z = 12)

(CI Sequence, Configuration: $1s^2 2s^2 2p\,nl$, $1s^2 2s 2p^2\,nl$ Singlet System)

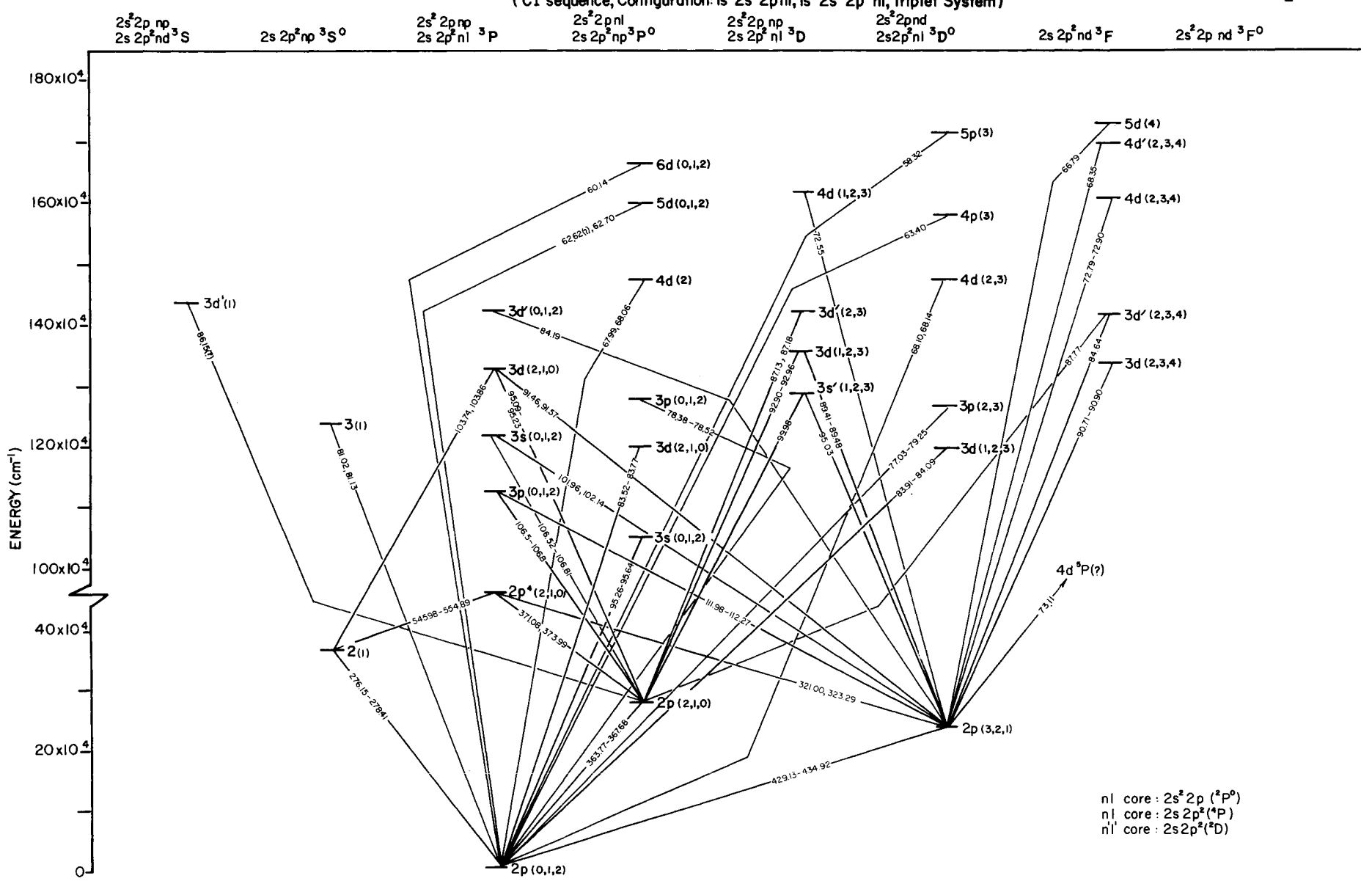


IONIZATION LIMIT
1814300 cm⁻¹
(224.94 eV)
[Mg VII $2s^2 2p^2\ ^3P_0$ ⟶ Mg VIII $2s^2 2p\ ^2P^o_{1/2}$]

nl core: $2s^2 2p\,(^2P^o)$
nl core: $2s\,2p^2\,(^4P)$
n'l' core: $2s\,2p^2\,(^2D)$

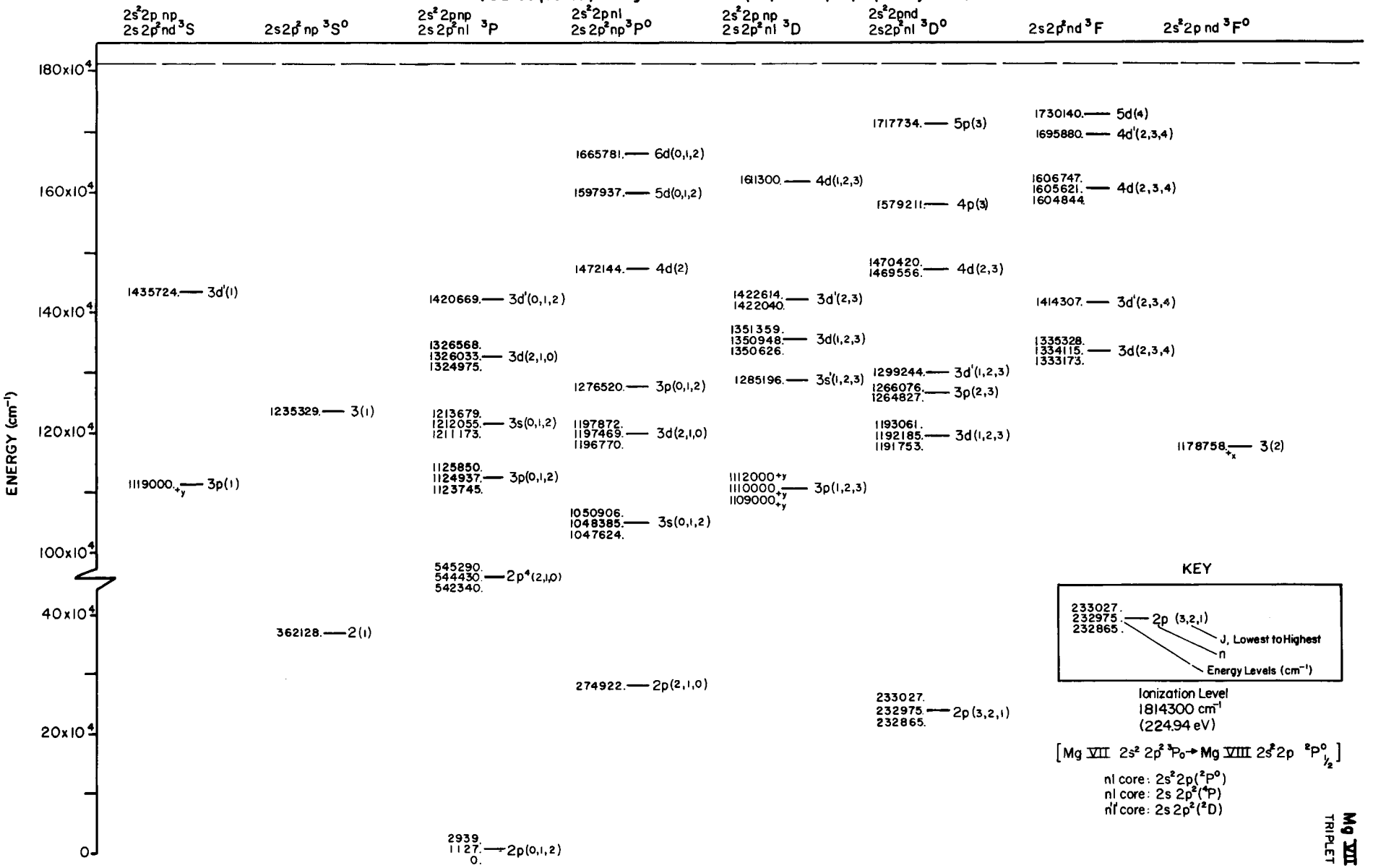
* See Fawcett J Phys. B. 4, 1115 (1971)

NOTE: ALL LEVELS UNCERTAIN BY ± y

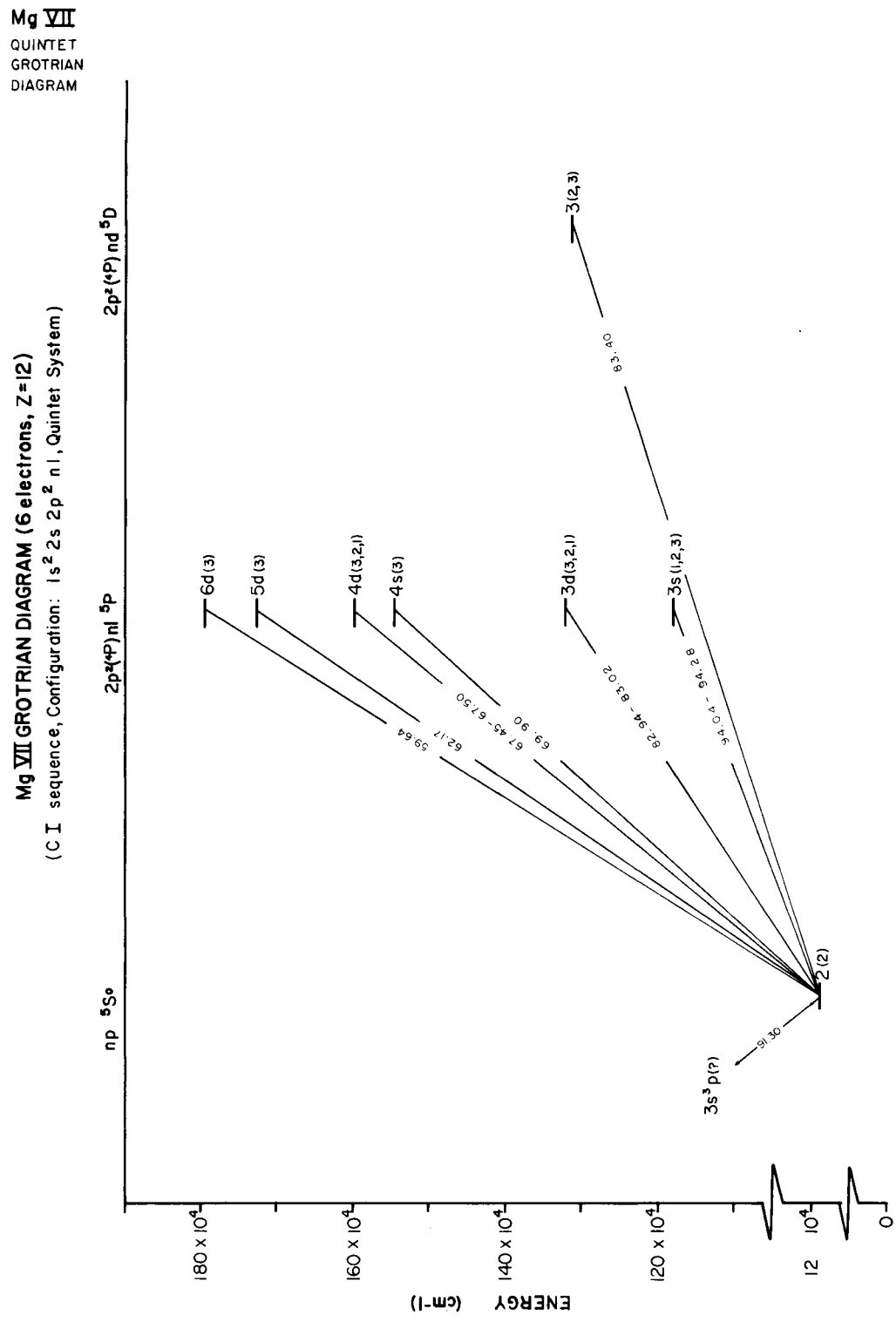

Mg VII GROTRIAN DIAGRAM (6 electrons, Z=12)
(CI sequence, Configuration: 1s²2s²2p nl, 1s²2s 2p² nl, Triplet System)
2s²2p np 2s 2p²nd ³S
2s 2p²np ³S°
2s²2p np 2s 2p²nl ³P
2s²2p nl 2s 2p²np ³P°
2s²2p np 2s 2p²nl ³D
2s²2p nd 2s2p²nl ³D°
2s 2p²nd ³F
2s²2p nd ³F°
ENERGY (cm⁻¹)
180x10⁴
160x10⁴
140x10⁴
120x10⁴
100x10⁴
40x10⁴
20x10⁴
0
3d'(1)
3(1)
2(1)
6d (0,1,2)
5d(0,1,2)
4d (2)
3d'(0,1,2)
3d (2,1,0)
3s'(0,1,2)
3p (0,1,2)
2p⁴(2,1,0)
2p (0,1,2)
4d (1,2,3)
3d'(2,3)
3d(1,2,3)
3s'(1,2,3)
3p (0,1,2)
3d (2,1,0)
3s (0,1,2)
2p (2,1,0)
5p(3)
4p(3)
4d (2,3)
3p(2,3)
3d(1,2,3)
2p (3,2,1)
5d (4)
4d'(2,3,4)
4d (2,3,4)
3d'(2,3,4)
3d (2,3,4)
4d ⁵P(?)
nl core : 2s²2p (²P°)
nl core : 2s2p²(⁴P)
nl' core : 2s2p²(²D)

Mg VII ENERGY LEVELS (6 electrons, Z = 12)

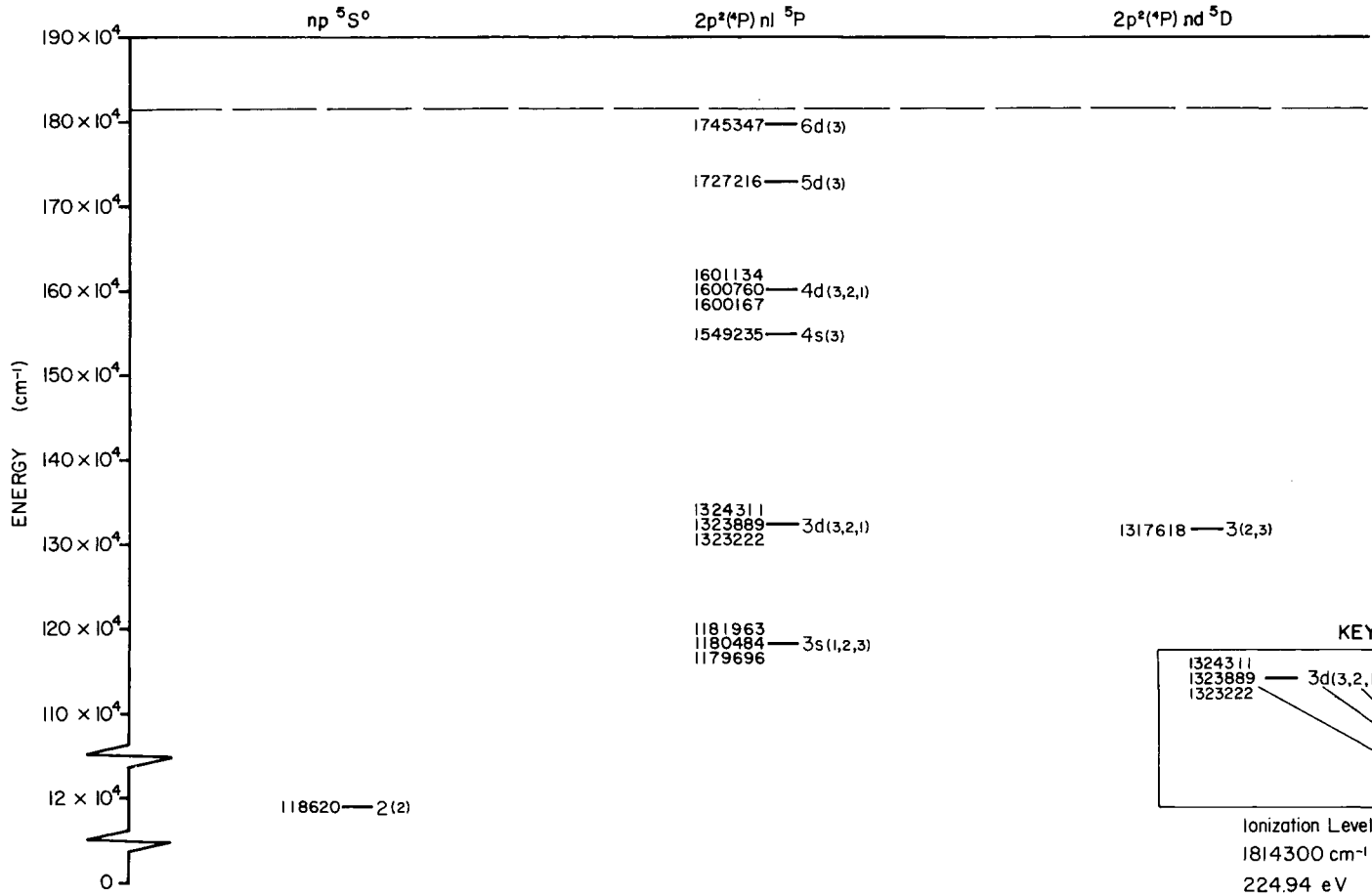
(C I Sequence, Configuration: $1s^2 2s^2 2pnl$, $1s^2 2s\,2p^2 nl$, Triplet System)



Mg VII
TRIPLET


Mg VII
QUINTET
GROTRIAN
DIAGRAM
Mg VII GROTRIAN DIAGRAM (6 electrons, Z=12)
(C I sequence, Configuration: 1s² 2s 2p² n l, Quintet System)
np ⁵S₀
2p²(⁴P)nl ⁵P
2p²(⁴P)nd ⁵D
6d(3)
5d(3)
4d(3,2,1)
4s(3)
3d(3,2,1)
3s(1,2,3)
3(2,3)
2(2)
3s³p(?)
59.64
62.17
67.45-67.50
69.90
82.94-83.02
94.04-94.28
83.40
96.16
180 x 10⁴
160 x 10⁴
140 x 10⁴
120 x 10⁴
12 10⁴
0
ENERGY (cm-1)

Mg VII ENERGY LEVELS (6 electrons, Z=12)
(C I sequence, Configuration: $1s^2 2s\, 2p^2\, nl$, Quintet System)

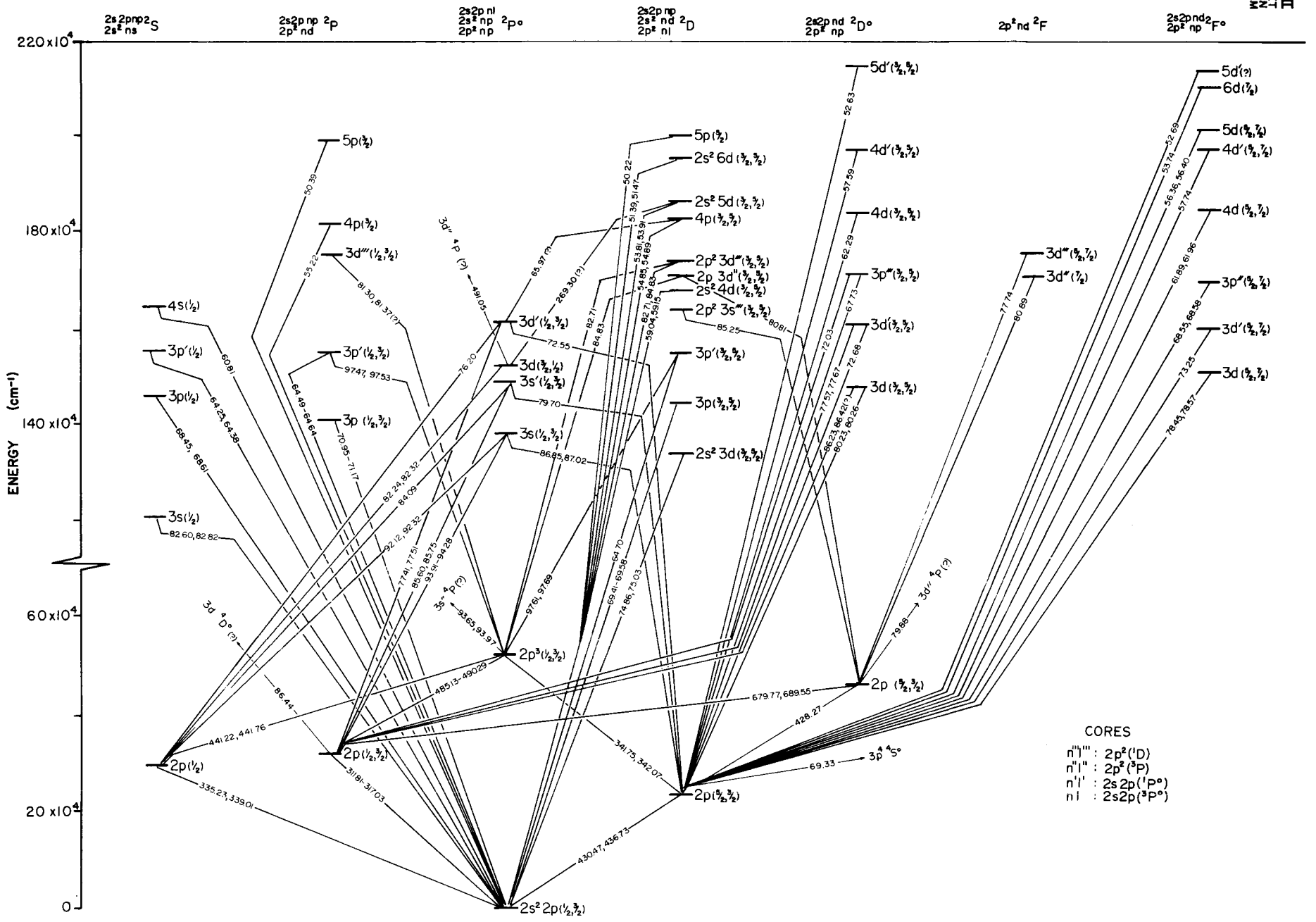


Ionization Level
1814300 cm^{-1}
224.94 eV
[Mg VII $1s^2 2s^2 2p^2\ ^3P_0$ → Mg VIII $1s^2 2s^2 2p\ ^2P^o_{1/2}$]

Note: all levels uncertain by ± Y

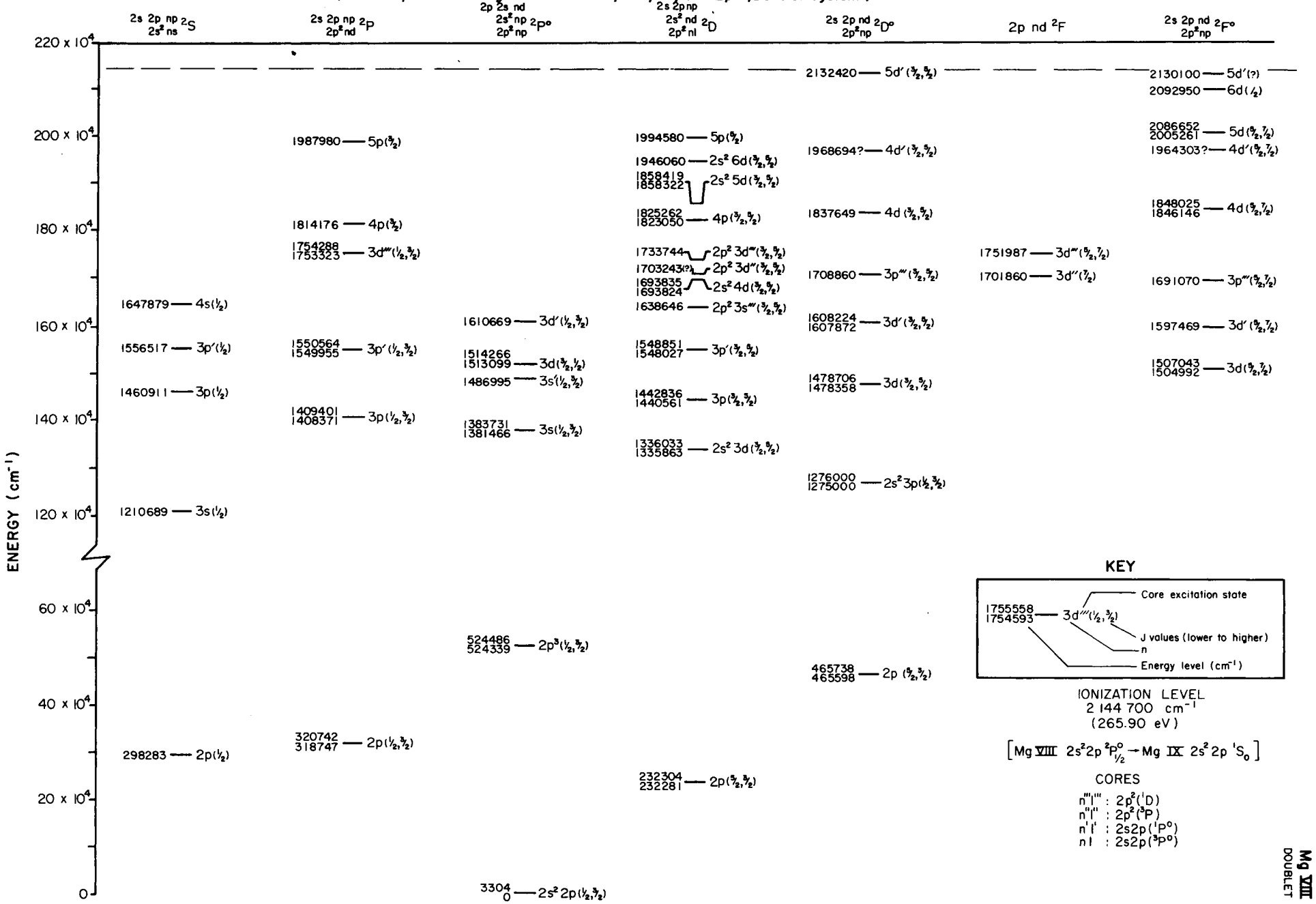
Mg VIII GROTRIAN DIAGRAM (5 electrons, Z=12)

(B I sequence, Configuration: $1s^2 2s^2 nl$, $1s^2 2p^2 nl$, $1s^2 2s\,2p\,nl$, Doublet System)

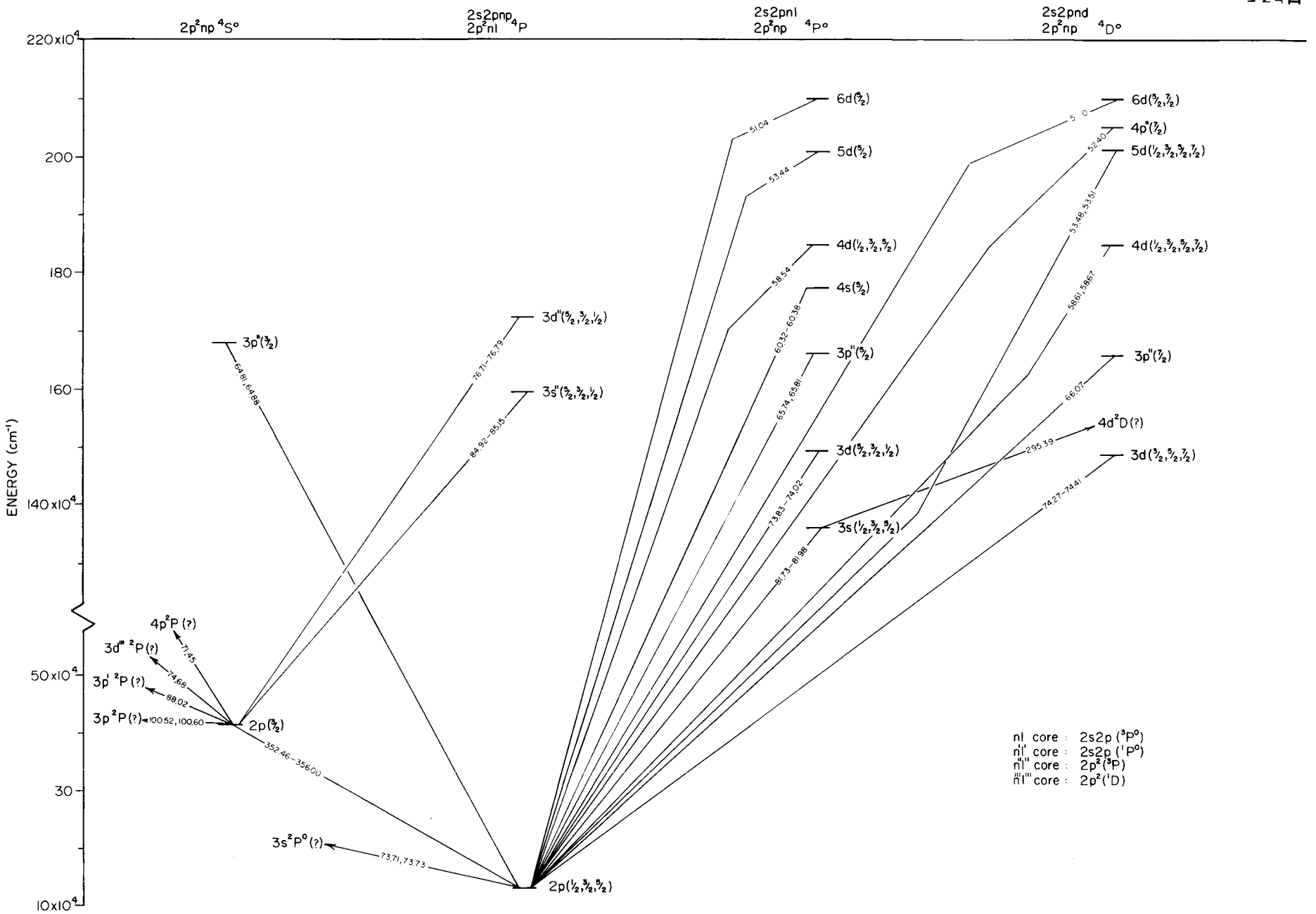


Mg VIII ENERGY LEVELS (5 electrons, Z = 12)

(BI Sequence Configuration: $1s^2 2s^2 nl$, $1s^2 2p^2 nl$, $1s^2 2s2pnl$, Doublet System)

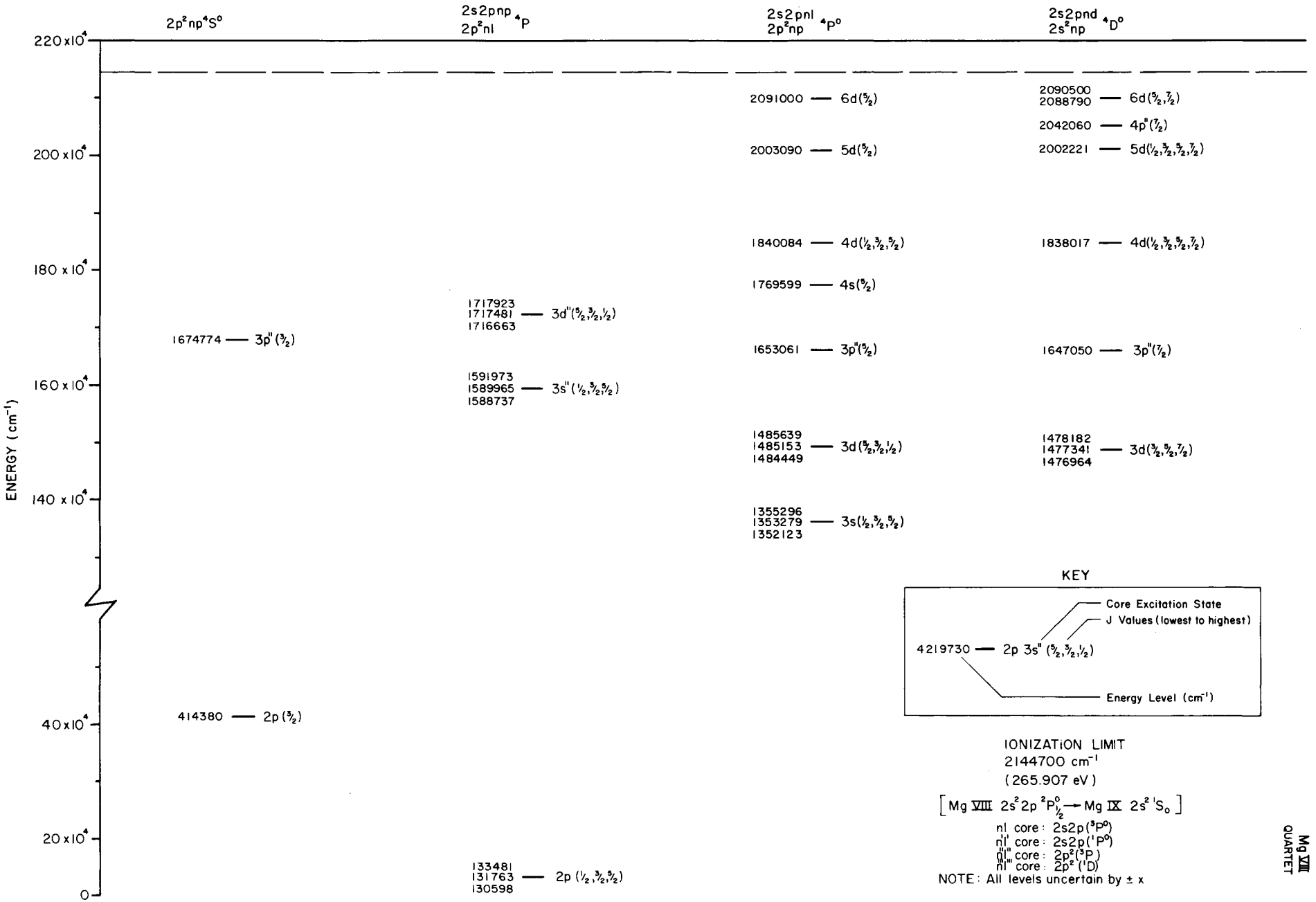


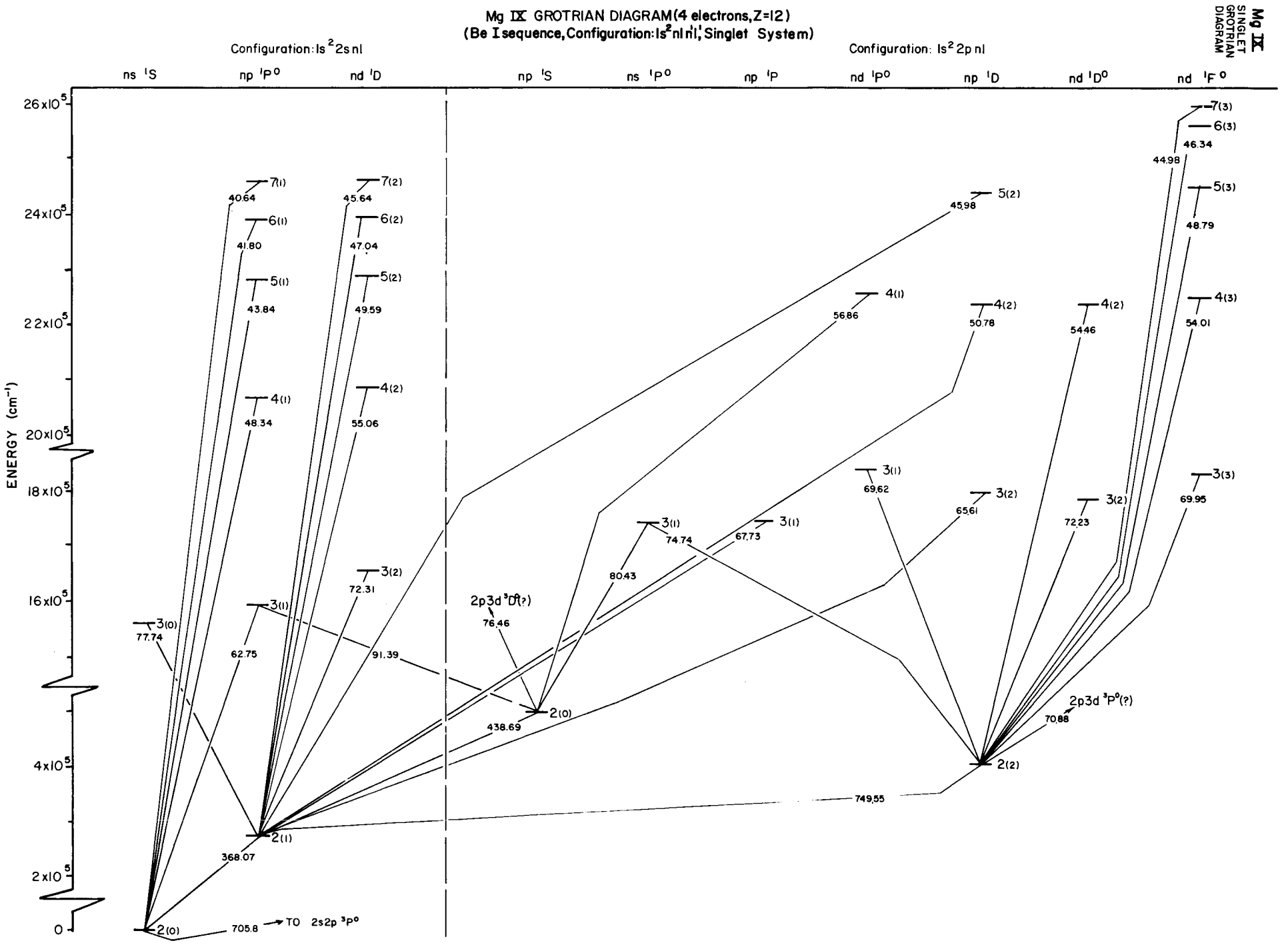
Mg VIII GROTRIAN DIAGRAM (5 electrons, Z=12)
(BI Sequence, Configuration $1s^2 2s^2 nl$, $1s^2 2p^2 nl$ Quartet System)



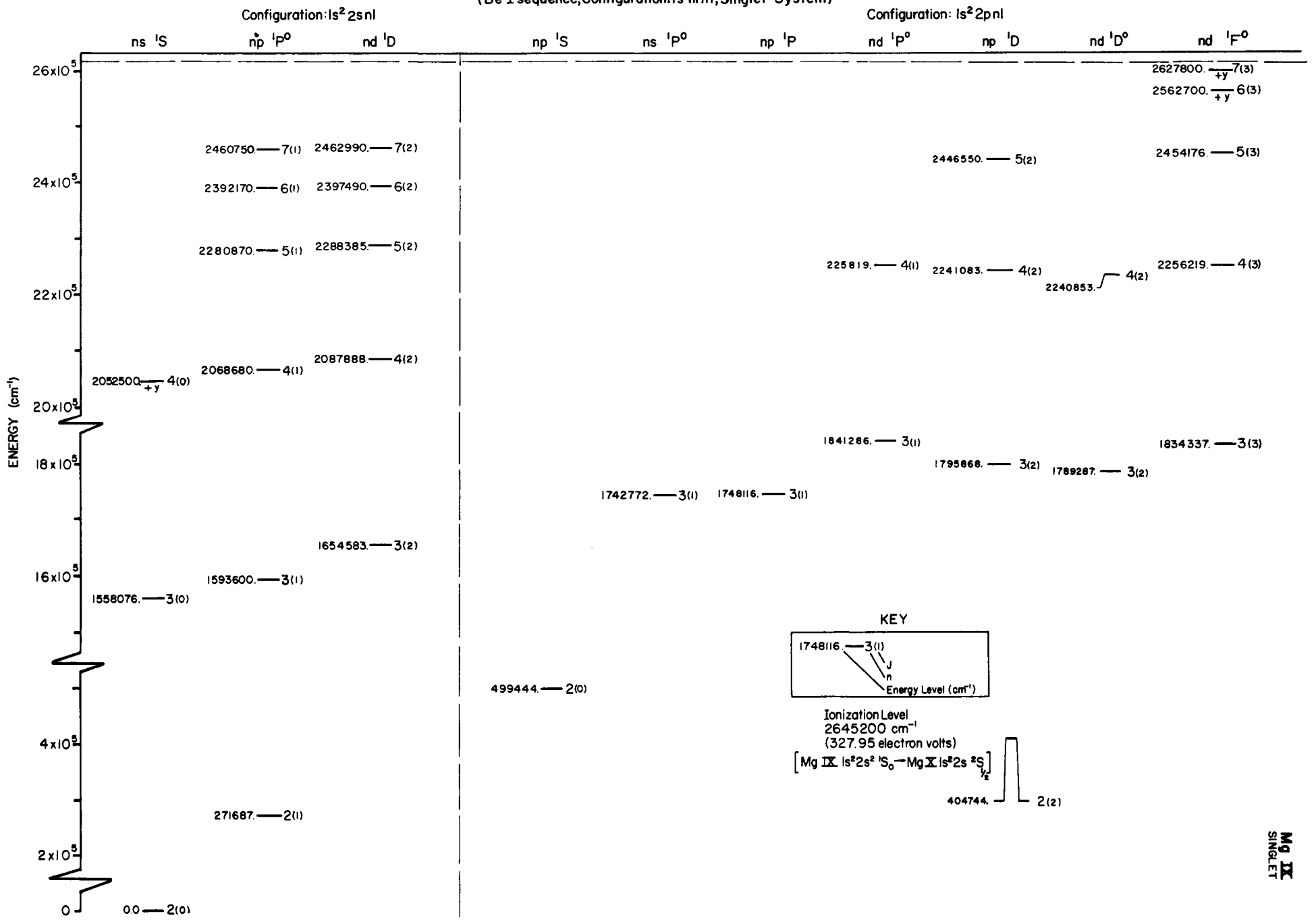
Mg VIII ENERGY LEVELS (5 electrons, Z=12)

(BI Sequence, Configuration $1s^2 2s^2 nl$, $1s^2 2p^2 nl$, Quartet System)

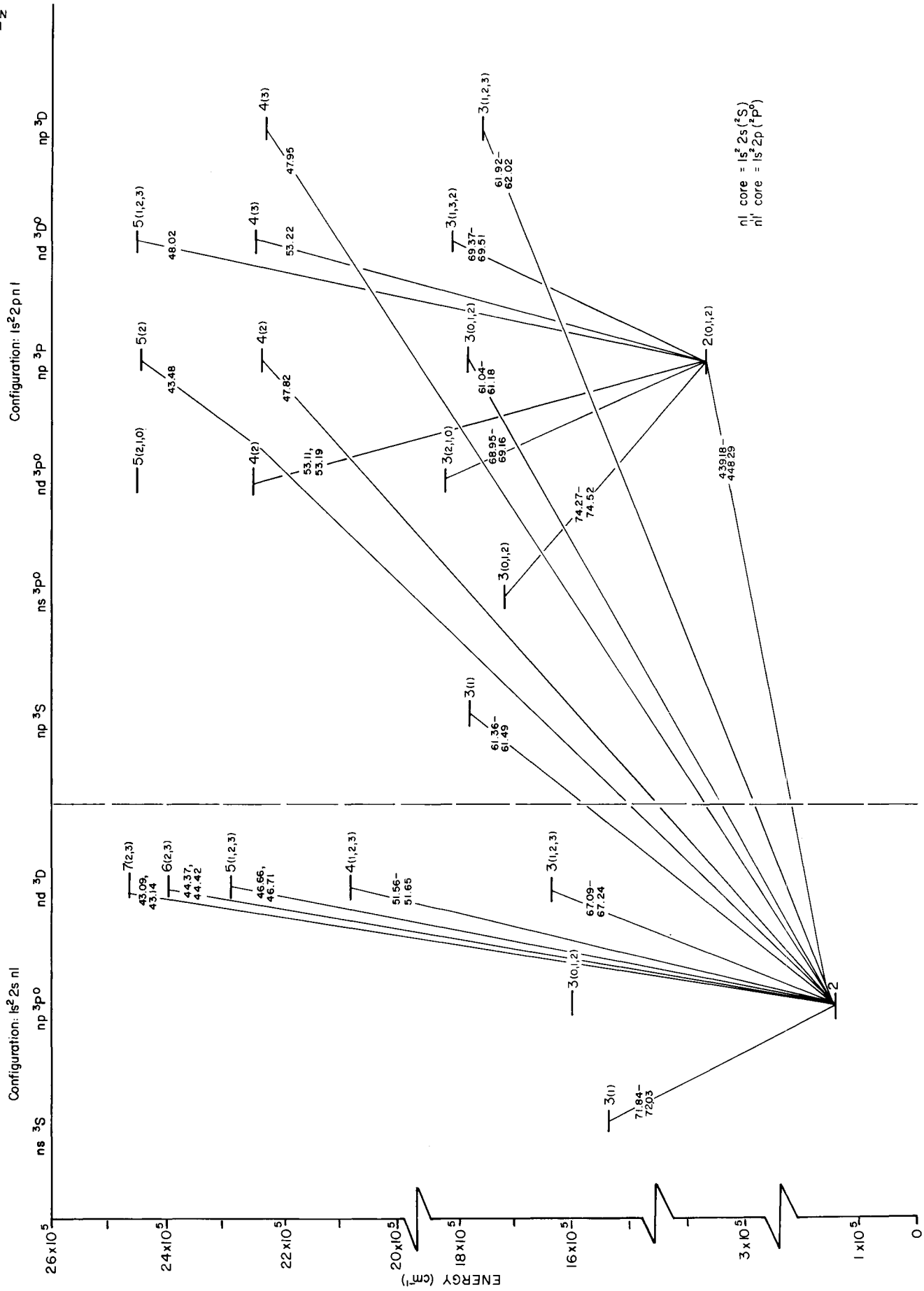



Mg IX GROTRIAN DIAGRAM (4 electrons, Z=12)
(Be I sequence, Configuration: $1s^2 nl n'l'$, Singlet System)
Mg IX SINGLET GROTRIAN DIAGRAM
Configuration: $1s^2 2s nl$
Configuration: $1s^2 2p nl$
ns ^1S
np $^1P^o$
nd ^1D
np ^1S
ns $^1P^o$
np ^1P
nd $^1P^o$
np ^1D
nd $^1D^o$
nd $^1F^o$
ENERGY (cm^{-1})
26x10^5
24x10^5
22x10^5
20x10^5
18x10^5
16x10^5
4x10^5
2x10^5
0
7(1)
40.64
6(1)
41.80
5(1)
43.84
4(1)
48.34
3(1)
62.75
3(0)
77.74
2(0)
705.8 → TO 2s2p $^3P^o$
2(1)
368.07
7(2)
45.64
6(2)
47.04
5(2)
49.59
4(2)
55.06
3(2)
72.31
91.39
2p3d $^3D^o$(?)
76.46
2(0)
438.69
80.43
3(1)
74.74
3(1)
67.73
4(1)
56.86
5(2)
45.98
3(1)
69.62
4(2)
50.78
3(2)
65.61
2(2)
749.55
4(2)
54.46
3(2)
72.23
2p3d $^3P^o$(?)
70.88
7(3)
6(3)
46.34
44.98
5(3)
48.79
4(3)
54.01
3(3)
69.95

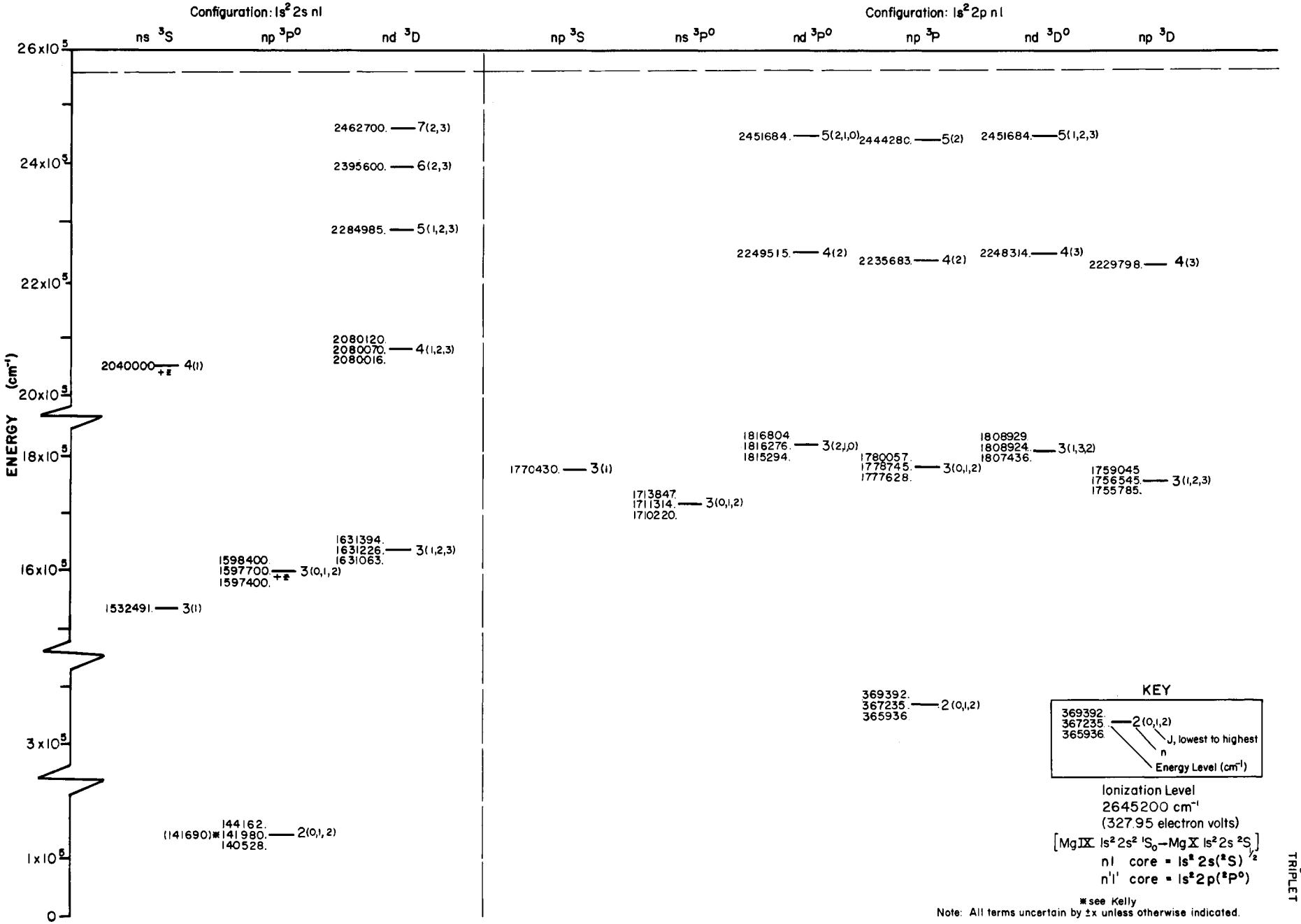
Mg IX ENERGY LEVELS (4 electrons, Z=12)
(Be I sequence, Configuration: $1s^2 n'l'n'l'$, Singlet System)



Mg IX
TRIPLET
GROTRIAN
DIAGRAM

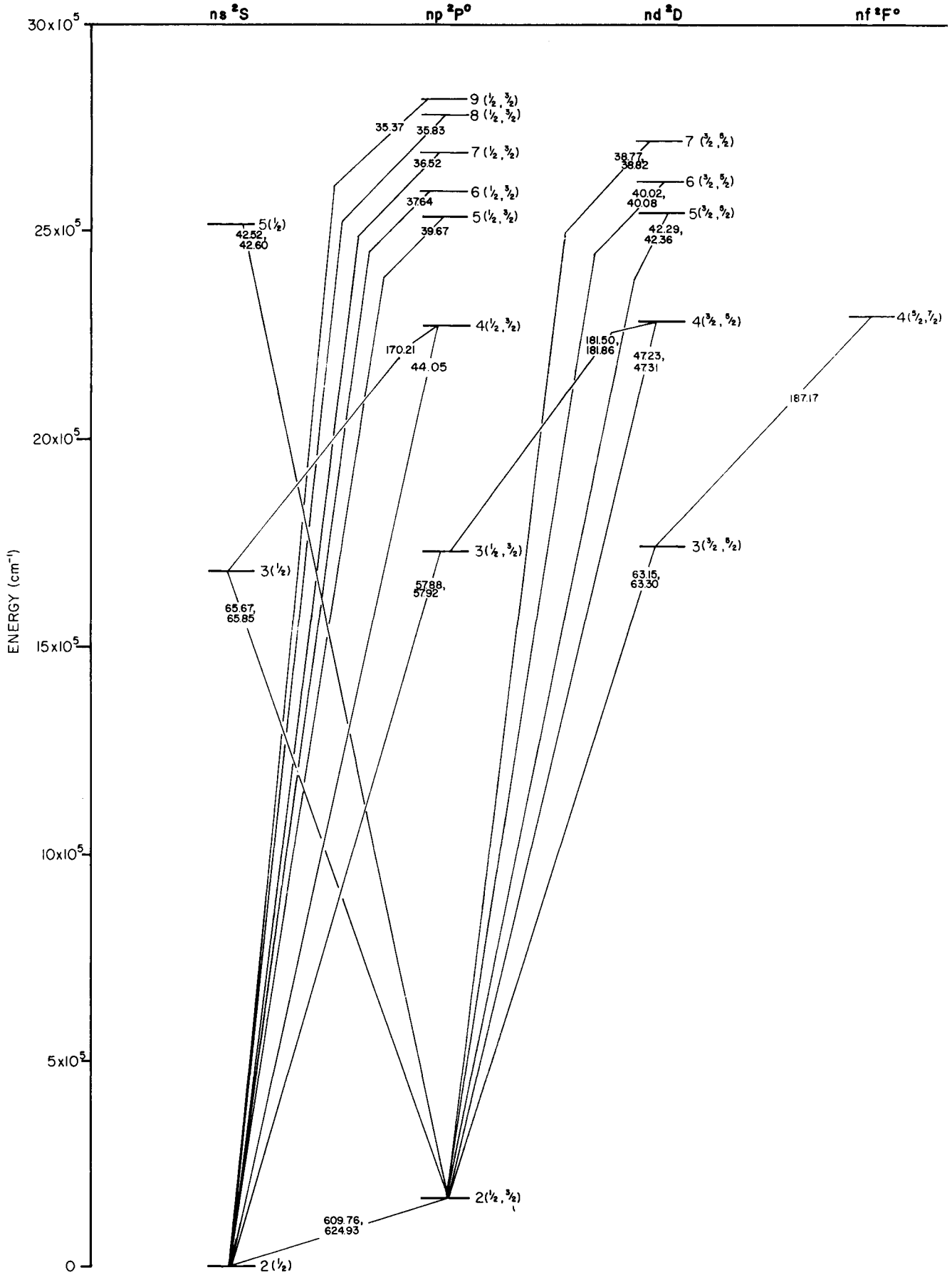


Mg IX ENERGY LEVELS (4 electrons, Z=12)
(Be I sequence, Configuration: $1s^2 2snl$, $1s^2 2pnl$, Triplet System)

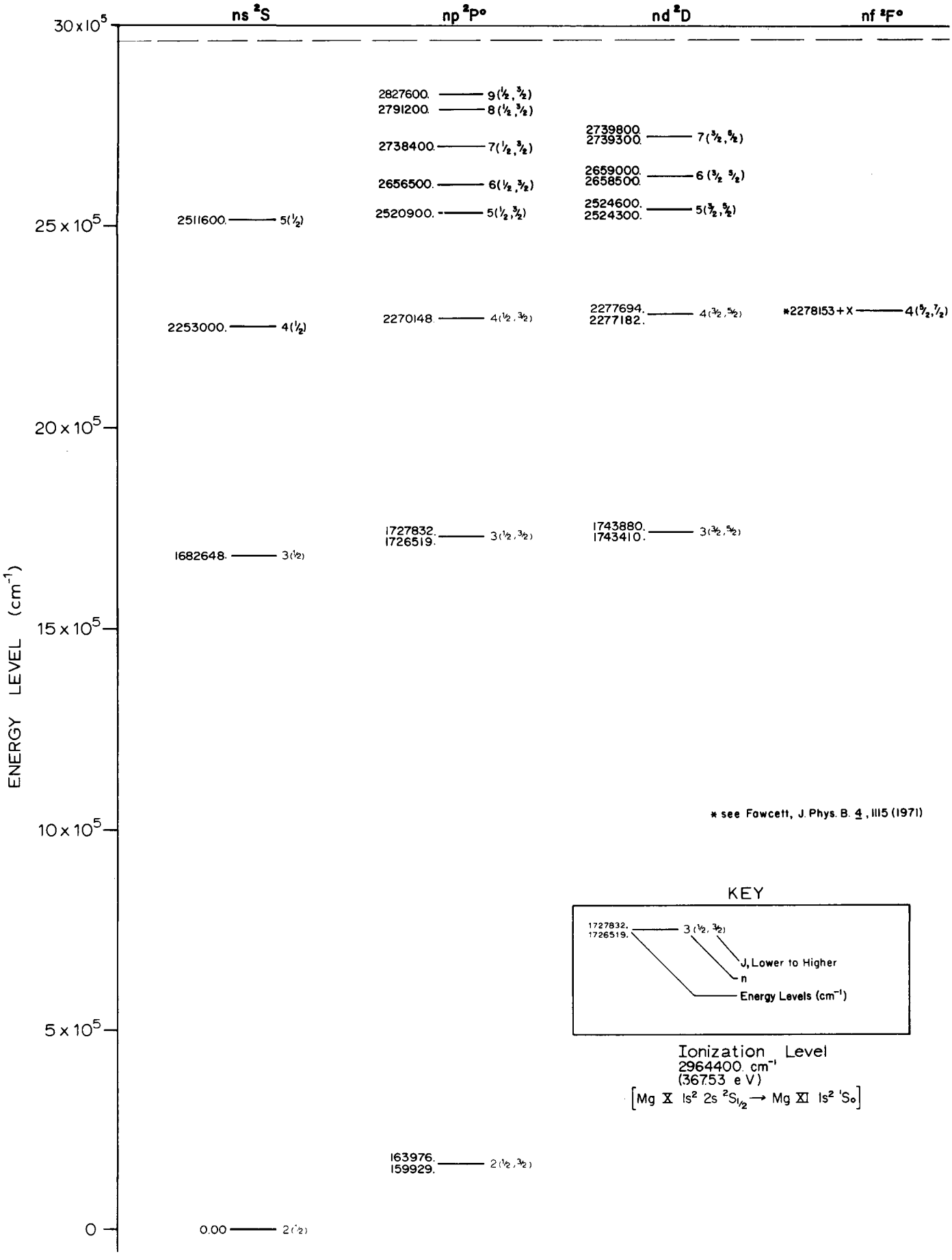


Mg X
DOUBLET
GROTRIAN
DIAGRAM

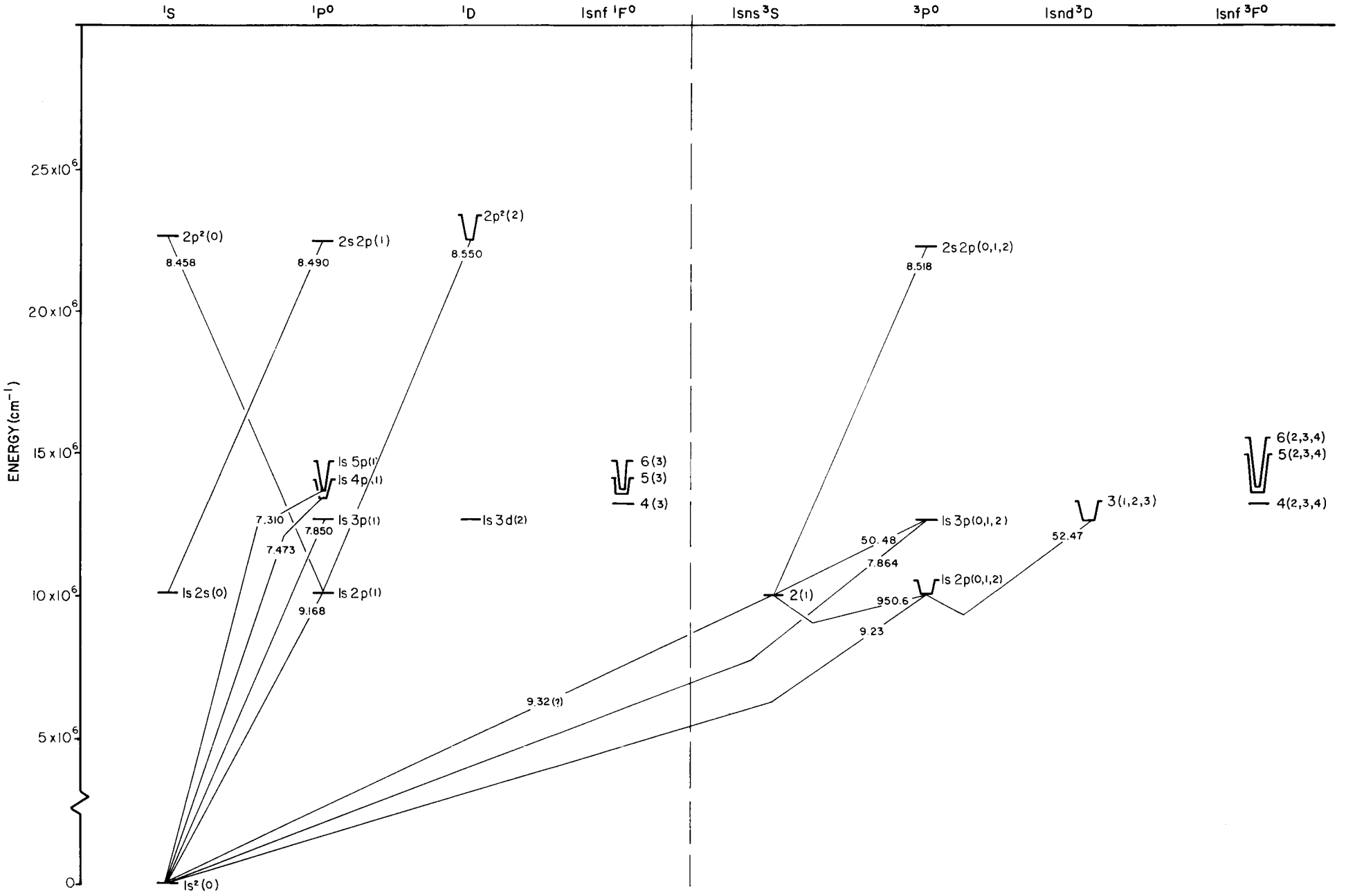
Mg X GROTRIAN DIAGRAM (3 electrons, Z=12)
(Li I sequence, Configuration: $1s^2nl$, Doublet)



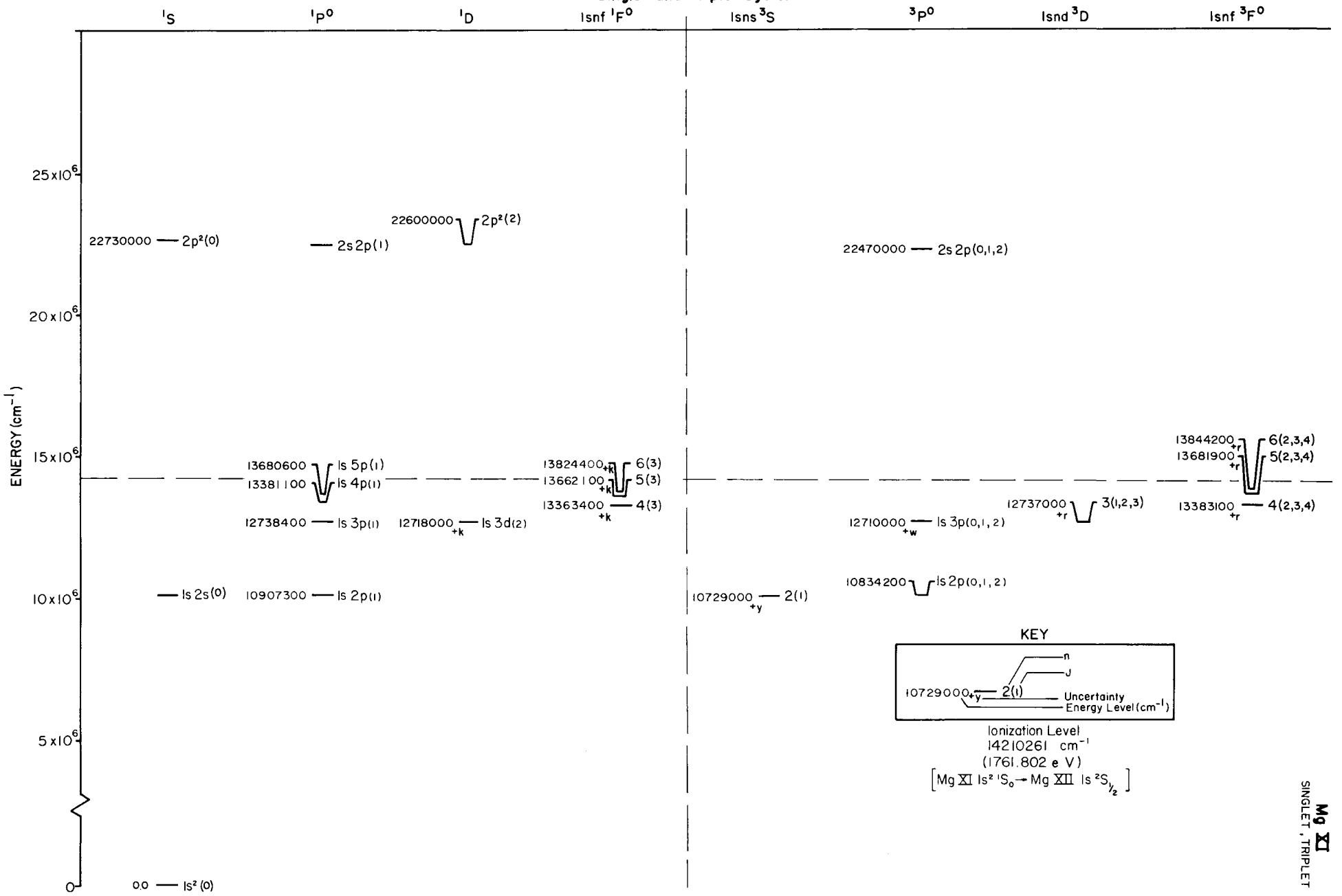
Mg X ENERGY LEVELS (3 electrons, Z=12)
(Li I sequence, Configuration: $1s^2$ nl, Doublet)



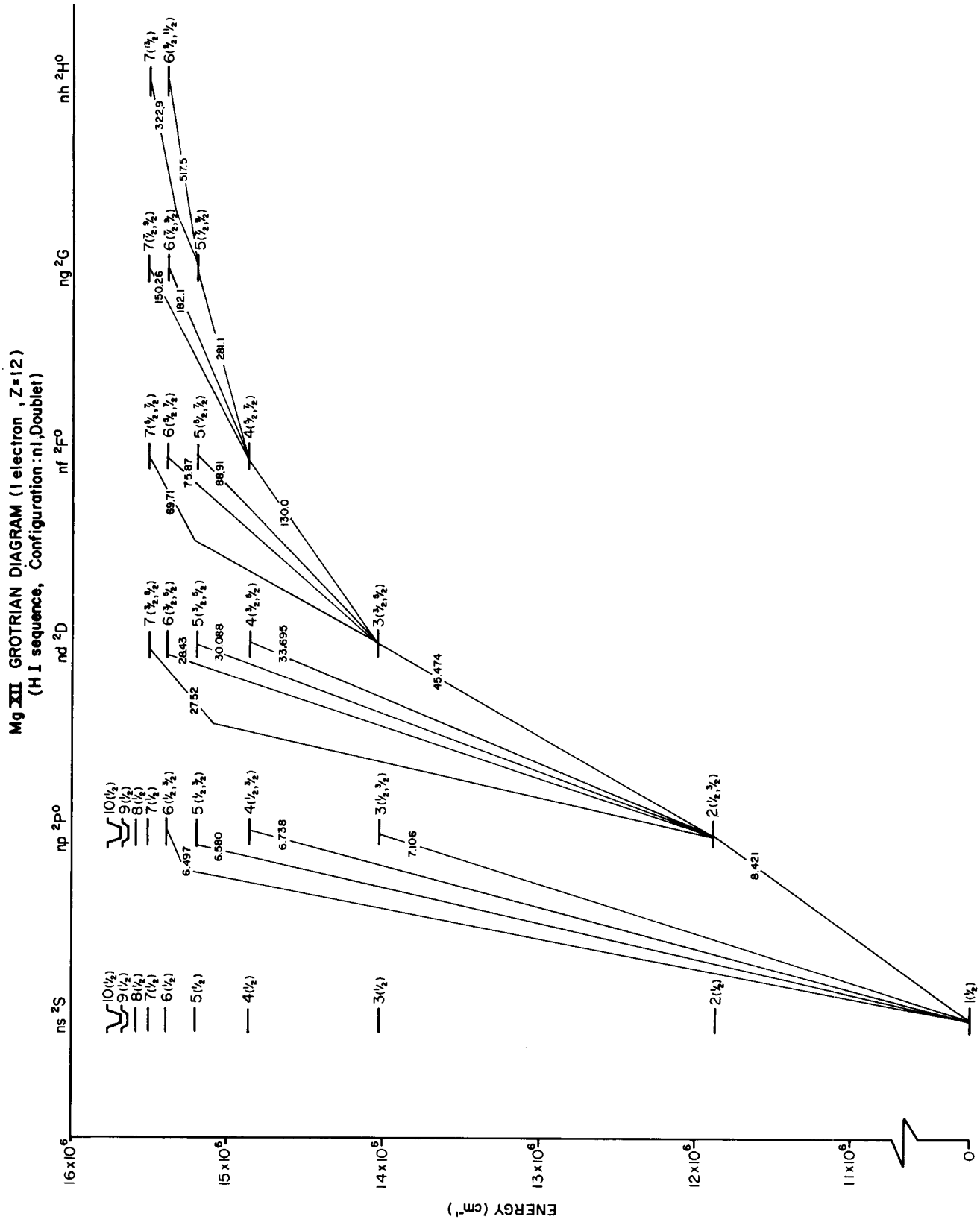
Mg XI GROTRIAN DIAGRAM (2 electrons, Z=12)
He I sequence, Configuration: nl n'l'
Singlet and Triplet Systems



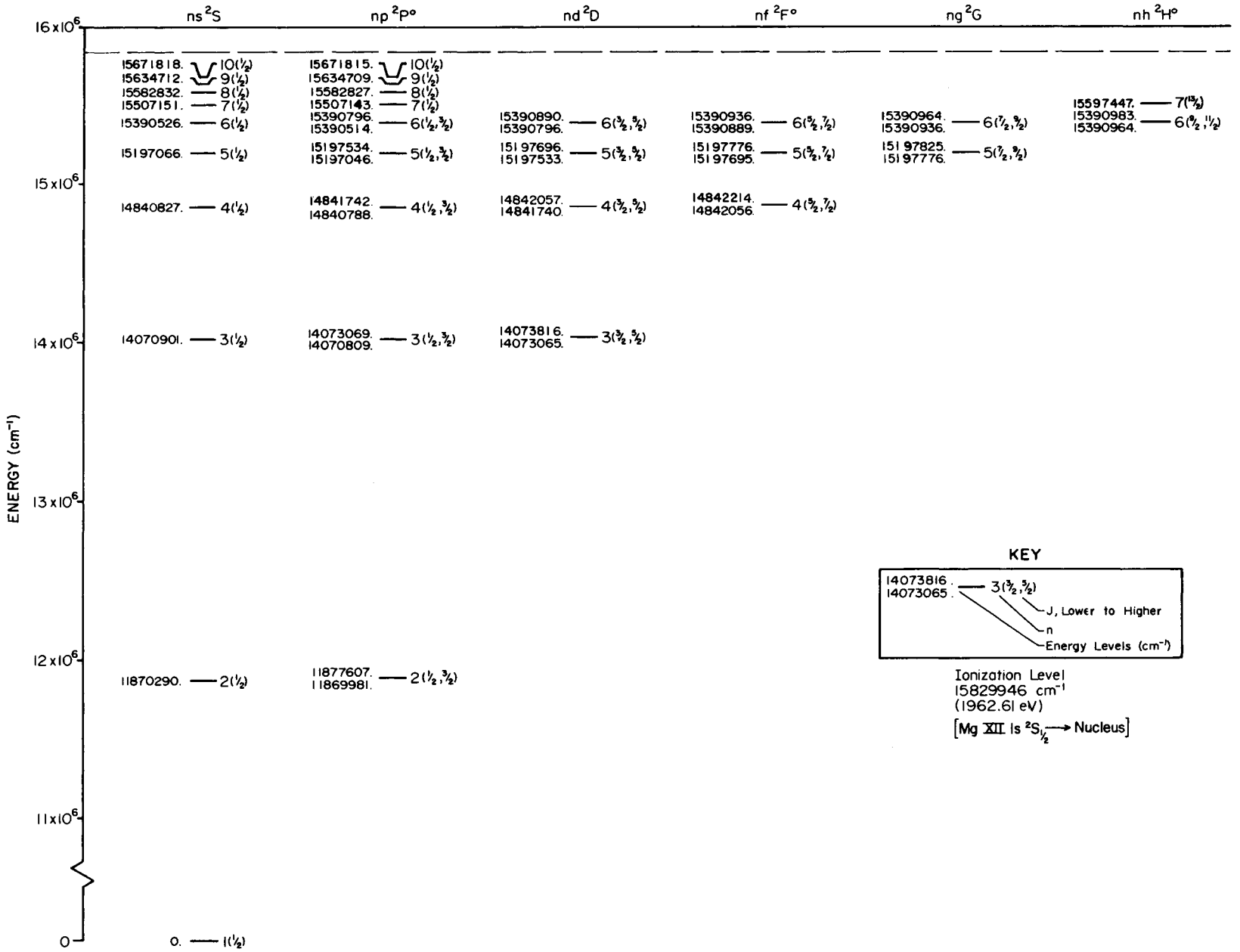
Mg XI ENERGY LEVELS (2 electrons, Z=12)
He I sequence, Configuration: nl n'l'
Singlet and Triplet Systems



Mg XII
DOUBLET
GROTRIAN
DIAGRAM



Mg XII ENERGY LEVELS (1 electron, Z = 12)
(H I sequence, Configuration: nl, Doublet)



Mg I $Z = 12$ 12 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives transition wavelengths from nebular observations.

J.W. Swensson and G. Risberg, Ark. Fys. **31**, 237 (1966).

Authors give line tables and identify those lines found in the solar spectrum.

Mg II $Z = 12$ 11 electrons

Please see the general references.

Mg III $Z = 12$ 10 electrons

Please see the general references.

The intermediate-coupling designations are given by Andersson and Johannesson, Physica Scripta **3**, 203 (1971).

Mg IV $Z = 12$ 9 electrons

Please see the general references.

Mg V $Z = 12$ 8 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line tables of predicted and observed lines.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Mg VI $Z = 12$ 7 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives tables of observed lines.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Mg VII $Z = 12$ 6 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives tables of lines calculated and observed.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

The following lines were omitted from the drawings:

$2s\,2p^3\ {}^1P^\circ - 2p^2\ ({}^2D)\,3d'\ {}^3S$		92.50 (?)
	$-2p^2\ ({}^4P)\ 3d\ {}^3D$	100.37 (?), 100.42 (?)
	$-\quad 3d\ {}^3F$	102.05 (?)
	$-\quad 3d\ {}^3P$	102.91 (?)
$2s\,2p^3\ {}^5S^\circ - 2p^2\ ({}^4P)\ 3s\ {}^3P$		91.30 (?)

Mg VIII $Z = 12$ 5 electrons

Please see the general references.

Mg IX $Z = 12$ 4 electrons

Please see the general references.

Mg X $Z = 12$ 3 electrons

Please see the general references.

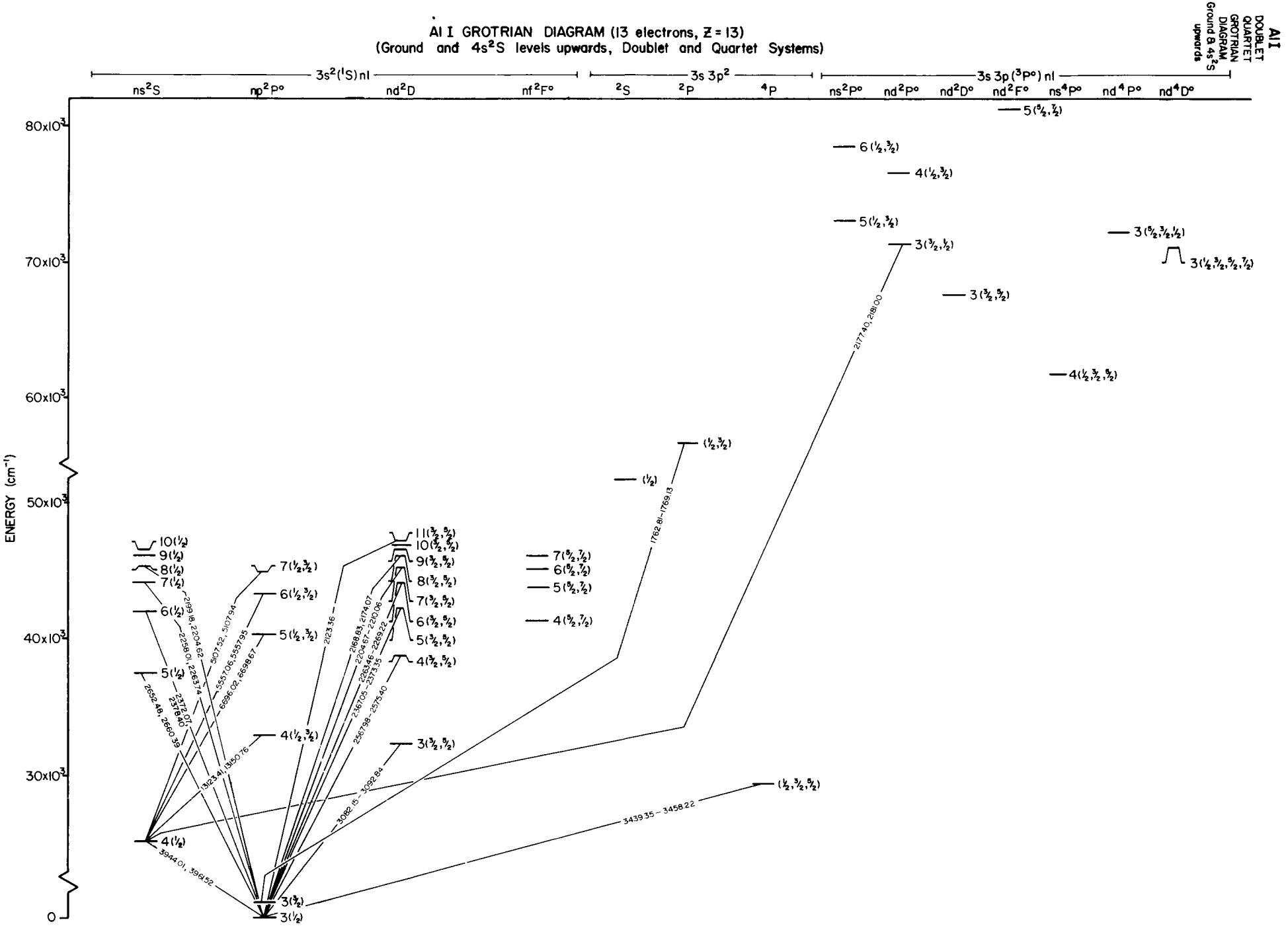
Mg XI $Z = 12$ 2 electrons

Please see the general references.

Mg XII $Z = 12$ 1 electron

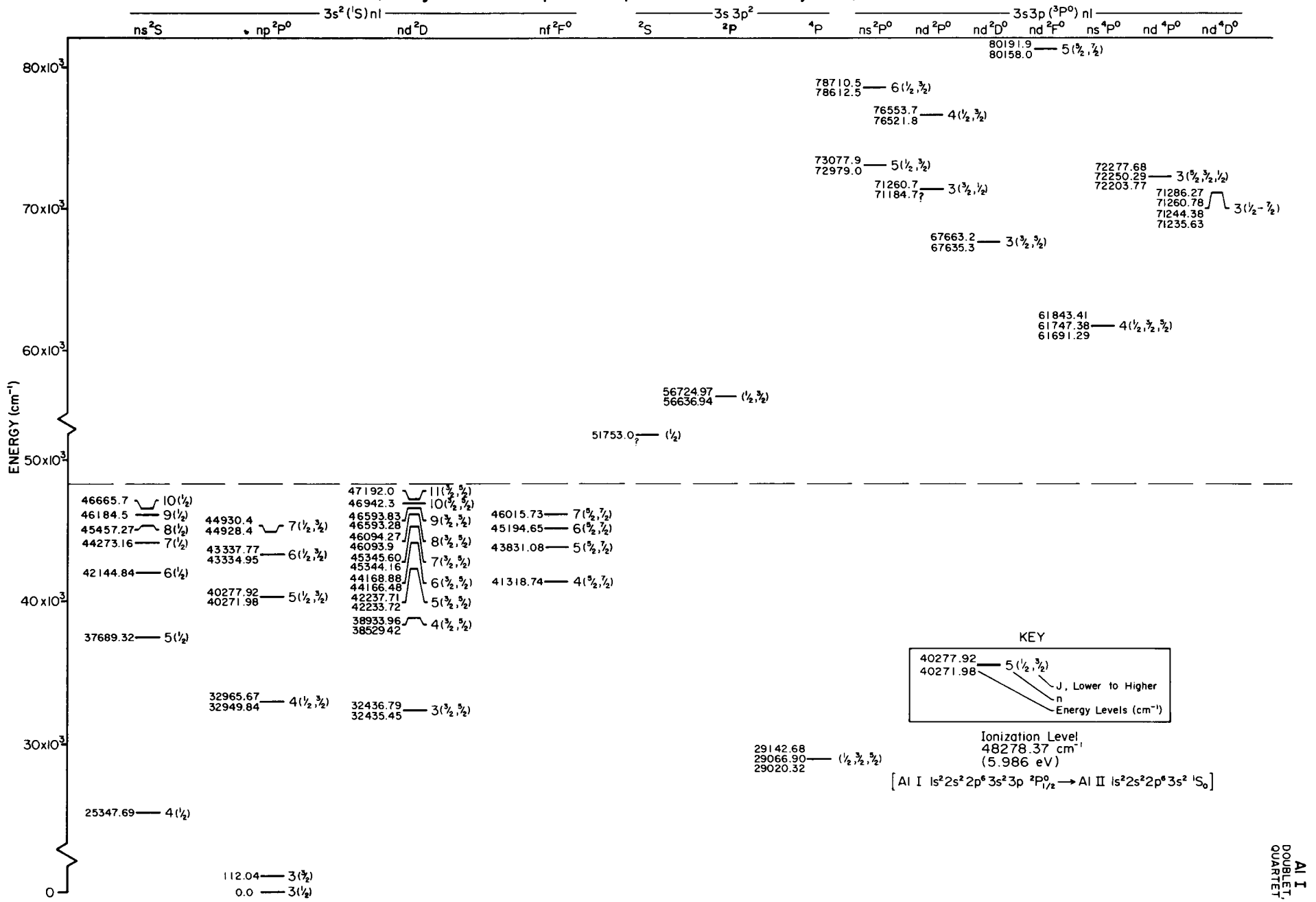
Please see the general references.

Aluminium (Al)

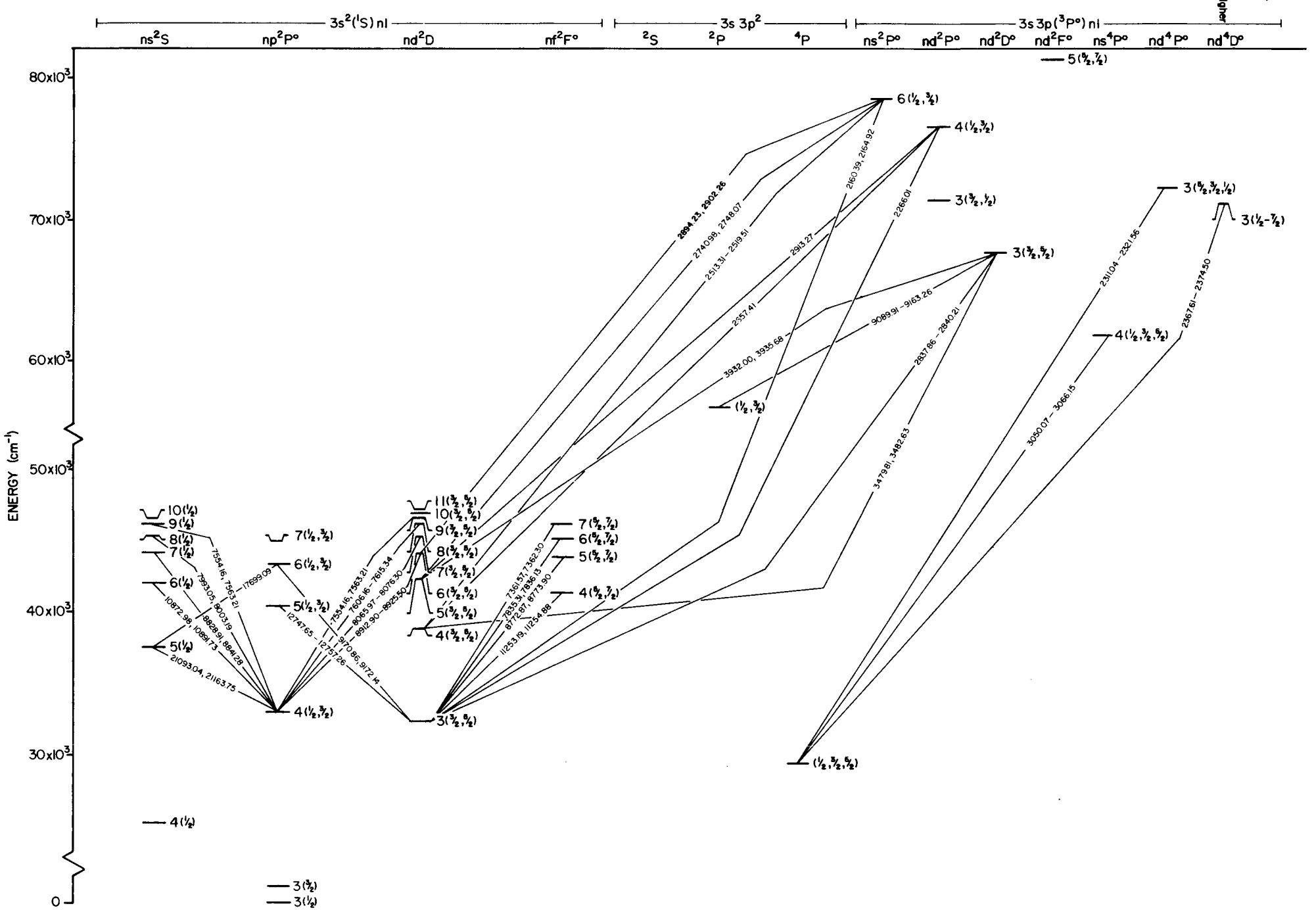

Al I GROTRIAN DIAGRAM (13 electrons, Z = 13)
(Ground and 4s²S levels upwards, Doublet and Quartet Systems)
Al I
DOUBLET
QUARTET
GROTRIAN
DIAGRAM
Ground & 4s²S
upwards
3s²(¹S)nl
3s 3p²
3s 3p(³P°)nl
ns²S
np²P°
nd²D
nf²F°
²S
²P
⁴P
ns²P°
nd²P°
nd²D°
nd²F°
ns⁴P°
nd⁴P°
nd⁴D°
ENERGY (cm⁻¹)
80x10³
70x10³
60x10³
50x10³
40x10³
30x10³
0
2177.40, 2181.00
1762.81–1769.13
3439.35 – 3458.22
3082.15 – 3092.84
2565.98 – 2575.40
2361.05 – 2373.35
2263.46 – 2269.22
2204.67 – 2210.06
2168.83, 2174.07
2123.36
2652.48, 2660.39
2372.07, 2378.40
2258.01, 2263.74
2199.18, 2204.62
5107.52, 5107.94
5551.06, 5557.95
6695.02, 6698.67
3123.41, 3130.76
3944.01, 3948.52

Al I ENERGY LEVELS (13 electrons, Z=13)

(Configuration: $1s^2 2s^2 2p^6 3s\,nl\,n'l'$, Doublet and Quartet Systems)

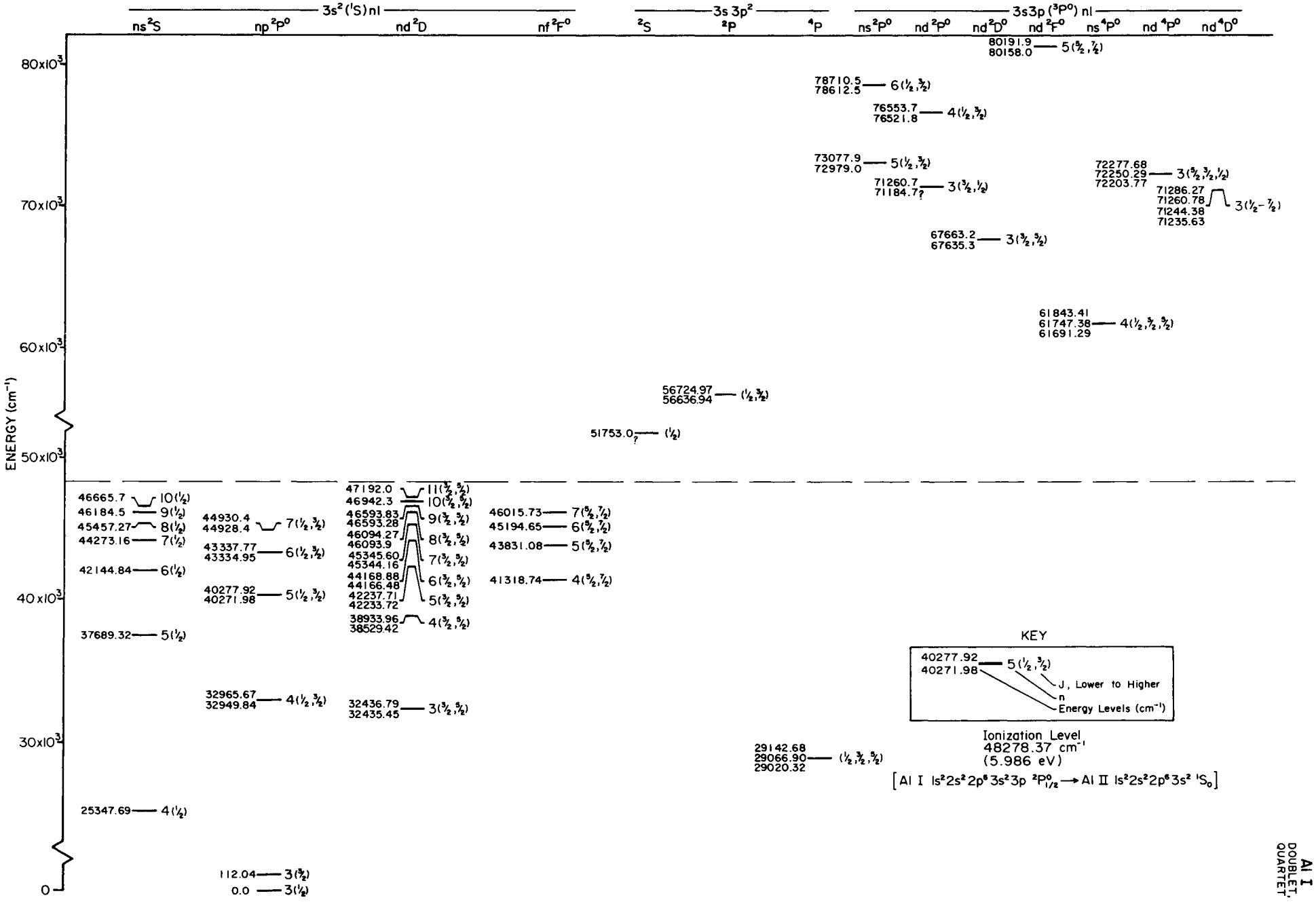


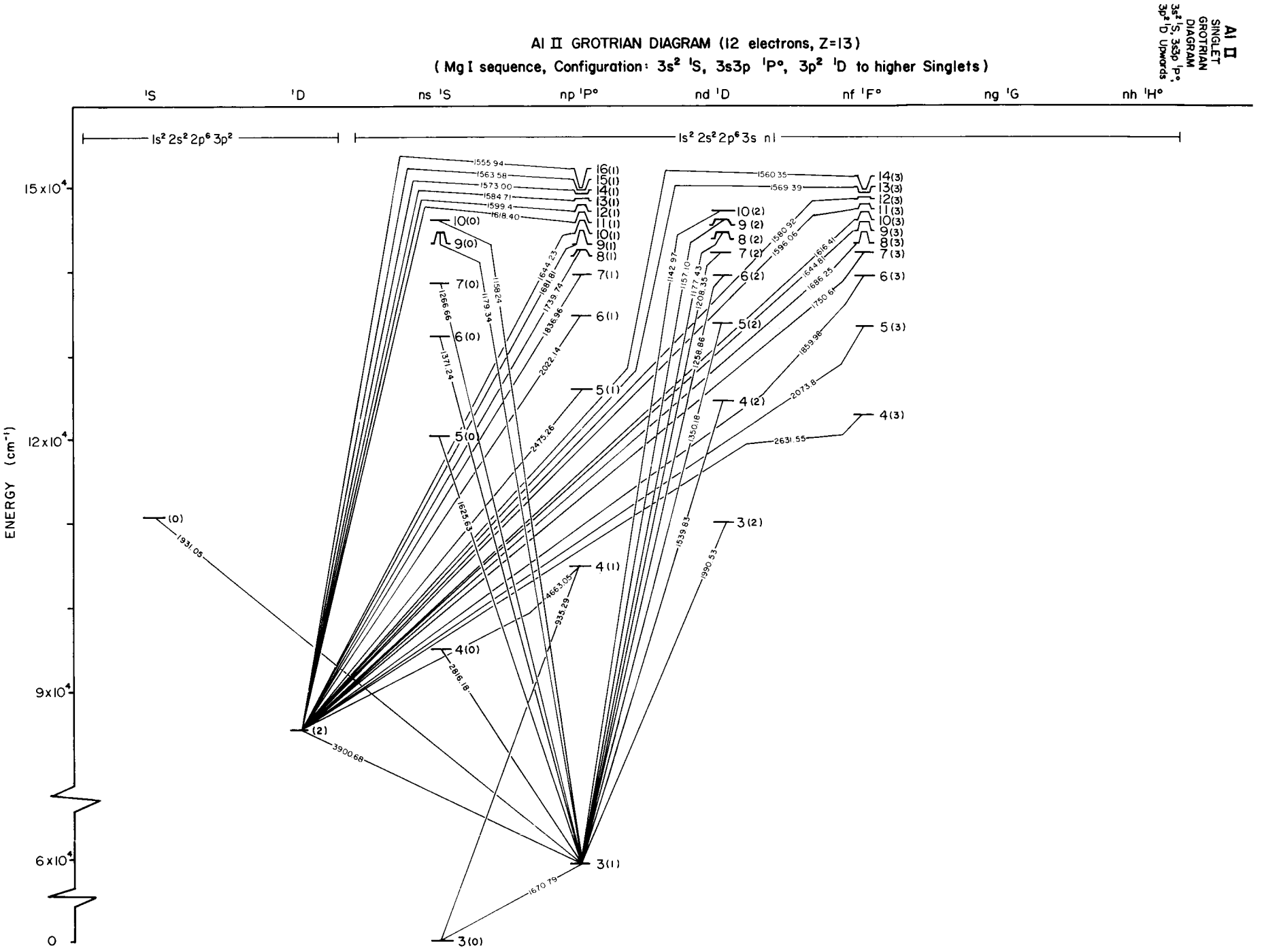
Al I GROTRIAN DIAGRAM (13 electrons, Z = 13)
($3p^2\,^4P$ and higher levels upward, Doublet and Quartet Systems)



Al I ENERGY LEVELS (13 electrons, Z=13)

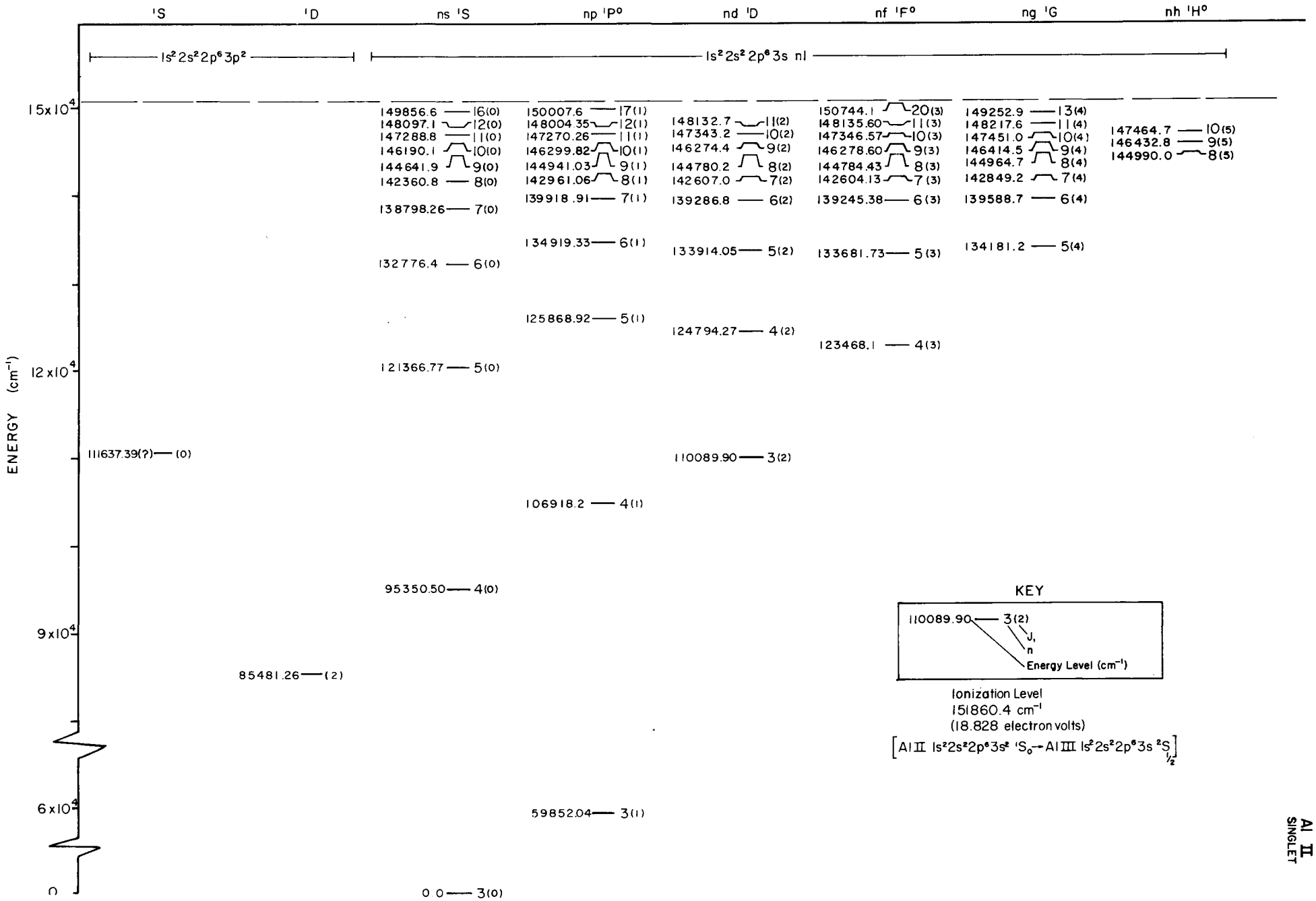
(Configuration: $1s^2 2s^2 2p^6 3s\ nl\ n'l'$, Doublet and Quartet Systems)

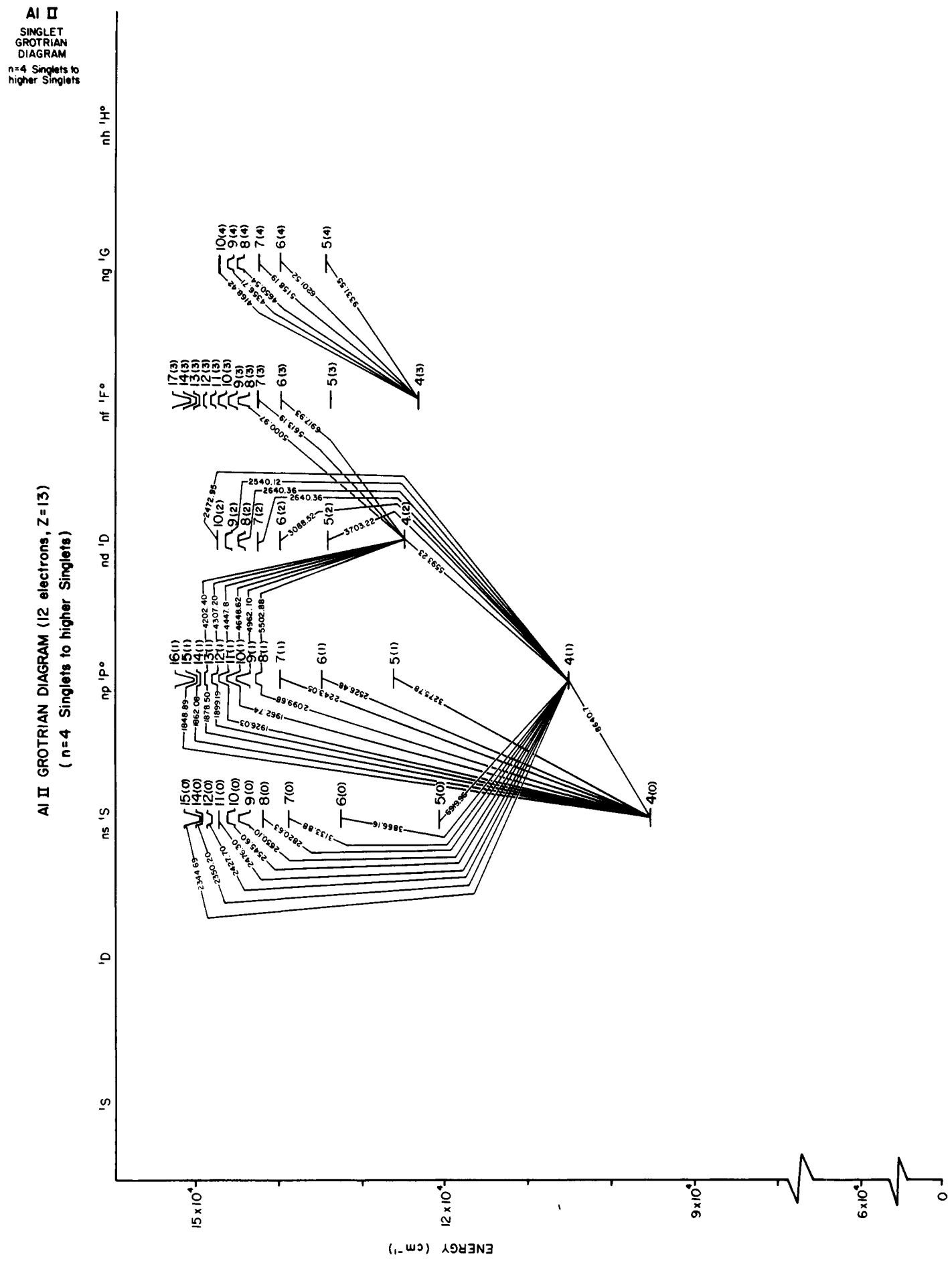



Al II GROTRIAN DIAGRAM (12 electrons, Z=13)
(Mg I sequence, Configuration: 3s² ¹S, 3s3p ¹P°, 3p² ¹D to higher Singlets)
Al II
SINGLET
GROTRIAN
DIAGRAM
3s² ¹S, 3s3p ¹P°,
3p² ¹D Upwards
¹S
¹D
ns ¹S
np ¹P°
nd ¹D
nf ¹F°
ng ¹G
nh ¹H°
1s² 2s² 2p⁶ 3p²
1s² 2s² 2p⁶ 3s nl
ENERGY (cm⁻¹)
15x10⁴
12x10⁴
9x10⁴
6x10⁴
0
(0)
(2)
3(0)
3(1)
3(2)
4(0)
4(1)
4(2)
4(3)
5(0)
5(1)
5(2)
5(3)
6(0)
6(1)
6(2)
6(3)
7(0)
7(1)
7(2)
7(3)
8(1)
8(2)
8(3)
9(0)
9(1)
9(2)
9(3)
10(0)
10(1)
10(2)
10(3)
11(1)
11(3)
12(1)
12(3)
13(1)
13(3)
14(1)
14(3)
15(1)
16(1)
1931.05
3900.68
1670.79
2816.18
4663.05
935.29
1625.63
1371.24
1256.66
1179.34
1158.24
1555.94
1563.58
1573.00
1584.71
1599.4
1618.40
1644.23
1681.81
1739.74
1836.96
2022.14
2475.26
1560.35
1569.39
1142.97
1157.10
1177.43
1208.35
1258.86
1350.18
1539.83
1990.53
1580.92
1596.06
1616.41
1644.8
1686.25
1750.61
1859.98
2073.8
2631.55

Al II ENERGY LEVELS (12 electrons, Z=13)

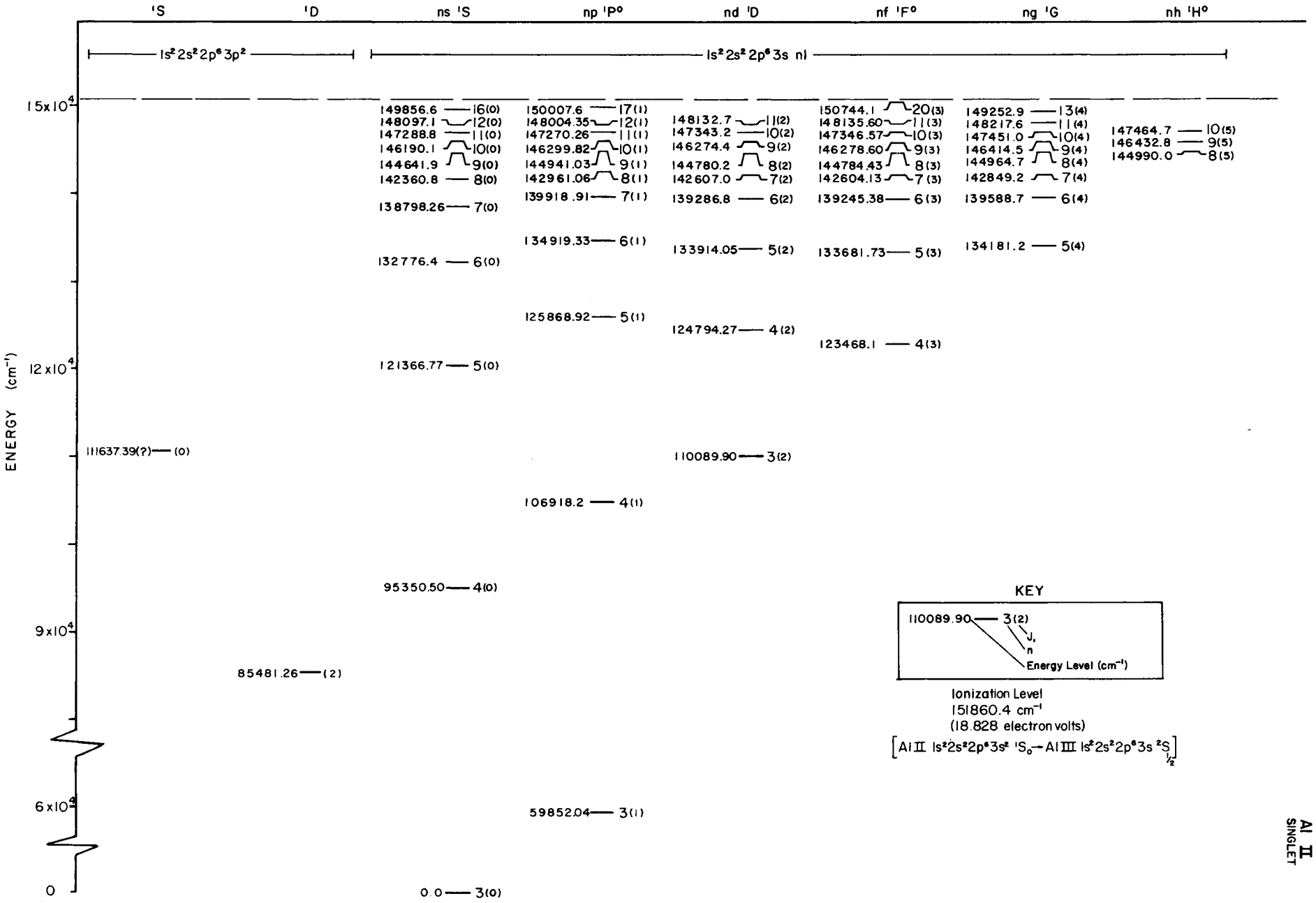
(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\ nl$, Singlet System)




Al II
SINGLET
GROTRIAN
DIAGRAM
n=4 Singlets to higher Singlets
Al II GROTRIAN DIAGRAM (12 electrons, Z=13)
(n=4 Singlets to higher Singlets)
ENERGY (cm⁻¹)
15 x 10⁴
12 x 10⁴
9 x 10⁴
6 x 10⁴
0
¹S
¹D
ns ¹S
np ¹P°
nd ¹D
nf ¹F°
ng ¹G
nh ¹H°

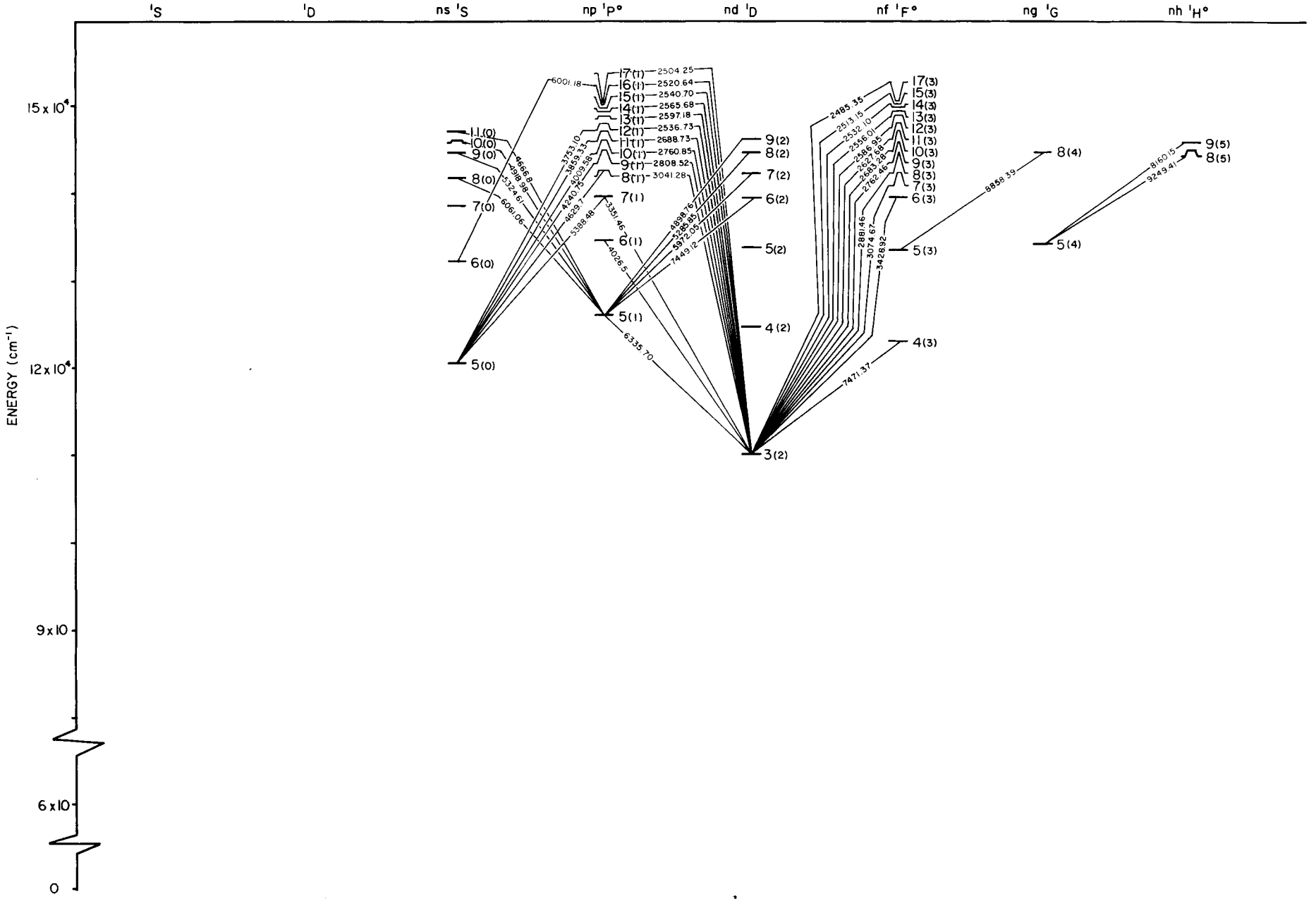
Al II ENERGY LEVELS (12 electrons, Z=13)

(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\ nl$, Singlet System)



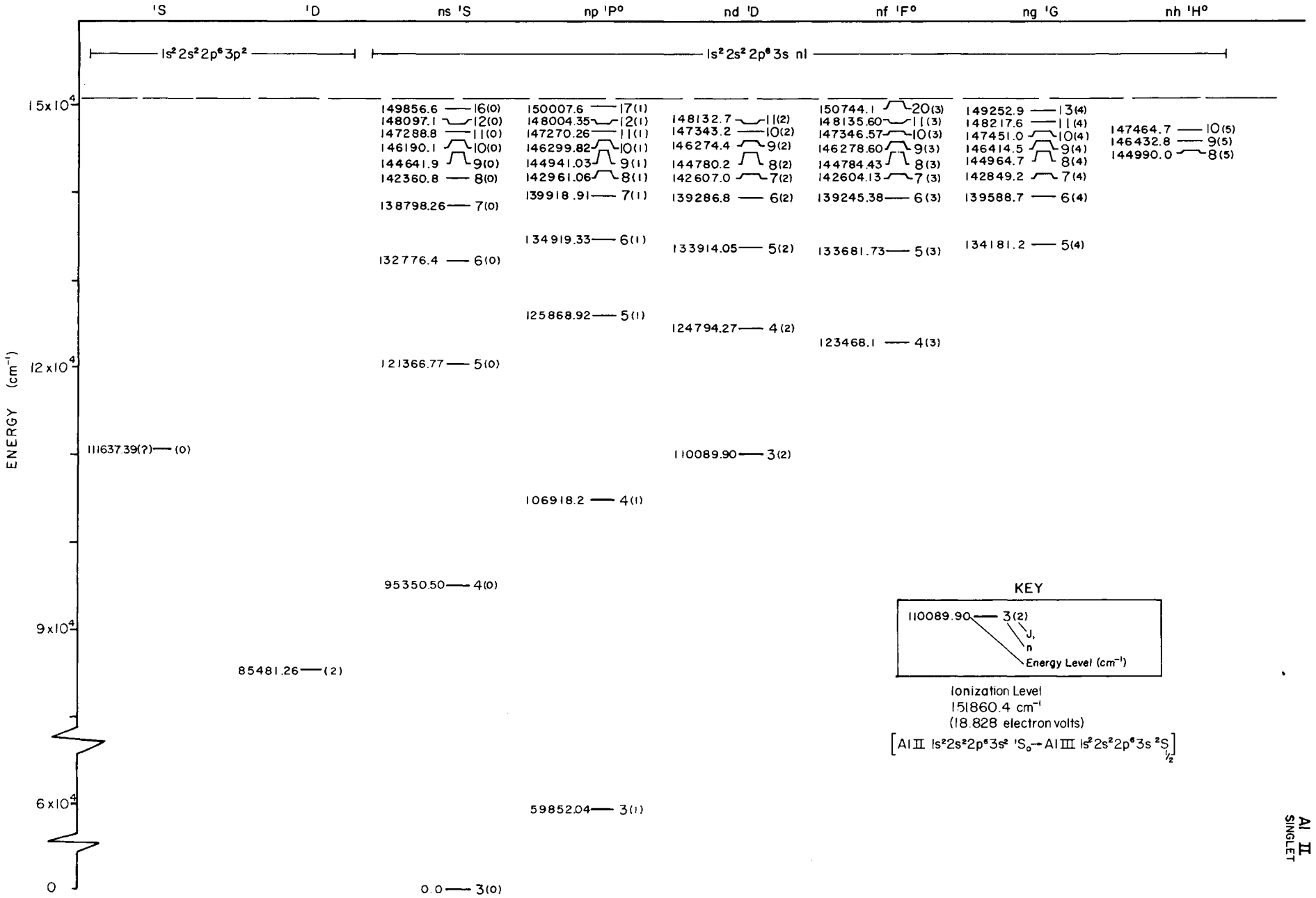
Al II GROTRIAN DIAGRAM (12 electrons, Z=13)

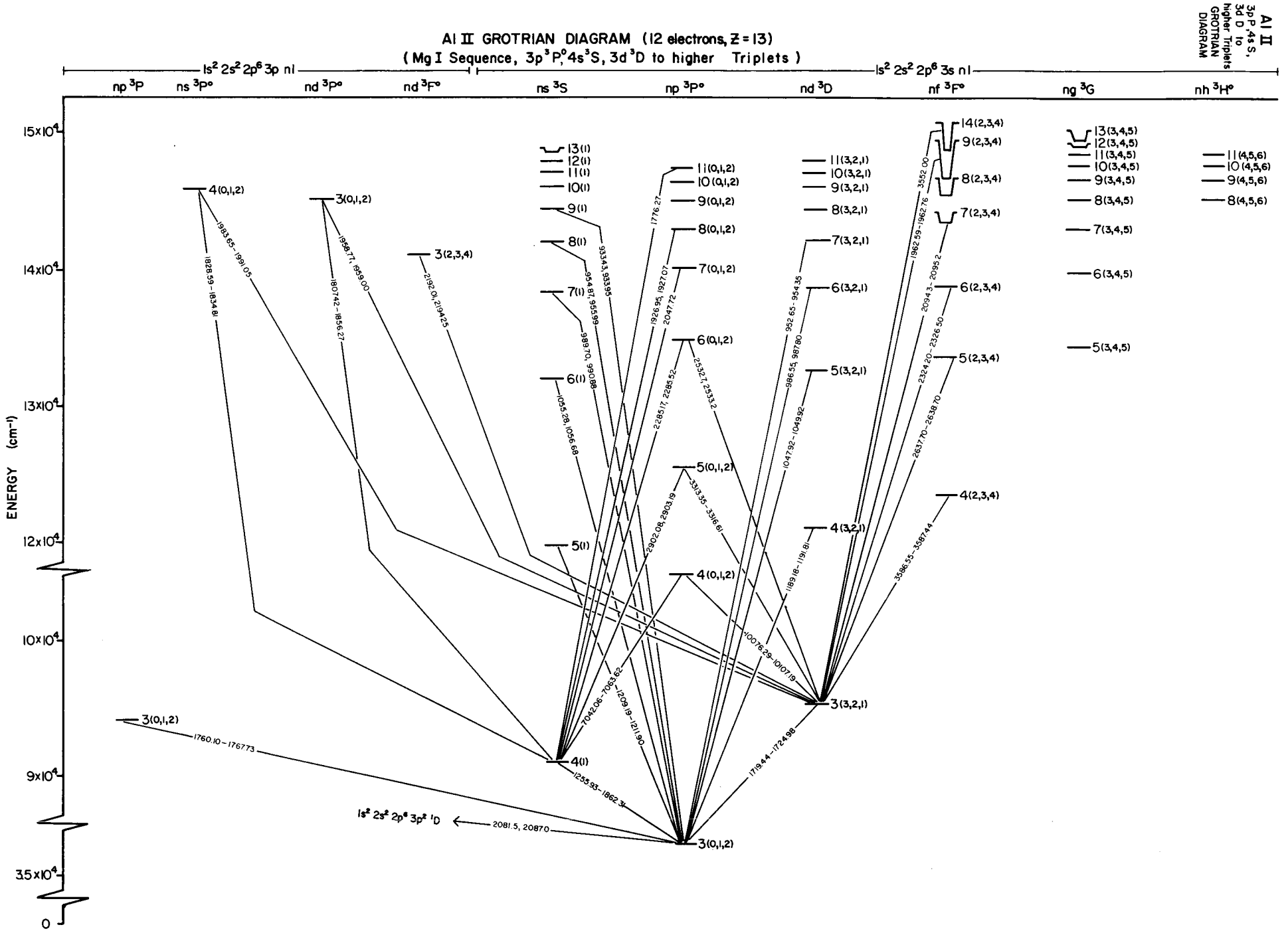
(3d ¹D and n=5 Singlets to higher Singlets)



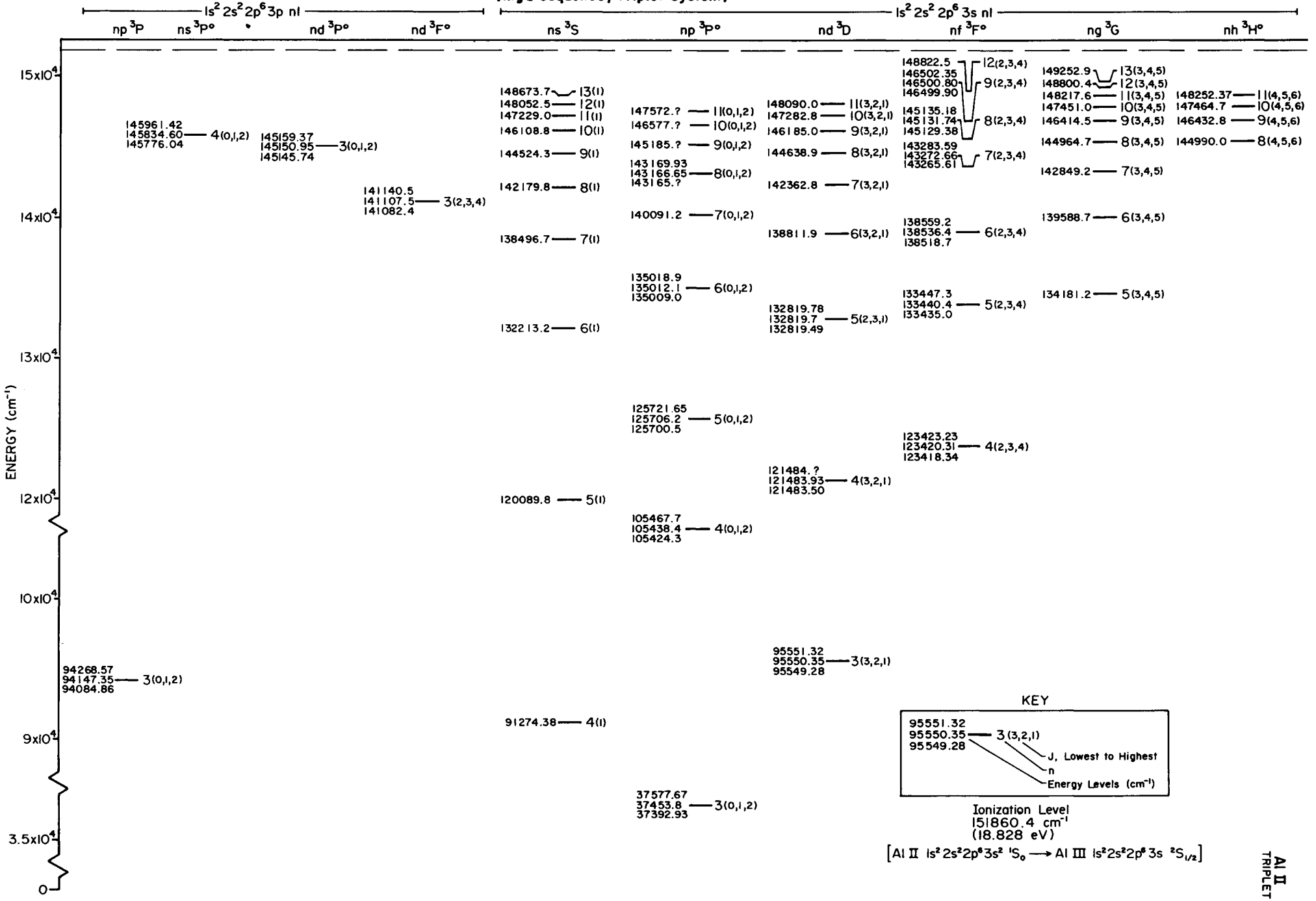
Al II ENERGY LEVELS (12 electrons, Z=13)

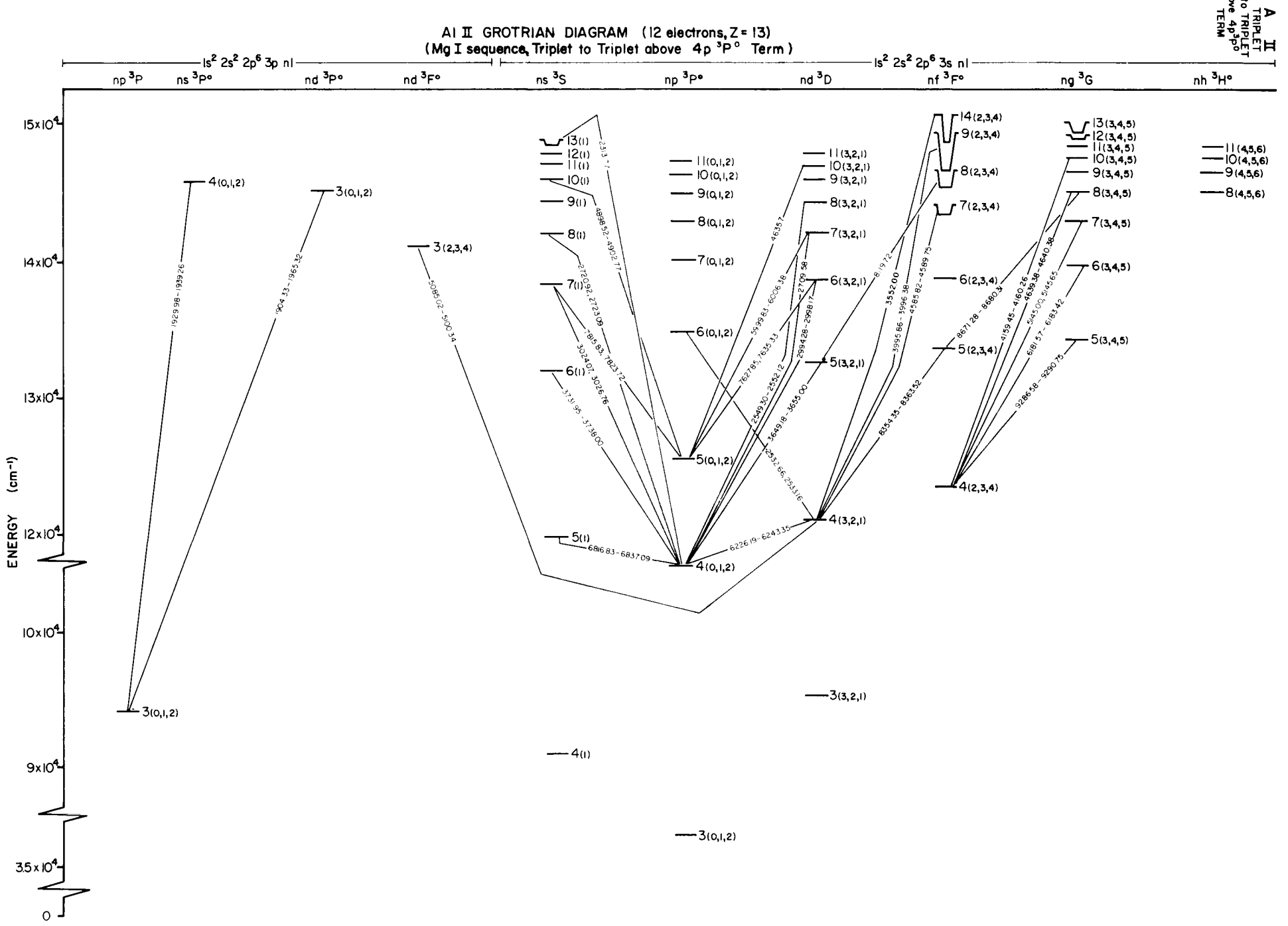
(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\ nl$, Singlet System)



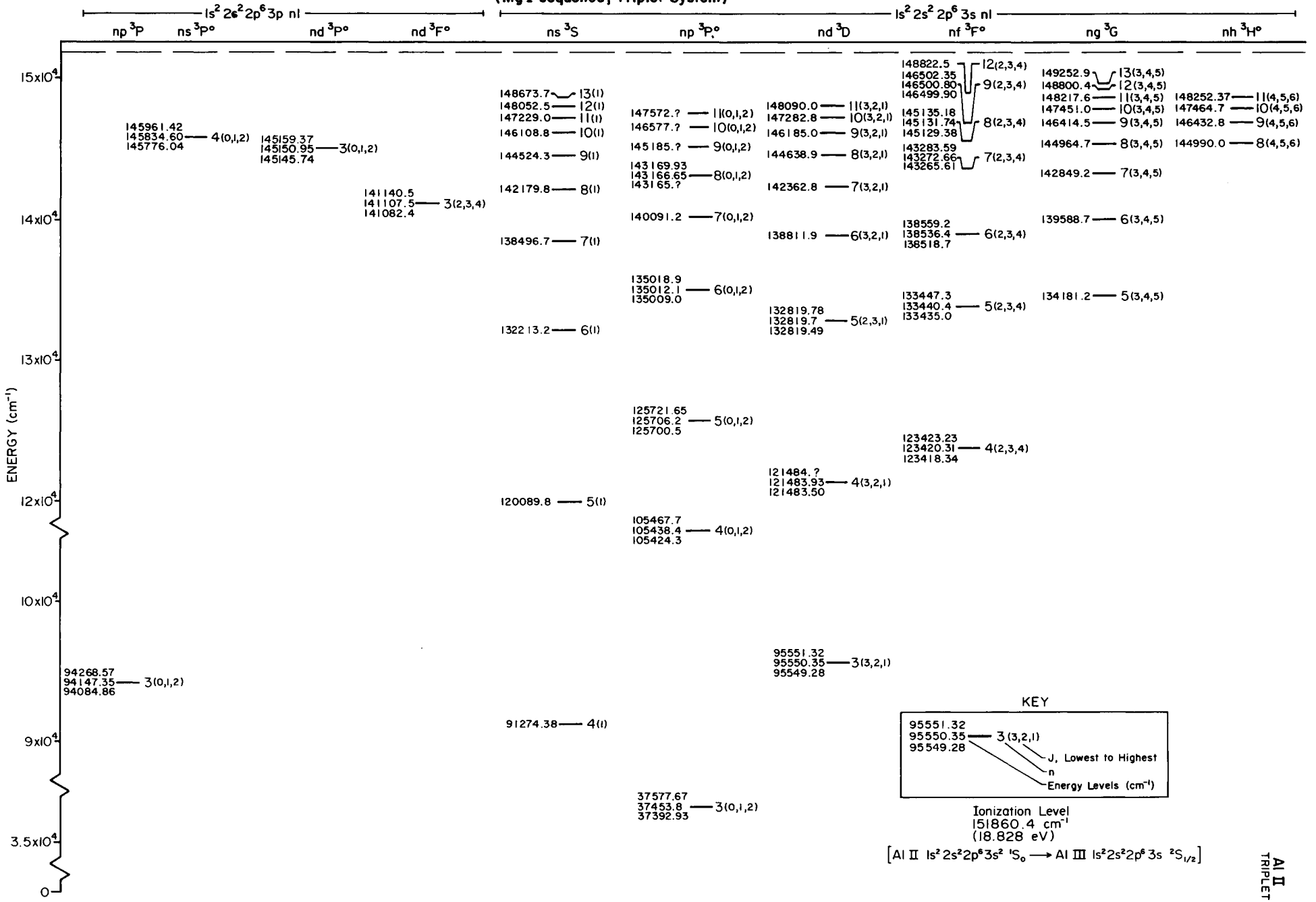

Al II GROTRIAN DIAGRAM (12 electrons, Z = 13)
(Mg I Sequence, 3p ³P°, 4s ³S, 3d ³D to higher Triplets)
Al II
3p ³P°, 4s ³S, 3d ³D to higher Triplets
GROTRIAN DIAGRAM
1s² 2s² 2p⁶ 3p nl
1s² 2s² 2p⁶ 3s nl
np ³P
ns ³P°
nd ³P°
nd ³F°
ns ³S
np ³P°
nd ³D
nf ³F°
ng ³G
nh ³H°
ENERGY (cm⁻¹)
15x10⁴
14x10⁴
13x10⁴
12x10⁴
10x10⁴
9x10⁴
3.5x10⁴
0
1s² 2s² 2p⁶ 3p² ¹D
2081.5, 20870

Al II ENERGY LEVELS (12 electrons, Z = 13)
(Mg I sequence, Triplet System)

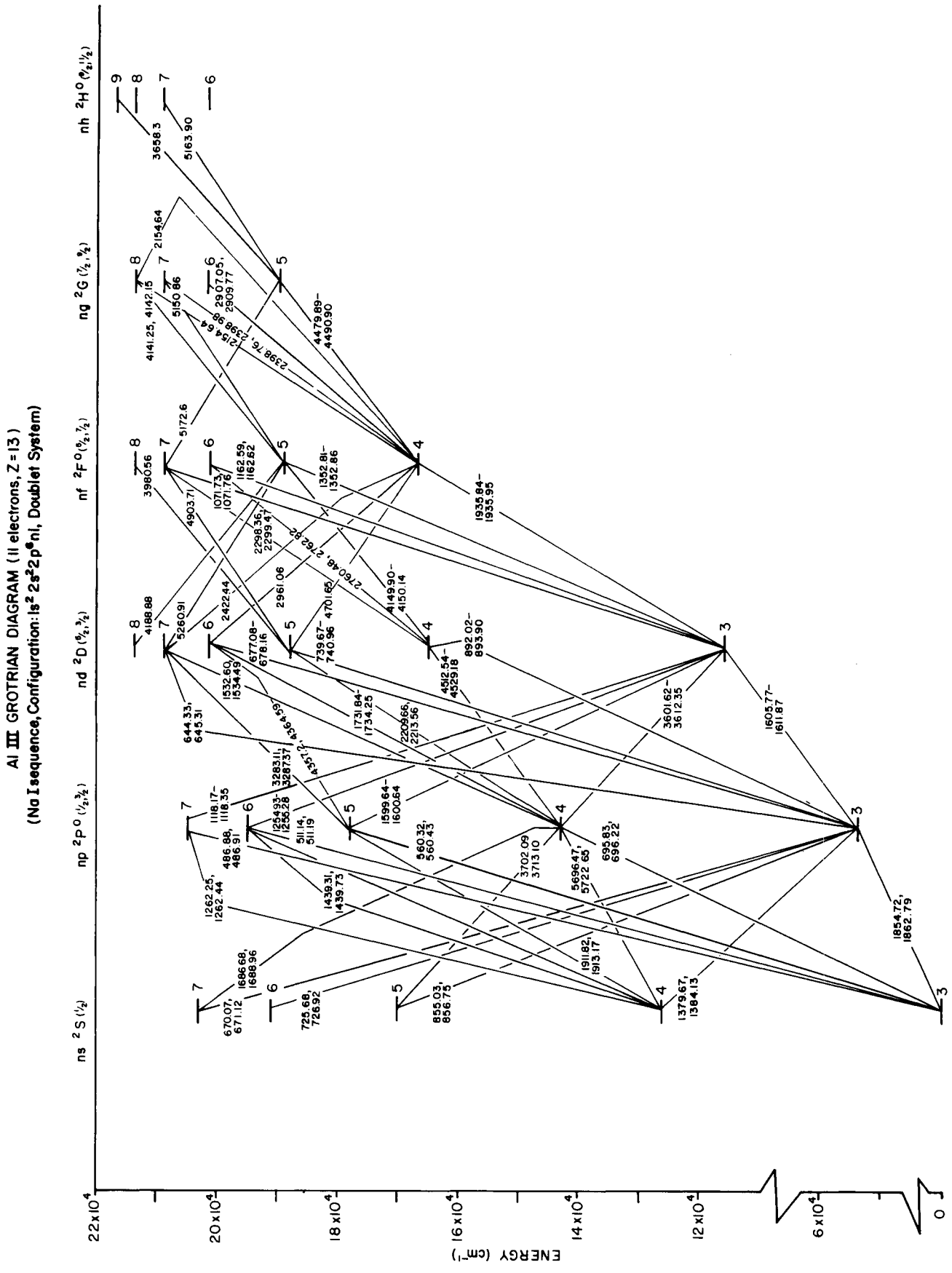



Al II GROTRIAN DIAGRAM (12 electrons, Z = 13)
(Mg I sequence, Triplet to Triplet above 4p ³P° Term)
Al II TRIPLET to TRIPLET above 4p³P° TERM
1s² 2s² 2p⁶ 3p nl
1s² 2s² 2p⁶ 3s nl
np ³P
ns ³P°
nd ³P°
nd ³F°
ns ³S
np ³P°
nd ³D
nf ³F°
ng ³G
nh ³H°
ENERGY (cm⁻¹)
15x10⁴
14x10⁴
13x10⁴
12x10⁴
10x10⁴
9x10⁴
3.5x10⁴
0
1929.98 - 1939.26
904.33 - 1965.32
5085.02 - 5100.34
4938.52 - 4902.77
2172.92, 2723.09
786.83, 1823.72
3024.07, 3025.76
3731.95 - 3738.00
6816.83 - 6837.09
4635.7
5999.83 - 6006.36
6278.15, 7635.33
2549.30 - 2552.12
3649.18 - 3655.00
2532.66, 2533.16
6226.19 - 6243.35
2709.98
2994.28 - 2998.17
8197.2
3552.00
3995.66 - 3996.38
4585.82 - 4589.75
8354.35 - 8363.52
8671.28 - 8680.33
4159.45 - 4160.25
4639.38 - 4640.38
5145.00, 5145.65
6181.57 - 6183.42
9286.38 - 9290.75

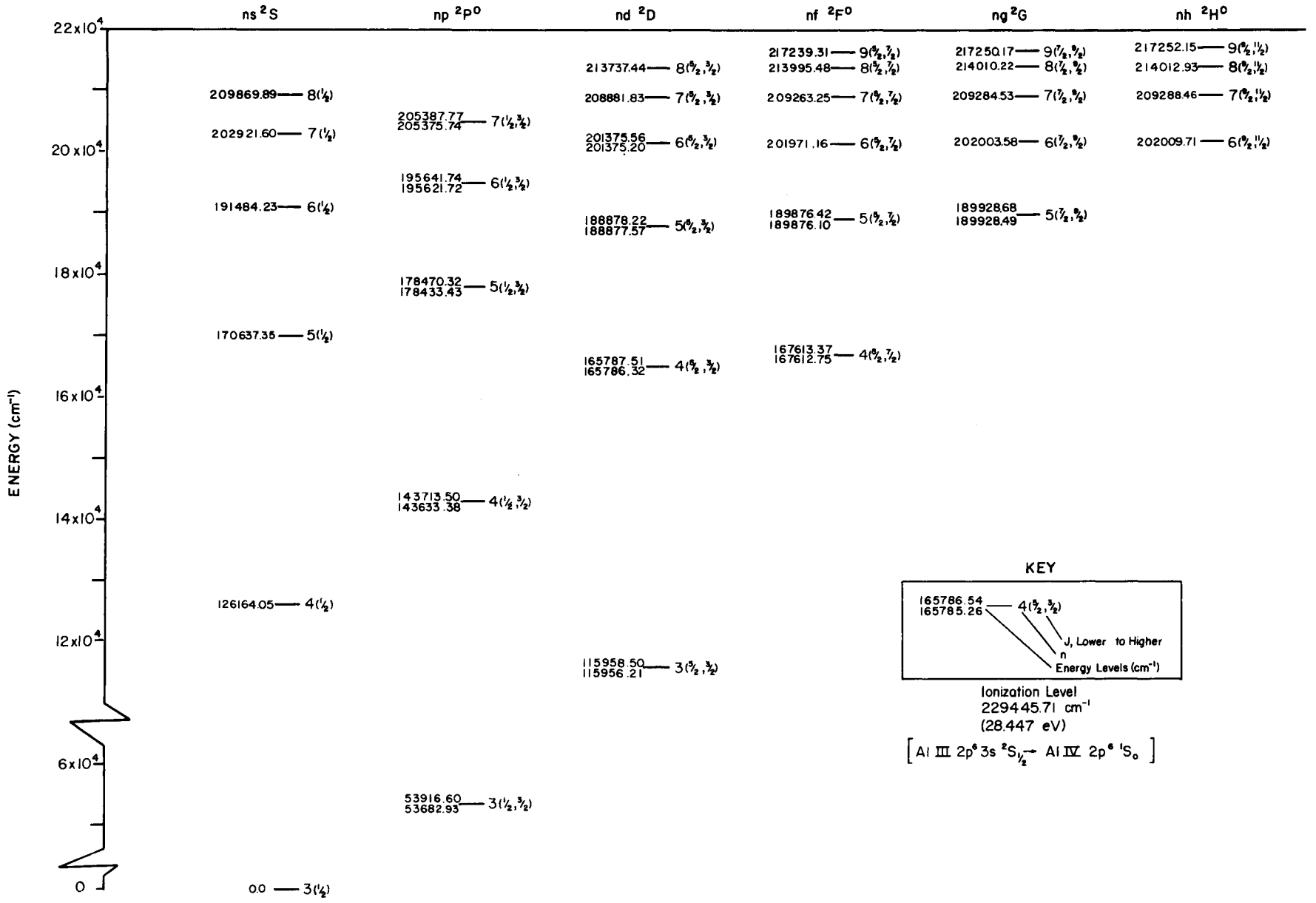
Al II ENERGY LEVELS (12 electrons, Z = 13)
(Mg I sequence, Triplet System)



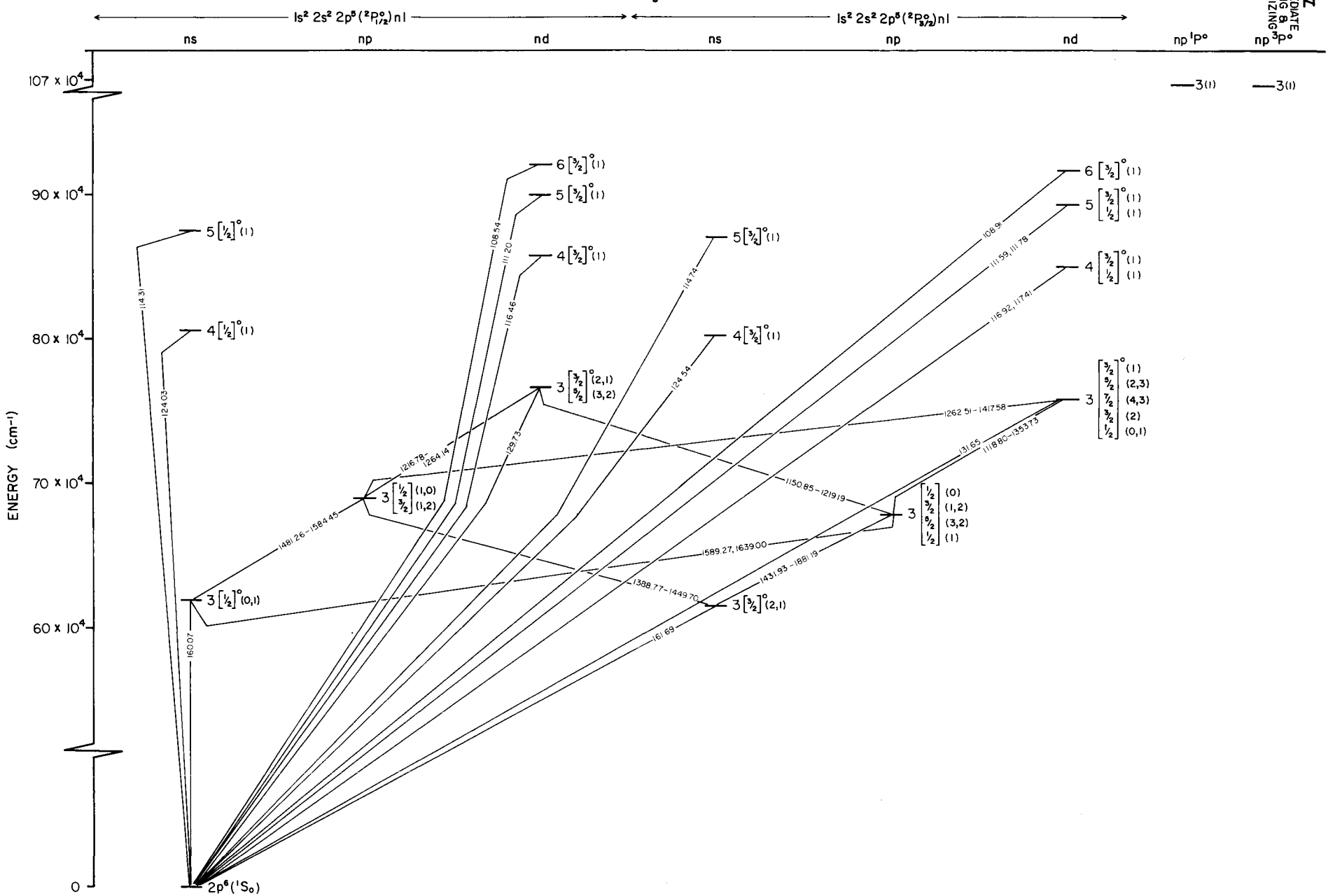
Al III
DOUBLET
GROTRIAN
DIAGRAM



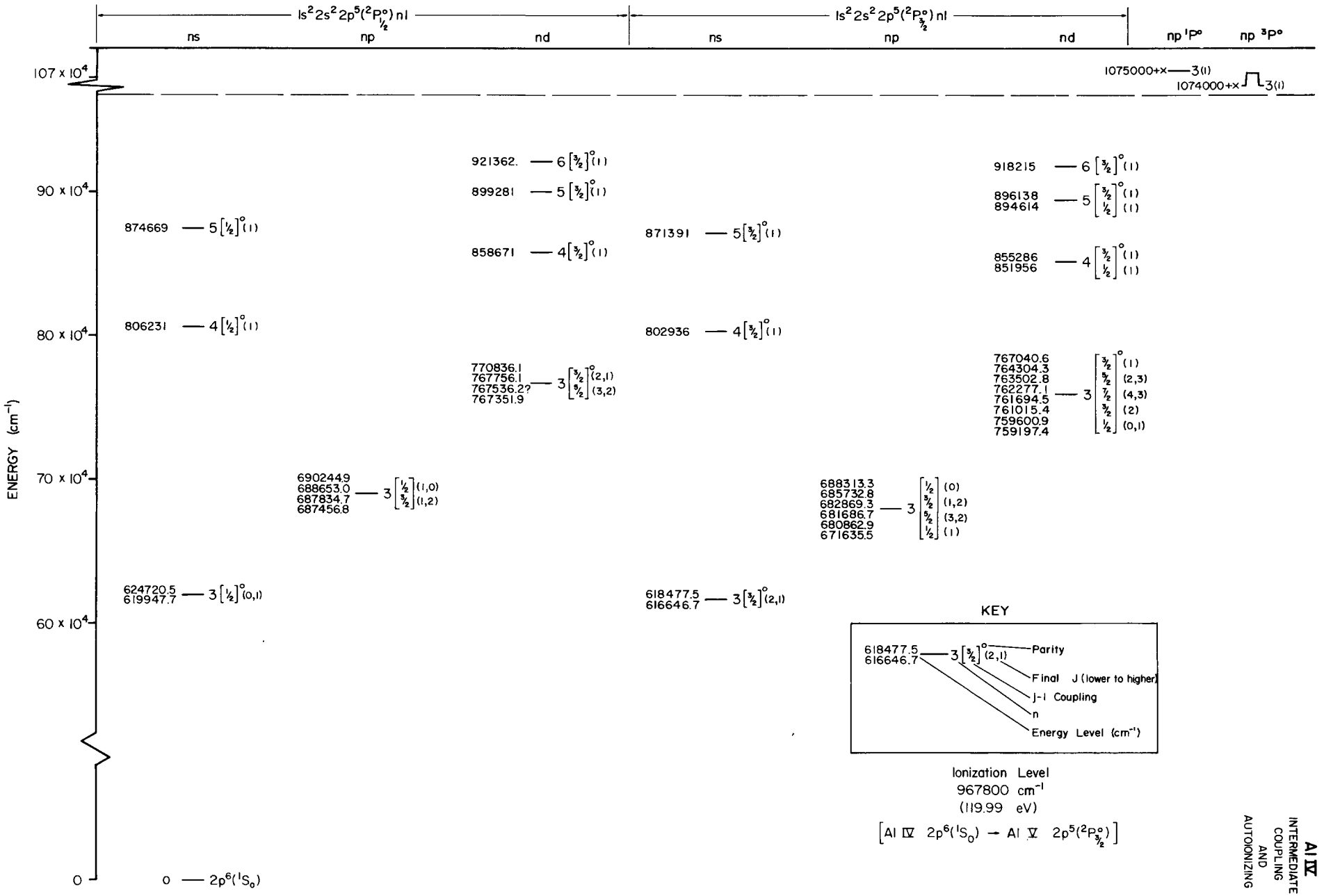
Al III ENERGY LEVELS (11 electrons, Z=13)
(Na I sequence, Configuration: $1s^2 2s^2 2p^6 nl$, Doublet System)



Al IV GROTRIAN DIAGRAM (10 electrons, Z = 13)
(Ne I sequence, Intermediate Coupling and Autoionizing Terms)

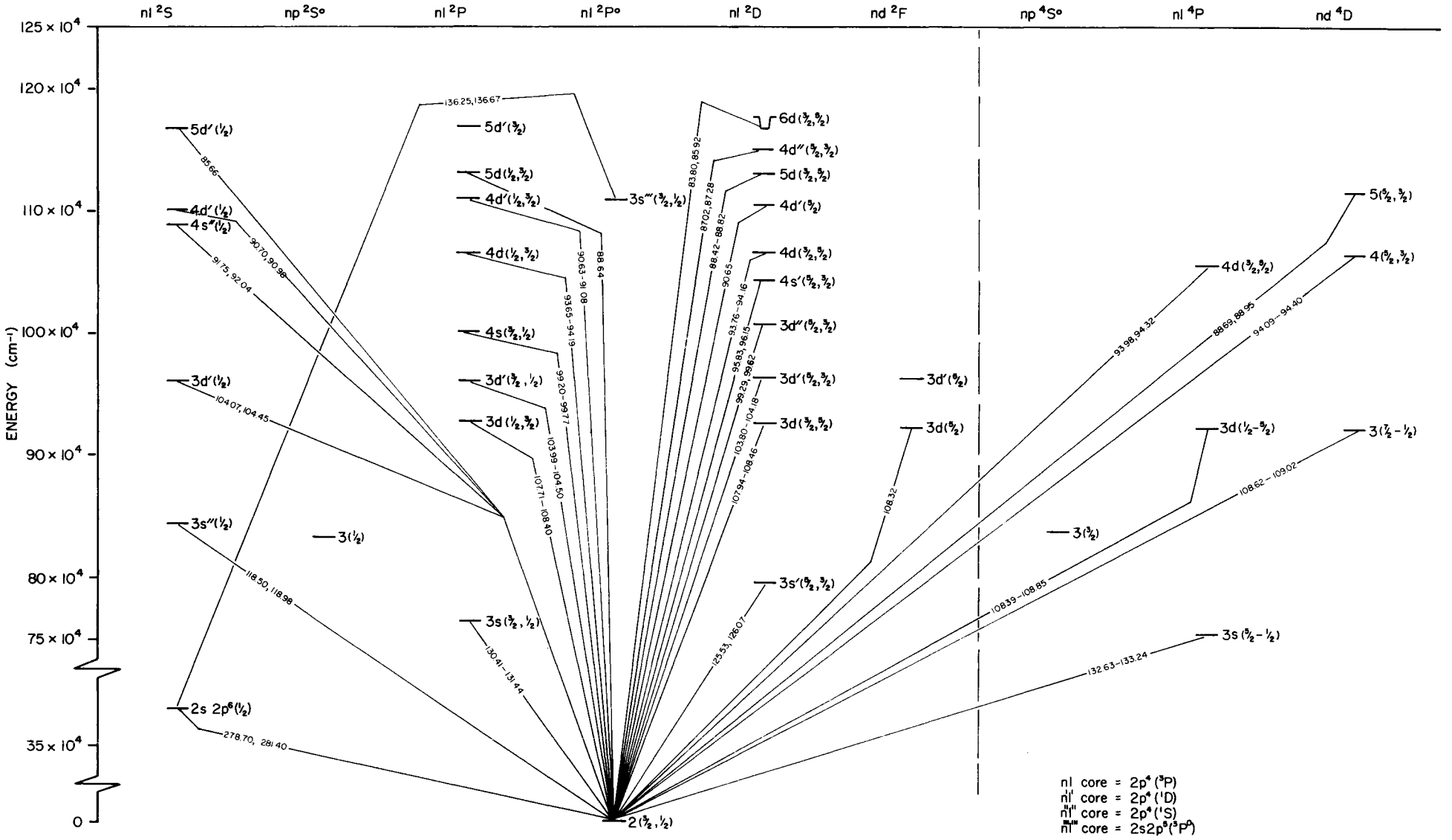


Al IV ENERGY LEVELS (10 electrons, Z = 13)
(Ne I sequence, Intermediate Coupling and Autoionizing Terms)



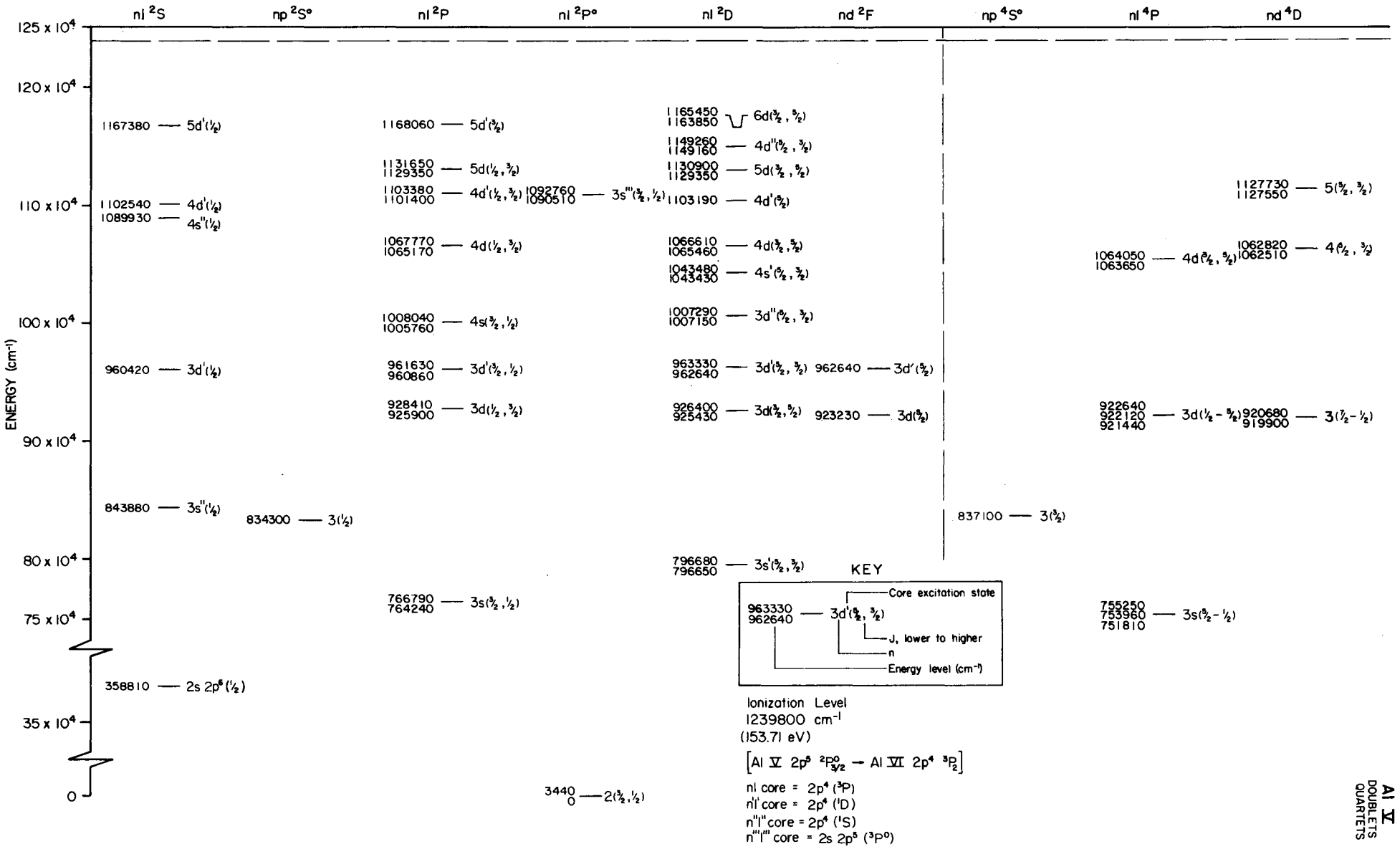
Al V GROTRIAN DIAGRAM (9 electrons, Z=13)

(F I sequence, Configuration: $1s^2\,2s^2\,2p^4\,nl$, Doublet and Quartet Systems)

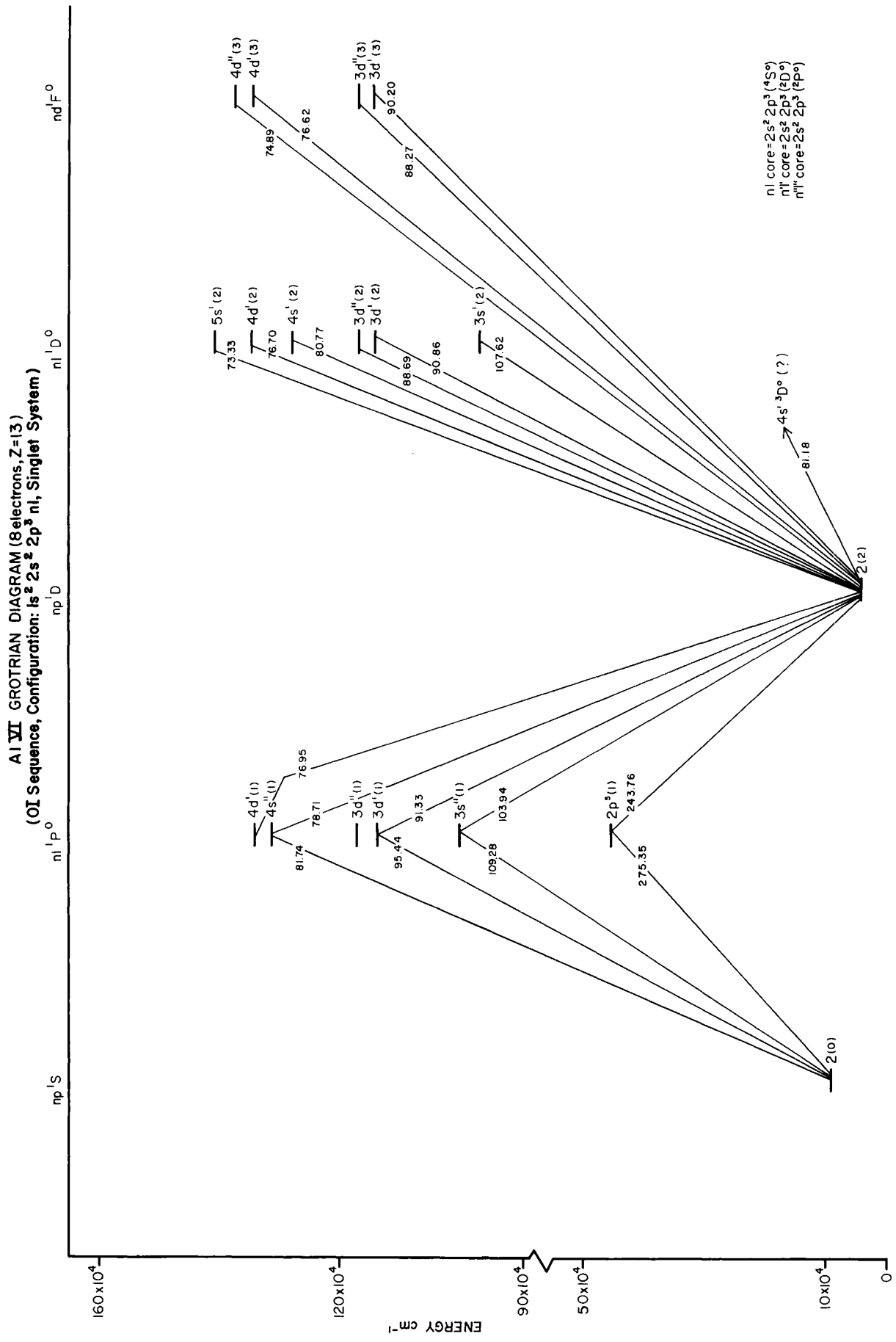


Al V ENERGY LEVELS (9 electrons, Z=13)

(F I sequence, Configuration: $1s^2\ 2s^2\ 2p^4\ nl$, Doublet and Quartet Systems)

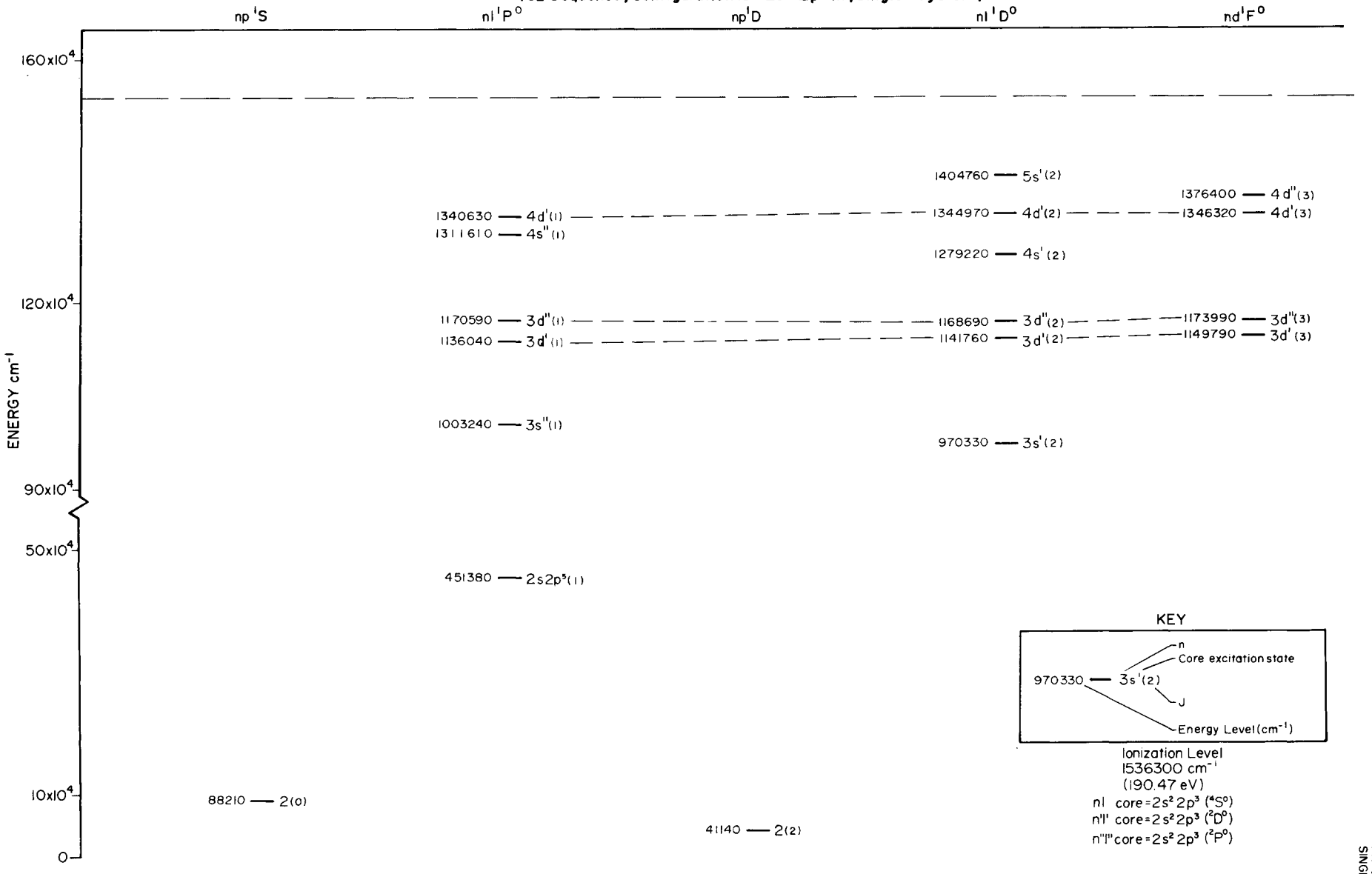


Al VI
SINGLET
GROTRIAN
DIAGRAM



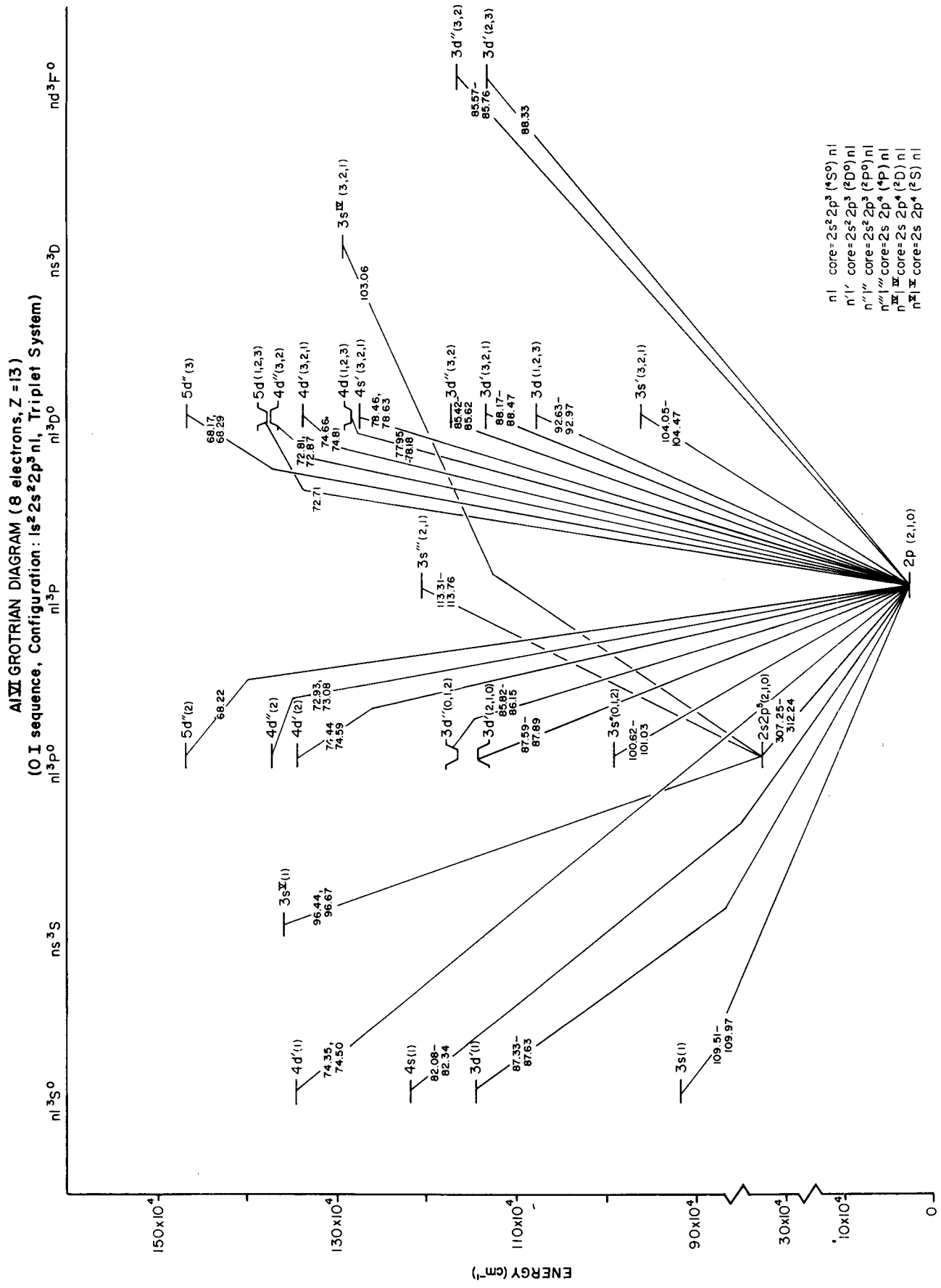
Al VI ENERGY LEVELS (8 electrons, Z=13)

(OI Sequence, Configuration: $1s^2\ 2s^2\ 2p^3\ nl$, Singlet System)

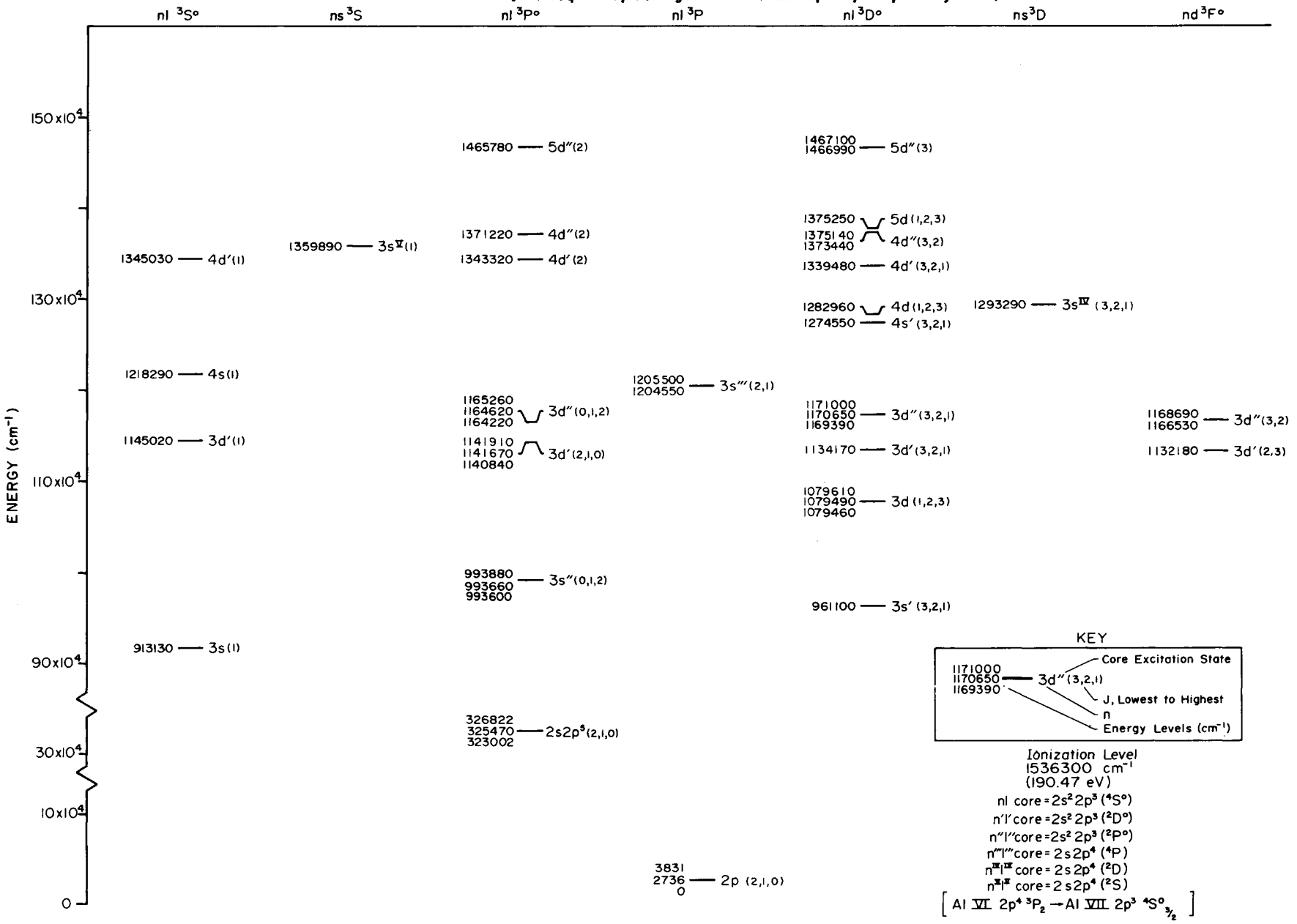


[Al VI $1s^2 2s^2 2p^4\ ^3P_2 \longrightarrow$ Al VII $1s^2 2s^2 2p^3\ ^4S^\circ_{3/2}$]

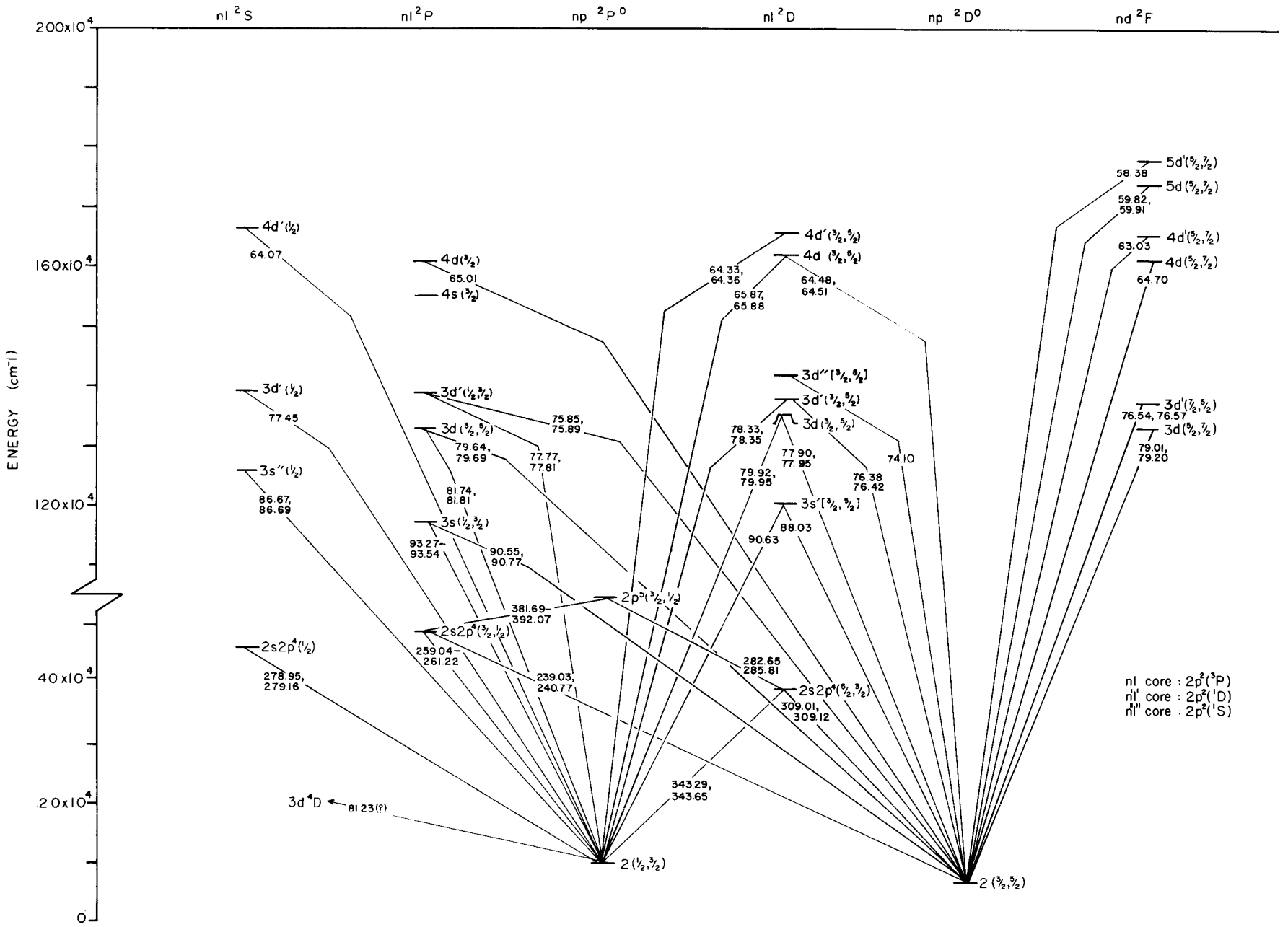
Al VI
TRIPLET
GROTRIAN
DIAGRAM



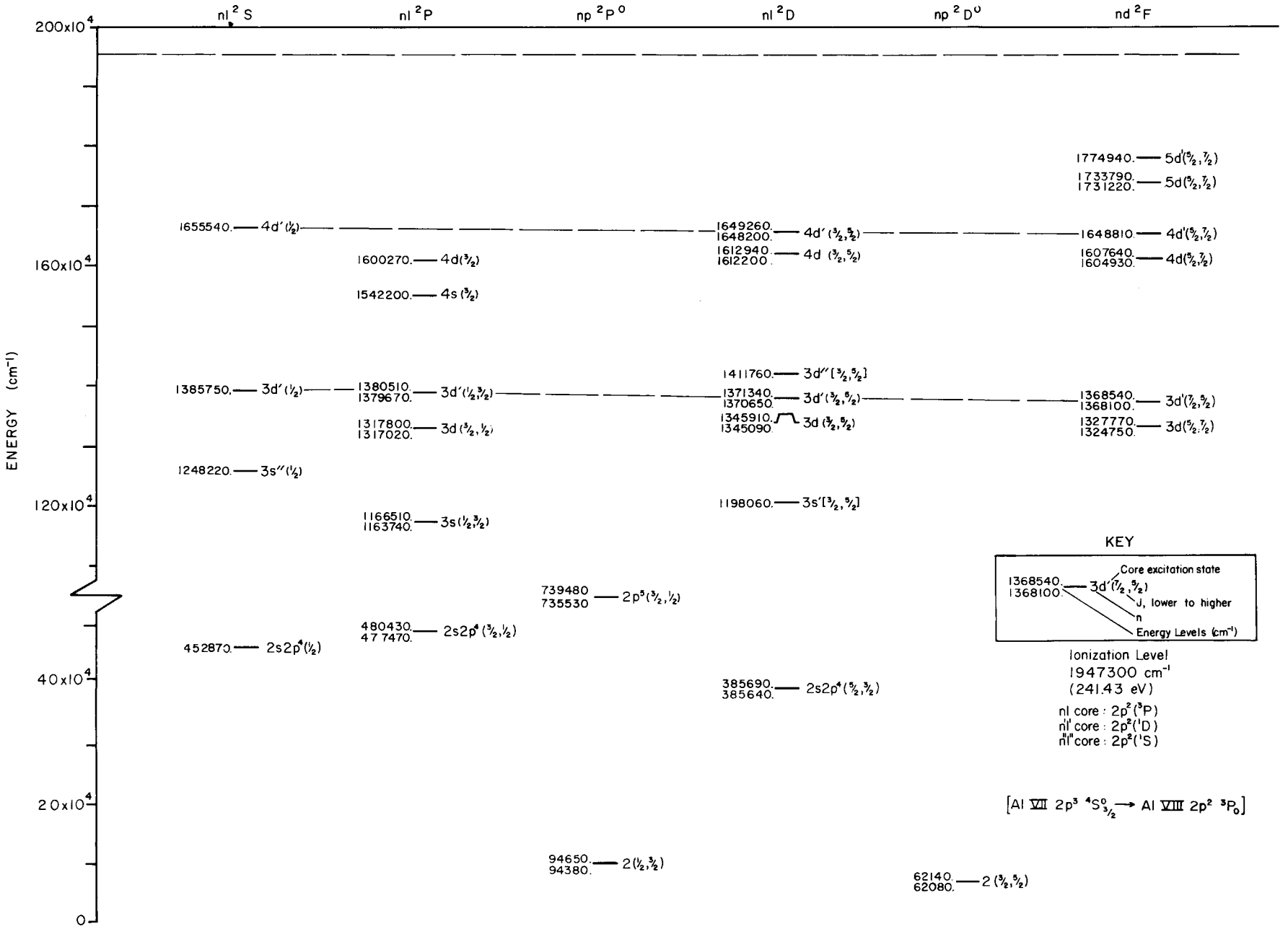
Al VI ENERGY LEVELS (8 electrons, Z = 13)
(O I sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)



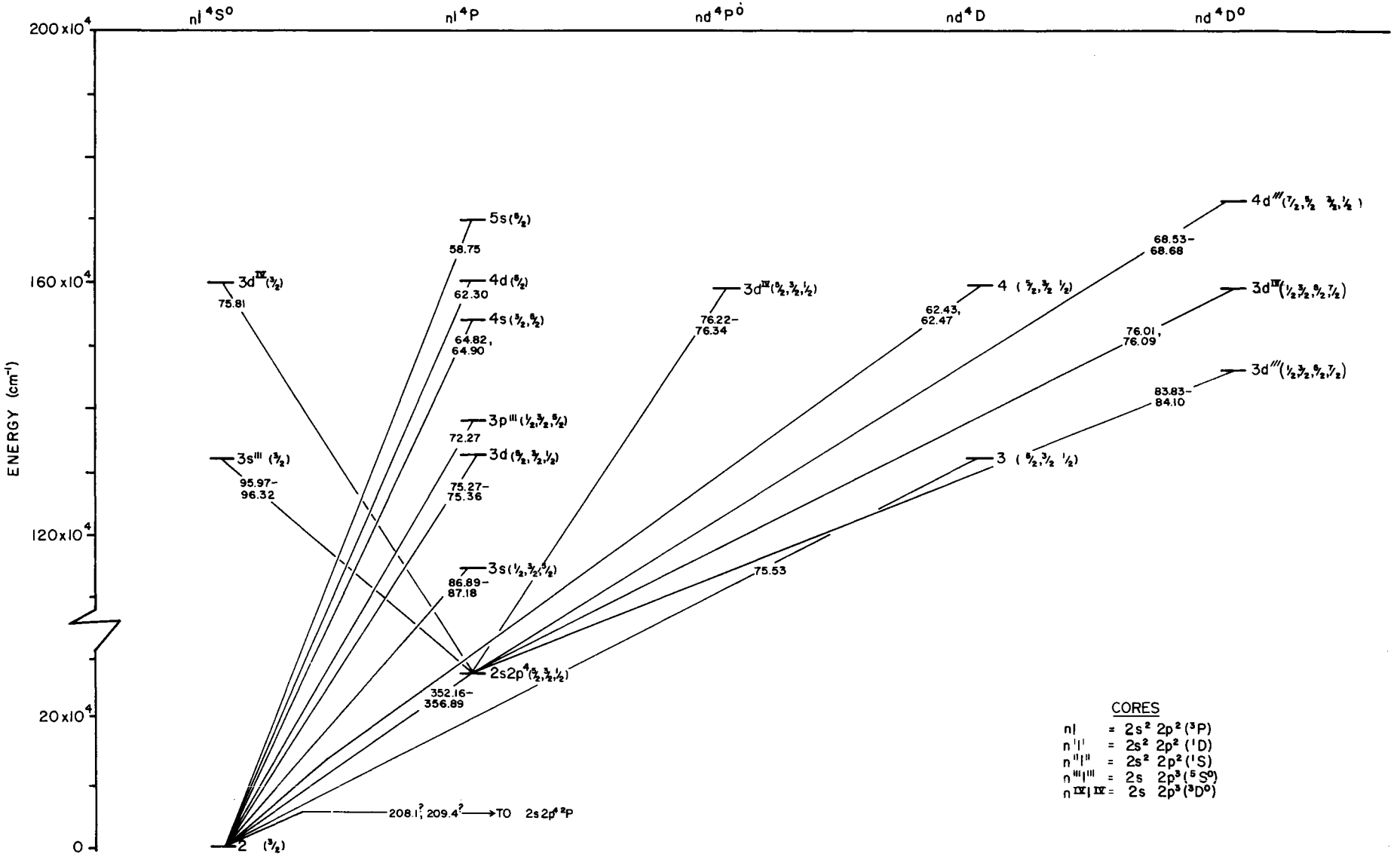
Al VII GROTRIAN DIAGRAM (7 electrons, Z=13)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



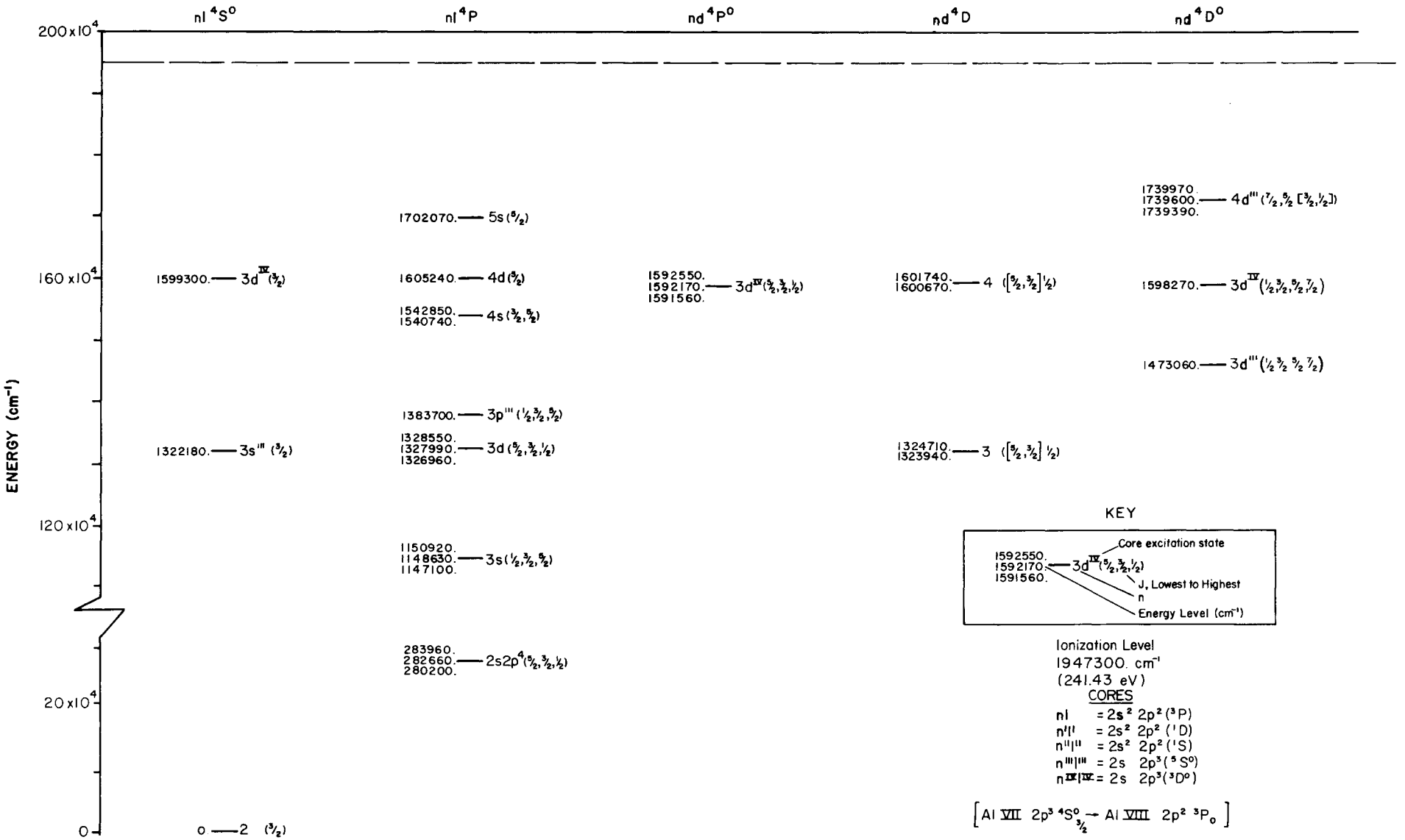
Al VII ENERGY LEVELS (7 electrons, Z=13)
(NI sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



Al VII GROTRIAN DIAGRAM (7 electrons, Z=13)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Quartet System)



Al VII ENERGY LEVELS (7 electrons, Z=13)
(N I sequence, Configuration; $1s^2 2s^2 2p^2 nl$, Quartet System)

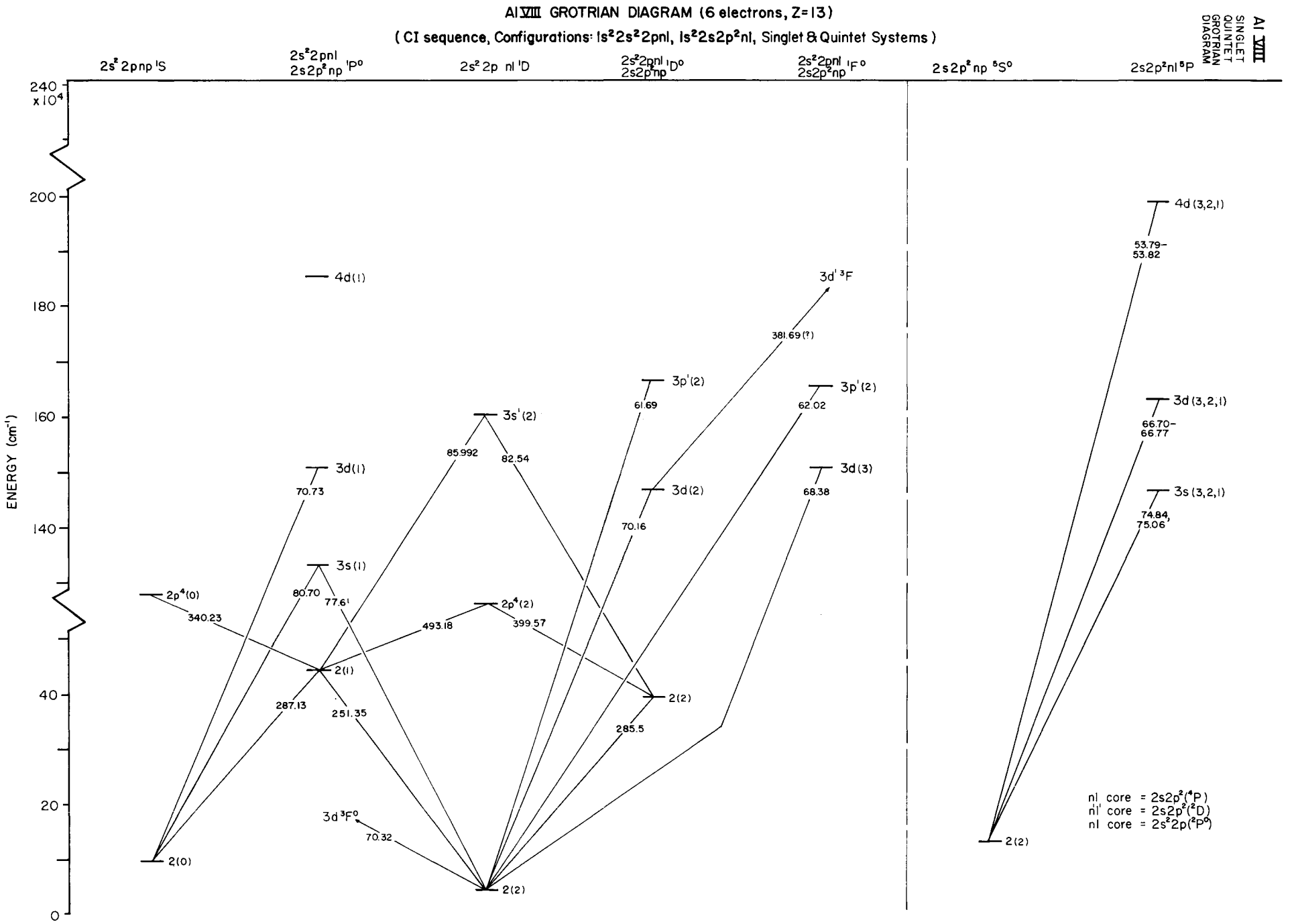


Ionization Level
1947300. cm⁻¹
(241.43 eV)

CORES

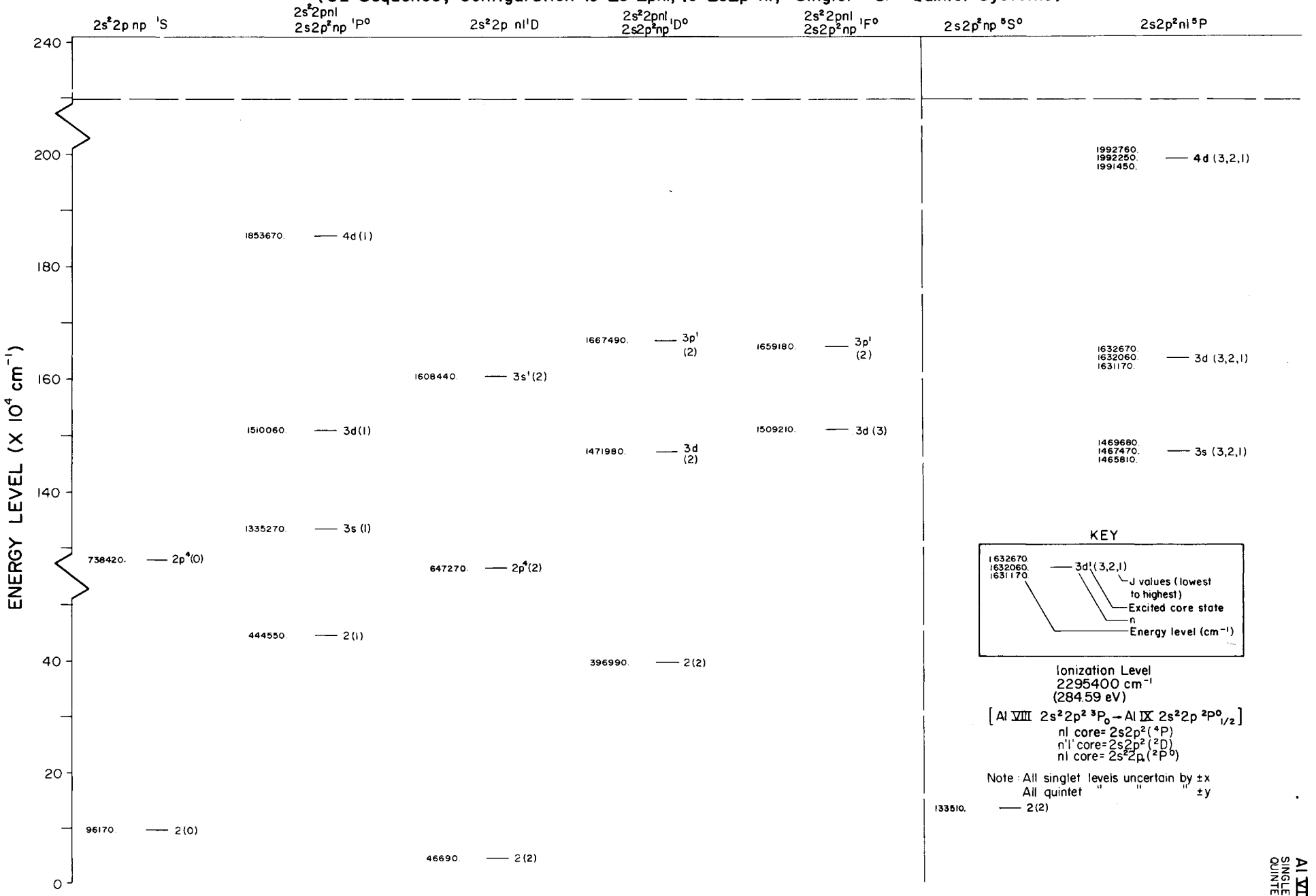
nl	$= 2s^2\ 2p^2\ (^3P)$
n'l'	$= 2s^2\ 2p^2\ (^1D)$
n''l''	$= 2s^2\ 2p^2\ (^1S)$
n'''l'''	$= 2s\ \ 2p^3\ (^5S^o)$
n^IV l^IV	$= 2s\ \ 2p^3\ (^3D^o)$

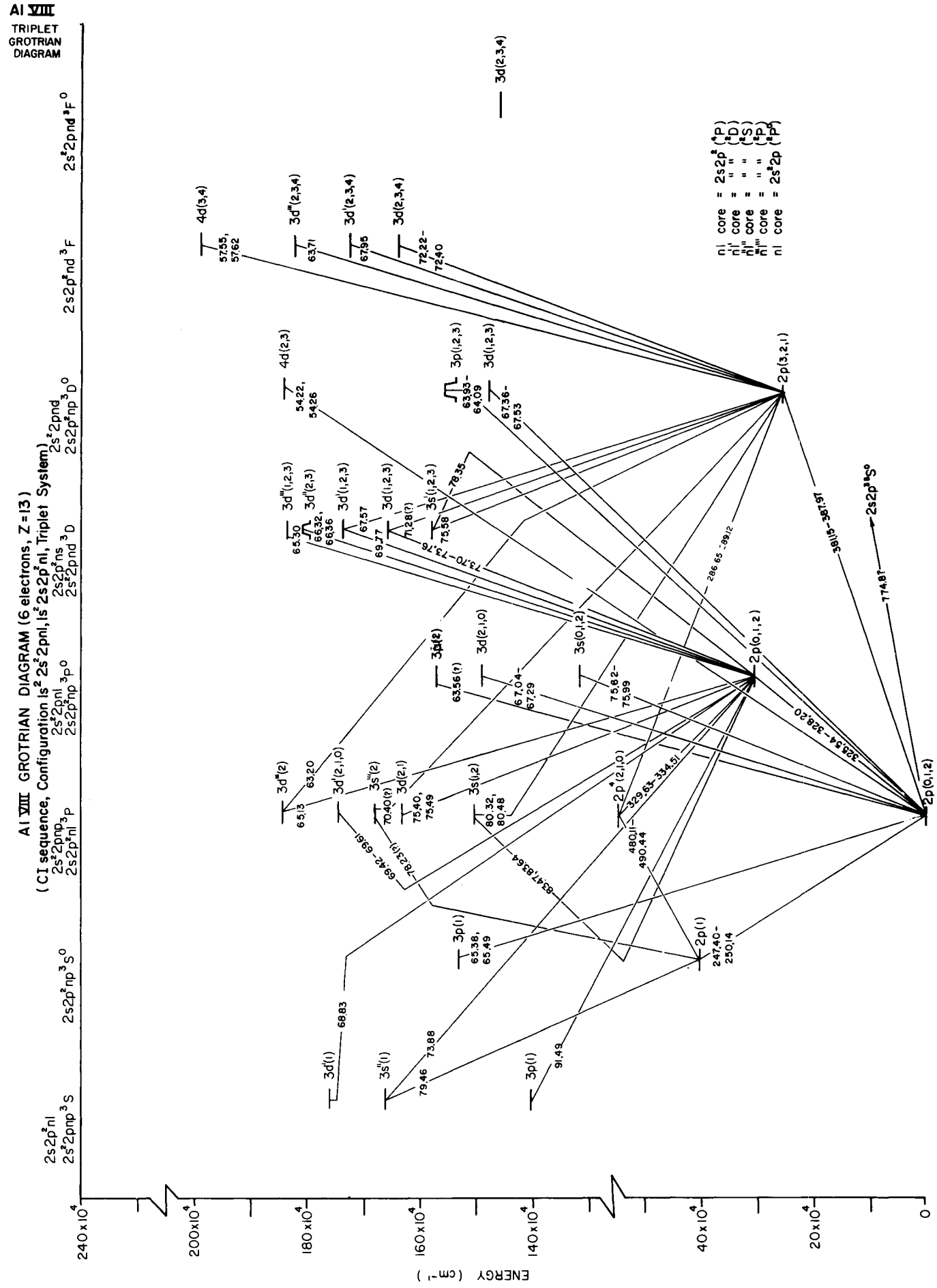
[Al VII $2p^3\ ^4S^o_{3/2}$ → Al VIII $2p^2\ ^3P_o$]


Al VIII GROTRIAN DIAGRAM (6 electrons, Z=13)
(CI sequence, Configurations: 1s²2s²2pnl, 1s²2s2p²nl, Singlet & Quintet Systems)
Al VIII
SINGLET
QUINTET
GROTRIAN
DIAGRAM
2s²2pnp ¹S
2s²2pnl
2s2p²np ¹P°
2s²2p nl ¹D
2s²2pnl
2s2p²np ¹D°
2s²2pnl
2s2p²np ¹F°
2s2p²np ⁵S°
2s2p²nl ⁵P
ENERGY (cm⁻¹)
240 x10⁴
200
180
160
140
40
20
0
4d(1)
3d(1)
3s(1)
2p⁴(0)
2(1)
2(0)
3s'(2)
2p⁴(2)
2(2)
3d ³F°
3p'(2)
3d(2)
3d' ³F
3p'(2)
3d(3)
4d (3,2,1)
3d (3,2,1)
3s (3,2,1)
2(2)
70.73
80.70
77.6'
340.23
287.13
251.35
85.992
82.54
493.18
399.57
70.32
61.69
70.16
285.5
381.69 (?)
62.02
68.38
53.79-
53.82
66.70-
66.77
74.84,
75.06
nl core = 2s2p²(⁴P)
nl' core = 2s2p²(²D)
nl core = 2s²2p(²P°)

Al VIII ENERGY LEVELS (6 electrons, Z = 13)

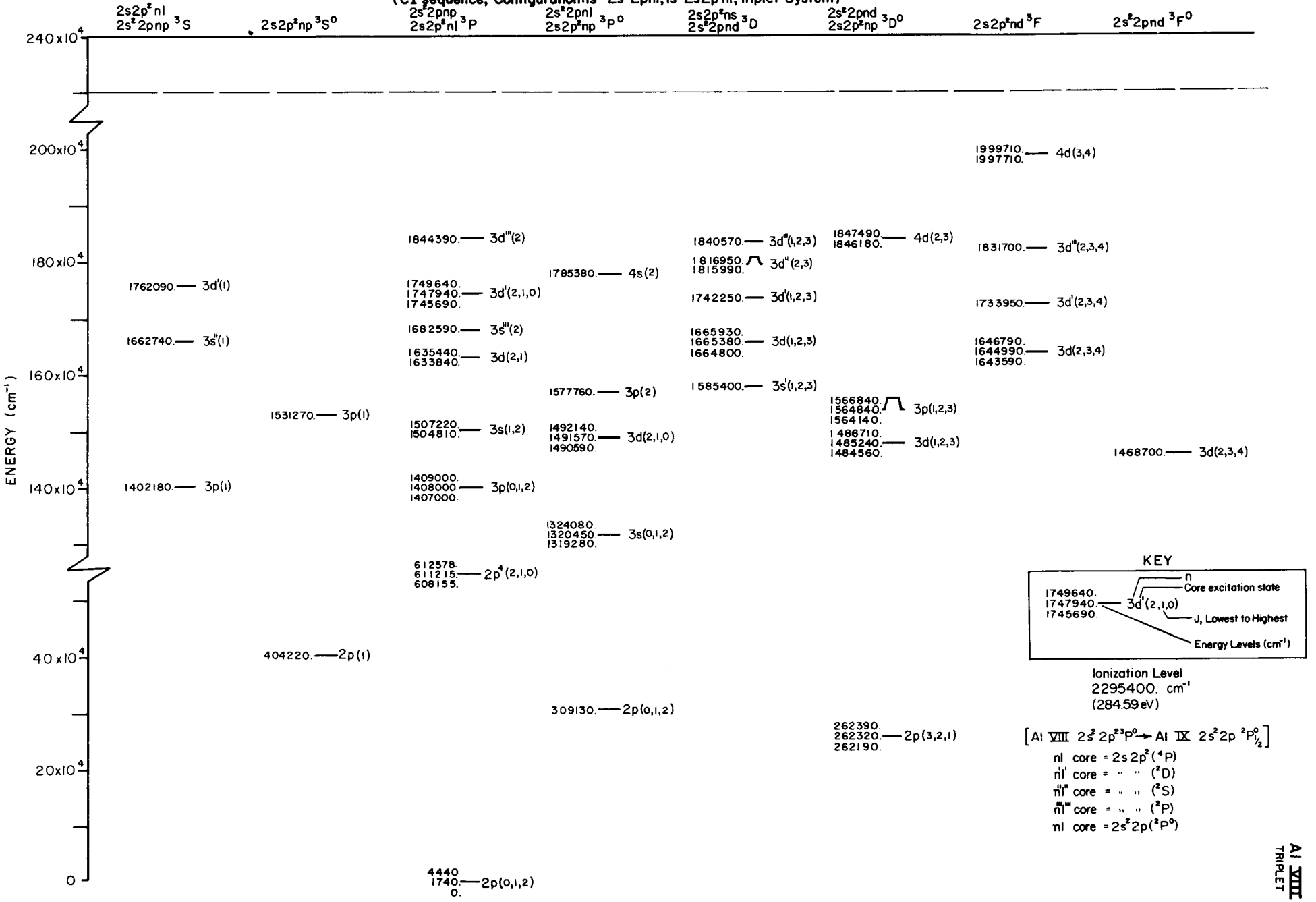
(CI Sequence, Configuration $1s^2 2s^2 2pnl$, $1s^2 2s2p^2nl$, Singlet & Quintet Systems)

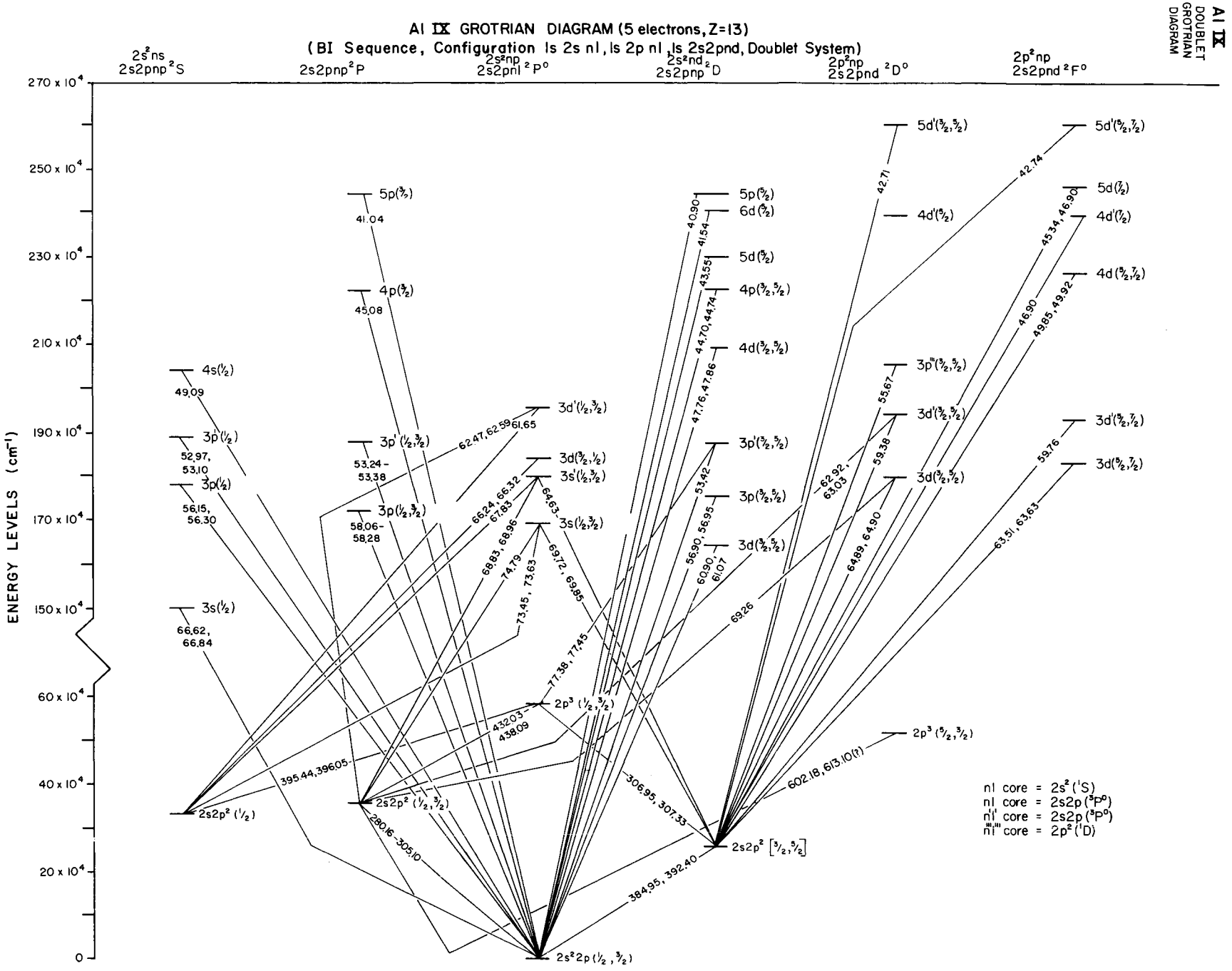



Al VIII
TRIPLET
GROTRIAN
DIAGRAM
Al VIII GROTRIAN DIAGRAM (6 electrons, Z=13)
(CI sequence, Configuration 1s² 2s²2pnl, 1s² 2s2p²nl, Triplet System)
ENERGY (cm⁻¹)
240x10⁴
200x10⁴
180x10⁴
160x10⁴
140x10⁴
40x10⁴
20x10⁴
0
2s²2pnd ³F°
2s²2pnd ³F
2s²2pnd ³D°
2s²2pnd ³D
2s²2pnp ³P°
2s²2pnp ³P
2s²2pnp ³S°
2s²2pnp ³S
2s²2pnl
2s²2pnl
2s²2pnl

Al VIII ENERGY LEVELS (6 electrons, Z=13)

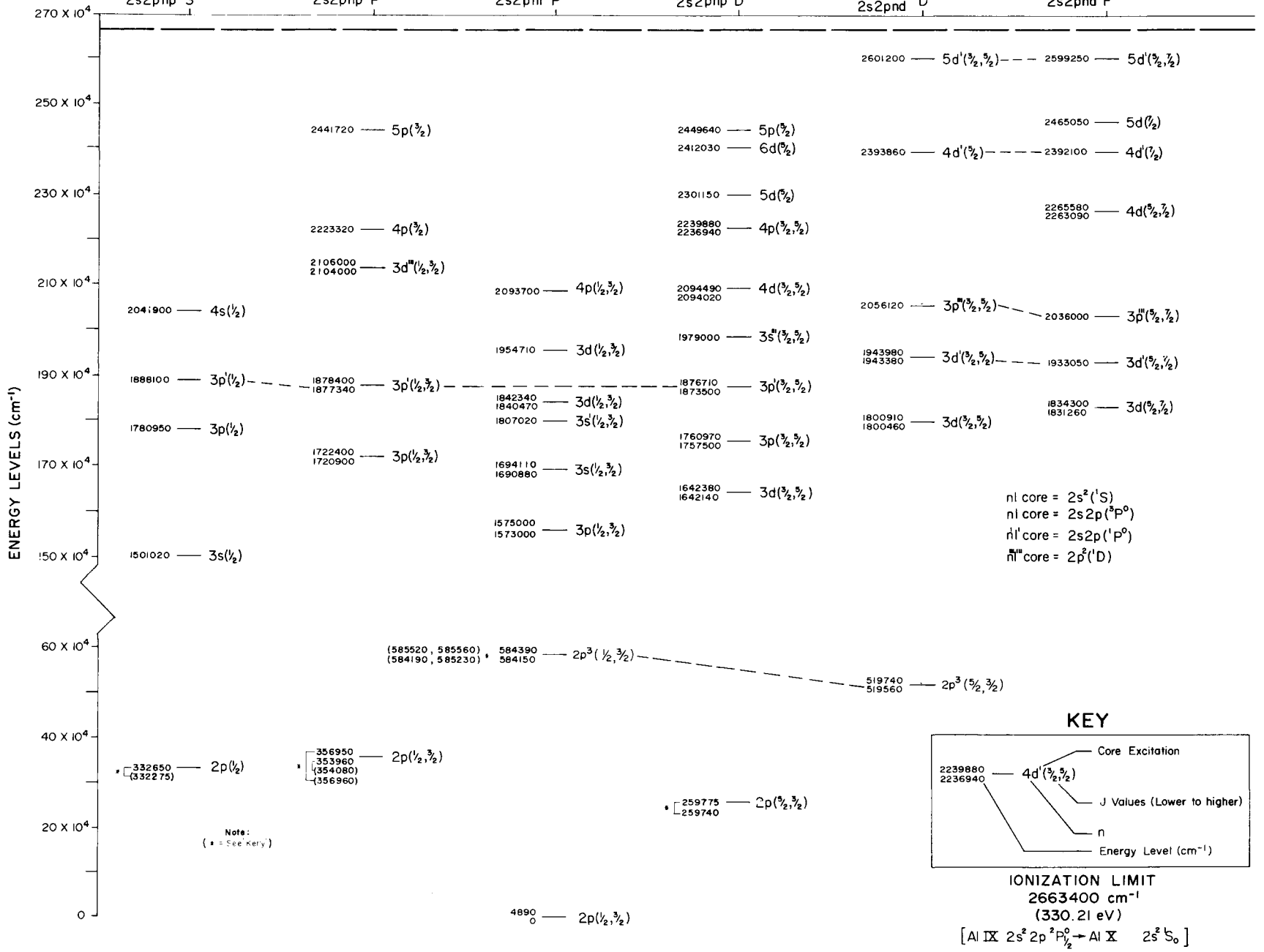
(CI sequence, Configuration: $1s^2\ 2s^2\ 2pnl$, $1s^2\ 2s2p^2nl$, Triplet System)




Al IX GROTRIAN DIAGRAM (5 electrons, Z=13)
(BI Sequence, Configuration 1s 2s nl, 1s 2p nl, 1s 2s2pnd, Doublet System)
2s²ns 2s2pnp ²S
2s2pnp ²P
2s²np 2s2pnl ²P°
2s²nd 2s2pnp ²D
2p²np 2s2pnd ²D°
2p²np 2s2pnd ²F°
ENERGY LEVELS (cm⁻¹)
270 x 10⁴
250 x 10⁴
230 x 10⁴
210 x 10⁴
190 x 10⁴
170 x 10⁴
150 x 10⁴
60 x 10⁴
40 x 10⁴
20 x 10⁴
0
4s(½)
49.09
3p'(½)
52.97, 53.10
3p(½)
56.15, 56.30
3s(½)
66.62, 66.84
5p(3/2)
41.04
4p(3/2)
45.08
3p'(½,3/2)
53.24 - 53.38
3p(½,3/2)
58.06 - 58.28
3d'(½,3/2)
3d(3/2,½)
3s'(½,3/2)
3s(½,3/2)
62.47, 62.59, 61.65
66.24, 66.32
67.83
64.63
68.83, 68.96
74.79
73.45, 73.63
69.72, 69.85
77.38, 77.45
2p³ (½,3/2)
43.203 - 438.09
395.44, 396.05
2s2p² (½)
2s2p² (½,3/2)
280.16 - 305.10
306.95, 307.33
2s²2p (½,3/2)
384.95, 392.40
5p(5/2)
6d(5/2)
5d(5/2)
4p(3/2,5/2)
4d(3/2,5/2)
3p'(3/2,5/2)
3p(3/2,5/2)
3d(3/2,5/2)
40.90
41.54
43.51
44.70, 44.74
47.76, 47.86
53.42
56.90, 56.95
60.90, 61.07
62.92, 63.03
64.89, 64.90
63.26
2s2p² [3/2,5/2]
602.18, 613.10(?)
2p³ (5/2,3/2)
5d'(3/2,5/2)
4d'(5/2)
3p''(3/2,5/2)
3d'(3/2,5/2)
3d(3/2,5/2)
42.71
55.67
59.38
5d'(5/2,7/2)
5d(7/2)
4d'(7/2)
4d(5/2,7/2)
3d'(5/2,7/2)
3d(5/2,7/2)
42.74
45.34, 46.90
46.90
49.85, 49.92
59.76
63.51, 63.63
nl core = 2s² (¹S)
nl core = 2s2p (³P°)
nl' core = 2s2p (³P°)
nl'' core = 2p² (¹D)

Al IX ENERGY LEVELS (5 electrons, Z=13)

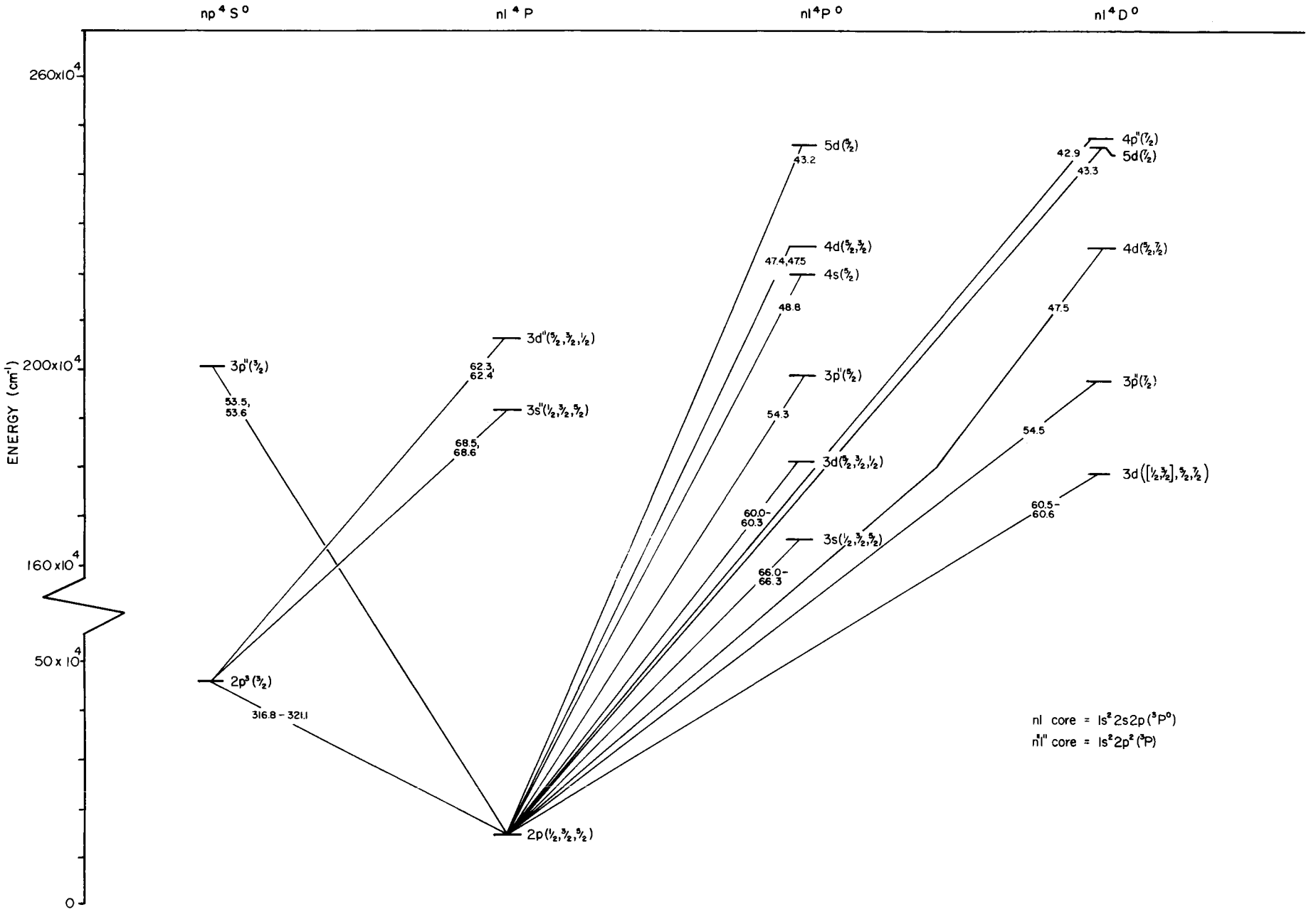
(B I Sequence, Configuration $1s^2 2s^2 nl$, $1s^2 2p^2 nl$, $1s^2 2s 2pnl$, Doublet System)



IONIZATION LIMIT
2663400 cm⁻¹
(330.21 eV)
[Al IX $2s^2 2p\,^2P^o_{1/2} \rightarrow$ Al X $2s^2\,^1S_0$]

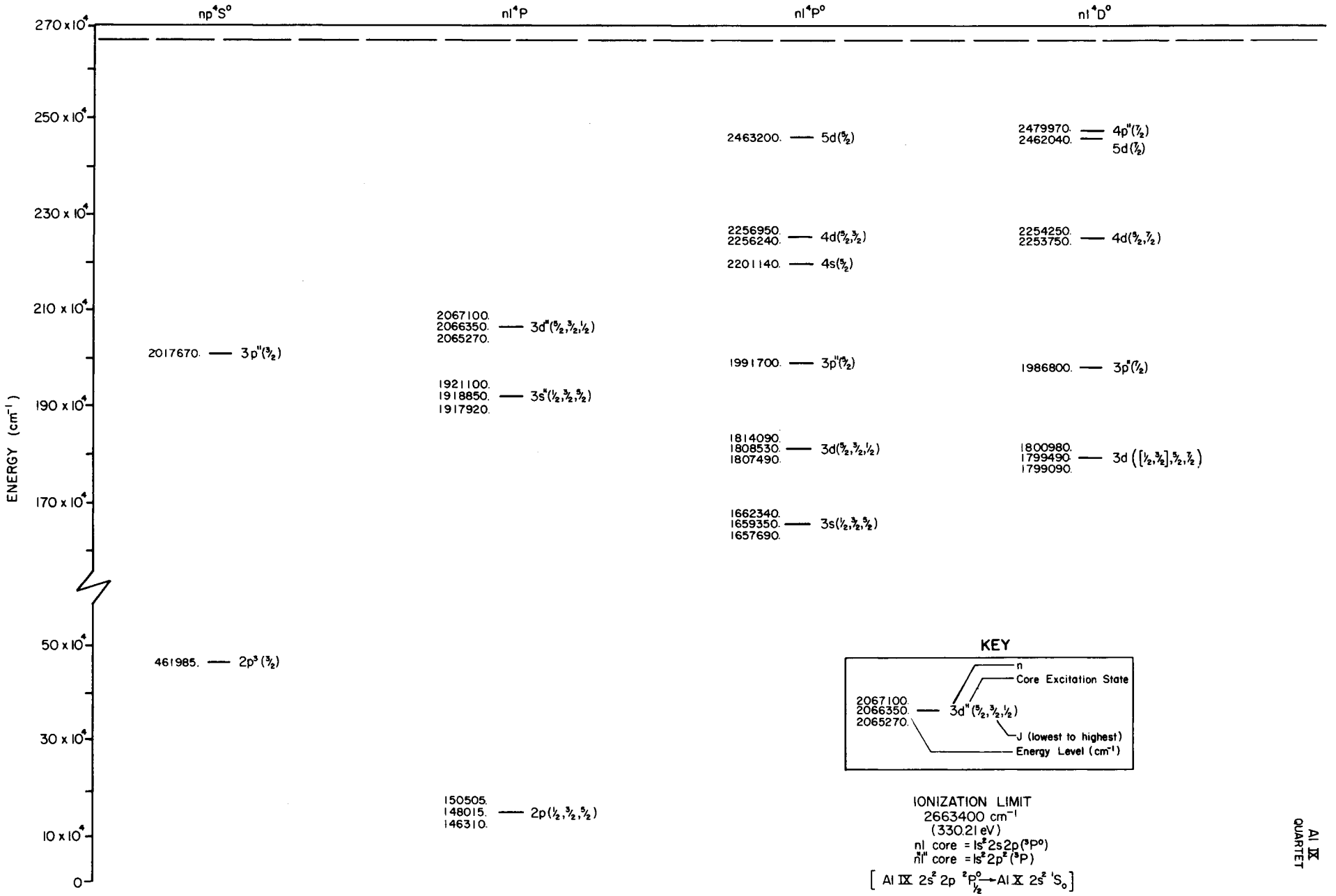
Al IX
DOUBLET

Al IX GROTRIAN DIAGRAM (5 electrons, Z=12)
(B I sequence, Configuration: $1s^2 2s2p(^3P^0)nl$, Quartet System)

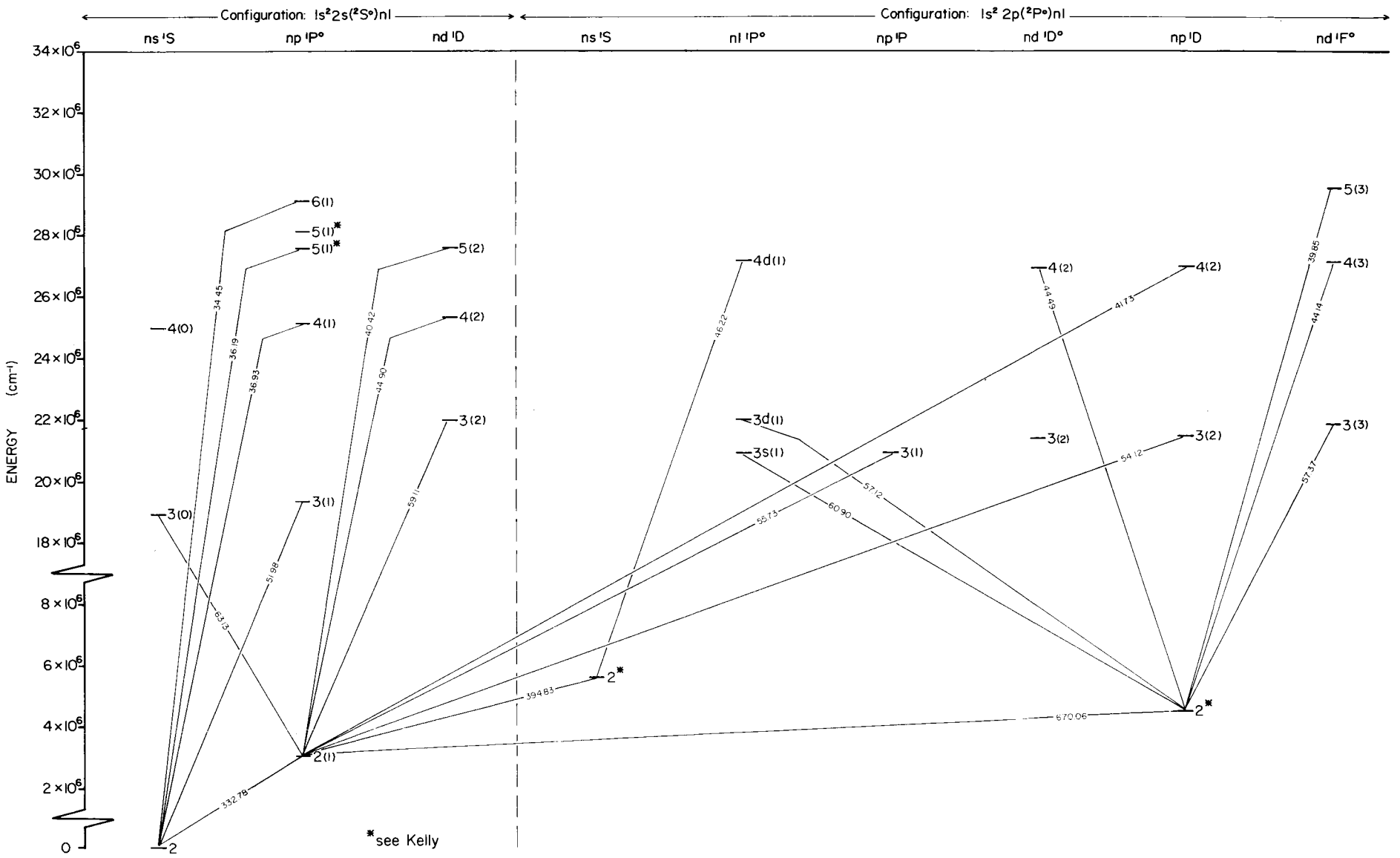


Al IX ENERGY LEVELS (5 electrons, Z=12)

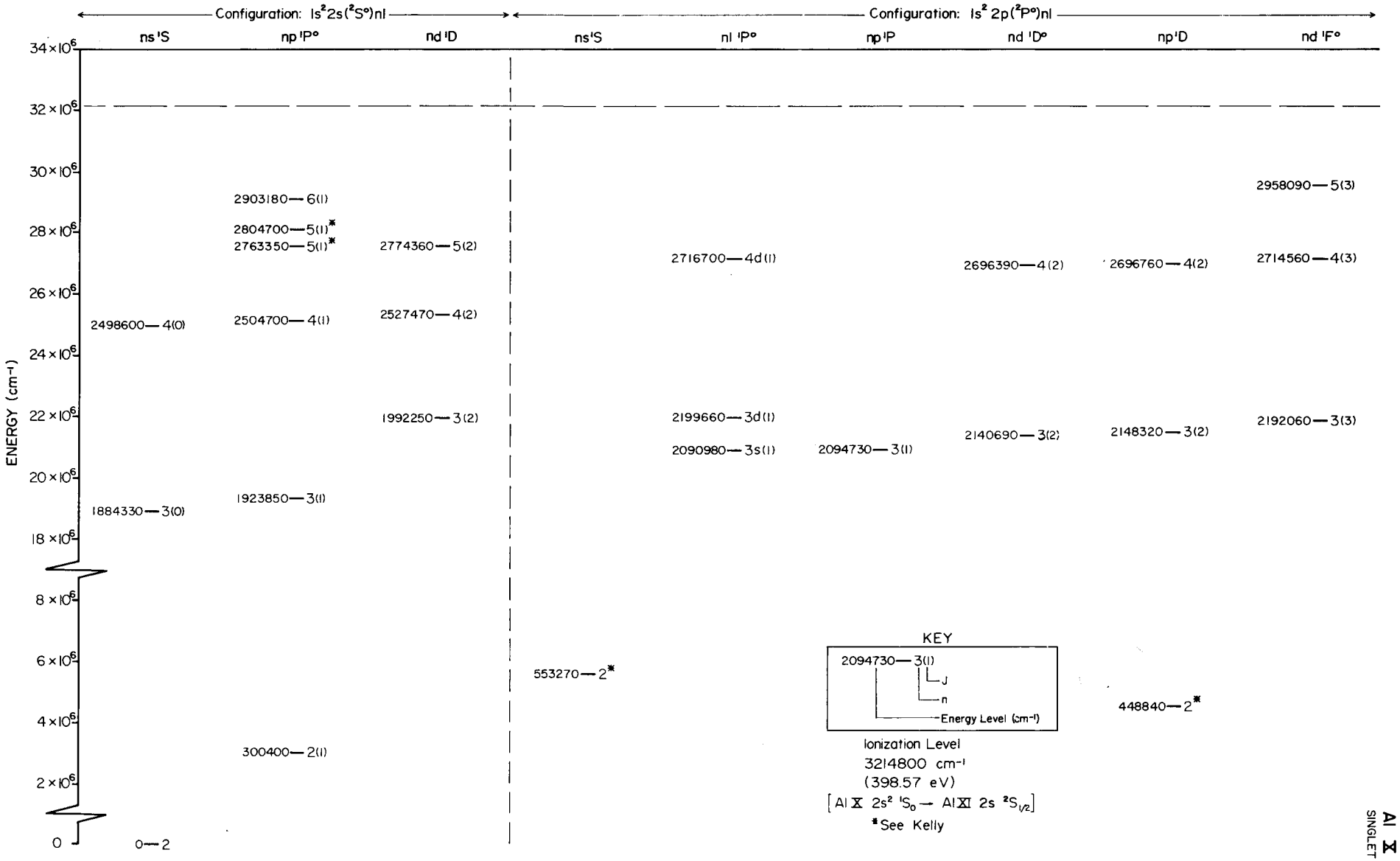
(BI Sequence, Configuration $1s^2 2s2p(^3P^o)nl$ Quartet System)



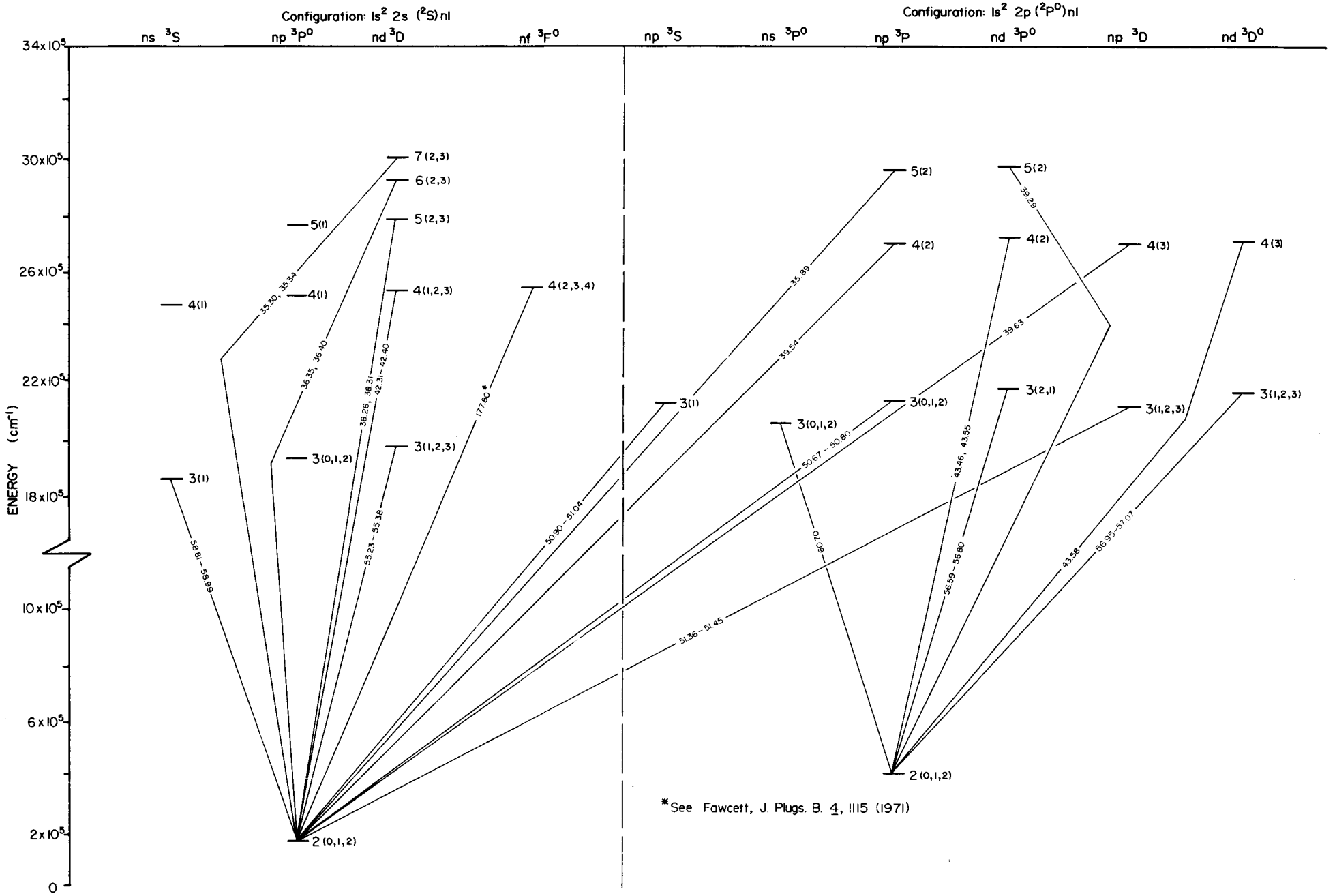
Al X GROTRIAN DIAGRAM (4 electrons, Z=13)
(Be I sequence, Singlet System)



Al X ENERGY LEVELS (4 electrons, Z = 13)
(Be I sequence, Singlet System)

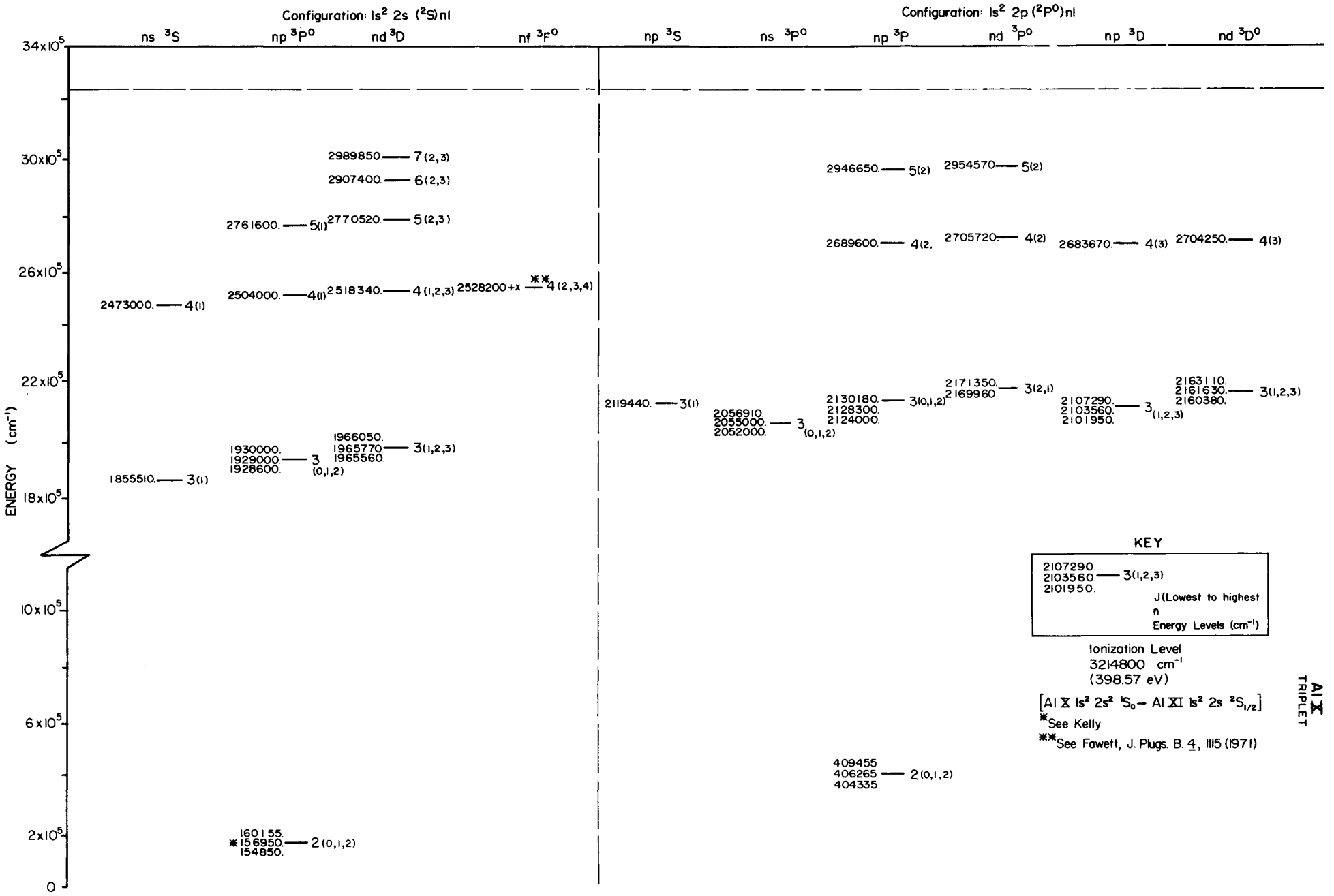


Al X GROTRIAN DIAGRAM (4 electrons, Z=13)
(Be I sequence, Triplet Term System)



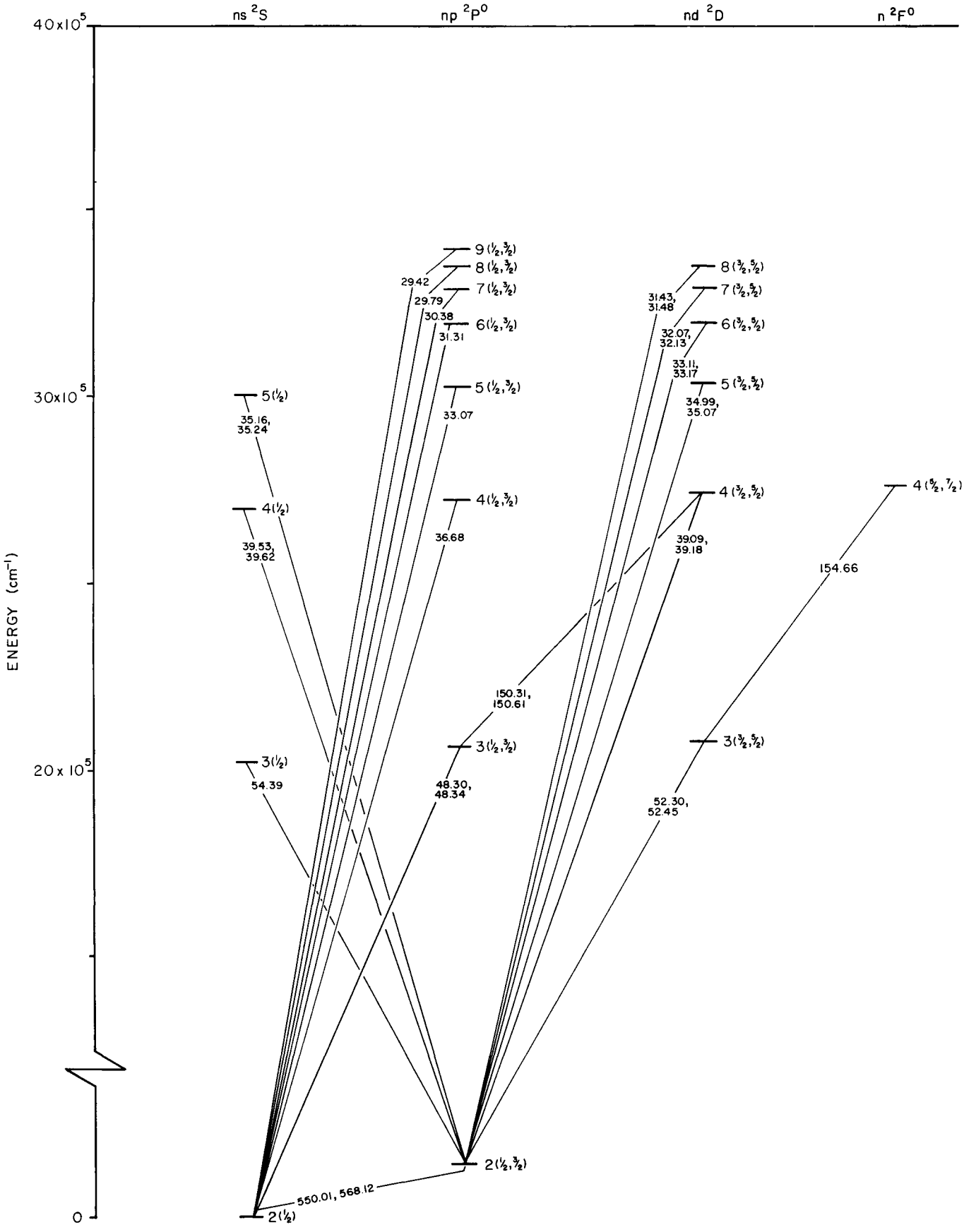
*See Fawcett, J. Plugs. B. 4, 1115 (1971)

Al X ENERGY LEVELS (4 electrons, Z=13)
(Be I sequence, Triplet Term System)

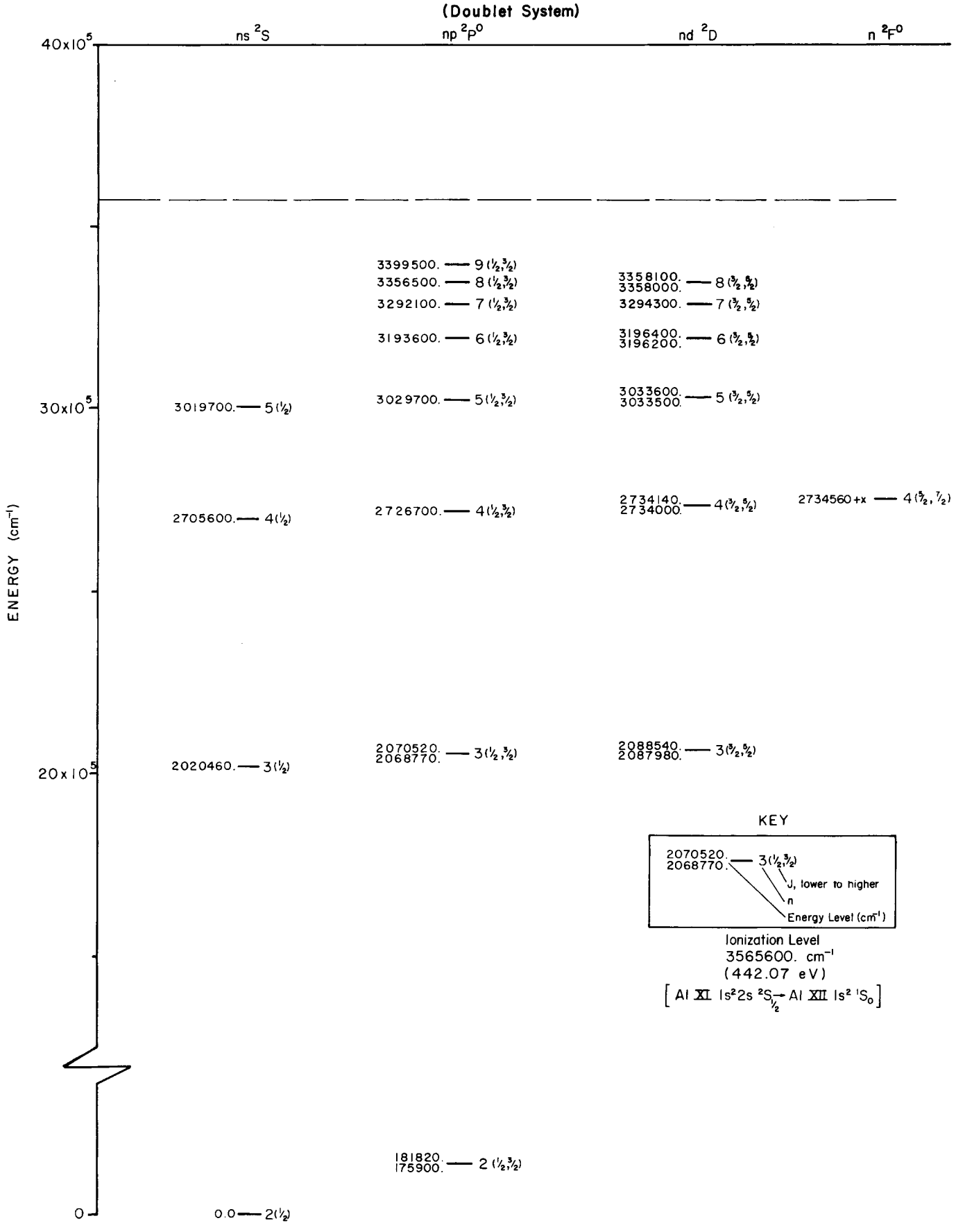


Al X TRIPLET

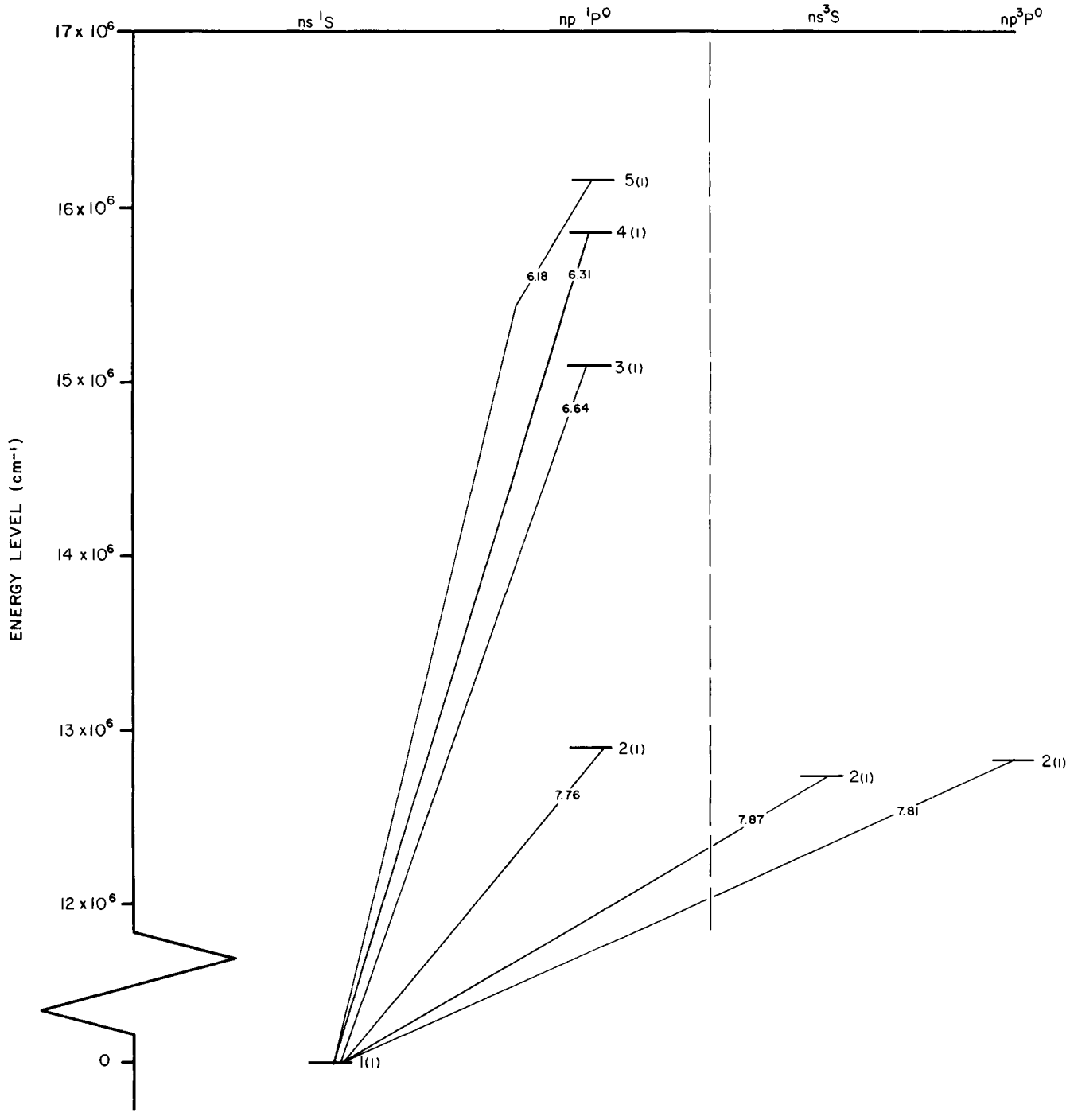
Al XI GROTRIAN DIAGRAM (3 electrons, Z=13)
(Li I sequence, Configuration: $1s^2nl$, Doublet System)



Al XI ENERGY LEVELS (3 electrons, Z=13)
(Li I sequence, Configuration: $1s^2\ nl$)
(Doublet System)



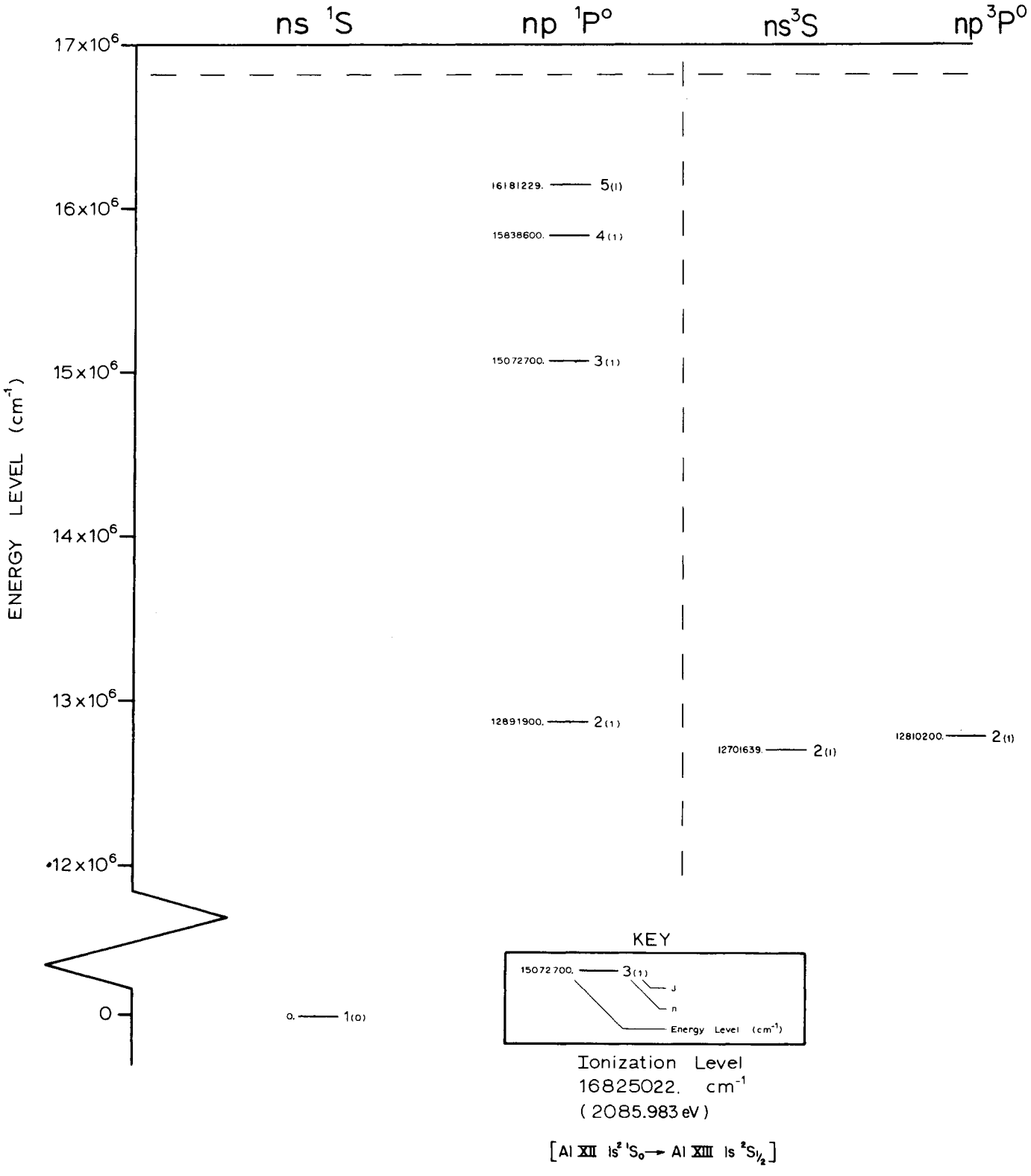
Al XII GROTRIAN DIAGRAM (2 electrons, Z=13)
(He I Sequence, Configuration : 1s nl, Singlets & Triplet System)



Al XII ENERGY LEVELS (2 electrons, Z=13)

(He I sequence, Configuration: 1s nl)

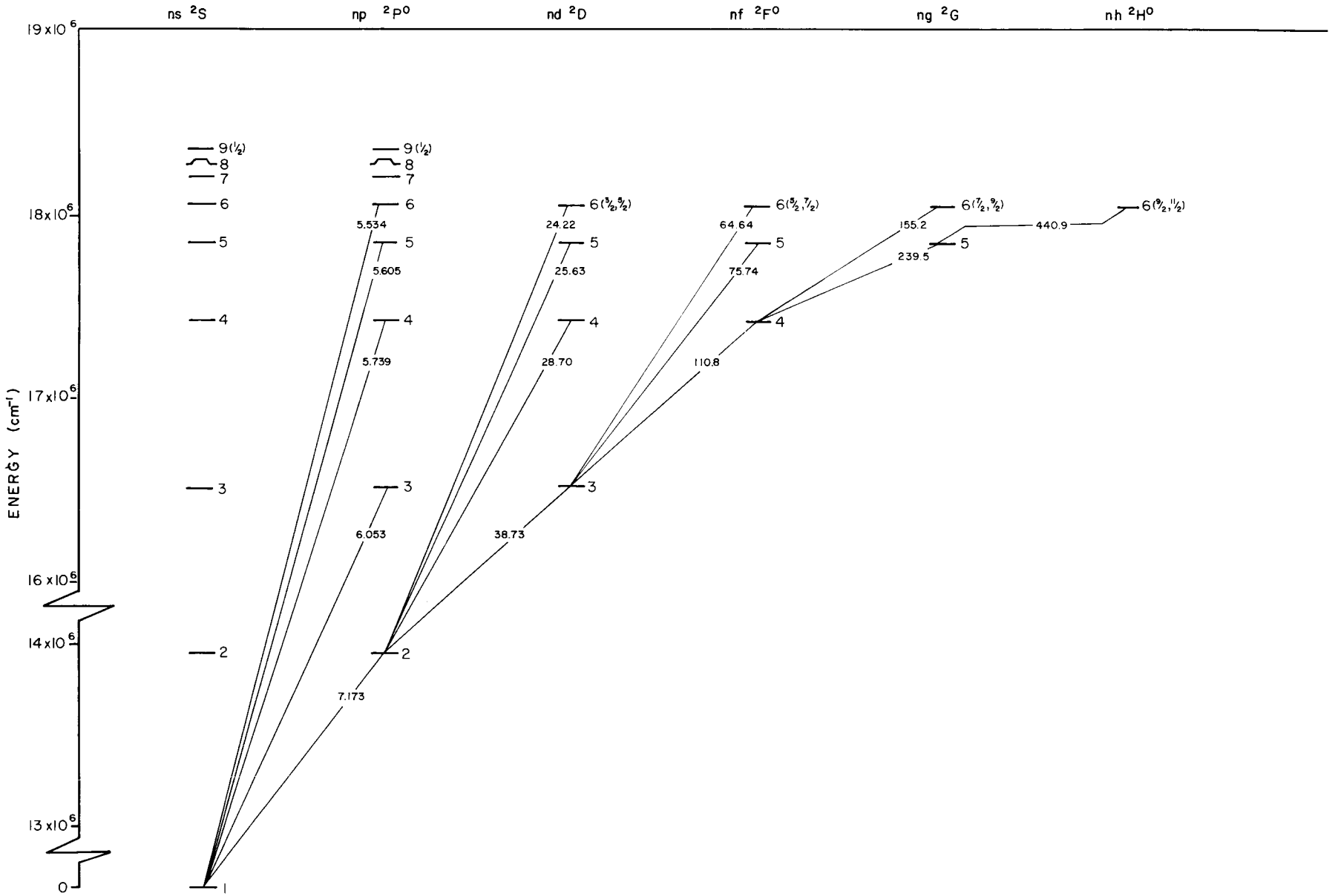
(Singlet and Triplet)



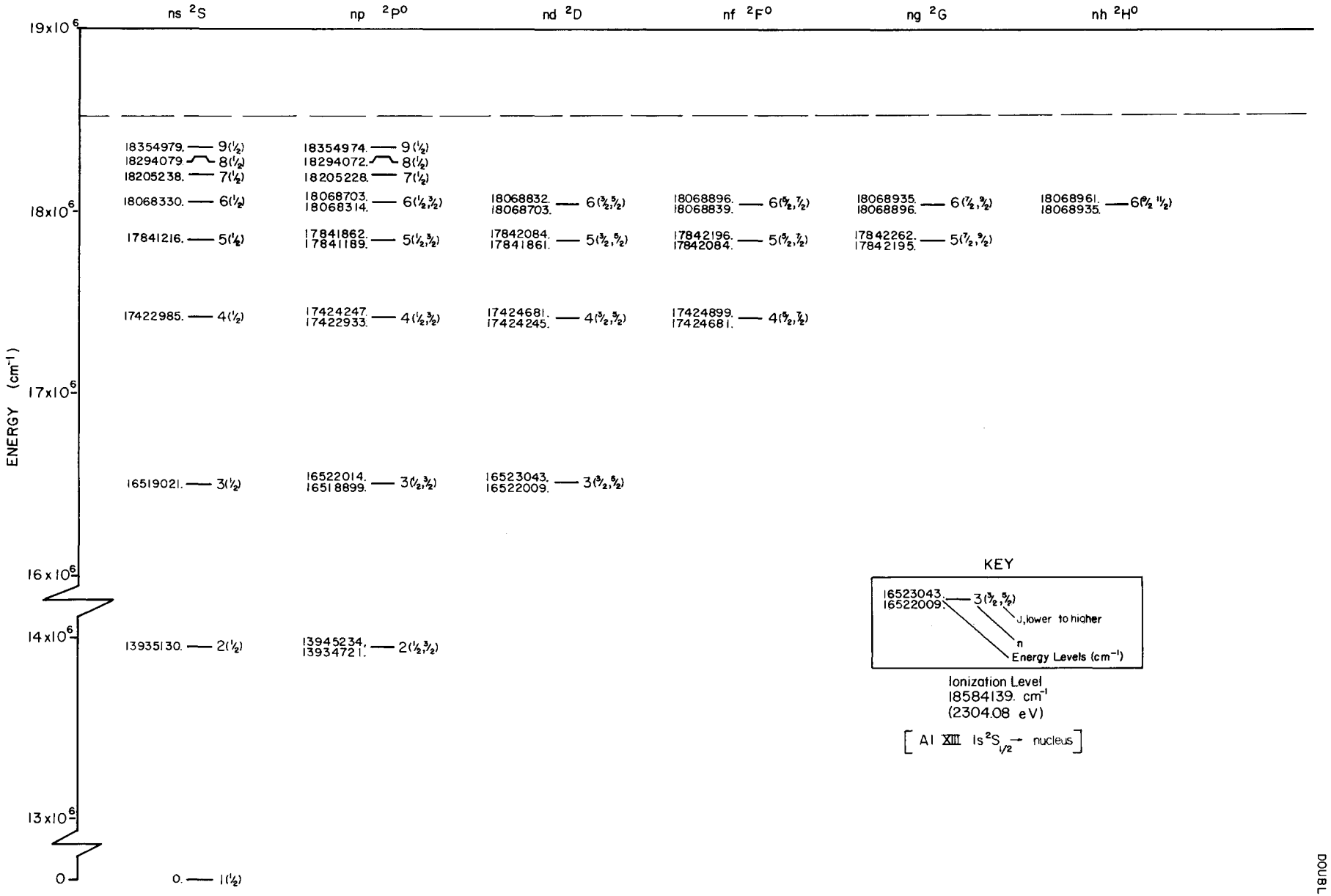
Ionization Level
16825022. cm^{-1}
(2085.983 eV)

[Al XII $1s^2\ ^1S_0 \rightarrow$ Al XIII $1s\ ^2S_{1/2}$]

Al XIII GROTRIAN DIAGRAM (1 electron, Z = 13)
(H I sequence, Configuration: nl, Doublet System)



Al XIII ENERGY LEVELS (1 electron, Z=13)
(HI sequence, Configuration; nl, Doublet System)



Al I $Z = 13$ 13 electrons

K.B.S. Eriksson and H.B.S. Isberg, Ark. Fys. **33**, 593 (1967).

Authors give line and energy level tables in comparison of their results with Penkin and Shabanova [Opt. and Spectros. **18**, 425 (1925)]

N.P. Penkin and L.N. Shabanova, Opt. and Spectros. **18**, 425 (1925).

Authors give line and energy level tables for lines observed in the region 2000–2300 Å.

E.W.H. Selwyn, Proc. Phys. Soc. **41**, 392 (1929).

Author gives a table of lines observed in the region 1600–2100 Å.

M. Shimauchi, Sci. of Light **7**, 101 (1958).

Author gives tables of lines observed in air, nitrogen, oxygen, and argon atmospheres.

M. Shimauchi, Sci. of Light **12**, 31 (1962).

Author gives a line table and spectrograms of observed lines in a helium atmosphere.

S. Weniger, Ann. d'Astrophysics Suppl. **28**, 117 (1965).

Author gives tables of lines observed in the region 4000–2100 Å studied under variations of temperature.

T. Yamashita, Sci. of Light **14**, 28 (1965).

Author gives line and term tables from lines observed in the region 2120–2080 Å.

Al II $Z = 13$ 12 electrons

S. Bashkin, W.S. Bickel, H.D. Dieselman, and J.B. Schroeder, J. Opt. Soc. Amer. **57**, 1395 (1967).

Authors give wavelengths of lines observed in the region 4140–4670 Å.

E.W.H. Selwyn, Proc. Phys. Soc. **41**, 392 (1929).

Author gives a table of lines observed in the region 1600–2100 Å.

S. Weniger, Ann. d'Astrophysics Suppl. **28**, 117 (1965).

Author gives tables of lines observed in the region 4000–2100 Å studied under variations of temperature.

Note: The third of the Grotrian diagrams for singlets is designated 3d ^{1}D and $n = 5$ singlets to higher singlets. The correct designation is 3d ^{1}D and singlets with $n \geqslant 5$ to higher singlets.

Al III $Z = 13$ 11 electrons

S. Bashkin, W.S. Bickel, H.D. Dieselman, and J.B. Schroeder, J. Opt. Soc. Amer. **57**, 1395 (1967).

Authors give wavelengths of lines observed in the region 4140–4670 Å.

E.W.H. Selwyn, Proc. Phys. Soc. **41**, 392 (1929).

Author gives a table of lines observed in the region 1600–2100 Å.

Al IV $Z = 13$ 10 electrons

Please see the general references. The intermediate-coupling designations are taken from Moore, *Atomic Energy Levels*, Vol. I, N.B.S. Circular 467 (1949).

Al V $Z = 13$ 9 electrons

Please see the general references.

Al VI $Z = 13$ 8 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives tables of lines observed and calculated for forbidden transitions.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Al VII $Z = 13$ 7 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives tables of observed lines of forbidden transitions.

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Al VIII $Z = 13$ 6 electrons

Please see the general references.

Al IX $Z = 13$ 5 electrons

L.J. Shamey, J. Opt. Soc. Amer. **61**, 942 (1971).

Author gives line and energy level tables of calculated values.

Al X $Z = 13$ 4 elecrons

Please see the general references.

Al XI $Z = 13$ 3 electrons

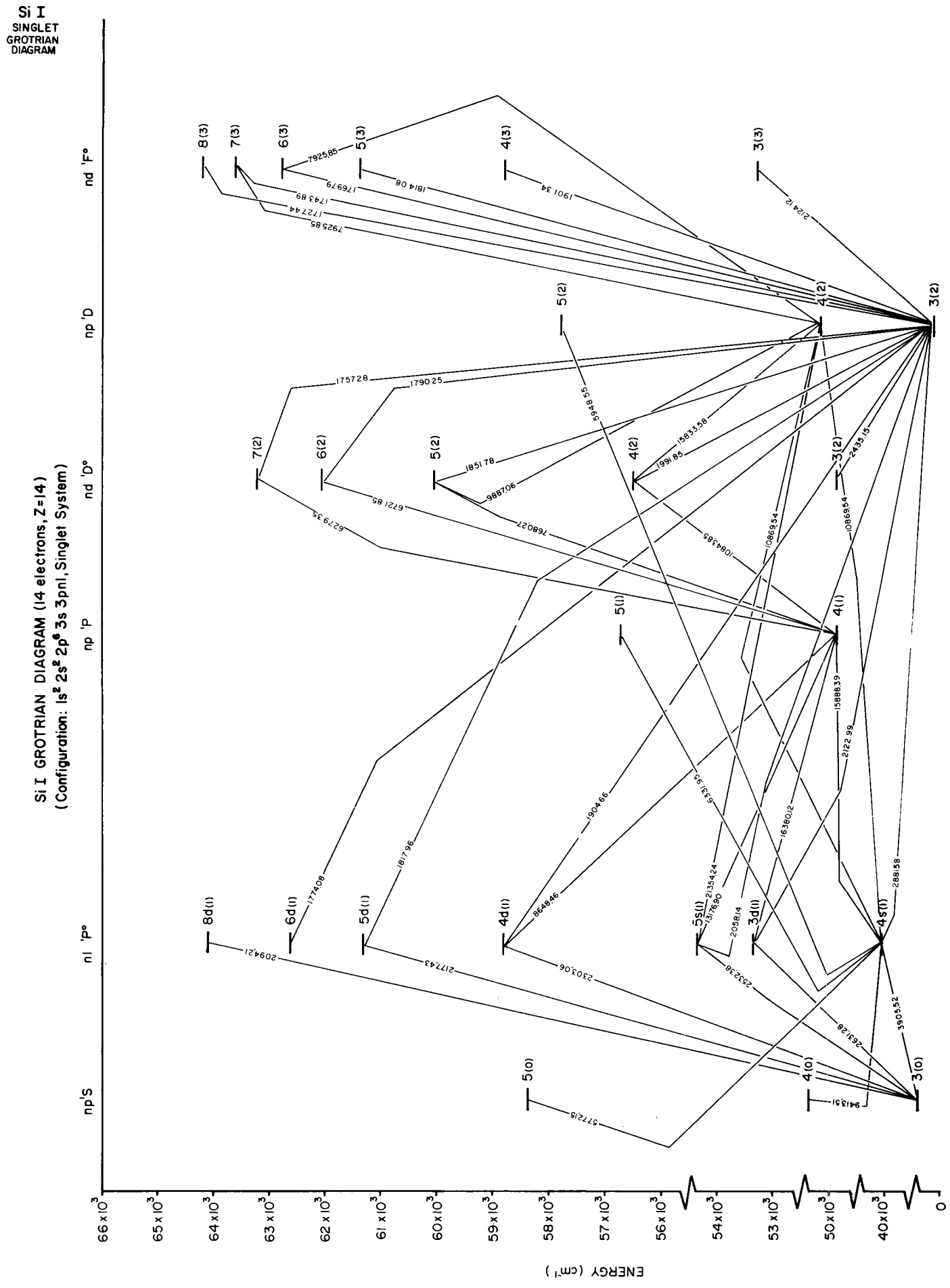
Please see the general references.

Al XII $Z = 13$ 2 electrons

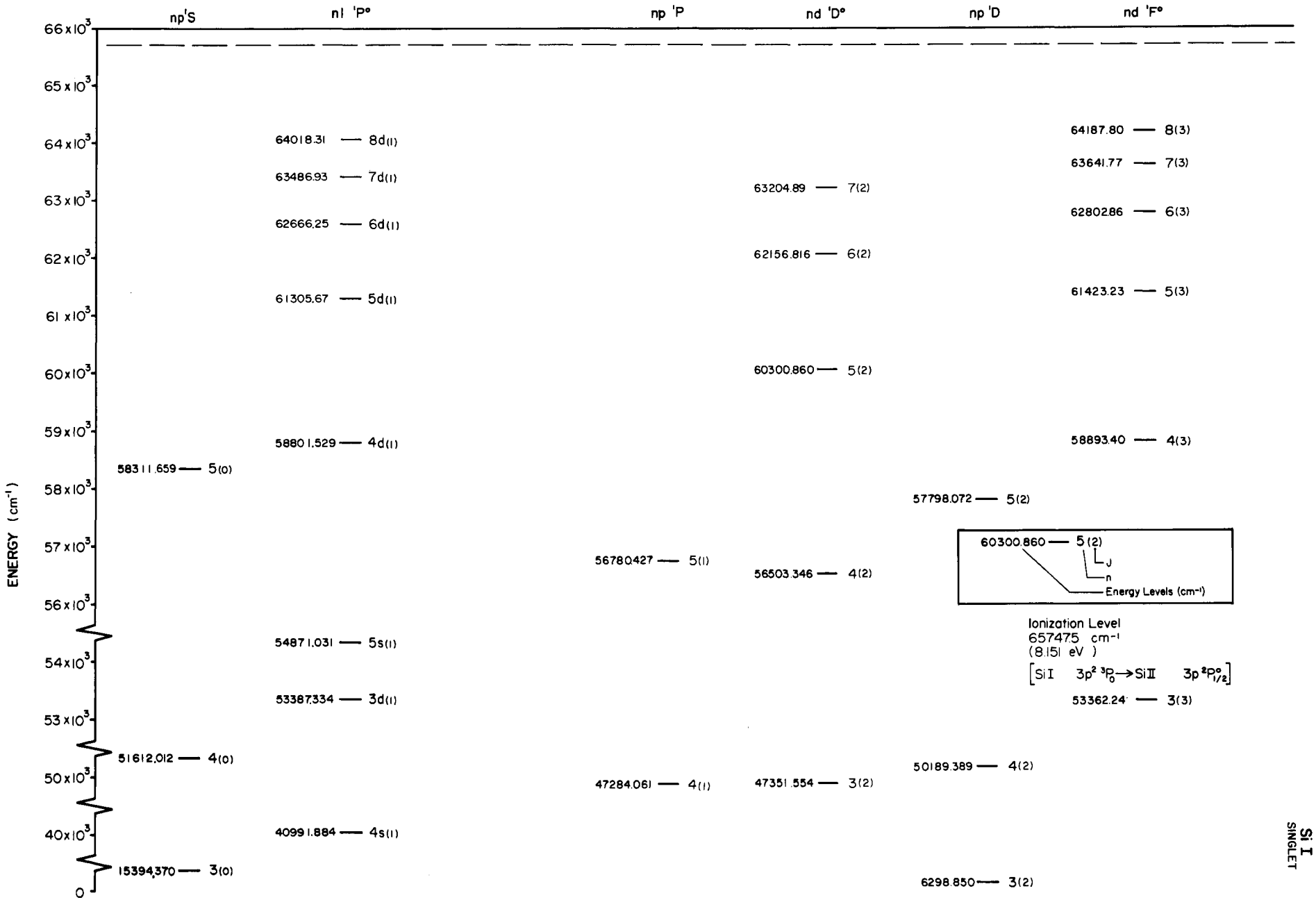
Please see the general references.

Please see the general references.

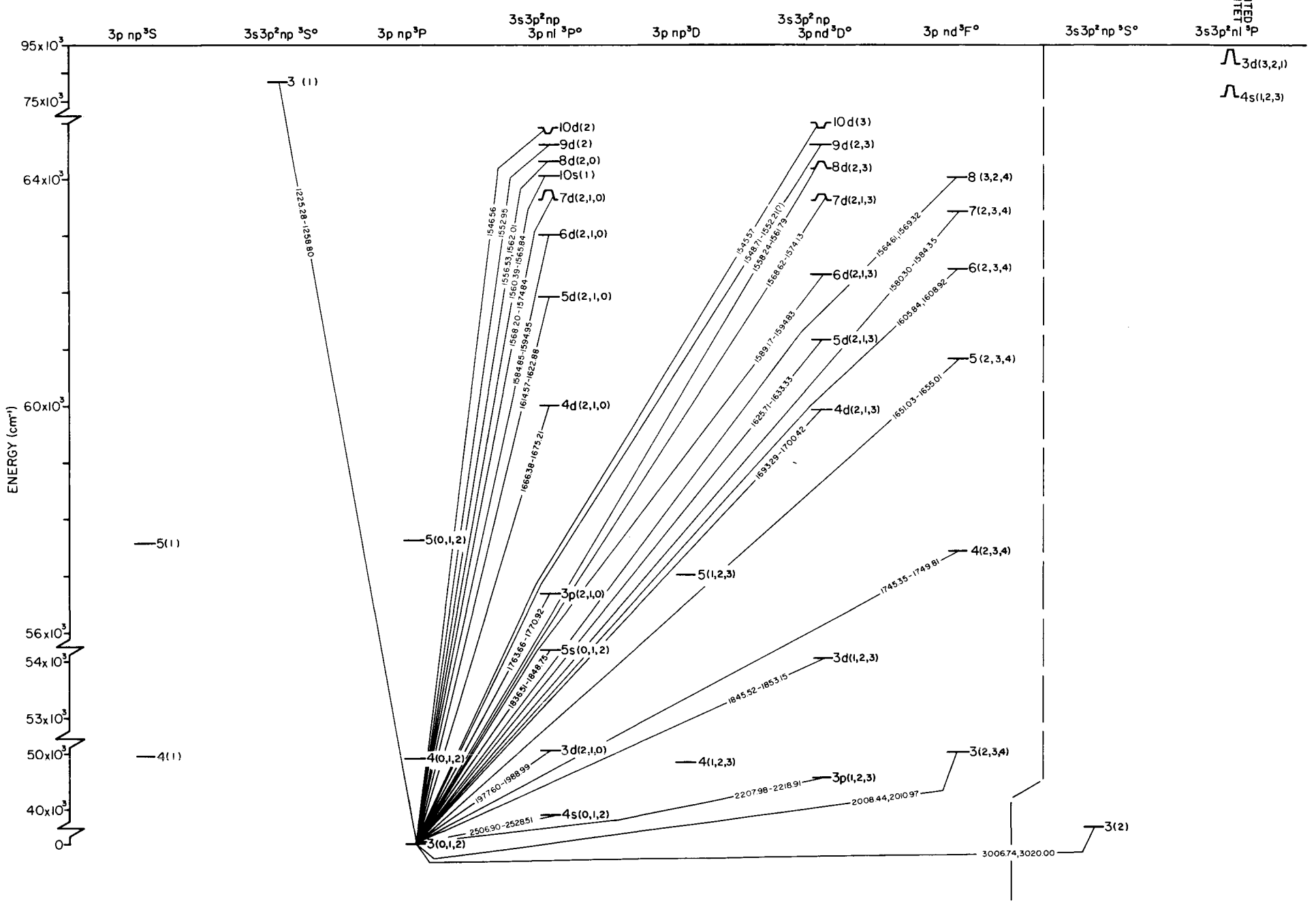
Silicium (Si)


Si I
SINGLET
GROTRIAN
DIAGRAM
Si I GROTRIAN DIAGRAM (14 electrons, Z=14)
(Configuration: 1s² 2s² 2p⁶ 3s 3pnl, Singlet System)
np ¹S
nl ¹P°
np ¹P
nd ¹D°
np ¹D
nd ¹F°
ENERGY (cm⁻¹)
66 x 10³
65 x 10³
64 x 10³
63 x 10³
62 x 10³
61 x 10³
60 x 10³
59 x 10³
58 x 10³
57 x 10³
56 x 10³
54 x 10³
53 x 10³
50 x 10³
40 x 10³
0
8(3)
7(3)
6(3)
5(3)
4(3)
3(3)
7(2)
6(2)
5(2)
4(2)
3(2)
5(1)
4(1)
8d(1)
6d(1)
5d(1)
4d(1)
5s(1)
3d(1)
4s(1)
5(0)
4(0)
3(0)
7925.85
1814.08
1769.79
1743.89
1727.44
1901.34
2124.12
1757.28
1790.25
5948.55
1851.78
1988.06
1768.27
6721.85
6279.35
1583.58
1991.85
1084.85
1086.54
2435.15
1588.39
2122.99
6531.95
1904.66
1638.12
1774.08
1817.96
8648.46
2135.24
1376.90
2058.14
2288.58
2094.21
2177.43
2303.06
2532.38
2631.28
3905.52
5772.18
9413.51

Si I ENERGY LEVELS, (14 electrons, Z = 14)
(Configuration: $1s^2\,2s^2\,2p^6\,3s^2\,3pnl$, Singlet System)

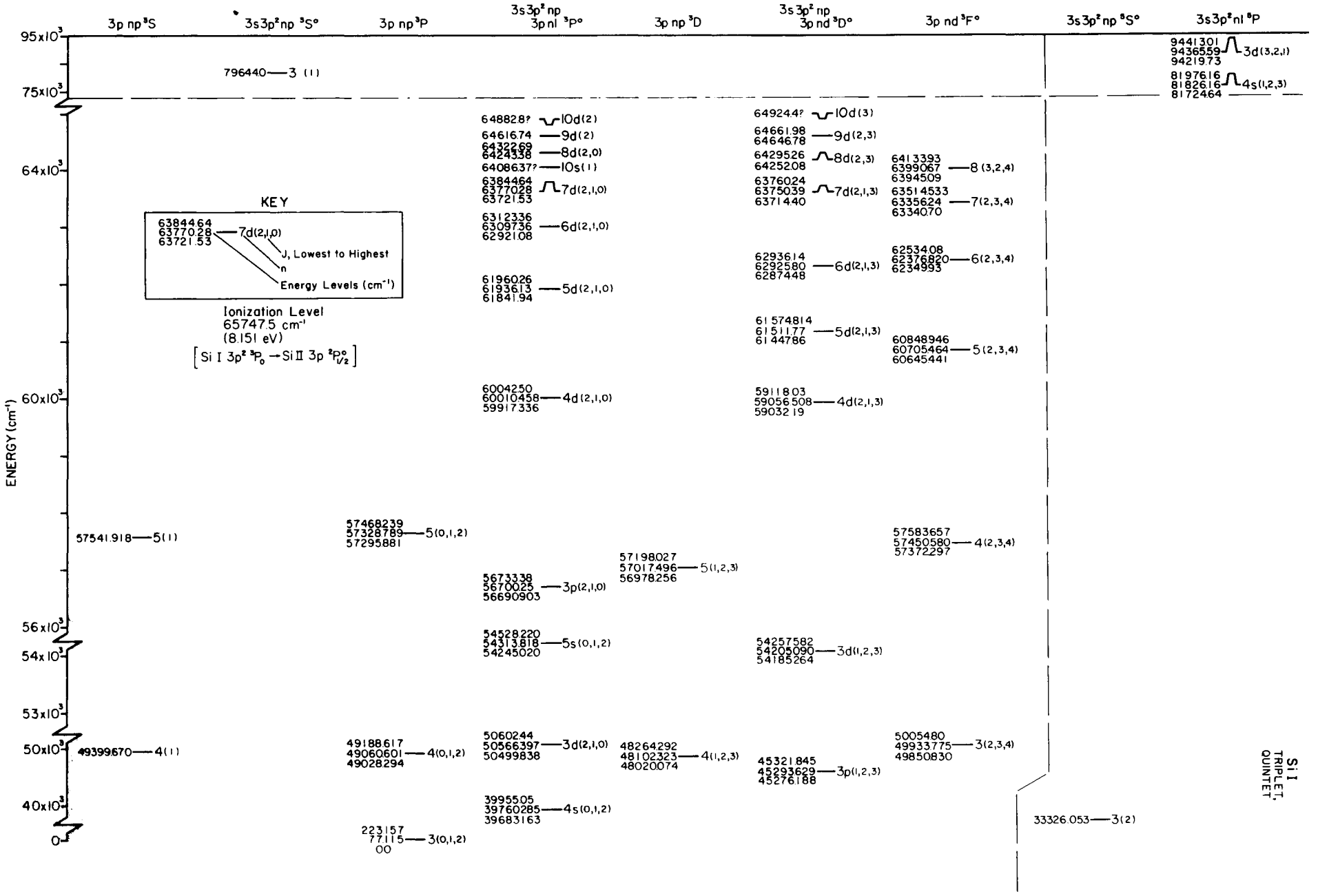


Si I GROTRIAN DIAGRAM (14 electrons, Z=14)
(Configuration: $1s^2 2s^2 2p^6 3s^2 3p\ nl$, Ground to Excited Triplet, Quintet Terms)

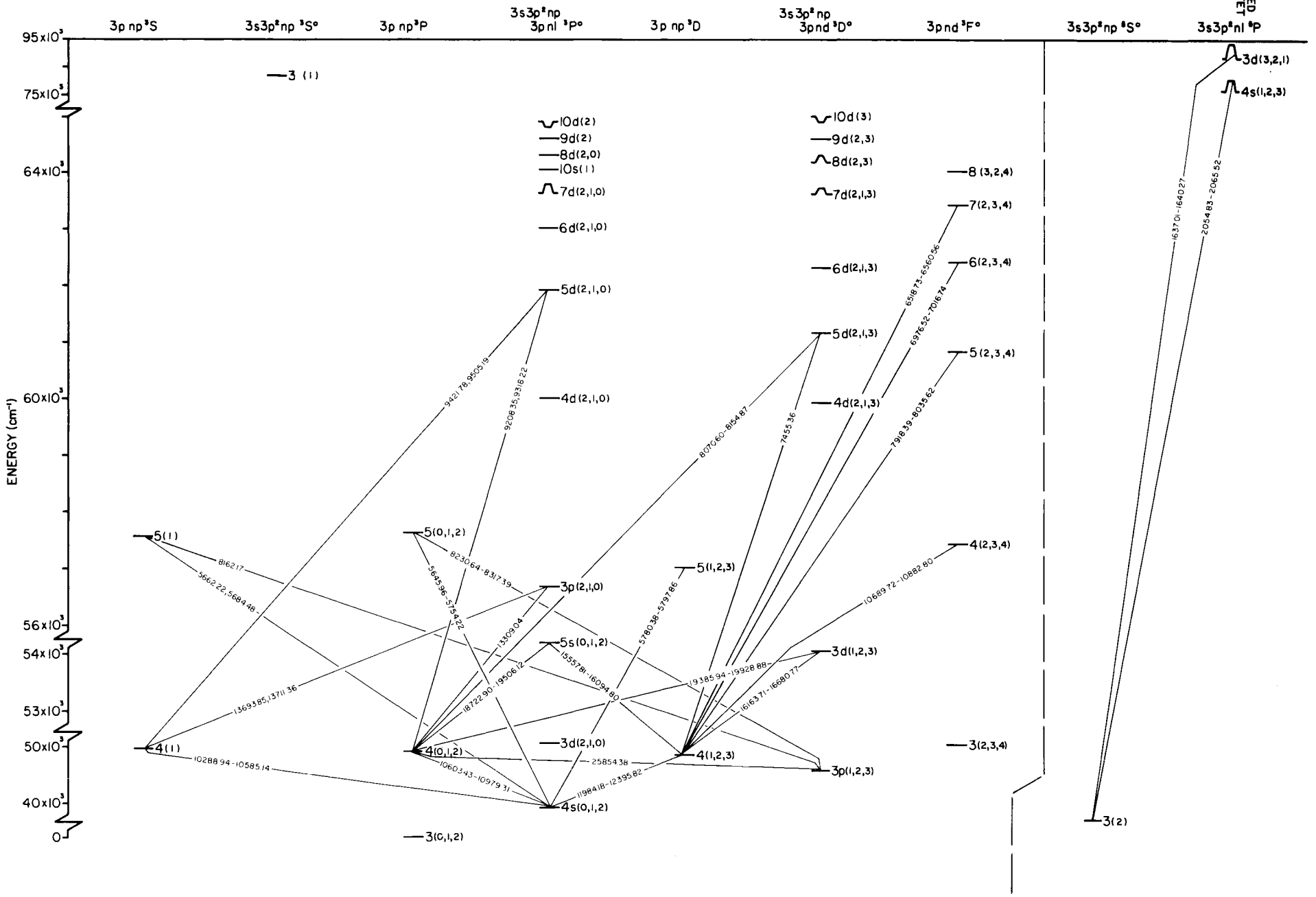


Si I ENERGY LEVELS, (14 electrons, Z=14)

(Configuration: $1s^2 2s^2 2p^6 3s^2 3p\,nl$, Triplet and Quintet Systems)

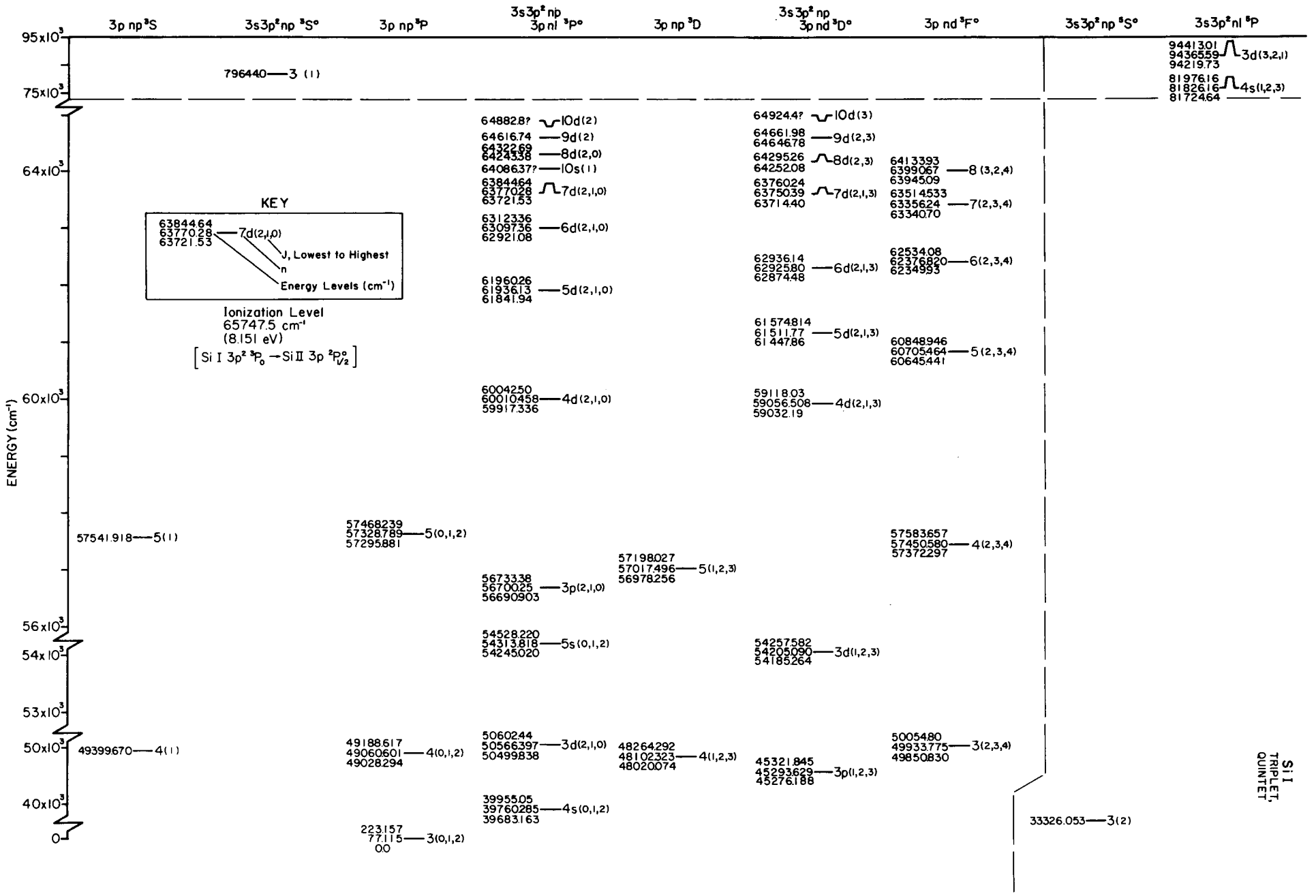


Si I GROTRIAN DIAGRAM (14 electrons, Z = 14)
(Configuration: $1s^2 2s^2 2p^6 3s^2 3p\,nl$, Excited-Excited Triplet, Quintet Terms)



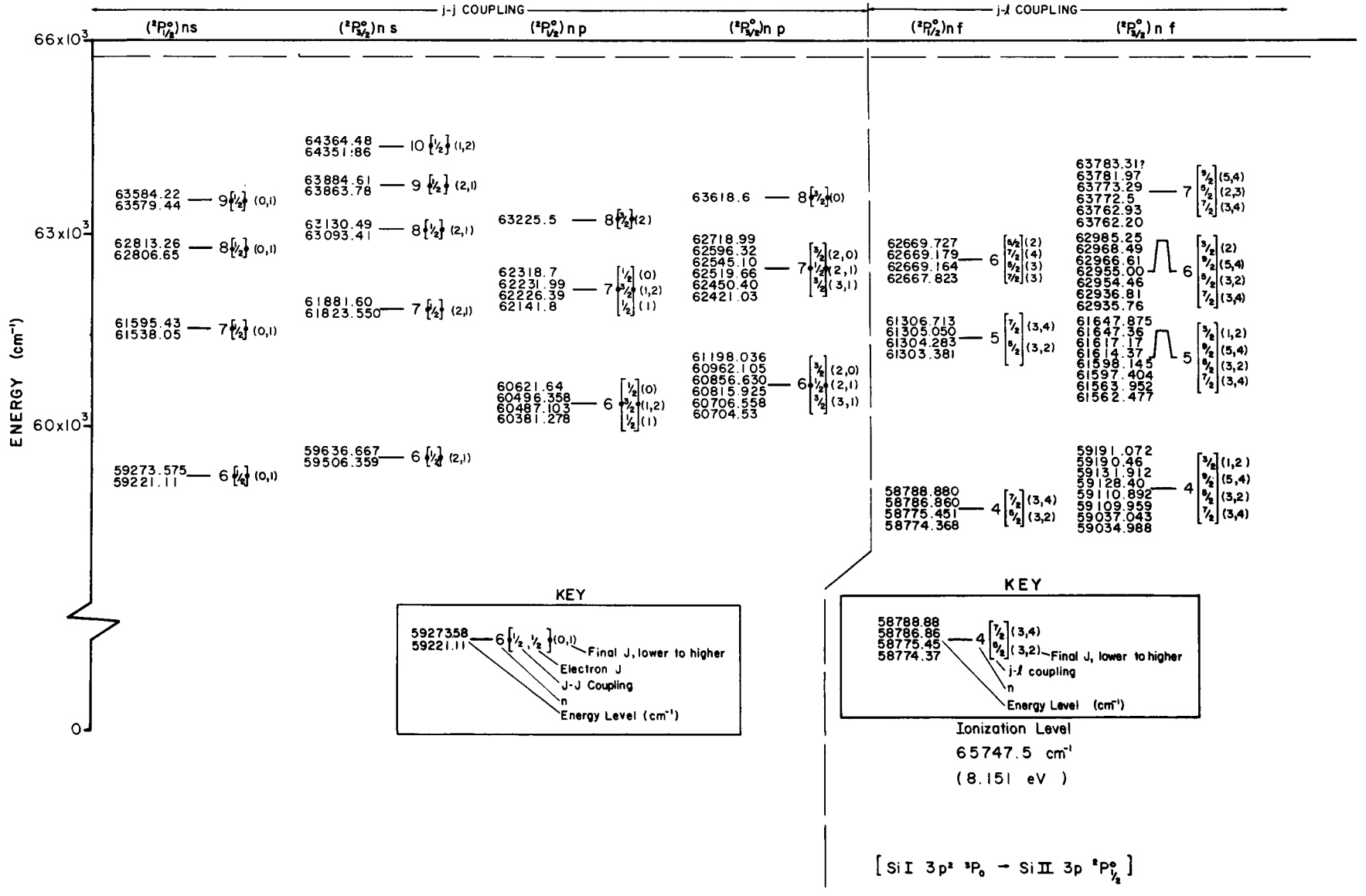
Si I ENERGY LEVELS, (14 electrons, Z=14)

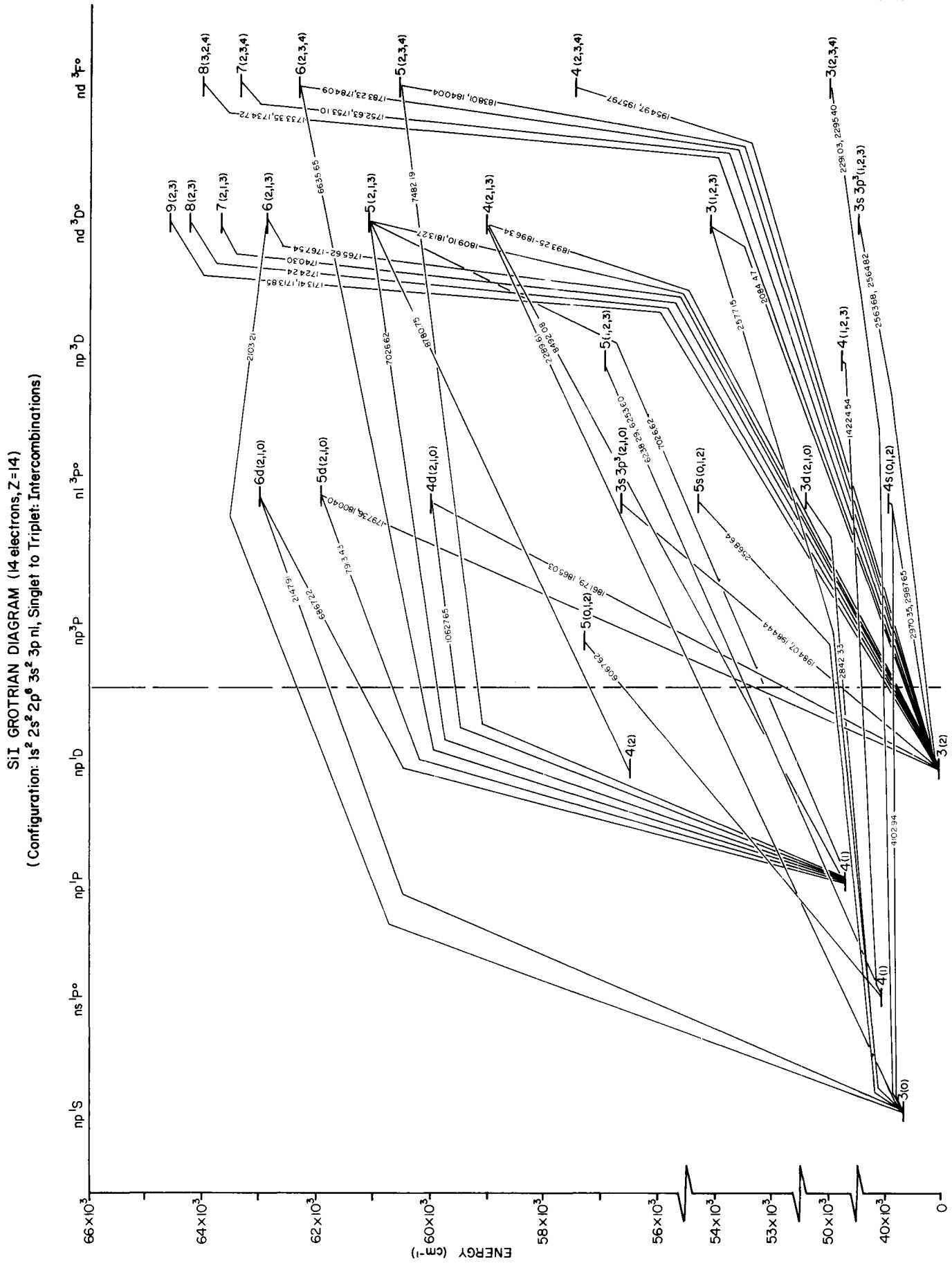
(Configuration: $1s^2 2s^2 2p^6 3s^2 3p\,nl$, Triplet and Quintet Systems)

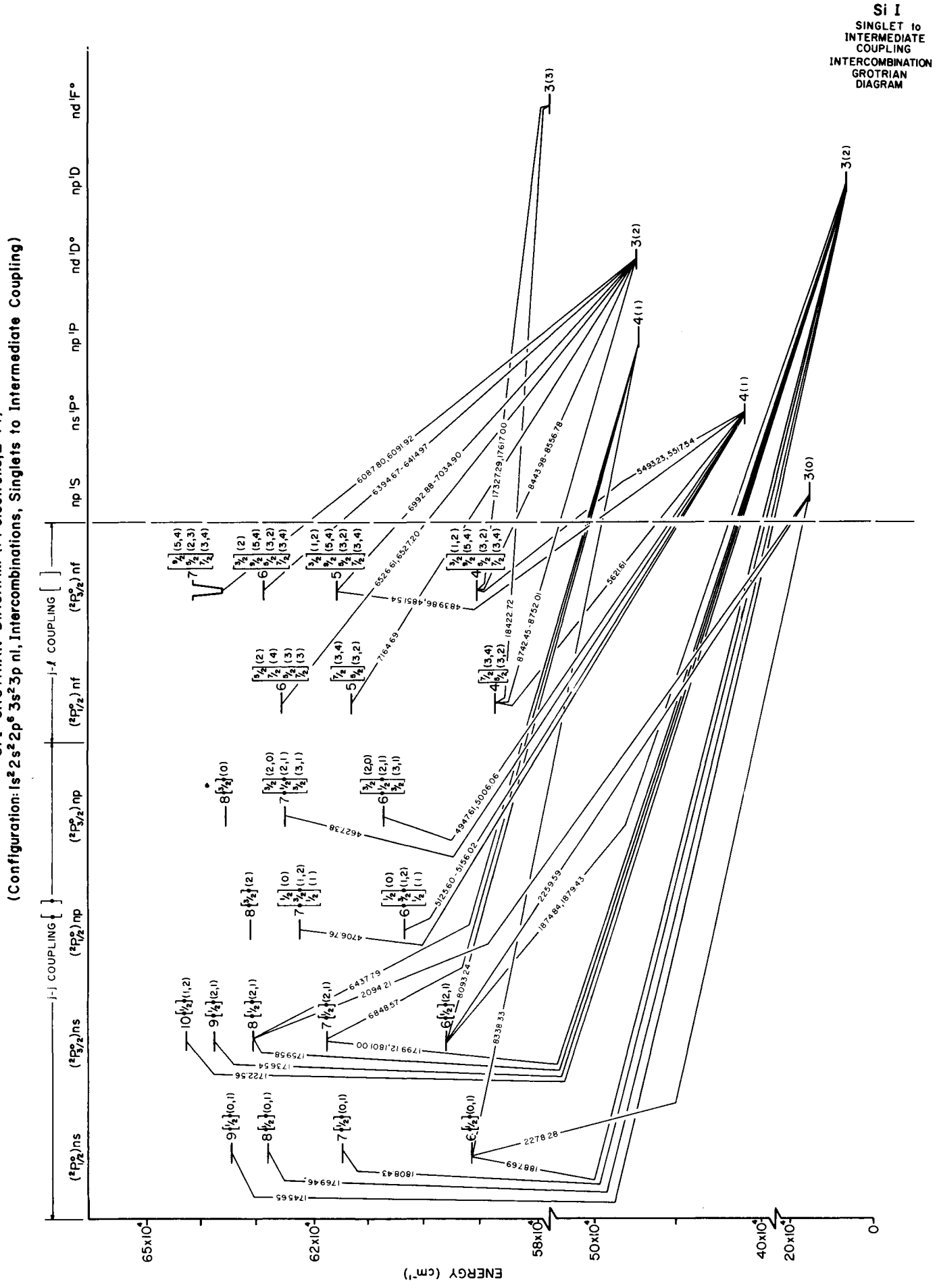


Si I ENERGY LEVELS (14 electrons, Z=14)

(Configuration: $1s^2 2s^2 2p^6 3s^2 3p(^2P^o)nl$, Intermediate Coupling)

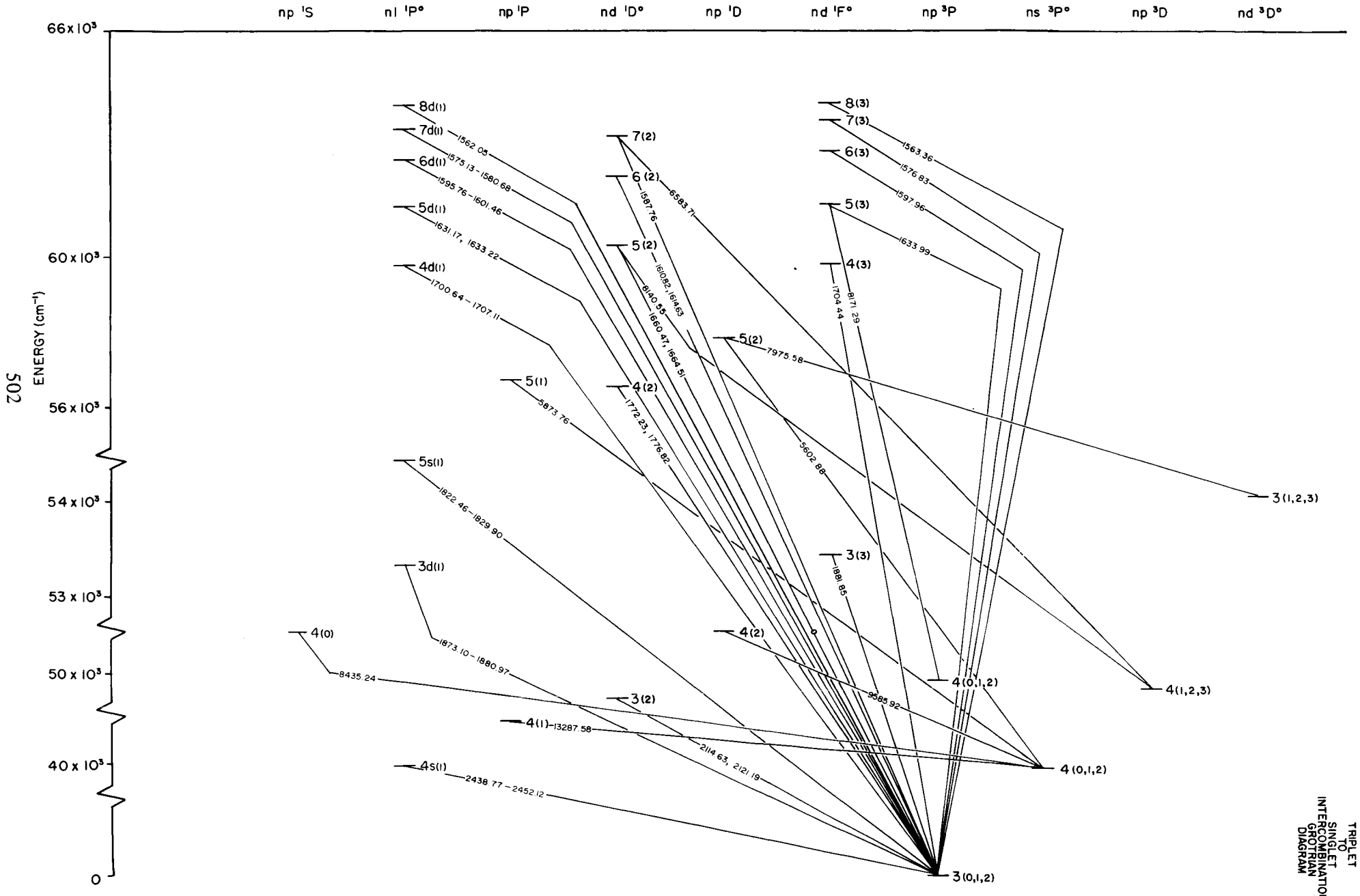



Si I GROTRIAN DIAGRAM (14 electrons, Z=14)
(Configuration: 1s² 2s² 2p⁶ 3s² 3p nl, Singlet to Triplet: Intercombinations)
np ¹S
ns ¹P°
np ¹P
np ¹D
np ³P
nl ³P°
np ³D
nd ³D°
nd ³F°
ENERGY (cm⁻¹)
66×10³
64×10³
62×10³
60×10³
58×10³
56×10³
54×10³
53×10³
50×10³
40×10³
0

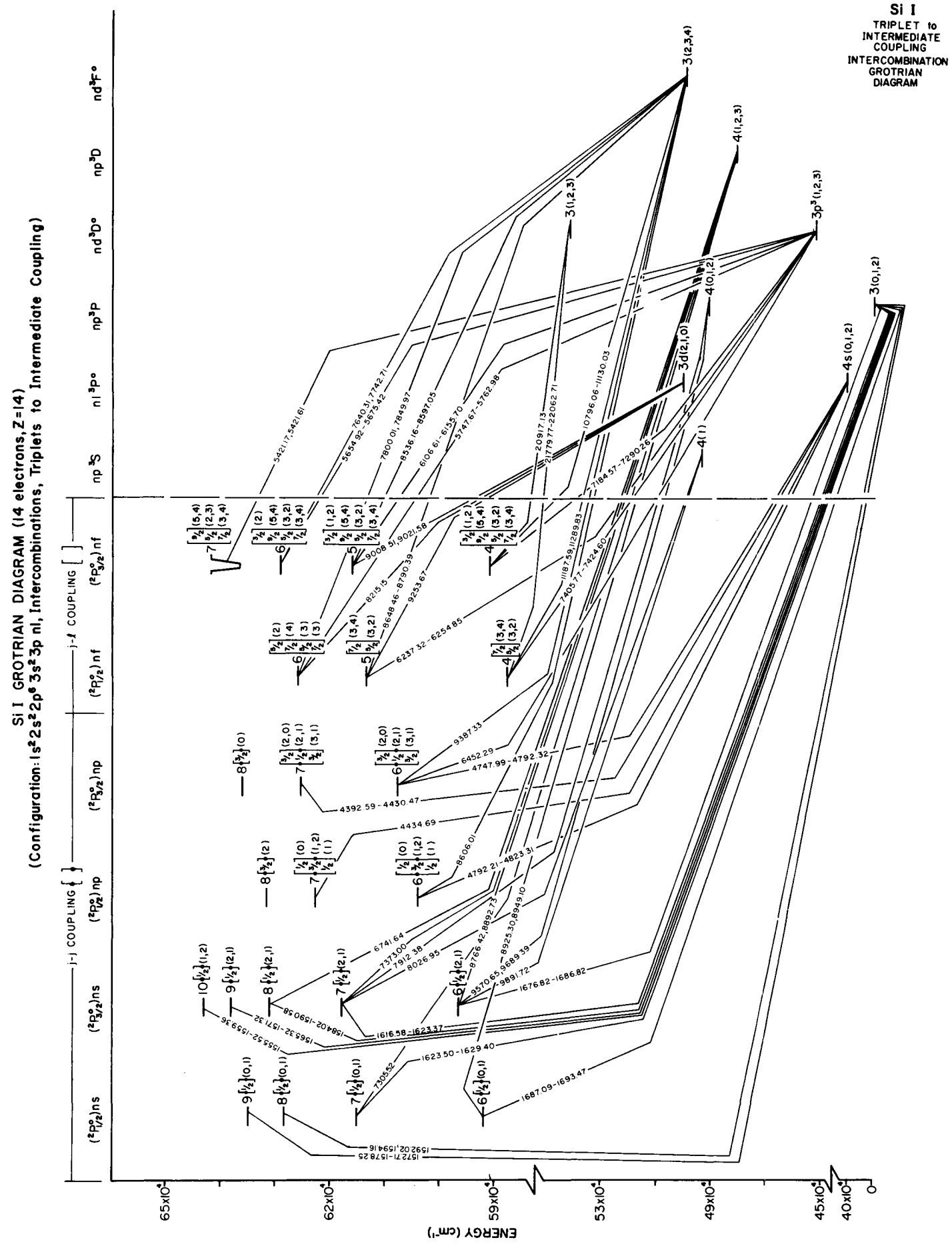

Si I
SINGLET to INTERMEDIATE COUPLING
INTERCOMBINATION GROTRIAN DIAGRAM
Si I GROTRIAN DIAGRAM (14 electrons, Z=14)
(Configuration: 1s²2s²2p⁶3s²3p nl, Intercombinations, Singlets to Intermediate Coupling)
j-j COUPLING
j-l COUPLING
ENERGY (cm⁻¹)
65x10⁴
62x10⁴
58x10⁴
50x10⁴
40x10⁴
20x10⁴
0

Si I INTERCOMBINATION GROTRIAN DIAGRAM (14 electrons, Z=14)

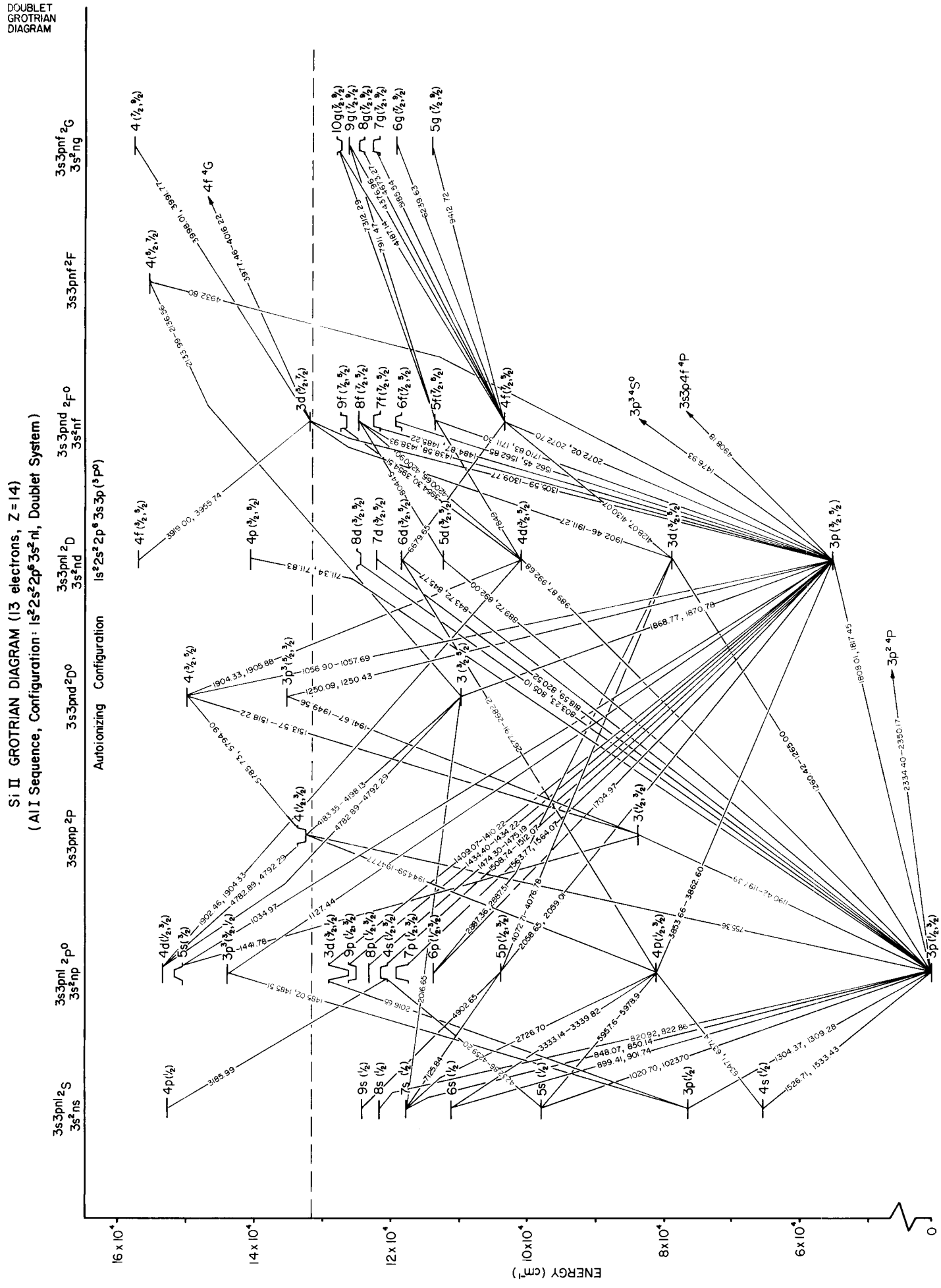
(Configuration: $1s^2\,2s^2\,2p^6\,3s^2\,3pnl$, Triplets to Singlets)



Si I
TRIPLET
TO
SINGLET
INTERCOMBINATION
GROTRIAN
DIAGRAM

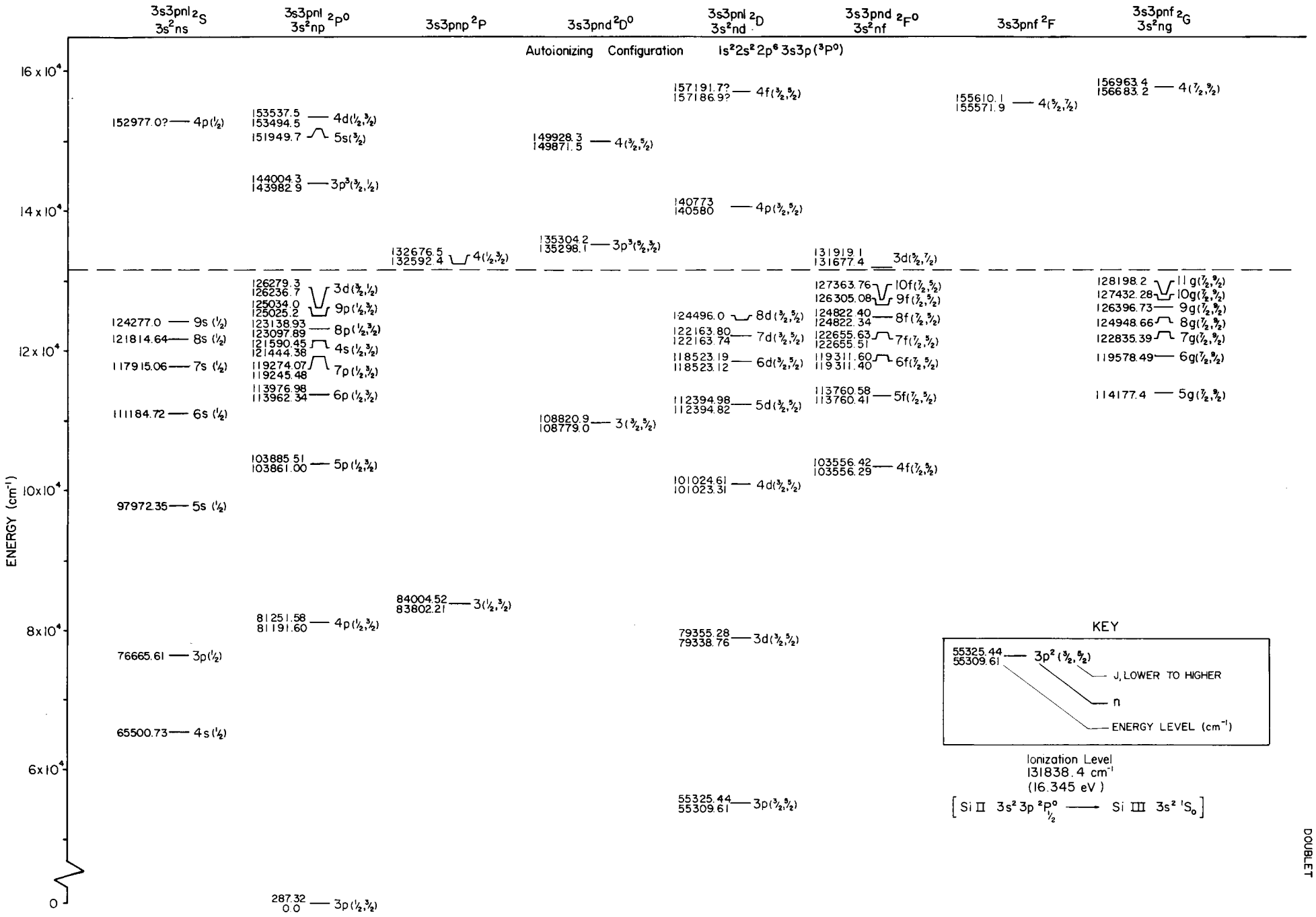

Si I
TRIPLET to INTERMEDIATE COUPLING INTERCOMBINATION GROTRIAN DIAGRAM
Si I GROTRIAN DIAGRAM (14 electrons, Z=14)
(Configuration: 1s²2s²2p⁶3s²3p nl, Intercombinations, Triplets to Intermediate Coupling)
j-j COUPLING
j-l COUPLING
ENERGY (cm⁻¹)
65x10³
62x10³
59x10³
53x10³
49x10³
45x10³
40x10³
0

Si II
DOUBLET
GROTRIAN
DIAGRAM

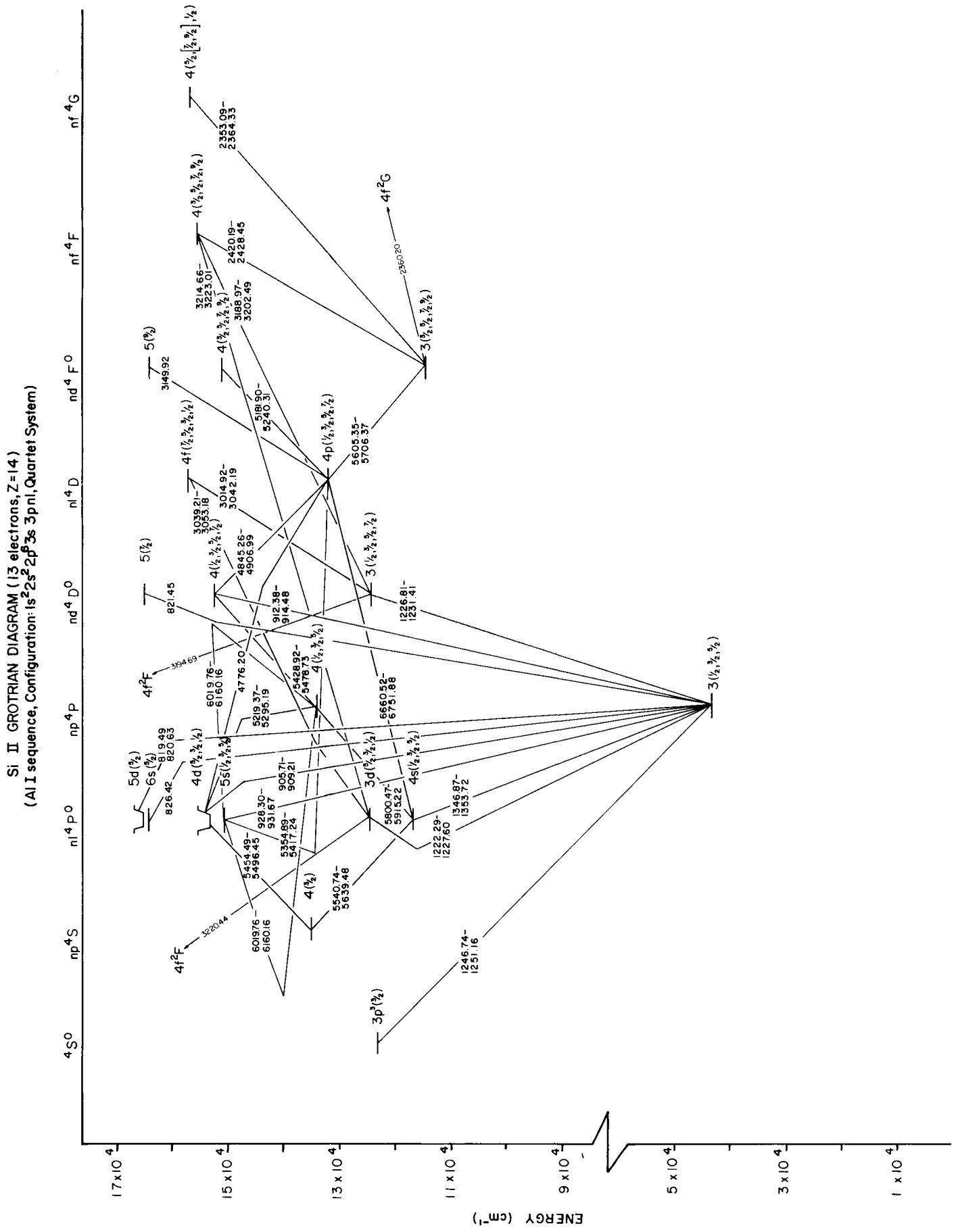


Si II ENERGY LEVELS (13 electrons, Z = 14)

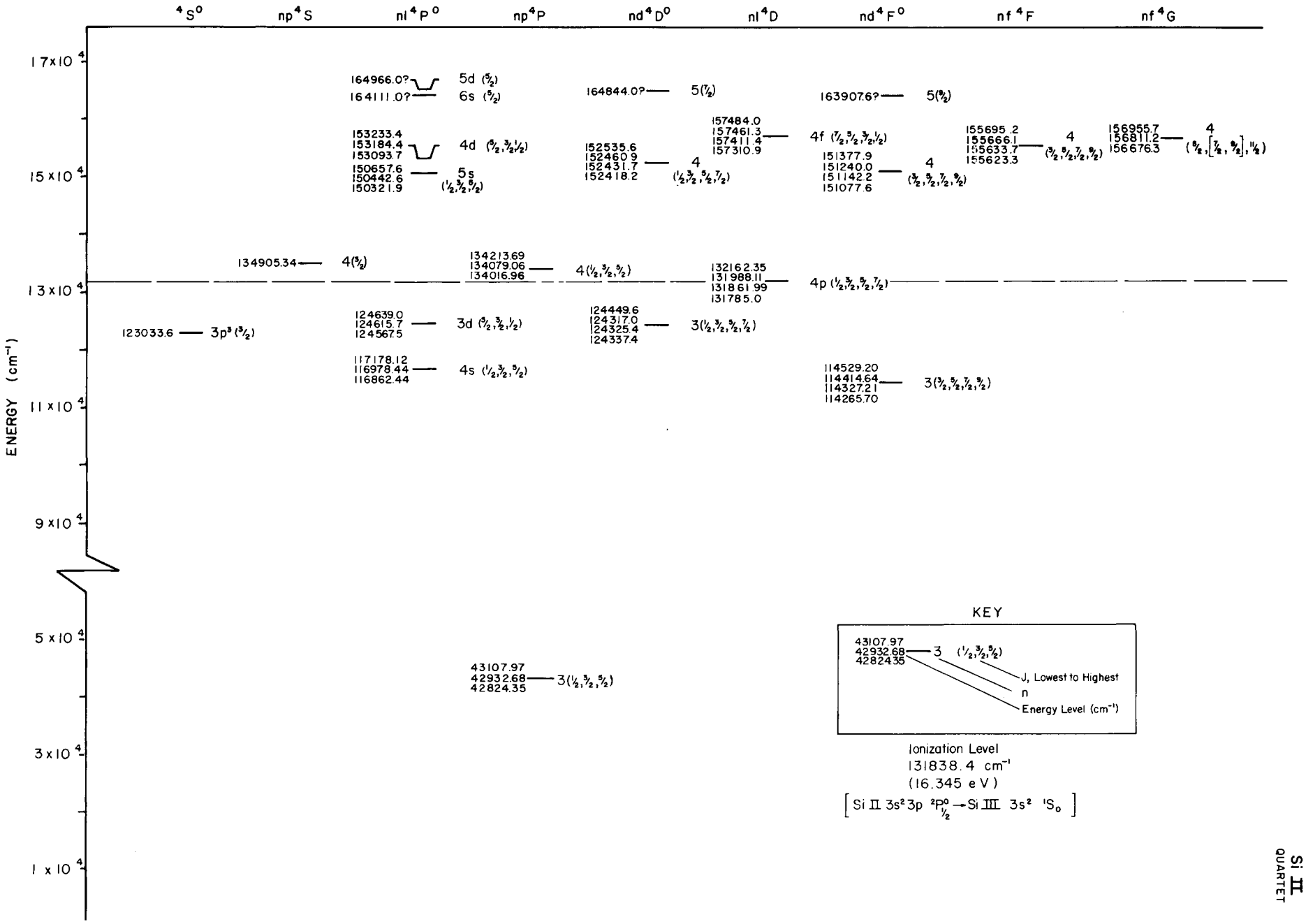
(Al I Sequence, Configuration: $1s^2 2s^2 2p^6 3s^2 nl$, Doublet System)



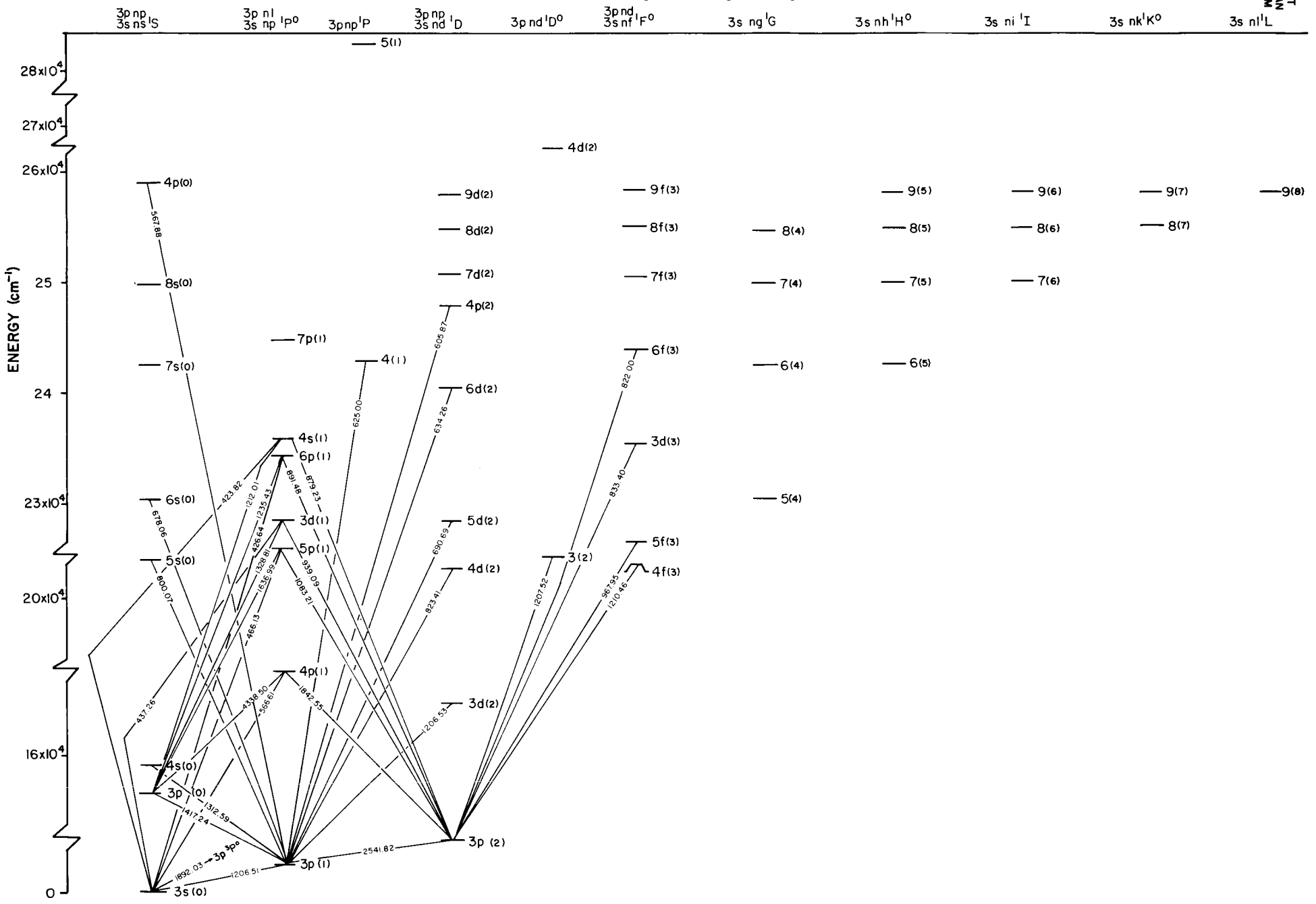
Si II
QUARTET
GROTRIAN DIAGRAM



Si II ENERGY LEVELS (15 electrons, Z=14)
(Al I sequence, Configuration: $1s^2 2s^2 2p^6 3s\,3p\,nl$, Quartet System)

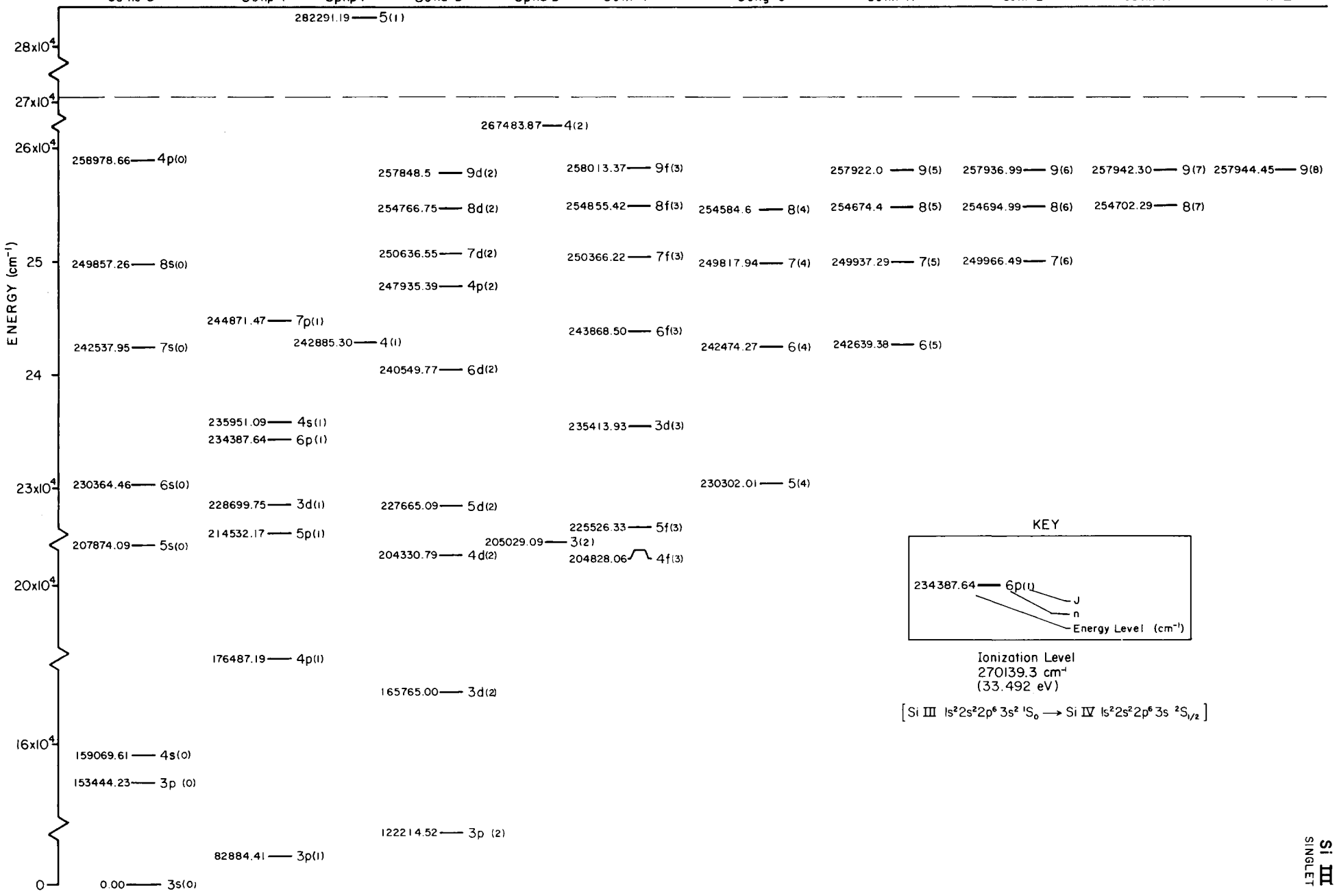


Si III GROTRIAN DIAGRAM (12 electrons, Z = 14)
(Mg I sequence, Lowest Four Singlets to Higher Singlets)



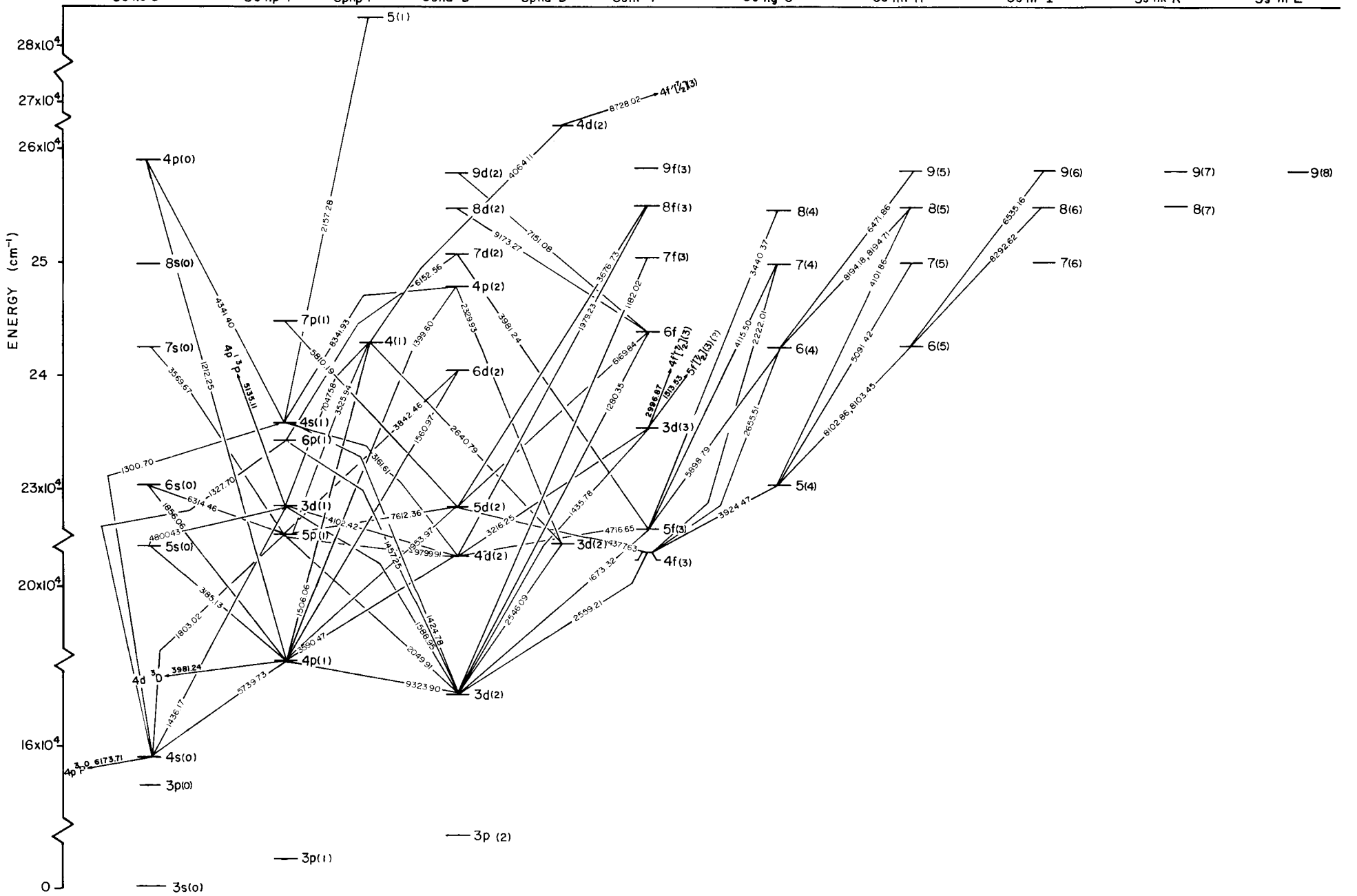
Si III ENERGY LEVELS (12 electrons, Z = 14)

(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\,nl$, $1s^2 2s^2 2p^6 3p\,nl$, Singlet System)



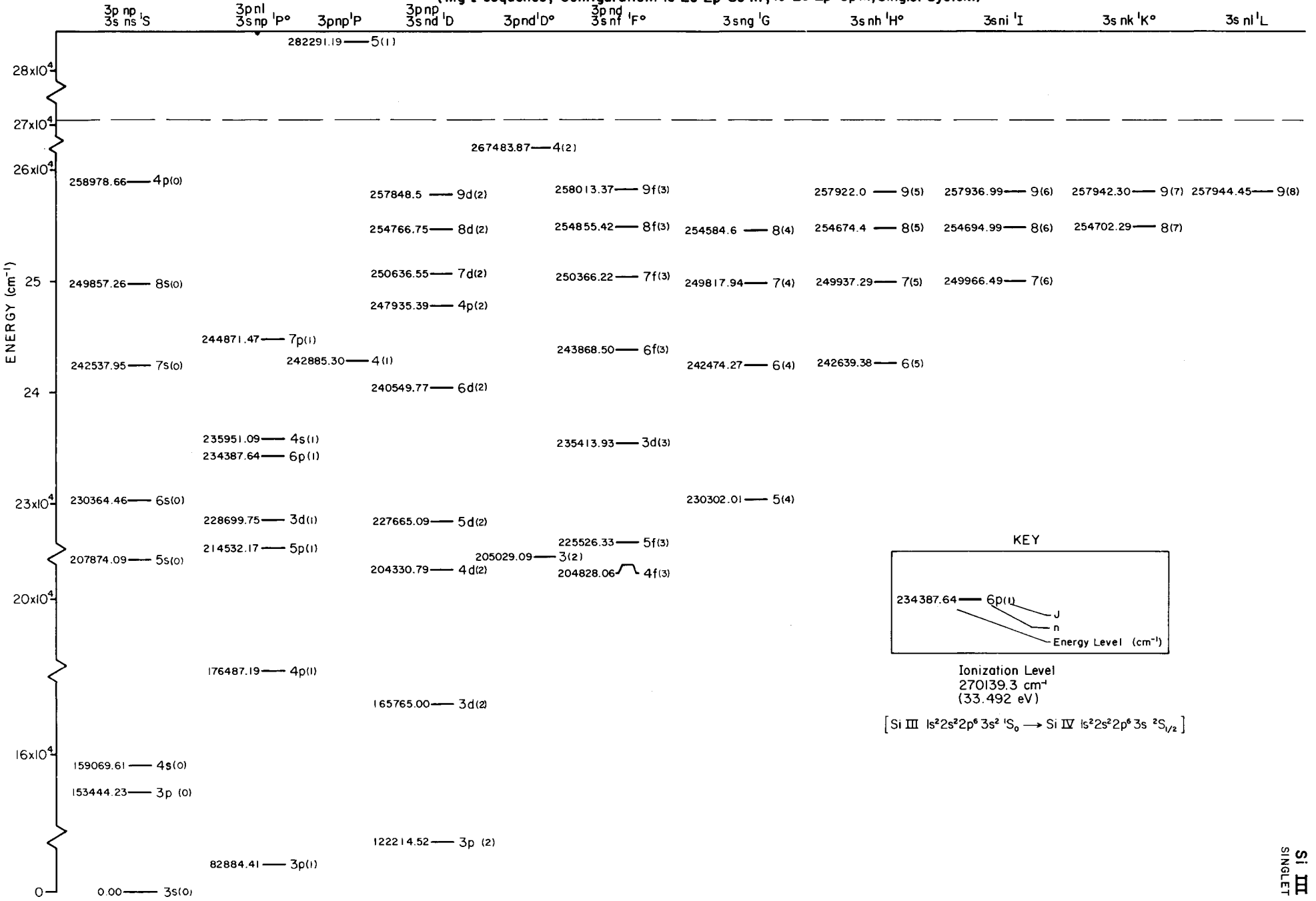
Si III GROTRIAN DIAGRAM (12 electrons, Z=14)

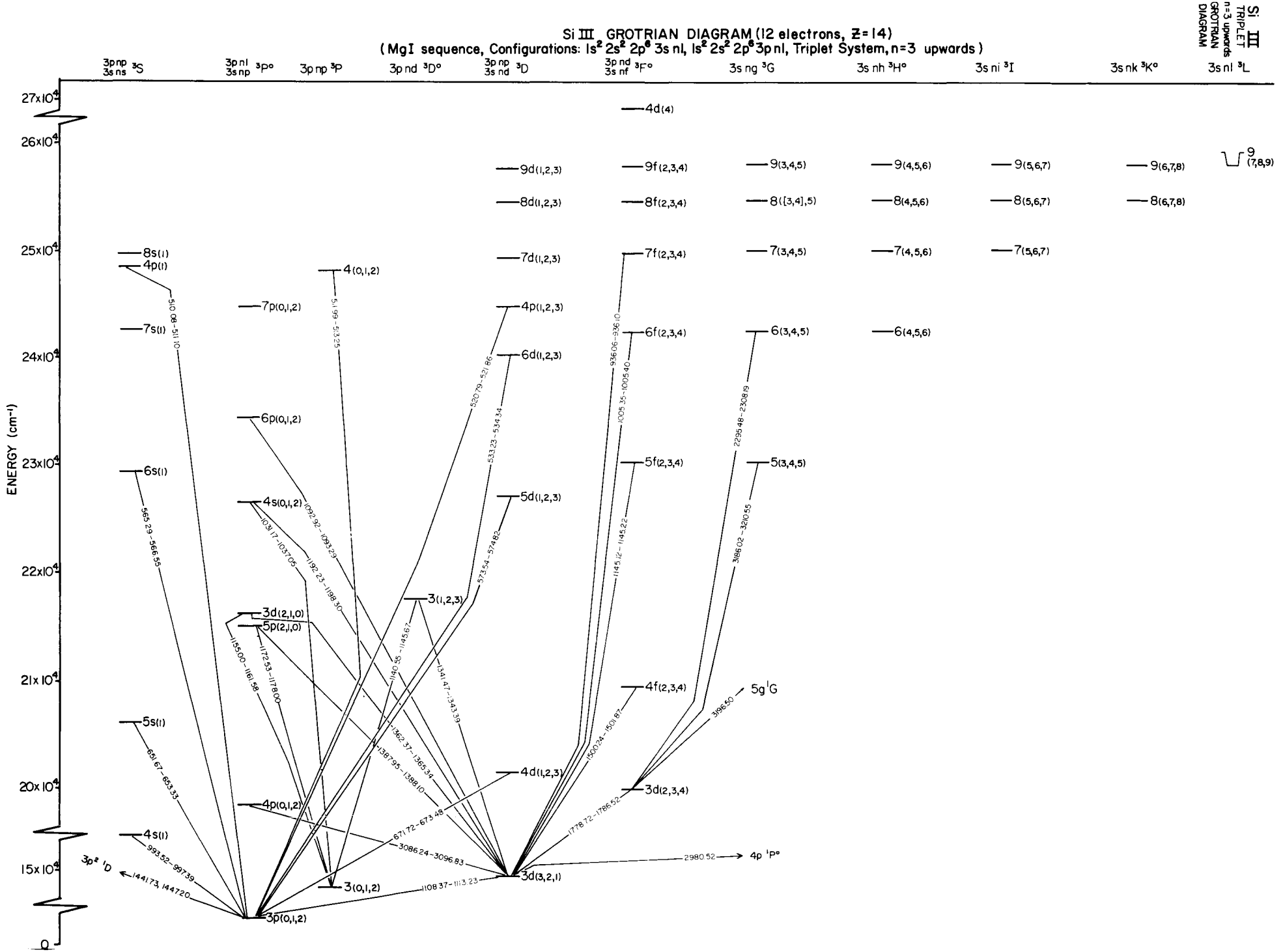
(Mg I sequence, Transitions between Singlets, 4s and above)



Si III ENERGY LEVELS (12 electrons, Z = 14)

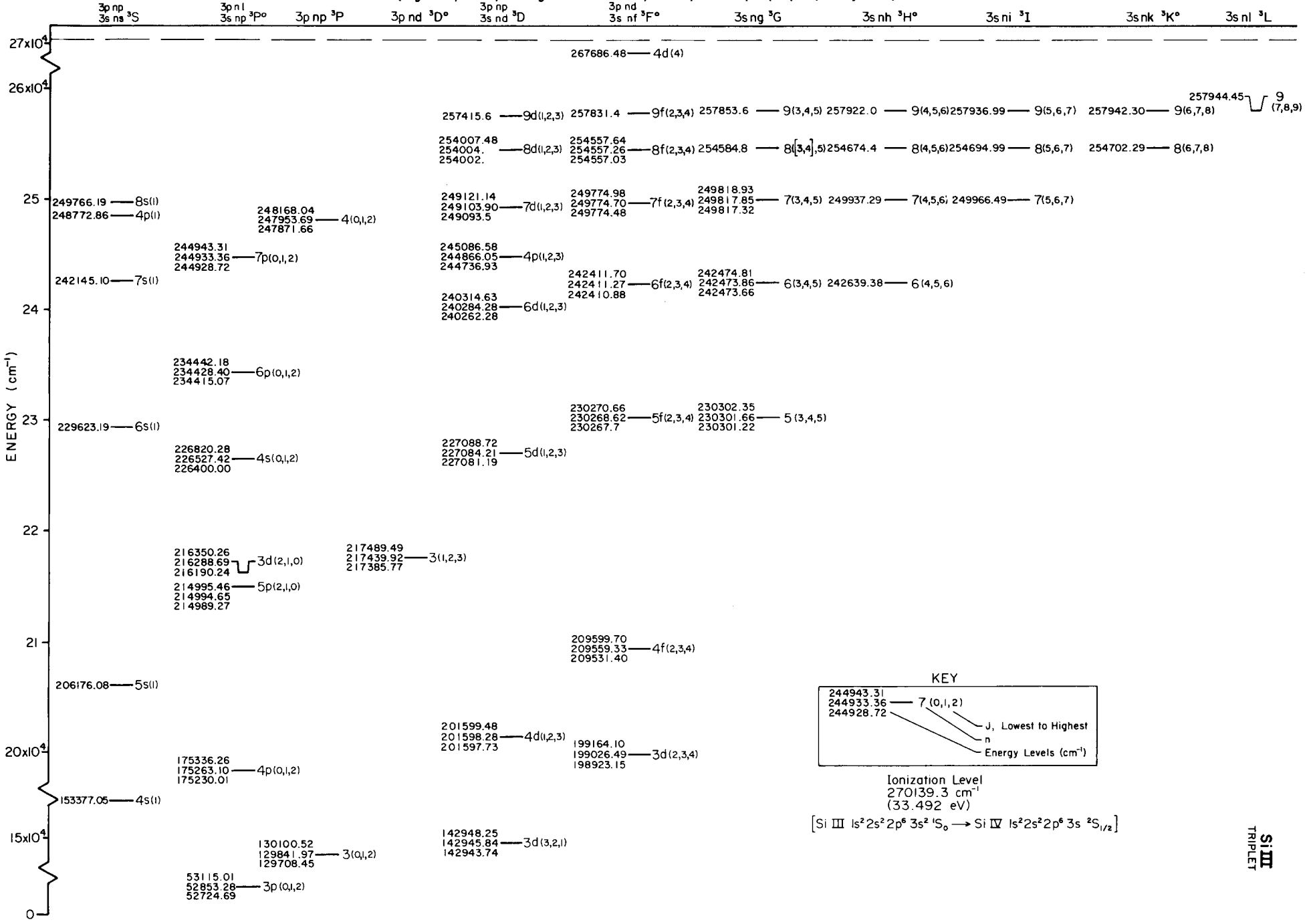
(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\,nl$, $1s^2 2s^2 2p^6 3p\,nl$, Singlet System)

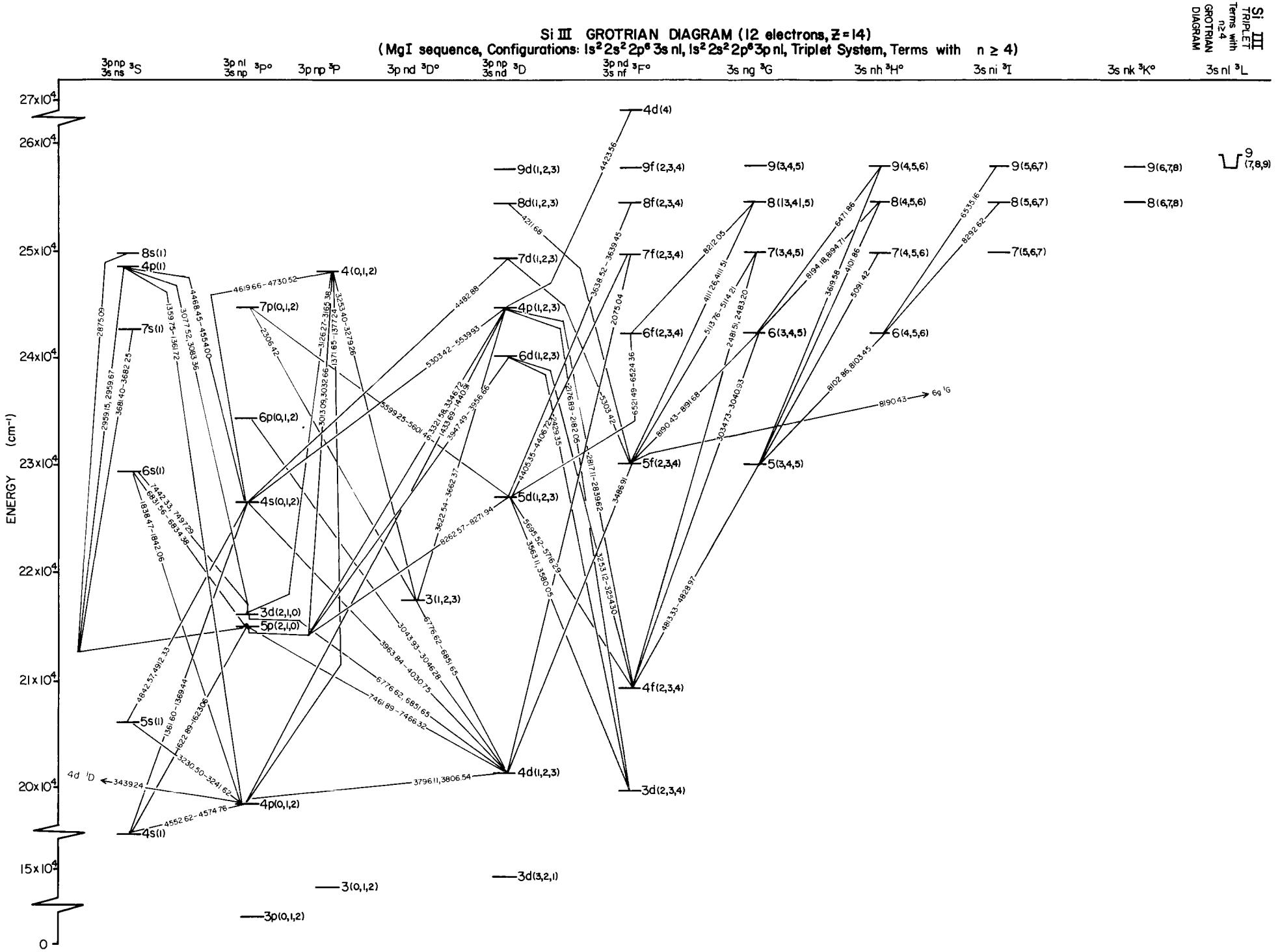



Si III GROTRIAN DIAGRAM (12 electrons, Z=14)
(MgI sequence, Configurations: 1s² 2s² 2p⁶ 3s nl, 1s² 2s² 2p⁶ 3p nl, Triplet System, n=3 upwards)
Si III TRIPLET n=3 upwards GROTRIAN DIAGRAM
3p np 3s ns ³S
3p nl 3s np ³P°
3p np ³P
3p nd ³D°
3p np 3s nd ³D
3p nd 3s nf ³F°
3s ng ³G
3s nh ³H°
3s ni ³I
3s nk ³K°
3s nl ³L
ENERGY (cm⁻¹)
27x10⁴
26x10⁴
25x10⁴
24x10⁴
23x10⁴
22x10⁴
21x10⁴
20x10⁴
15x10⁴
0
4d(4)
9d(1,2,3)
9f(2,3,4)
9(3,4,5)
9(4,5,6)
9(5,6,7)
9(6,7,8)
9 (7,8,9)
8d(1,2,3)
8f(2,3,4)
8([3,4],5)
8(4,5,6)
8(5,6,7)
8(6,7,8)
8s(1)
4p(1)
7d(1,2,3)
7f(2,3,4)
7(3,4,5)
7(4,5,6)
7(5,6,7)
4(0,1,2)
7p(0,1,2)
4p(1,2,3)
7s(1)
6f(2,3,4)
6(3,4,5)
6(4,5,6)
6d(1,2,3)
6p(0,1,2)
5f(2,3,4)
5(3,4,5)
6s(1)
4s(0,1,2)
5d(1,2,3)
3(1,2,3)
3d(2,1,0)
5p(2,1,0)
4f(2,3,4)
5g ¹G
5s(1)
4d(1,2,3)
3d(2,3,4)
4p(0,1,2)
4s(1)
3p² ¹D
3(0,1,2)
3d(3,2,1)
4p ¹P°
3p(0,1,2)
510.08-511.10
565.29-566.55
651.67-653.33
993.52-997.39
1441.73, 1447.20
513.99-513.25
1092.92-1093.23
1093.17-1037.05
1192.23-1198.30
1155.00-1161.58
1172.53-1178.00
1140.55-1145.67
1362.37-1365.34
1387.95-1388.10
671.72-673.48
3086.24-3096.83
1108.37-1113.23
520.79-521.86
533.23-534.34
573.54-574.82
1341.47-1343.39
936.06-936.10
1005.35-1005.40
1145.12-1145.22
1500.24-1501.87
1778.72-1786.52
2980.52
2295.48-2308.19
3186.02-3210.55
3196.50

Si III ENERGY LEVELS (12 electrons, Z=14)

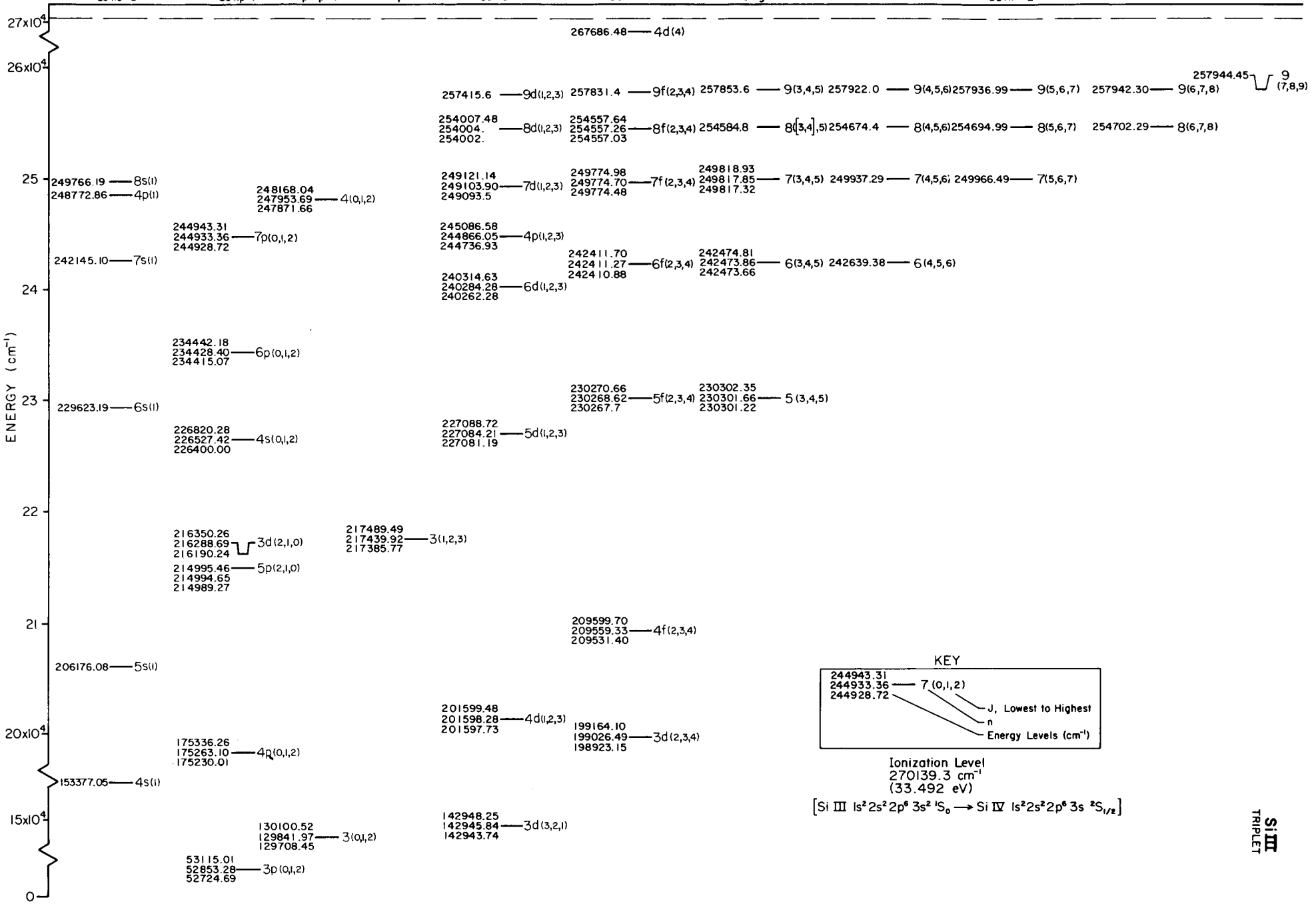
(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\,nl$, $1s^2 2s^2 2p^6 3p\,nl$, Triplet System)




Si III GROTRIAN DIAGRAM (12 electrons, Z = 14)
(MgI sequence, Configurations: 1s² 2s² 2p⁶ 3s nl, 1s² 2s² 2p⁶ 3p nl, Triplet System, Terms with n ≥ 4)
Si III TRIPLET Terms with n≥4 GROTRIAN DIAGRAM
3p np 3s ns ³S
3p nl 3s np ³P°
3p np ³P
3p nd ³D°
3p np 3s nd ³D
3p nd 3s nf ³F°
3s ng ³G
3s nh ³H°
3s ni ³I
3s nk ³K°
3s nl ³L
ENERGY (cm⁻¹)
27x10⁴
26x10⁴
25x10⁴
24x10⁴
23x10⁴
22x10⁴
21x10⁴
20x10⁴
15x10⁴
0
4d(4)
9d(1,2,3)
9f(2,3,4)
9(3,4,5)
9(4,5,6)
9(5,6,7)
9(6,7,8)
9 (7,8,9)
8d(1,2,3)
8f(2,3,4)
8(1,3,4,5)
8(4,5,6)
8(5,6,7)
8(6,7,8)
7d(1,2,3)
7f(2,3,4)
7(3,4,5)
7(4,5,6)
7(5,6,7)
4p(1,2,3)
6f(2,3,4)
6(3,4,5)
6(4,5,6)
6d(1,2,3)
5f(2,3,4)
5(3,4,5)
5d(1,2,3)
4f(2,3,4)
3d(2,3,4)
4d(1,2,3)
3d(3,2,1)
8s(1)
4p(1)
7s(1)
6s(1)
5s(1)
4s(1)
4(0,1,2)
7p(0,1,2)
6p(0,1,2)
4s(0,1,2)
3d(2,1,0)
5p(2,1,0)
3(1,2,3)
4p(0,1,2)
3(0,1,2)
3p(0,1,2)
4d ¹D
6g ¹G

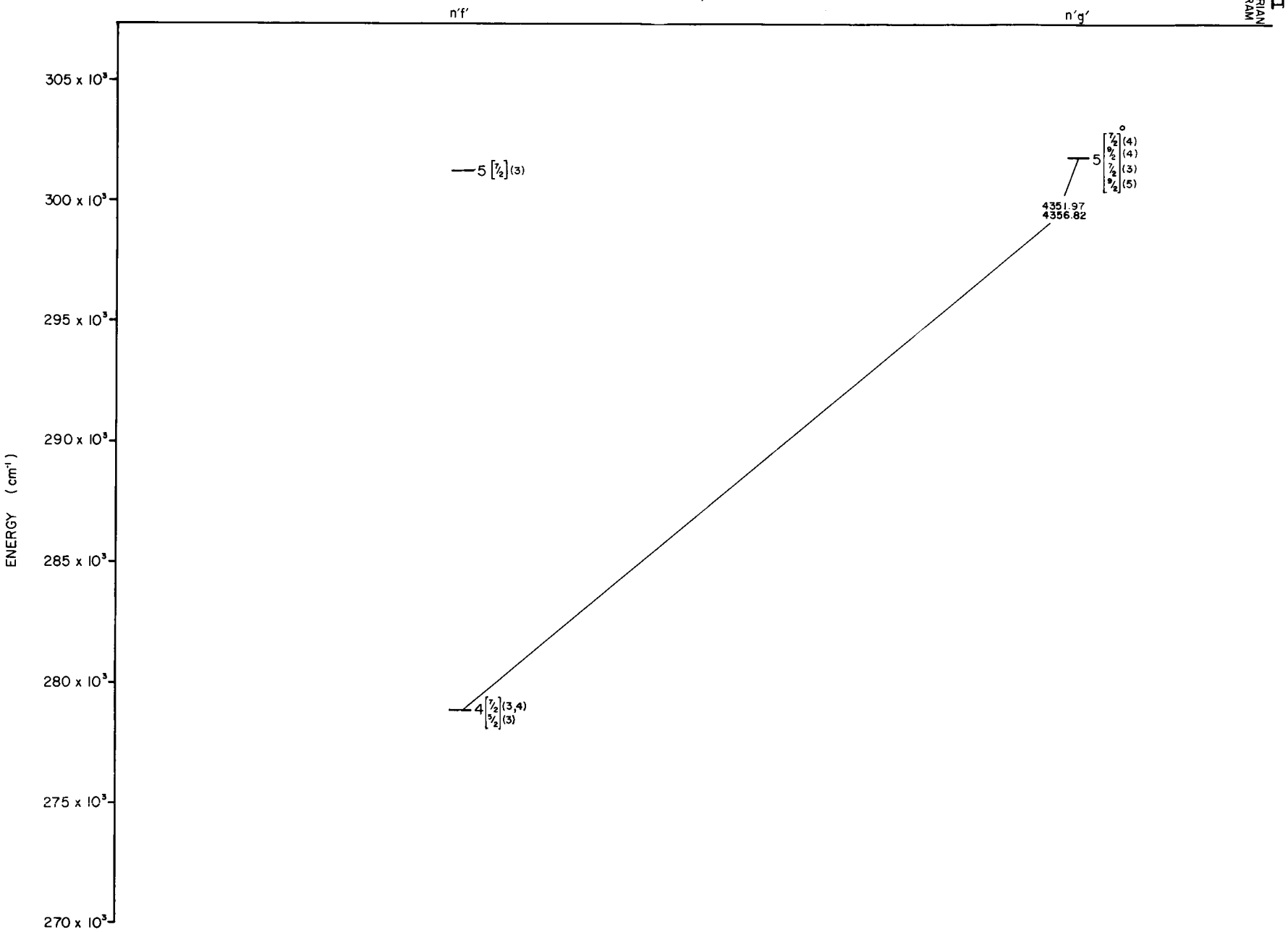
Si III ENERGY LEVELS (12 electrons, Z=14)

(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s\,nl$, $1s^2 2s^2 2p^6 3p\,nl$, Triplet System)

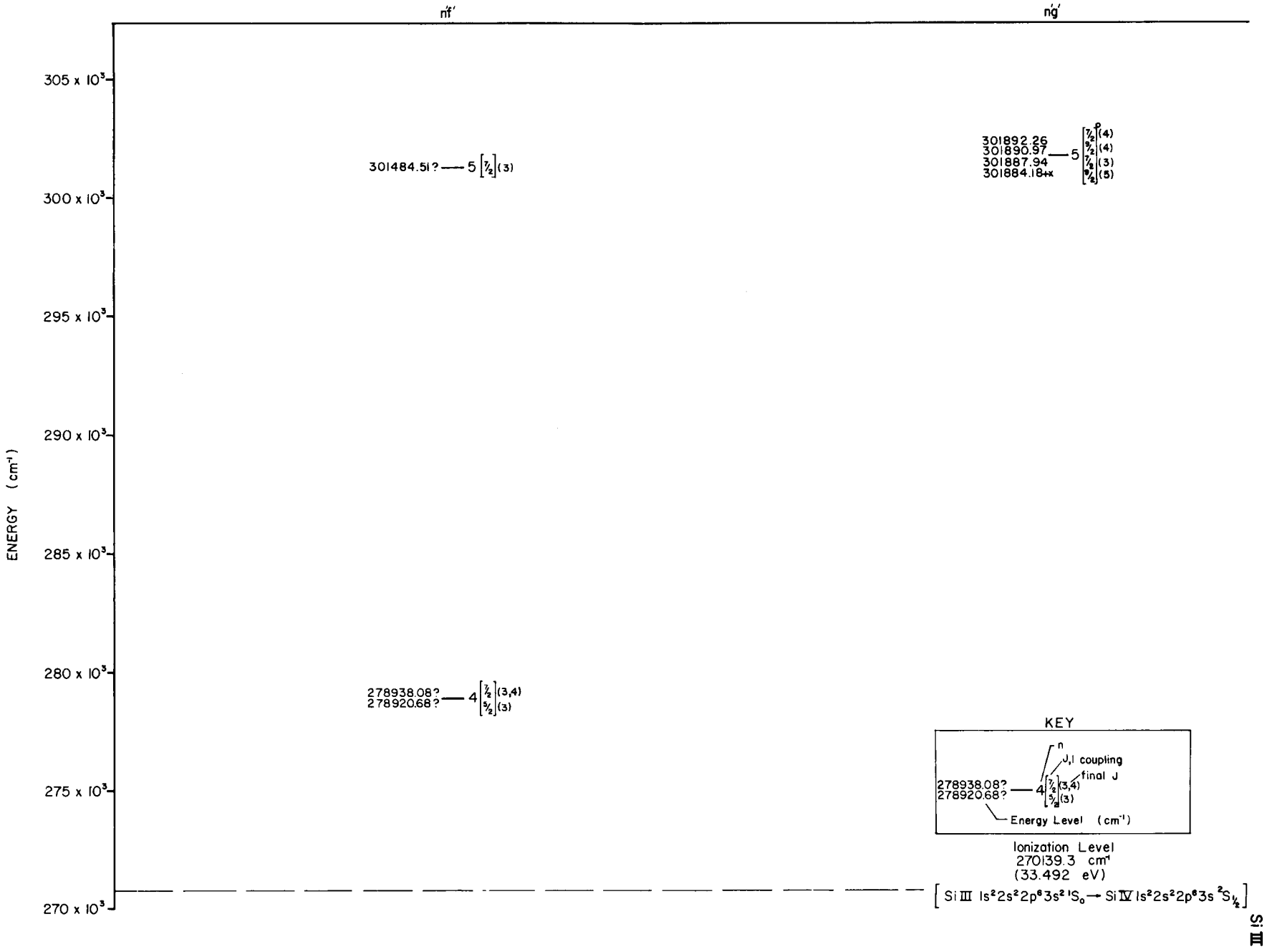


Si III TRIPLET

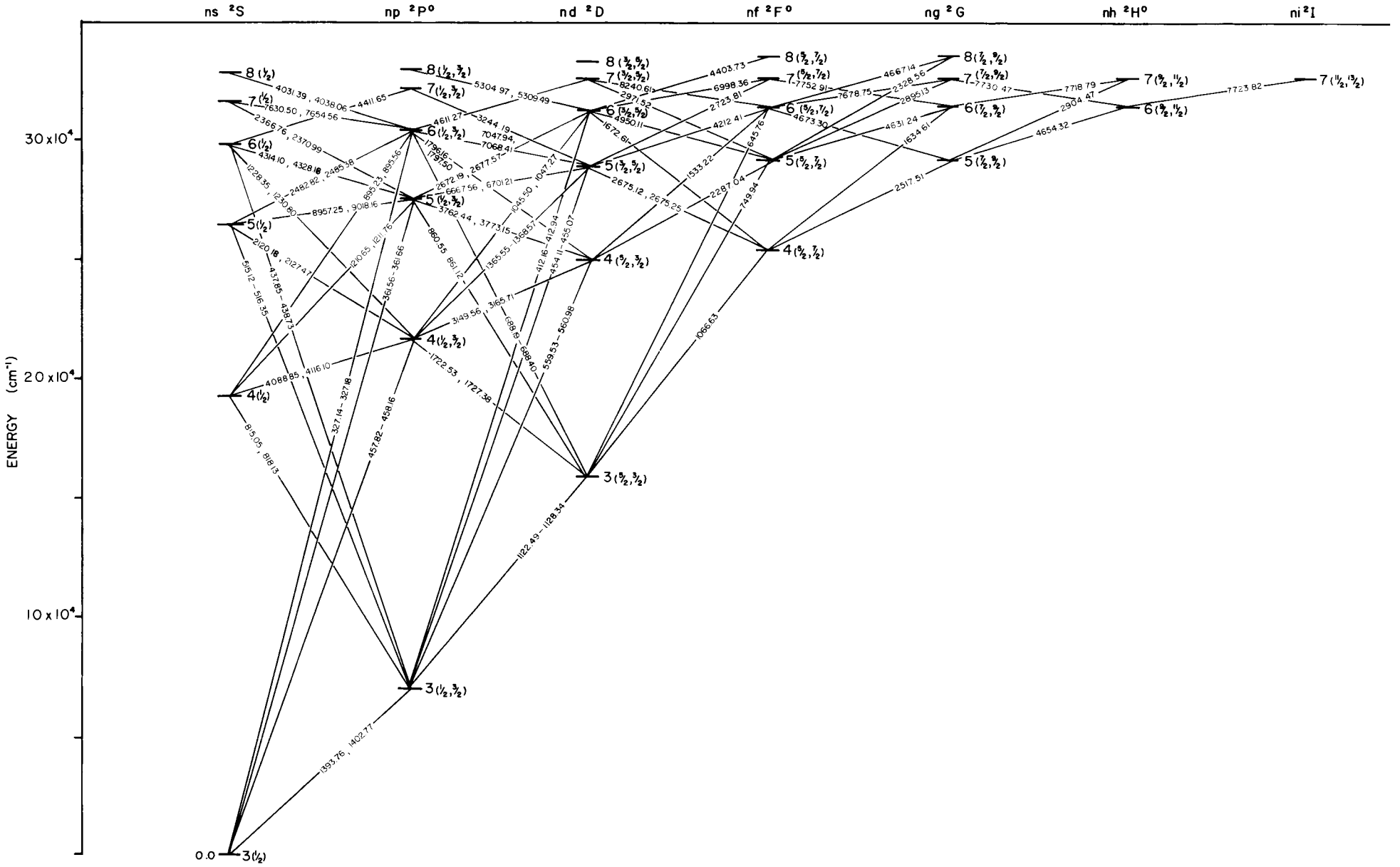
Si III GROTRIAN DIAGRAM (12 electrons, Z=14)
(Mg I sequence, Configuration; $1s^2 2s^2 2p^6 3p(^2P^o_{1/2})nl$)
Intermediate Coupling



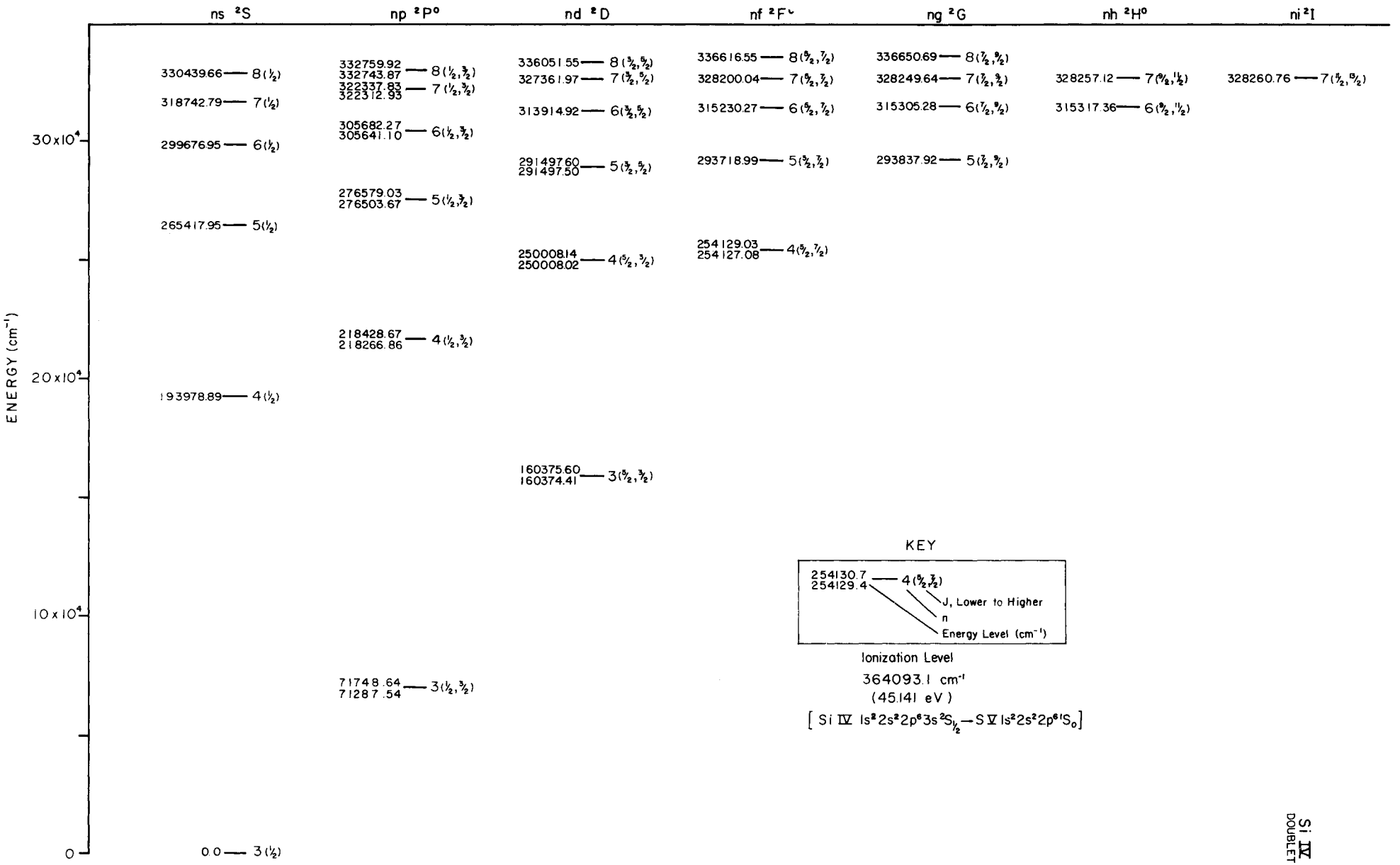
Si III ENERGY LEVELS (12 electrons, Z=14)
(Mg I sequence, Configuration; $1s^2 2s^2 2p^6 3p(^2P^o_{1/2})nl$)
Intermediate Coupling

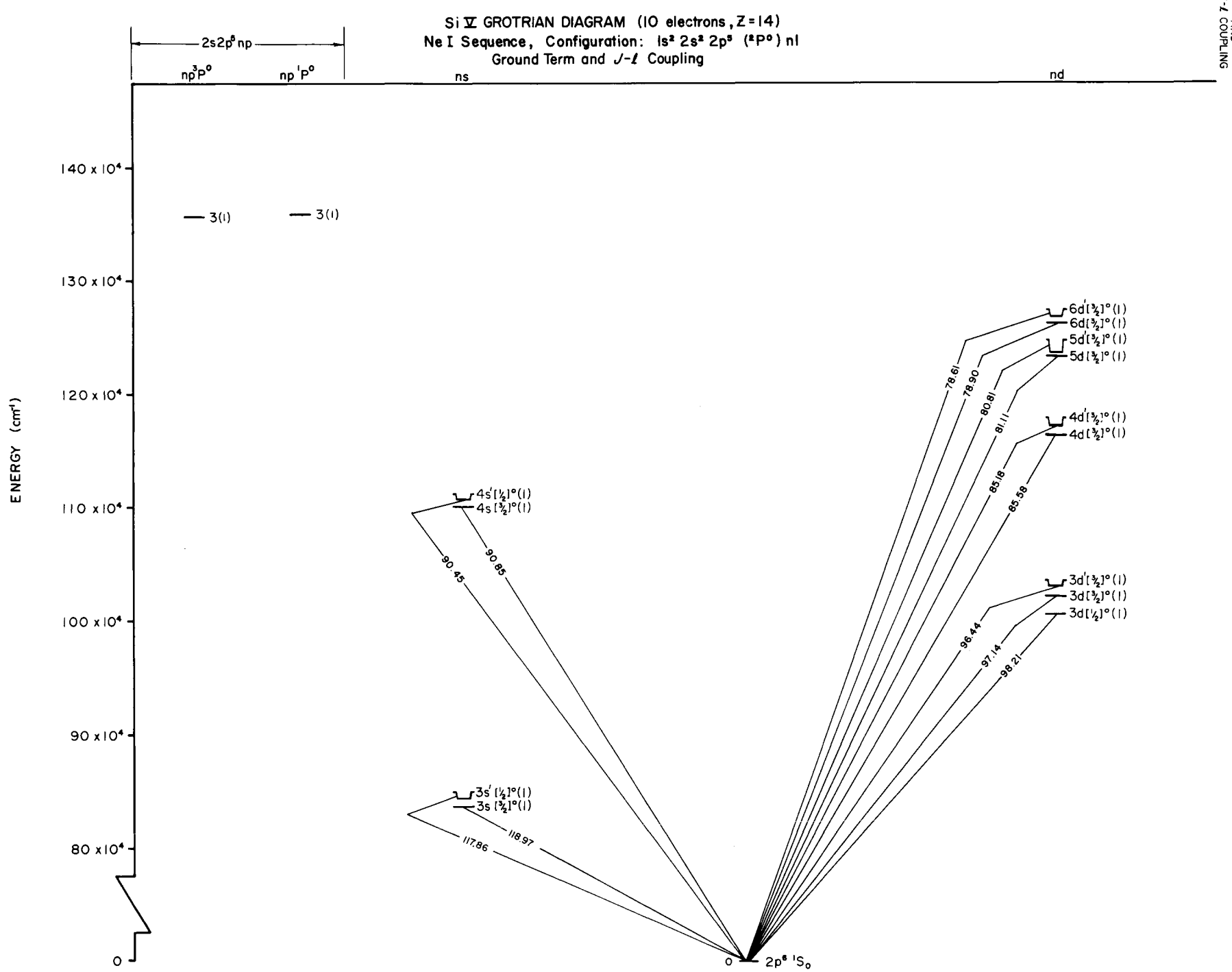


Si IV GROTRIAN DIAGRAM (11 electrons, Z=14)
(Na I sequence, Configuration: $1s^2 2s^2 2p^6 nl$, Doublet System)



Si IV ENERGY LEVELS (11 electrons, Z=14)
(Na I sequence, Configuration: $1s^2 2s^2 2p^6 nl$, Doublet System)

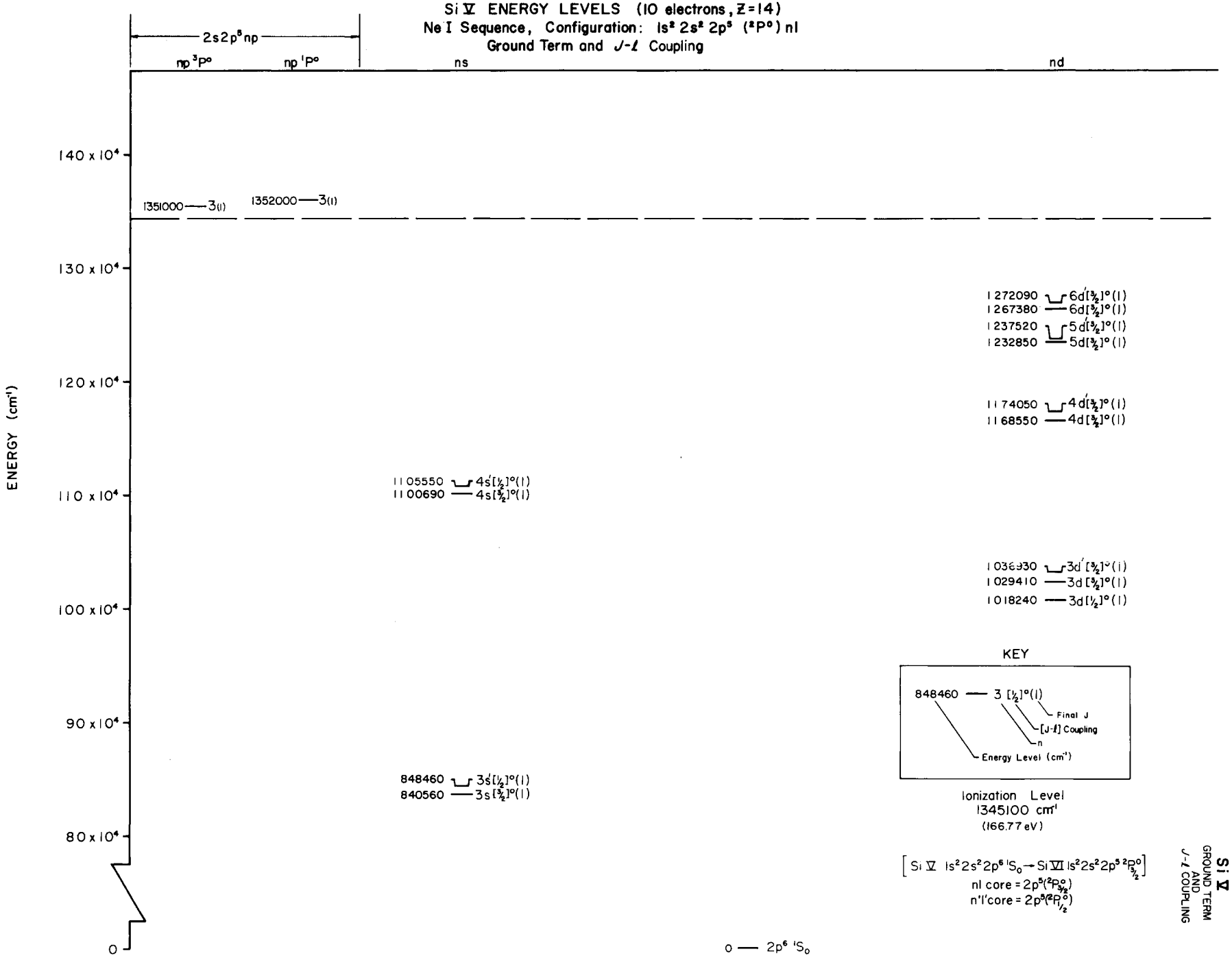



Si V GROTRIAN DIAGRAM (10 electrons, Z=14)
Ne I Sequence, Configuration: 1s² 2s² 2p⁵ (²P°) nl
Ground Term and J-ℓ Coupling
2s2p⁵np
np³P°
np¹P°
ns
nd
ENERGY (cm⁻¹)
140 x 10⁴
130 x 10⁴
120 x 10⁴
110 x 10⁴
100 x 10⁴
90 x 10⁴
80 x 10⁴
0
3(1)
3(1)
4s'[½]°(1)
4s[3/2]°(1)
3s'[½]°(1)
3s[3/2]°(1)
6d'[3/2]°(1)
6d[3/2]°(1)
5d'[3/2]°(1)
5d[3/2]°(1)
4d'[3/2]°(1)
4d[3/2]°(1)
3d'[3/2]°(1)
3d[3/2]°(1)
3d[½]°(1)
90.45
90.85
117.86
118.97
78.61
78.90
80.81
81.11
85.18
85.58
96.44
97.14
98.21
0
2p⁶ ¹S₀

Si V ENERGY LEVELS (10 electrons, Z=14)

Ne I Sequence, Configuration: $1s^2 2s^2 2p^5$ ($^2P^o$) nl

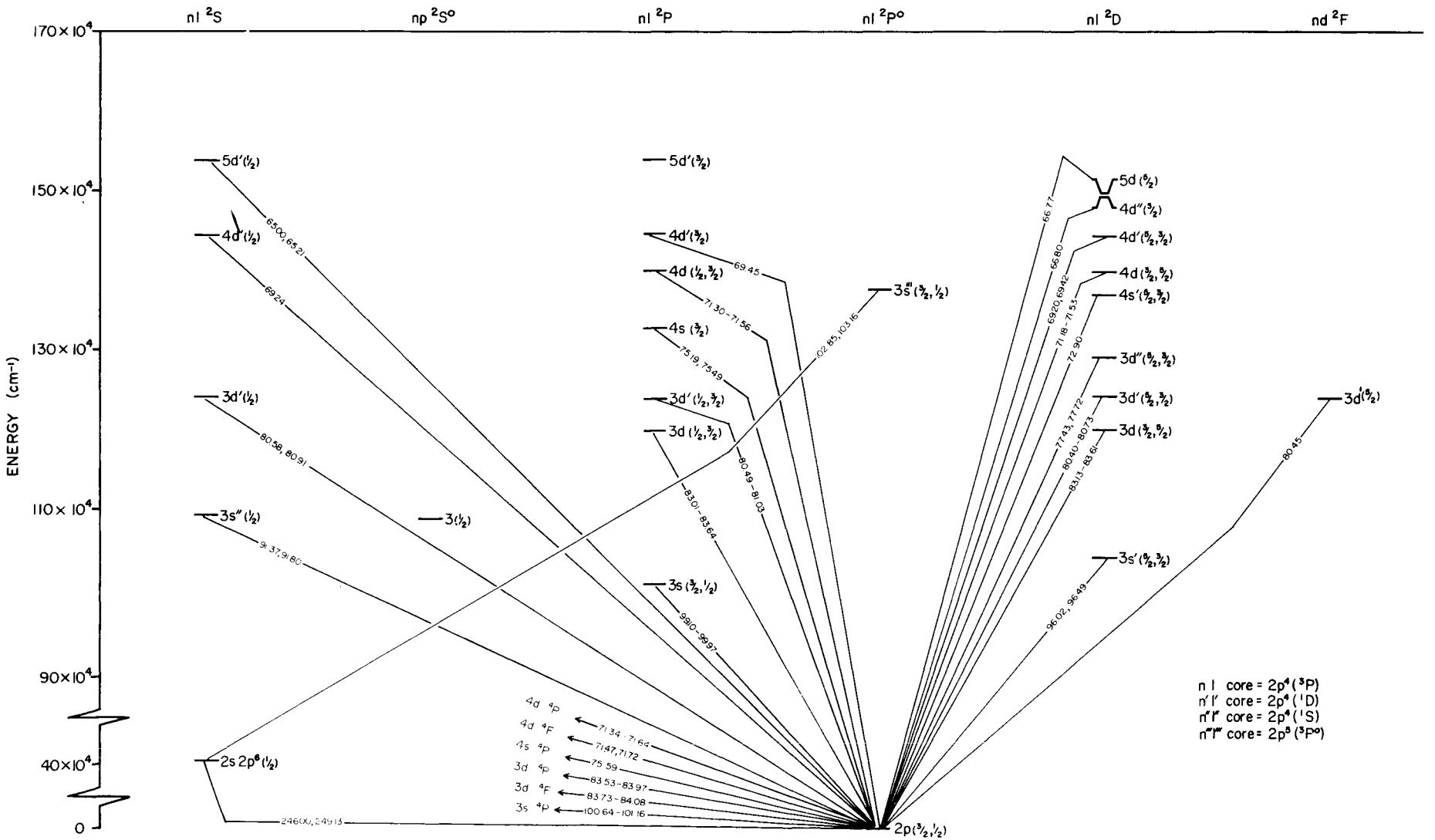
Ground Term and J-ℓ Coupling



Si V
GROUND TERM
AND
J-ℓ COUPLING

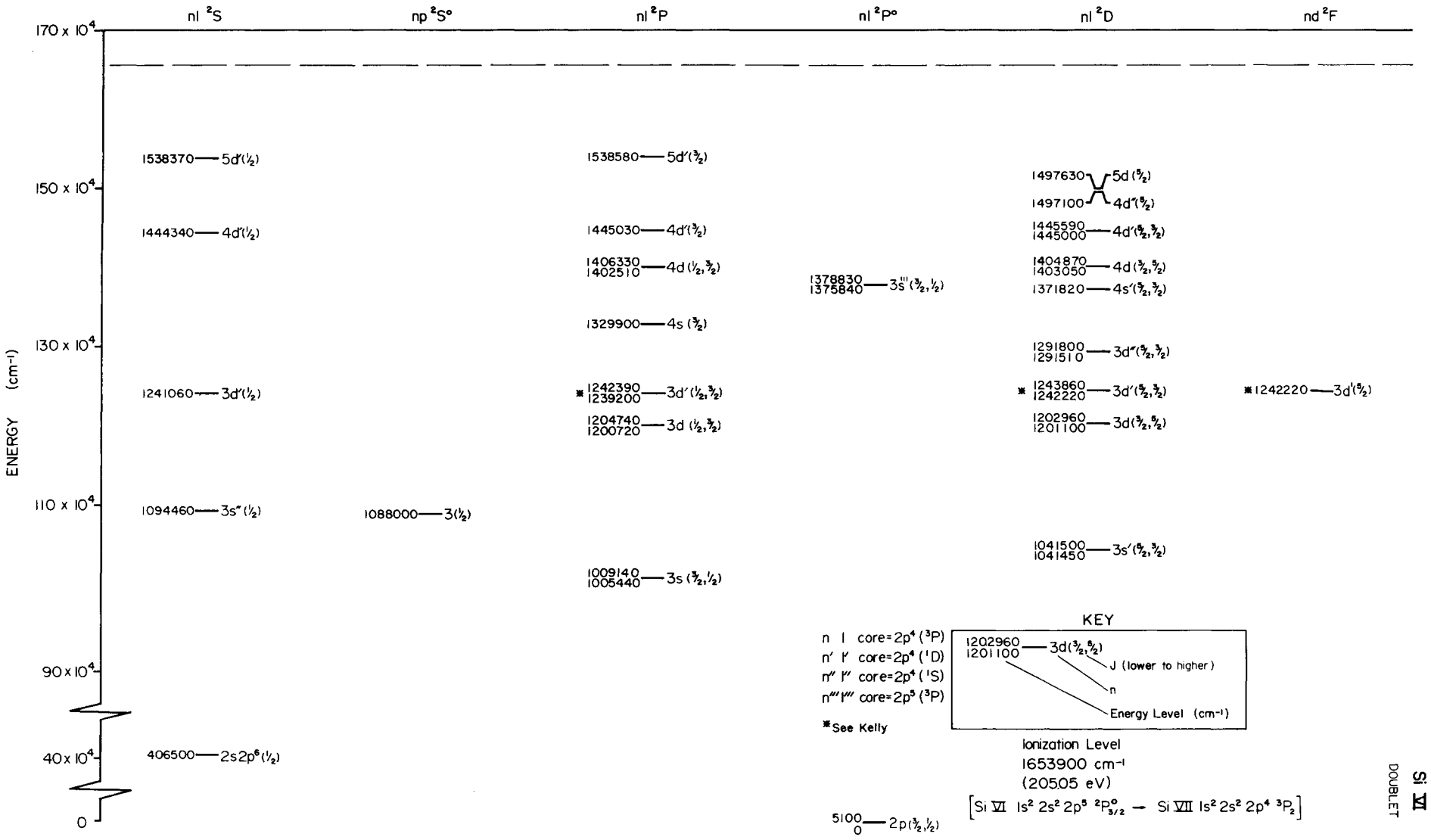
Si VI GROTRIAN DIAGRAM (9 electrons, Z=14)

(F I sequence, Configuration: $1s^2 2s^2 2p^4 (^3P) nl$, Doublet System)

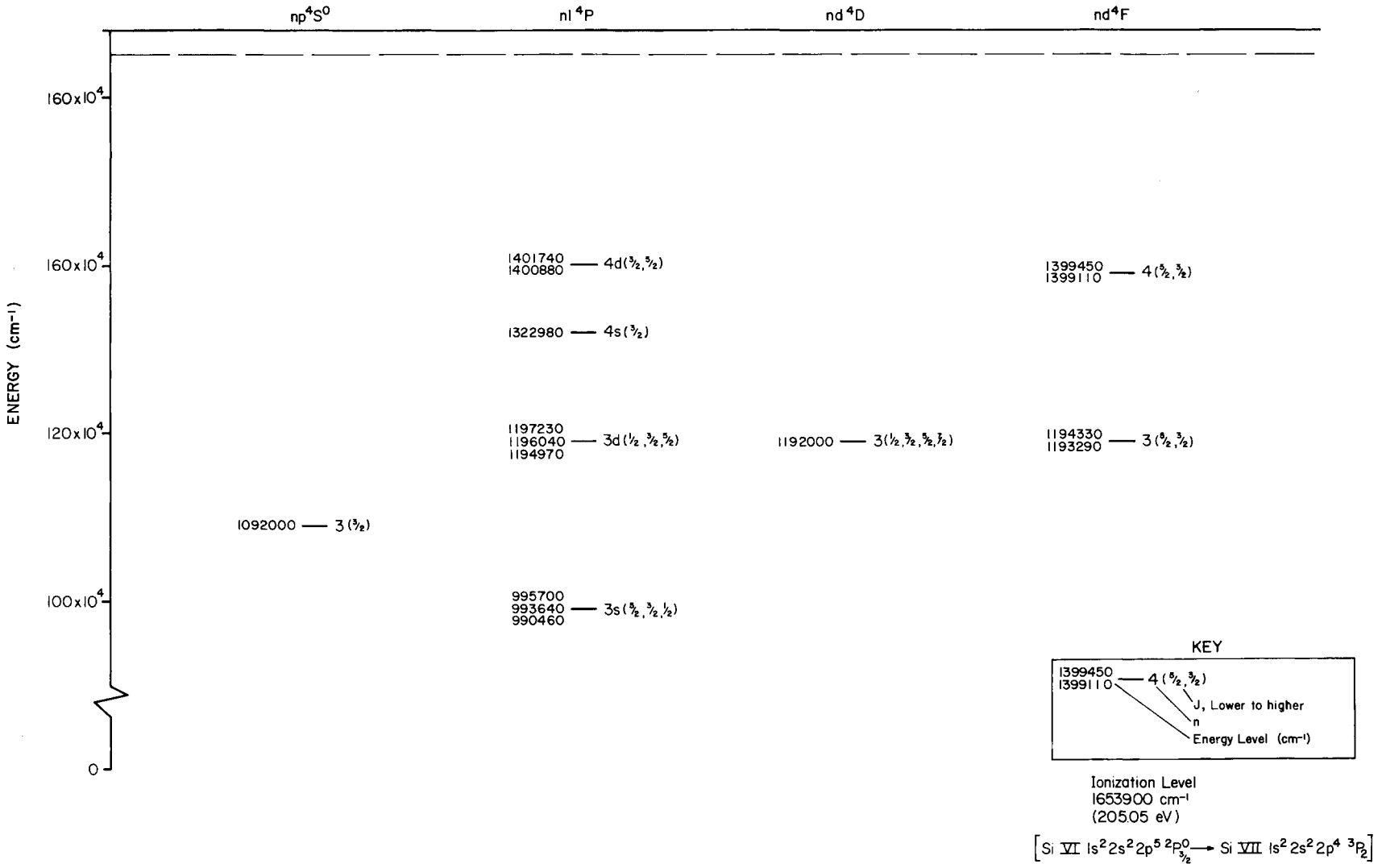


Si VI ENERGY LEVELS (9 electrons, Z=14)

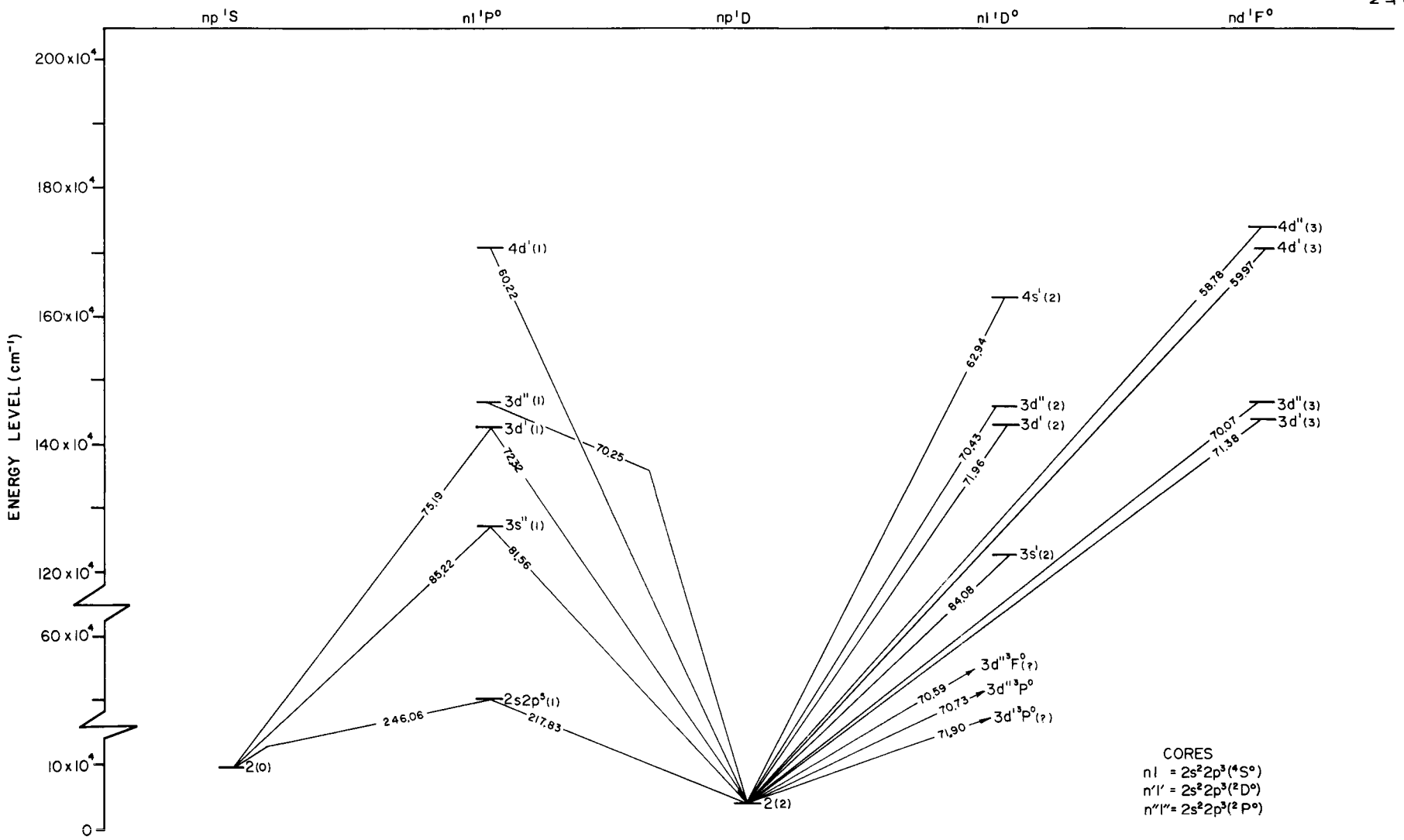
(F I sequence, Configuration: $1s^2 2s^2 2p^4 (^3P)nl$, Doublet System)



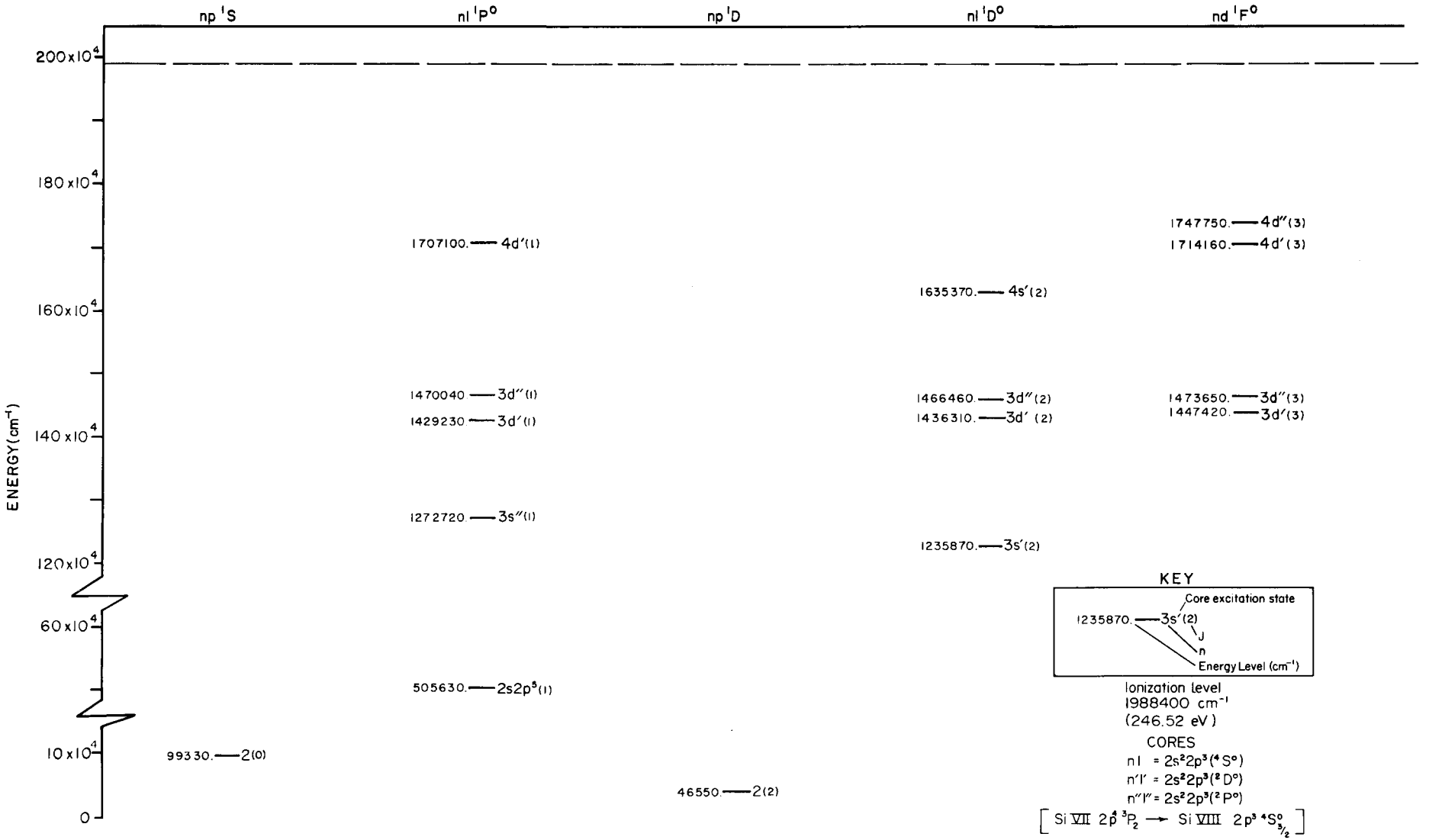
Si VI ENERGY LEVELS (9 electrons, Z=14)
(F I Sequence, Configuration: $1s^2 2s^2 2p^4(^3P)nl$, Quartet System)



Si VII GROTRIAN DIAGRAM (8 electrons, Z=14)
(OI sequence, Configuration: $1s^2\,2s^2\,2p^3\,nl$ Singlet System)

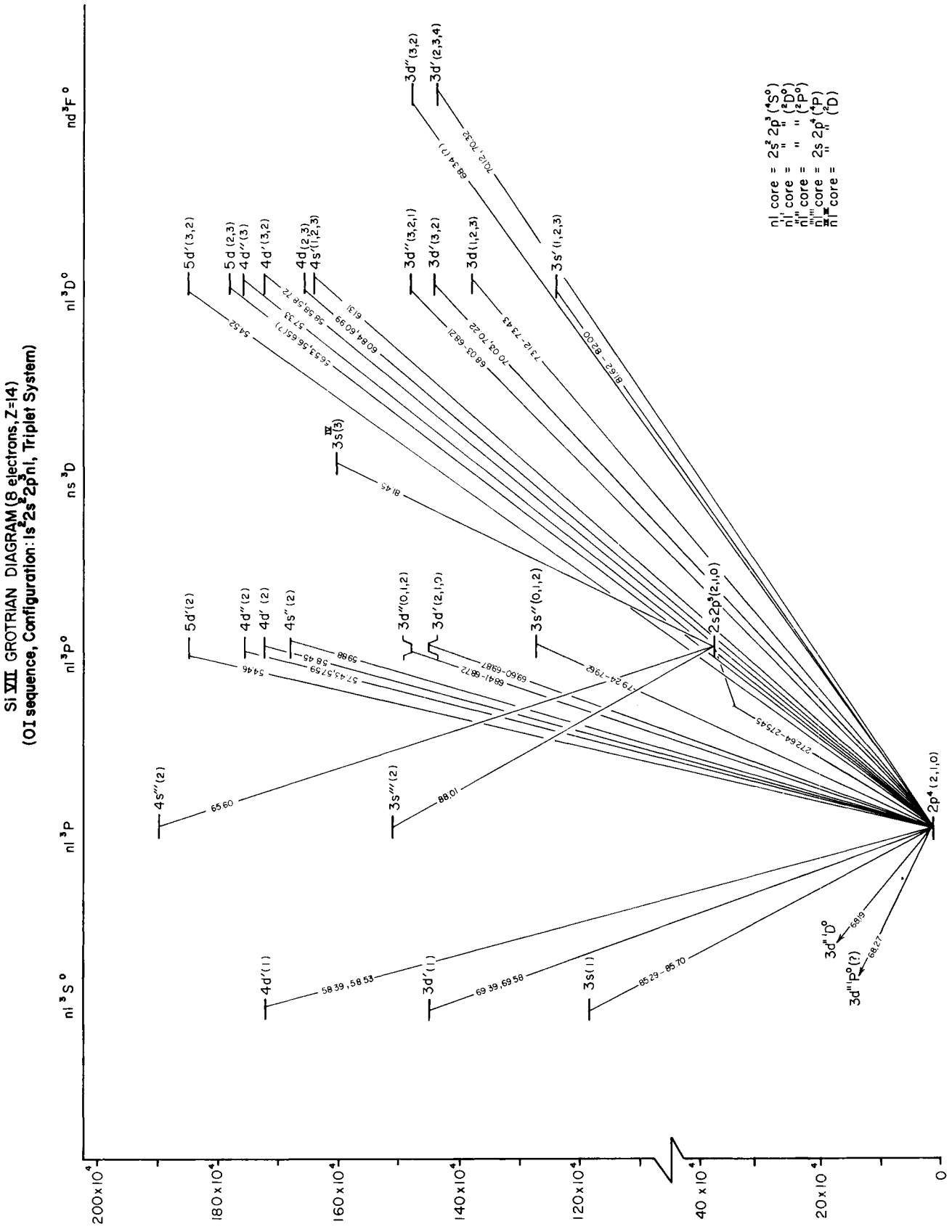


Si VII ENERGY LEVELS (8 electrons, Z = 14)
(O I sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Singlet System)

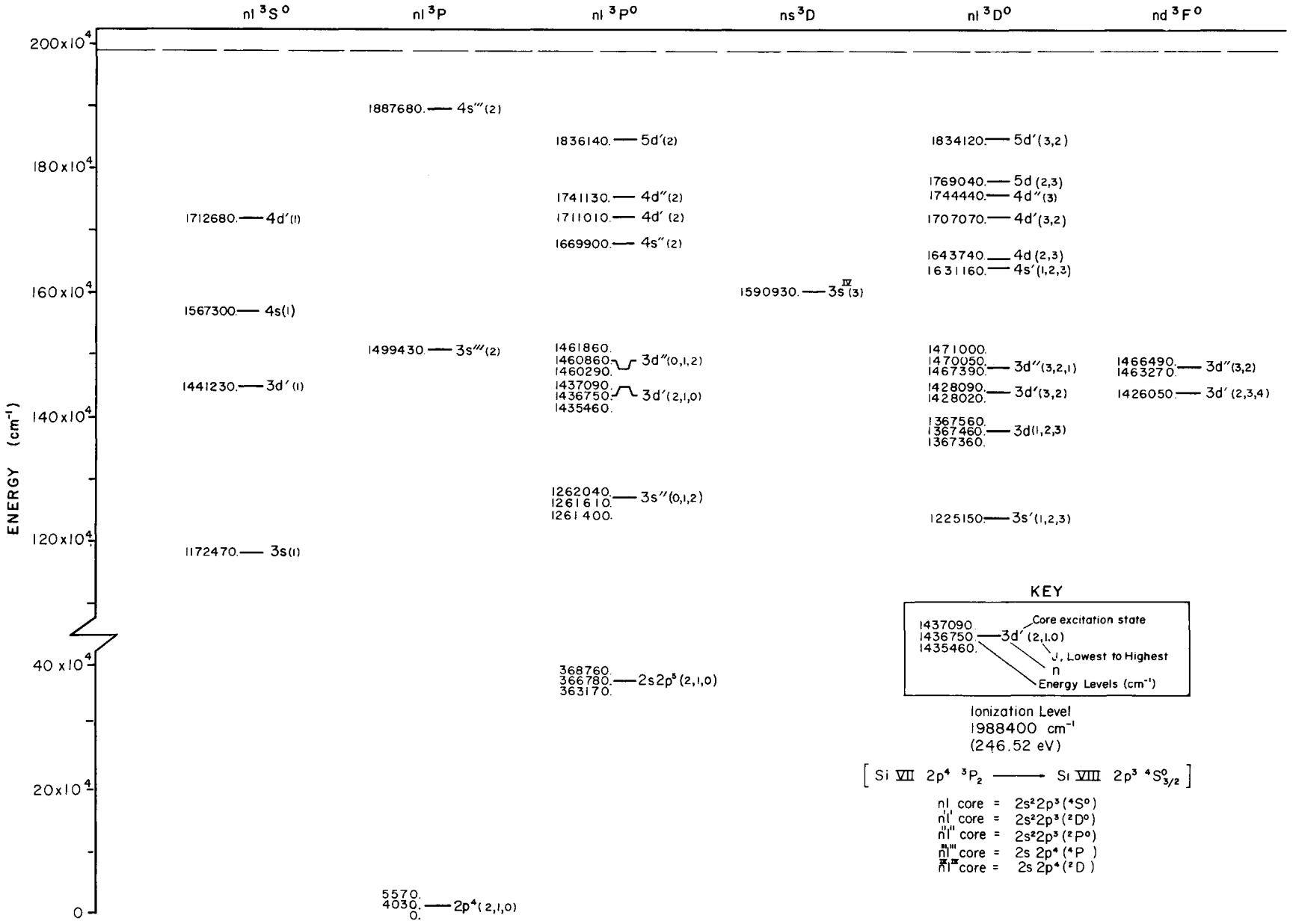


NOTE: All levels uncertain by ± x.

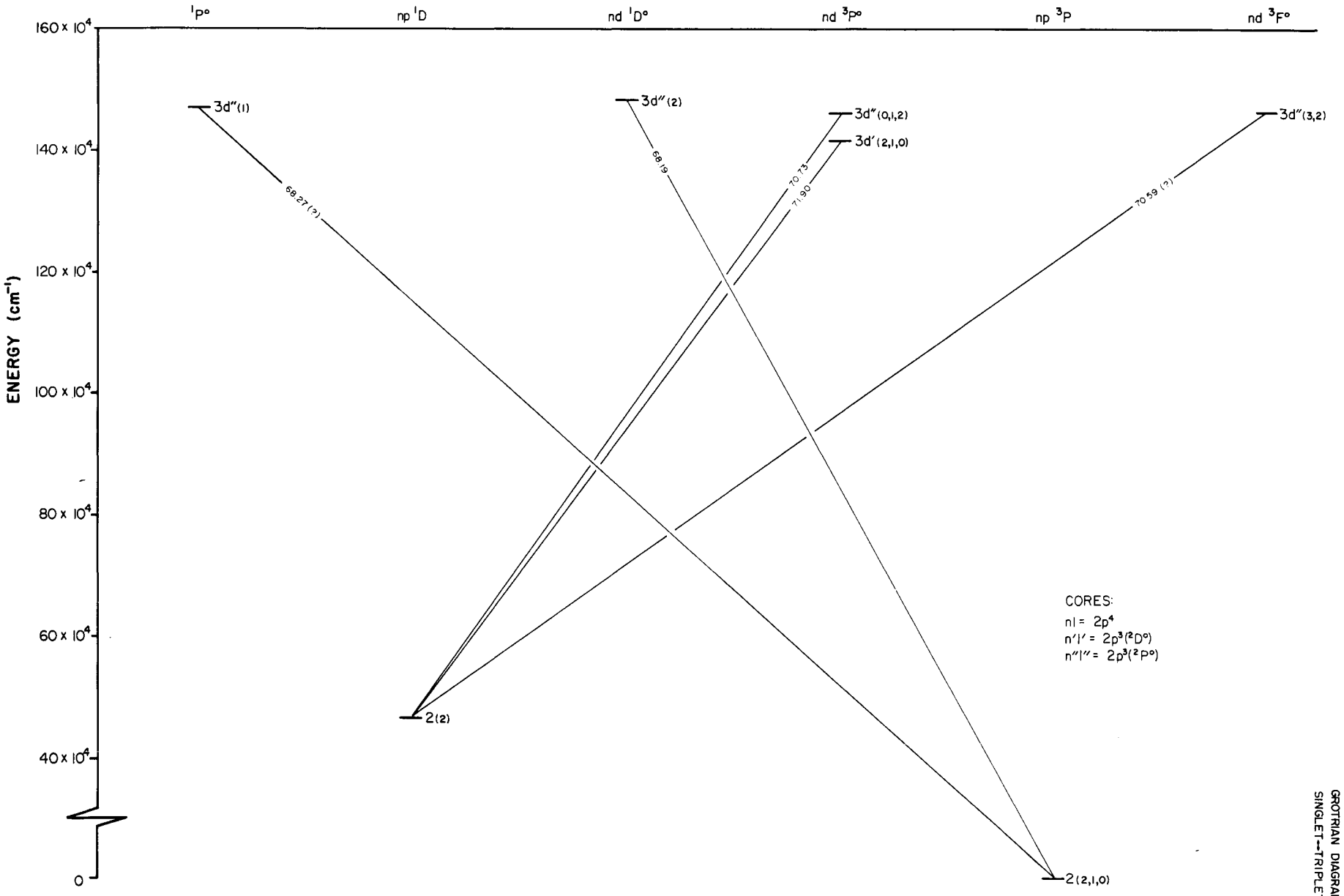
Si VII
TRIPLET
GROTRIAN
DIAGRAM



Si VII ENERGY LEVELS (8 electrons, Z=14)
(OI sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)

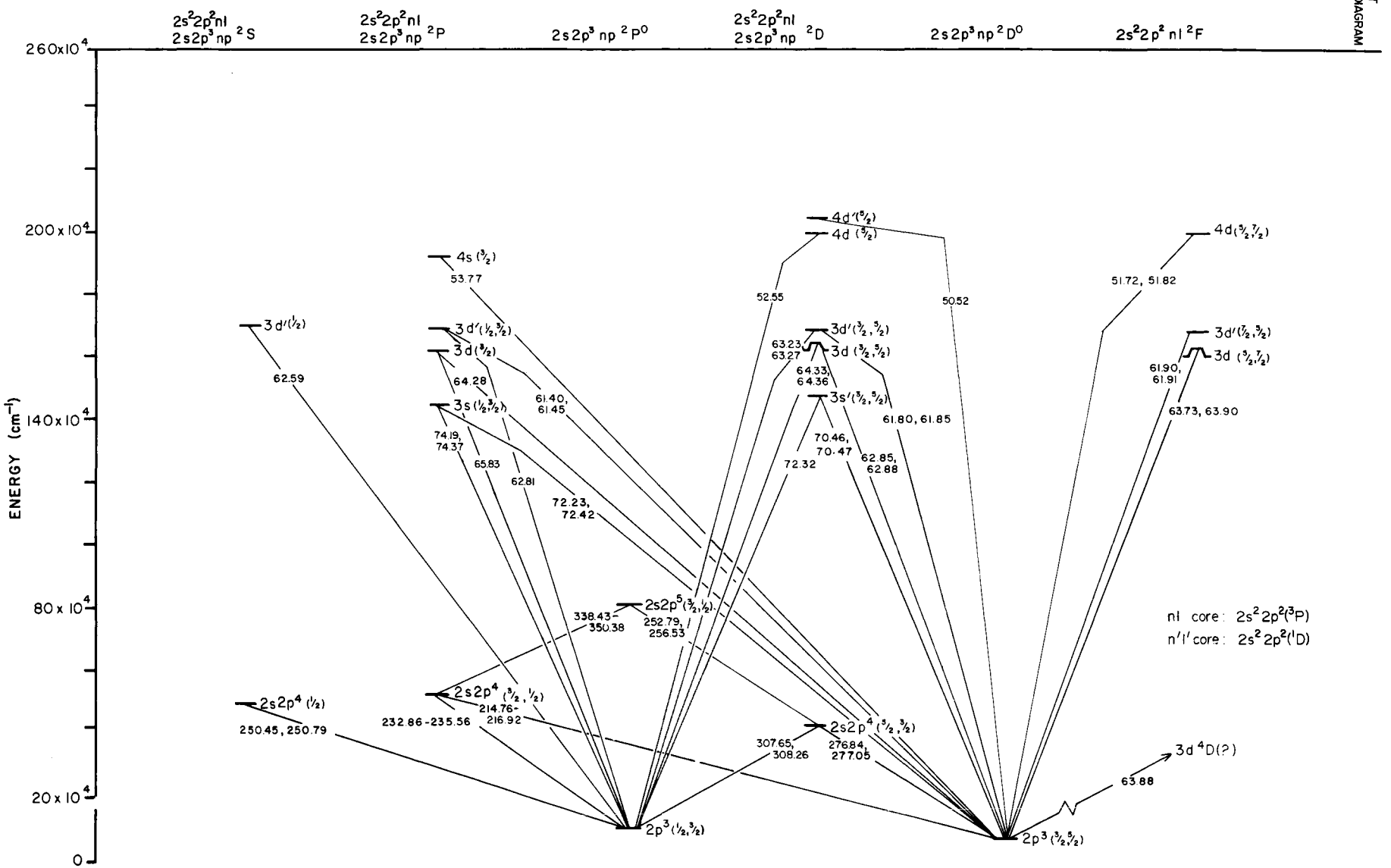


Si VII GROTRIAN DIAGRAM (8 electrons, Z=14)
(OI sequence, Configuration: $1s^2\ 2s^2\ 2p^3\ nl$, Singlets – Triplets)
INTERCOMBINATION

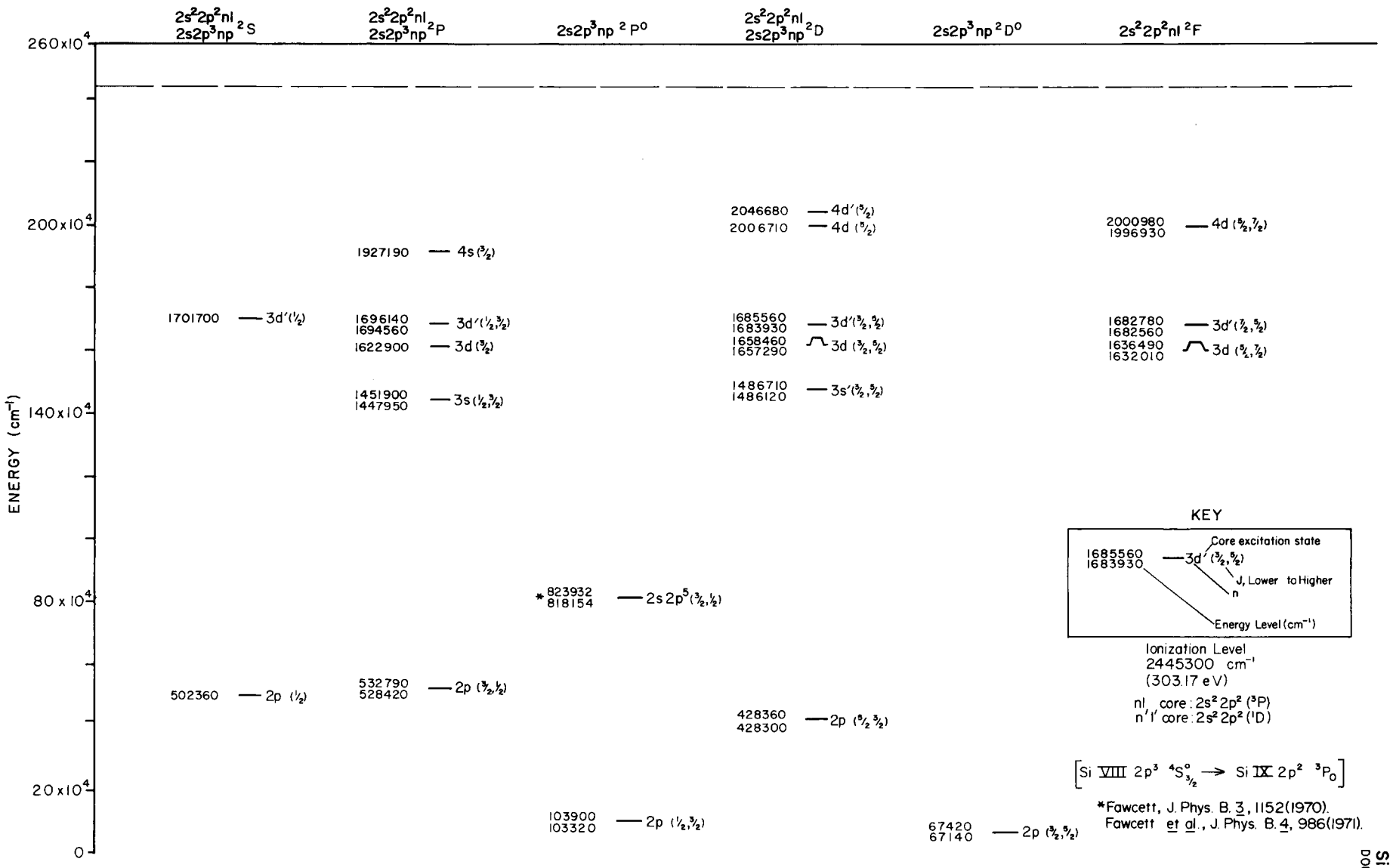


Si VII
INTERCOMBINATION
GROTRIAN DIAGRAM
SINGLET→TRIPLET

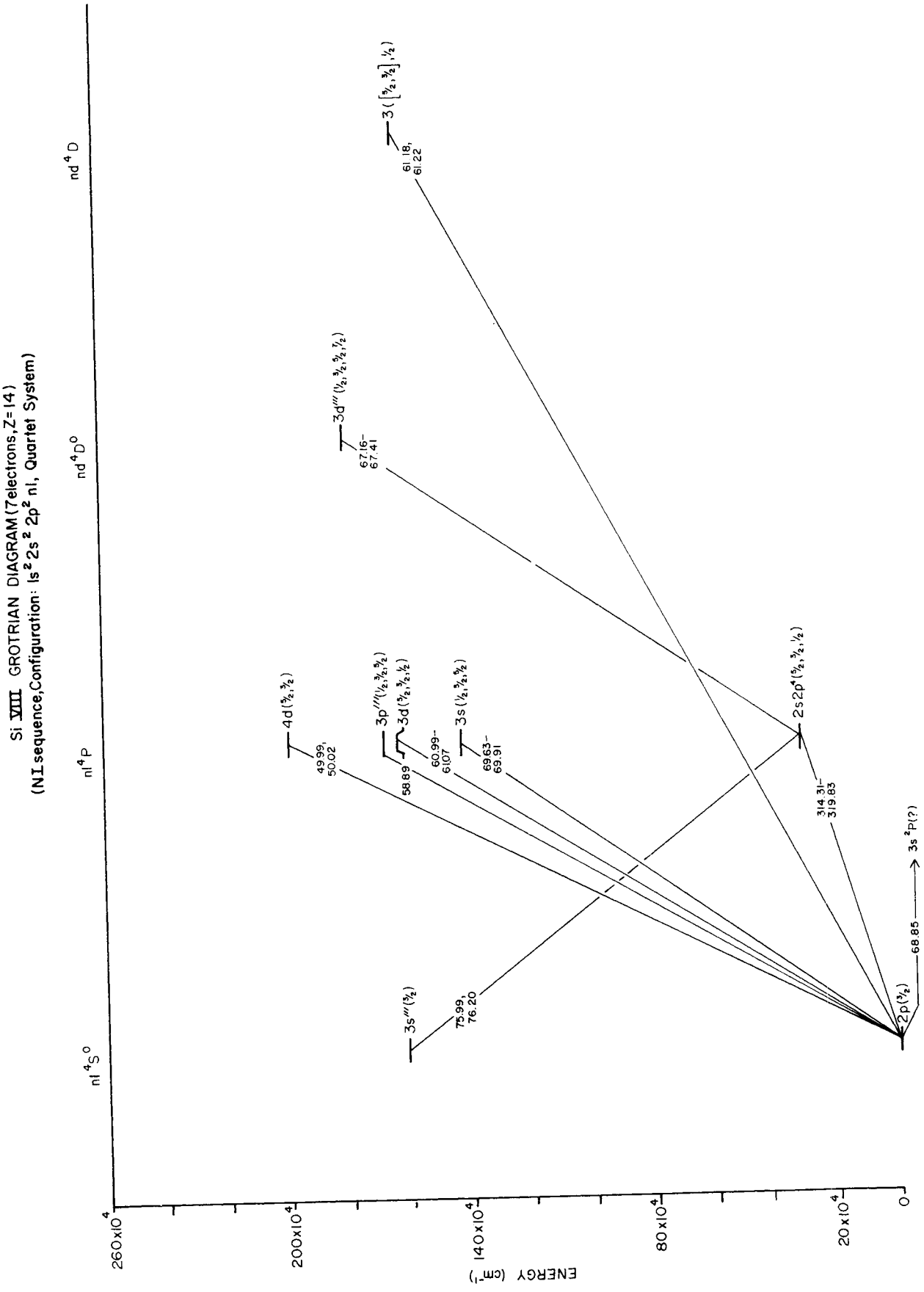
Si VIII GROTRIAN DIAGRAM (7 electrons, Z=14)
(NI sequence Configuration: $1s^2 2s^2 2p^2 nl$, $1s^2 2s 2p^3 nl$, Doublet System)



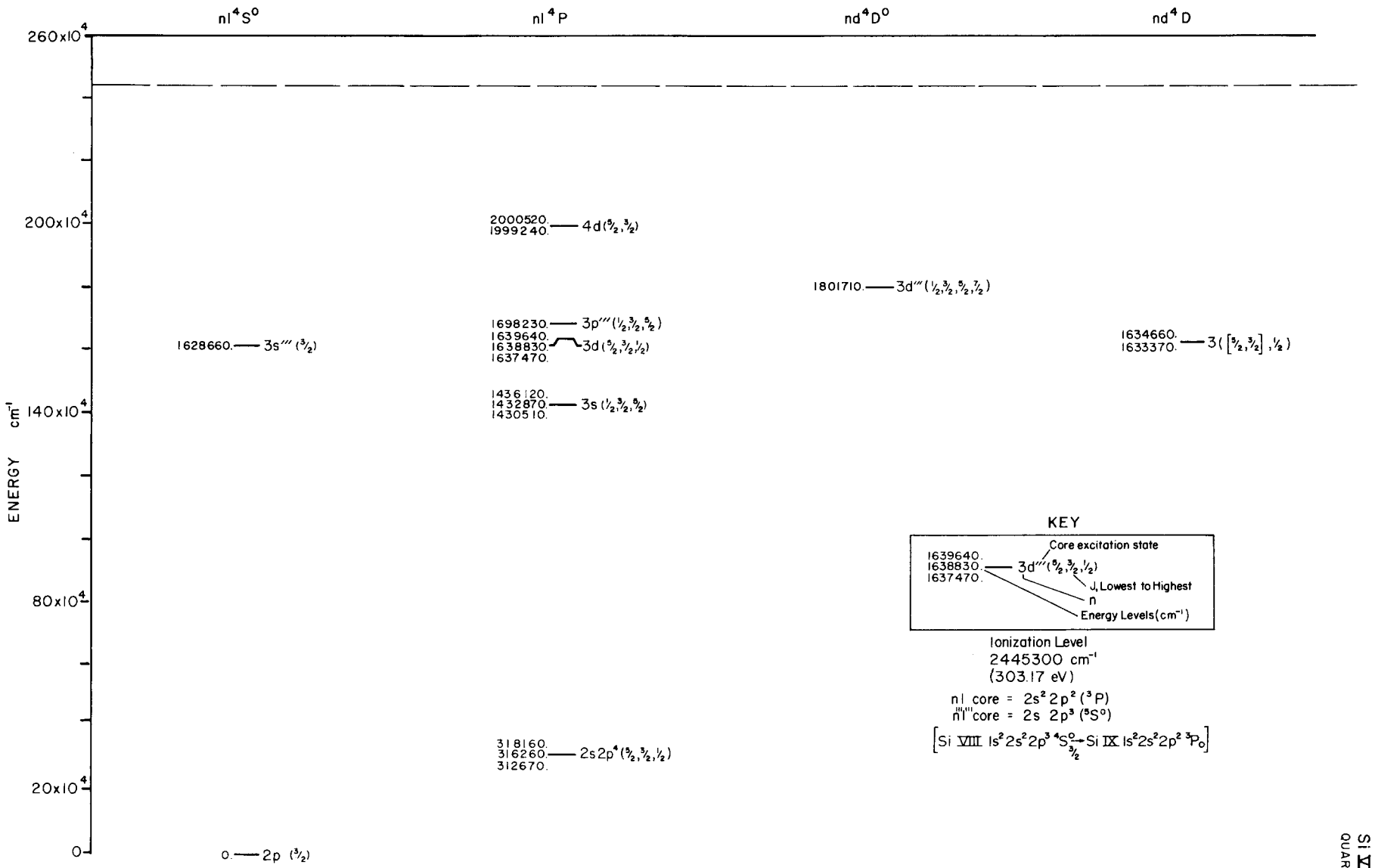
Si VIII ENERGY LEVELS (7 electrons, Z=14)
(NI sequence, Configuration: $1s^2 2s^2 2p^2 nl$, $1s^2 2s 2p^3 nl$, Doublet System)



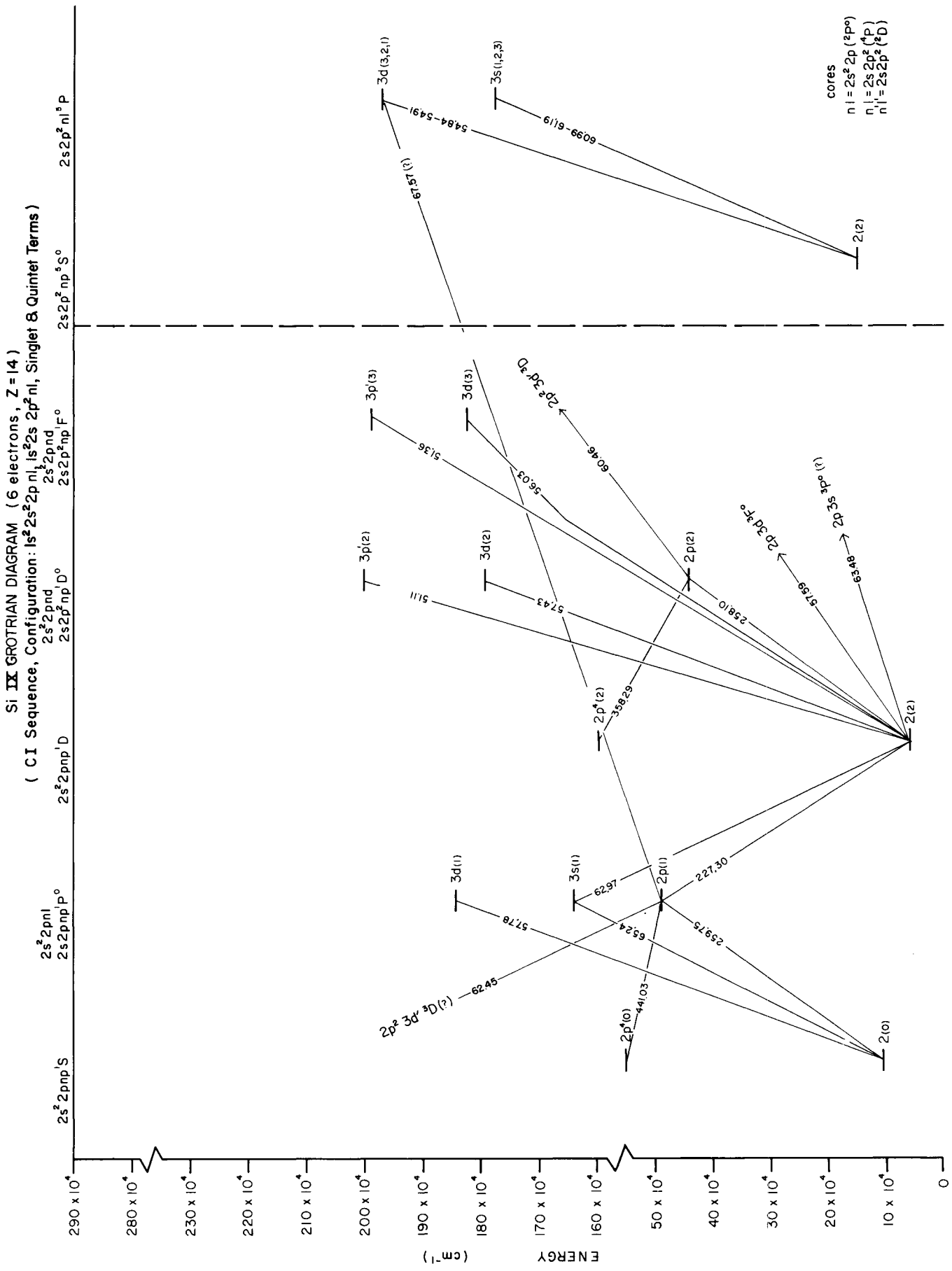
Si VIII
QUARTET
GROTRIAN
DIAGRAM



Si VIII ENERGY LEVELS (7 electrons, Z=14)
(NI sequence, Configuration: $1s^2\,2s^2\,2p^2\,nl$, Quartet System)

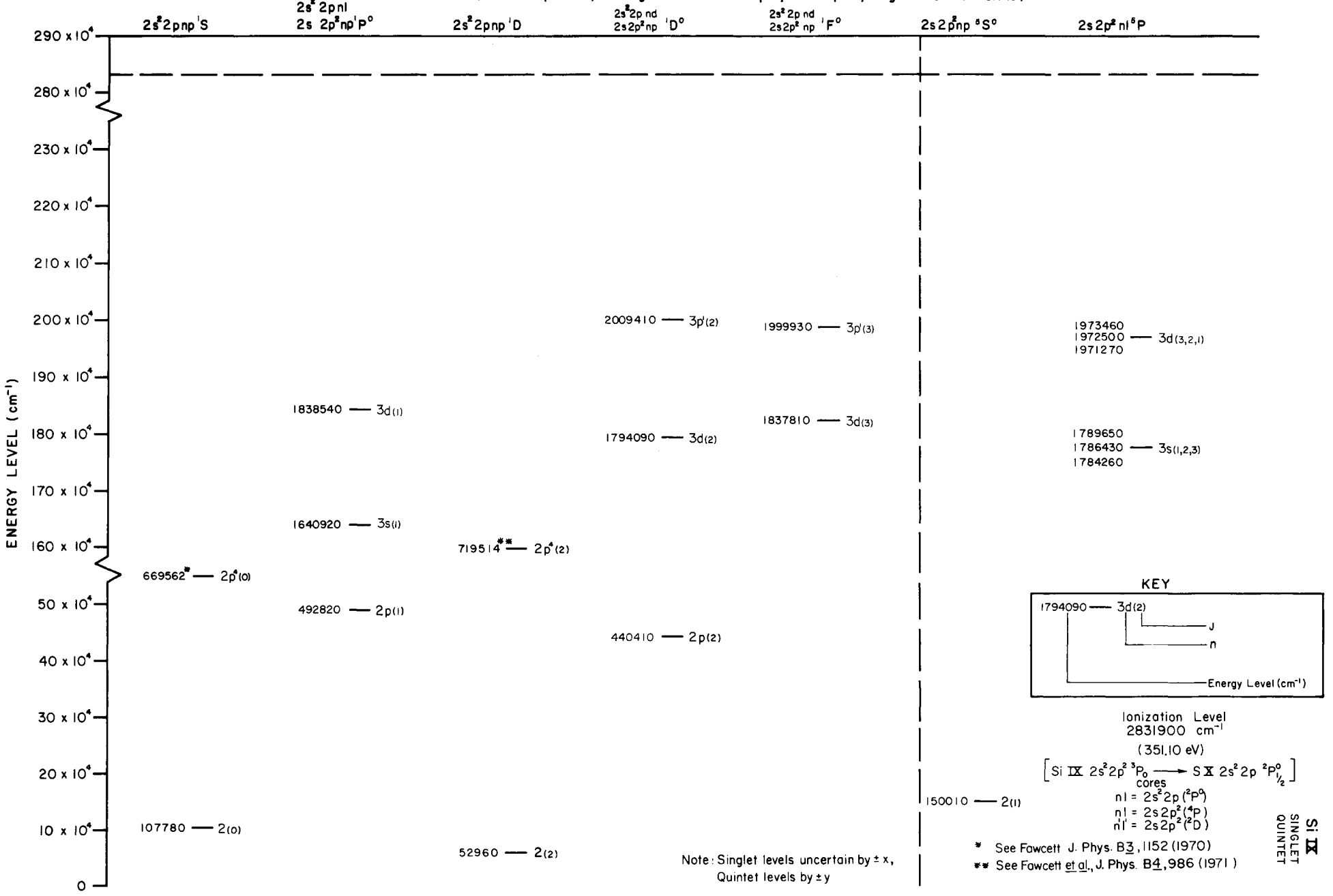


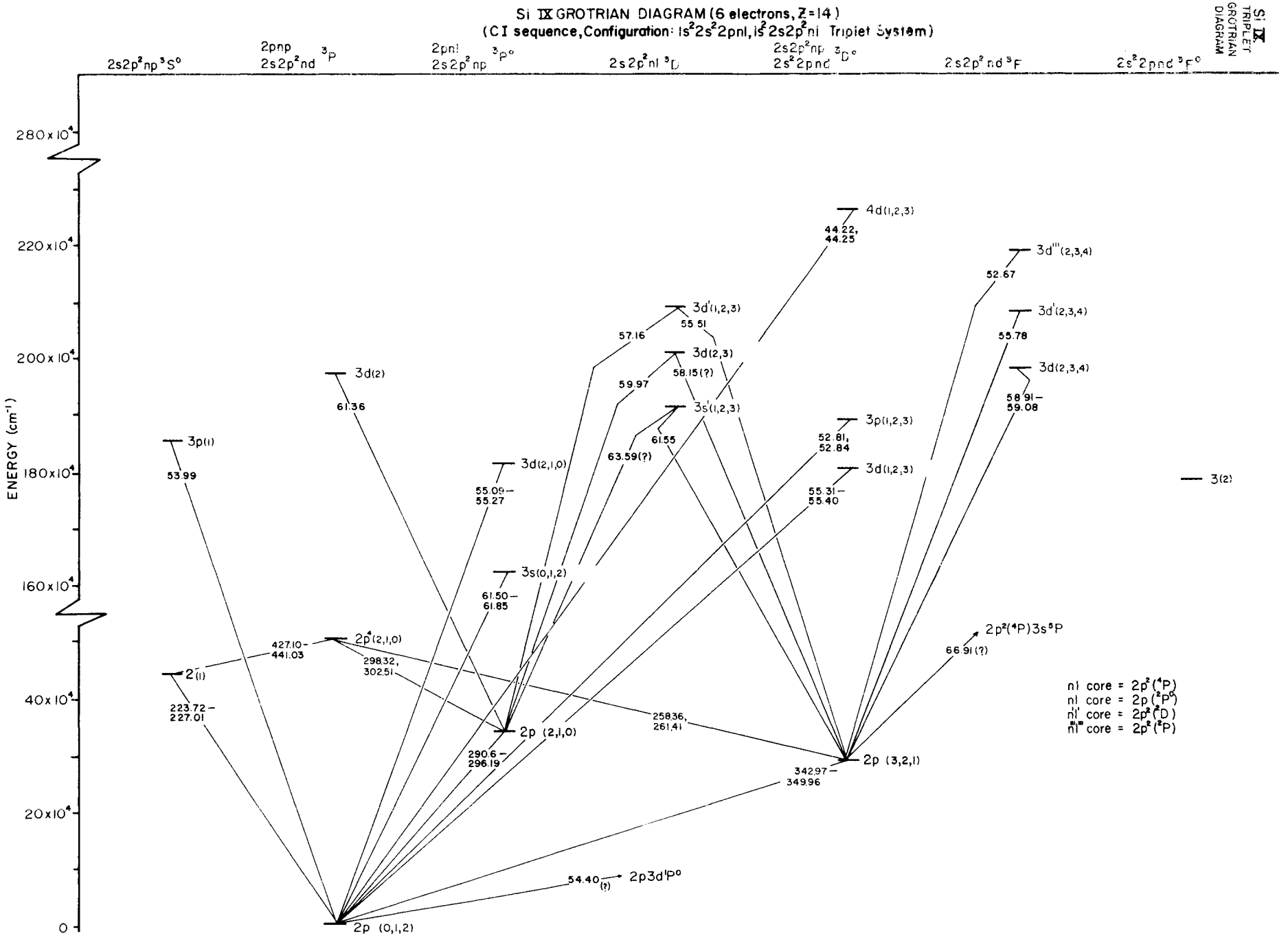
Si IX
SINGLET
QUINTET
GROTRIAN DIAGRAM



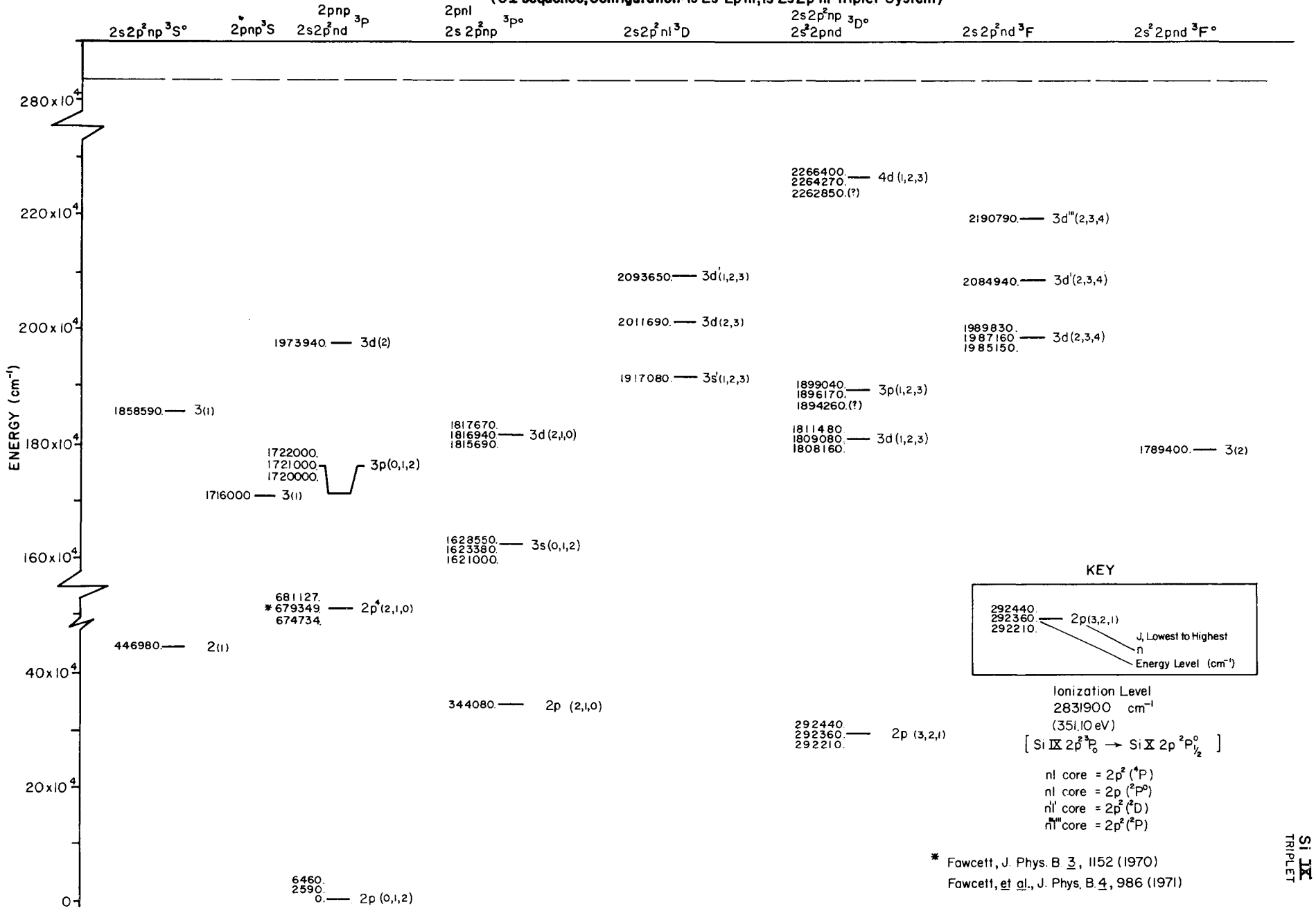
Si IX ENERGY LEVELS (6 electrons, Z=14)

(CI Sequence, Configuration: $1s^2\,2s^2\,2p\,nl$, $1s^2\,2s\,2p^2\,nl$, Singlet & Quintet Terms)



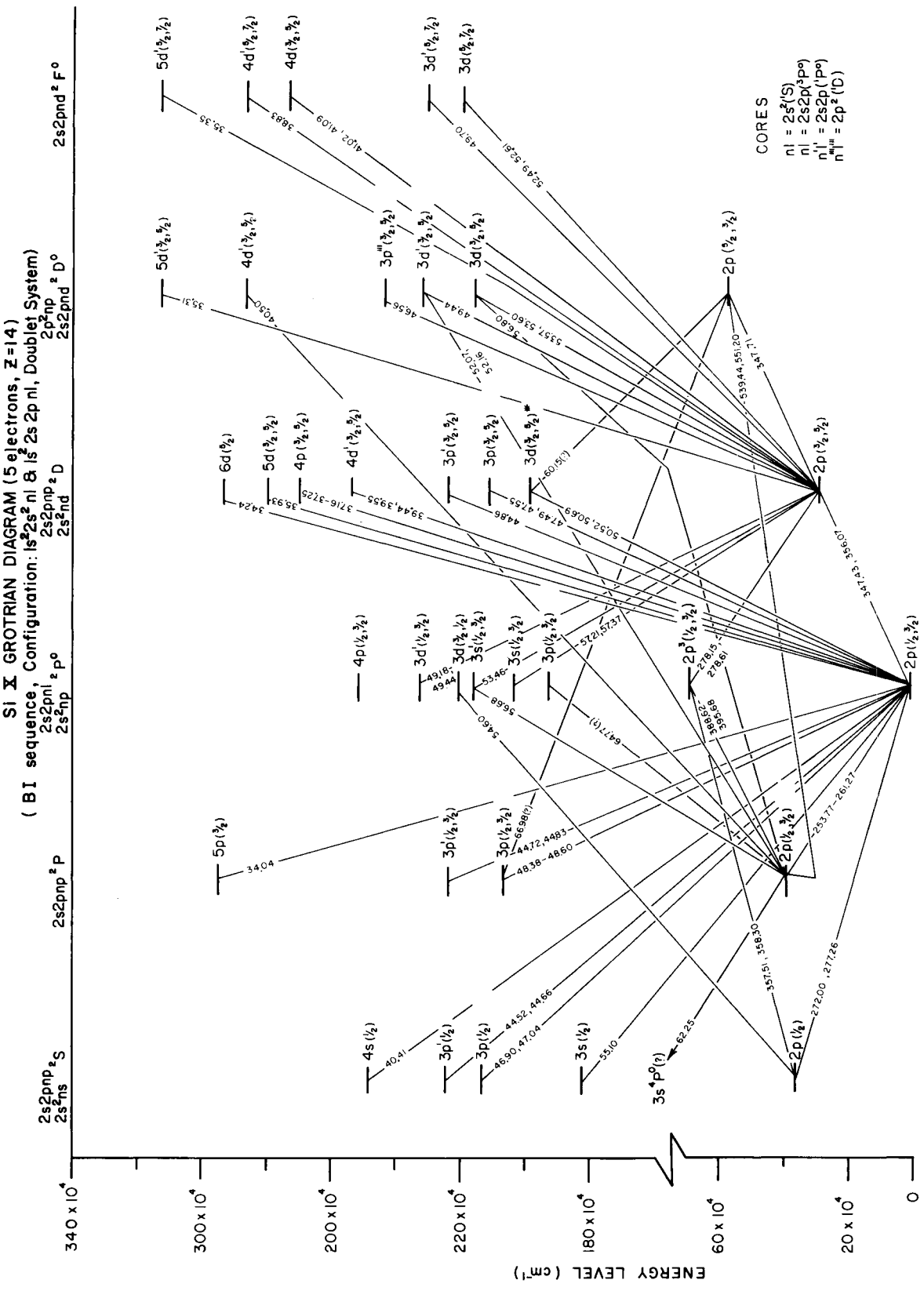

Si IX GROTRIAN DIAGRAM (6 electrons, Z=14)
(CI sequence, Configuration: 1s²2s²2pnl, 1s²2s2p²nl Triplet System)
2s2p²np ³S°
2pnp 2s2p²nd ³P
2pnl 2s2p²np ³P°
2s2p²nl ³D
2s2p²np 2s²2pnd ³D°
2s2p²nd ³F
2s²2pnd ³F°
ENERGY (cm⁻¹)
280x10⁴
220x10⁴
200x10⁴
180x10⁴
160x10⁴
40x10⁴
20x10⁴
0
3p(1)
53.99
2(1)
223.72–227.01
427.10–441.03
2p⁴(2,1,0)
298.32, 302.51
3d(2)
61.36
3d(2,1,0)
55.09–55.27
3s(0,1,2)
61.50–61.85
2p (2,1,0)
290.6–296.19
2p (0,1,2)
57.16
3d'(1,2,3)
55.51
59.97
3d(2,3)
58.15(?)
63.59(?)
3s'(1,2,3)
61.55
4d(1,2,3)
44.22, 44.25
52.81, 52.84
3p(1,2,3)
3d(1,2,3)
55.31–55.40
258.36, 261.41
2p (3,2,1)
342.97–349.96
54.40(?) 2p3d¹P°
66.91(?) 2p²(⁴P)3s⁵P
52.67
3d'''(2,3,4)
55.78
3d'(2,3,4)
58.91–59.08
3d(2,3,4)
3(2)
nl core = 2p²(⁴P)
nl core = 2p(²P°)
nl' core = 2p²(²D)
nl'' core = 2p²(²P)

Si IX ENERGY LEVELS (6 electrons, Z=14)
(C I sequence, Configuration: $1s^2 2s^2 2p\,nl$, $1s^2 2s 2p^2\,nl$ Triplet System)



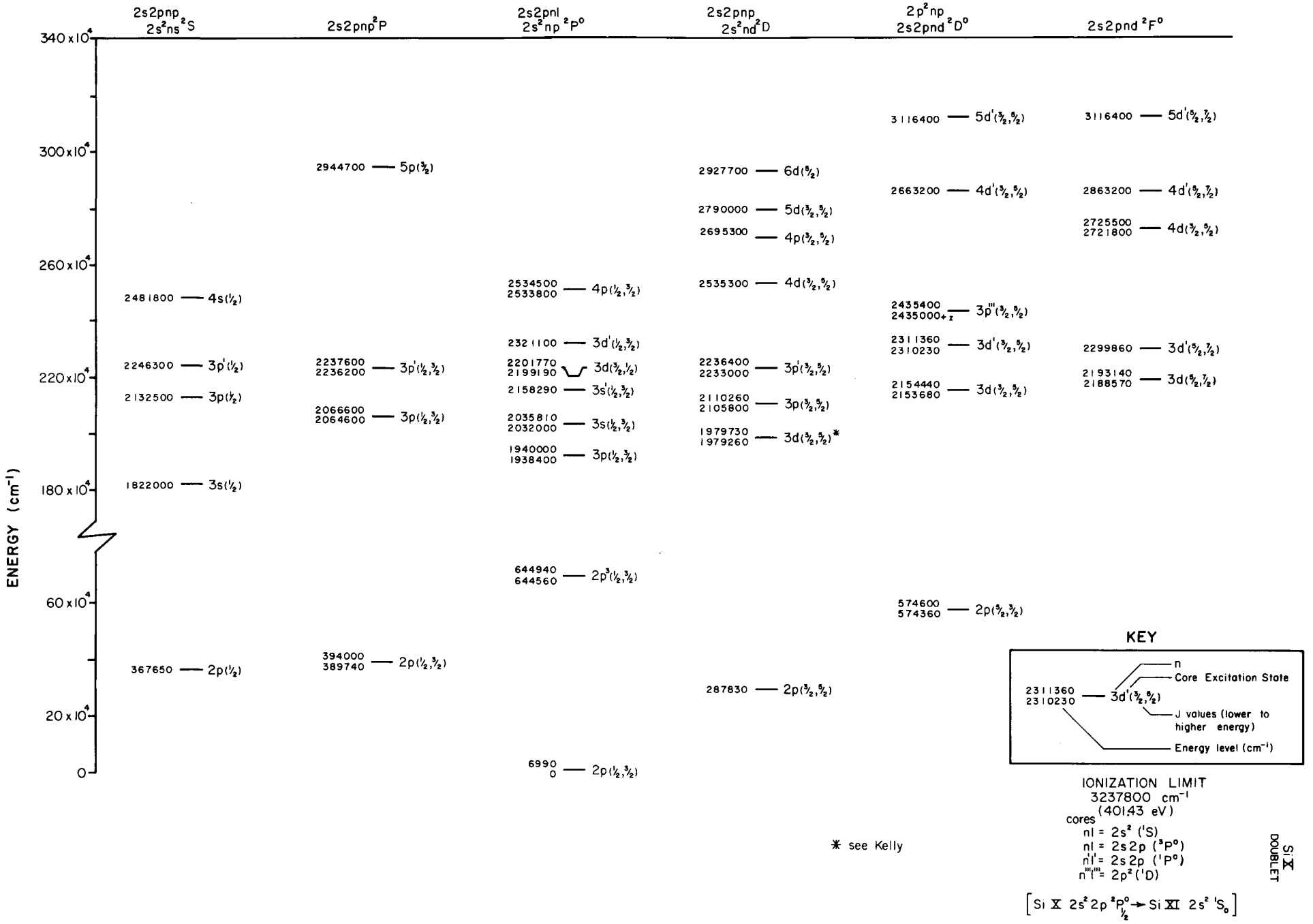
* Fawcett, J. Phys. B 3, 1152 (1970)
Fawcett, et al., J. Phys. B. 4, 986 (1971)

Si X
DOUBLET
GROTRIAN
DIAGRAM

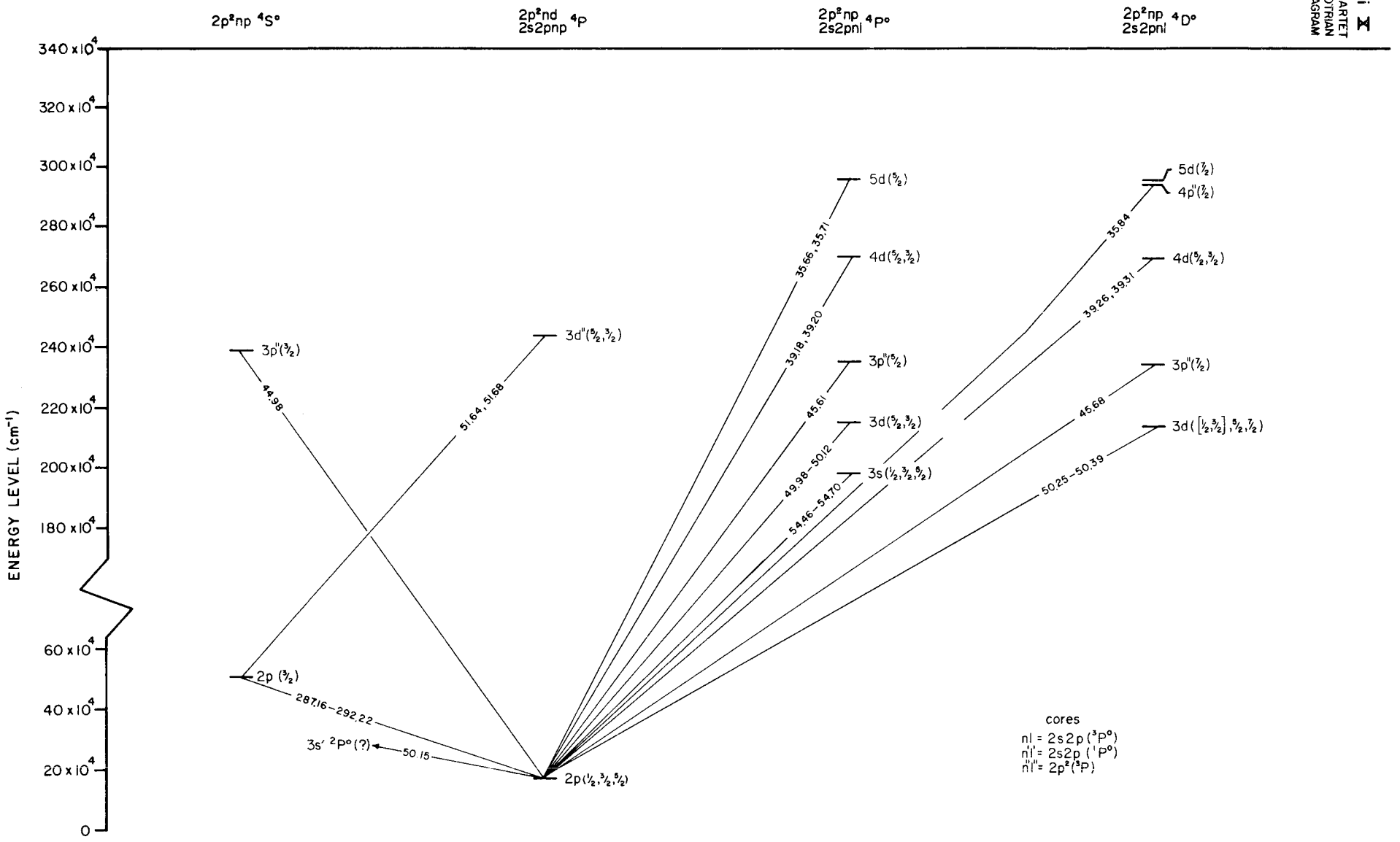


Si X ENERGY LEVELS (5 electrons, Z = 14)

(B I Sequence, Configuration : $1s^2 2s^2 nl$ & $1s^2 2s2pnl$, Doublet System)

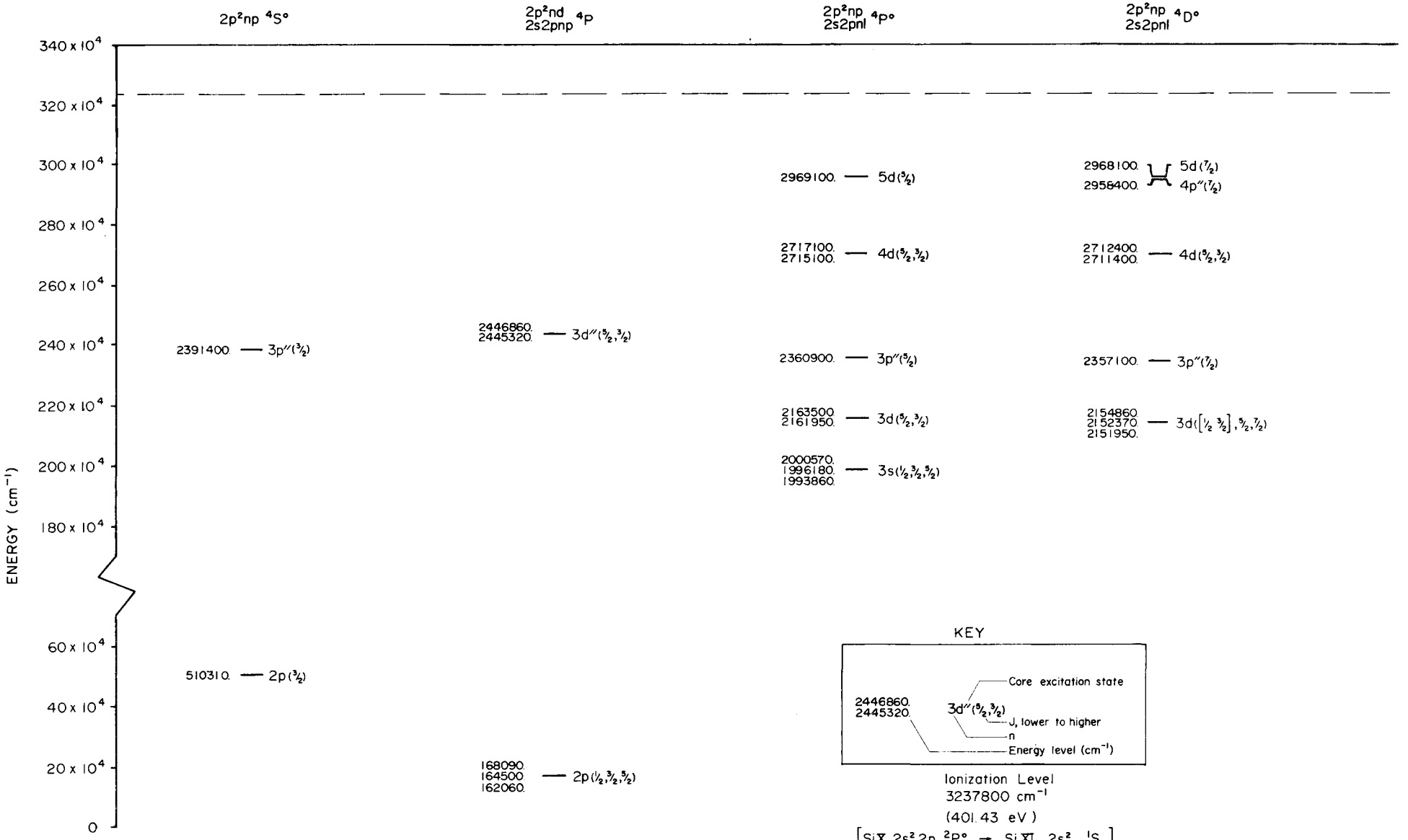


Si X GROTRIAN DIAGRAM (5 electrons, Z=14)
(B I Sequence, Configuration: $1s^2 2s2pnl$, $1s^2 2p^2 nl$, Quartet system)



Si X ENERGY LEVELS (5 electrons, Z = 14)

(B I Sequence, Configuration: $1s^2 2s2pnl$, $1s^2 2p^2 nl$, Quartet system)

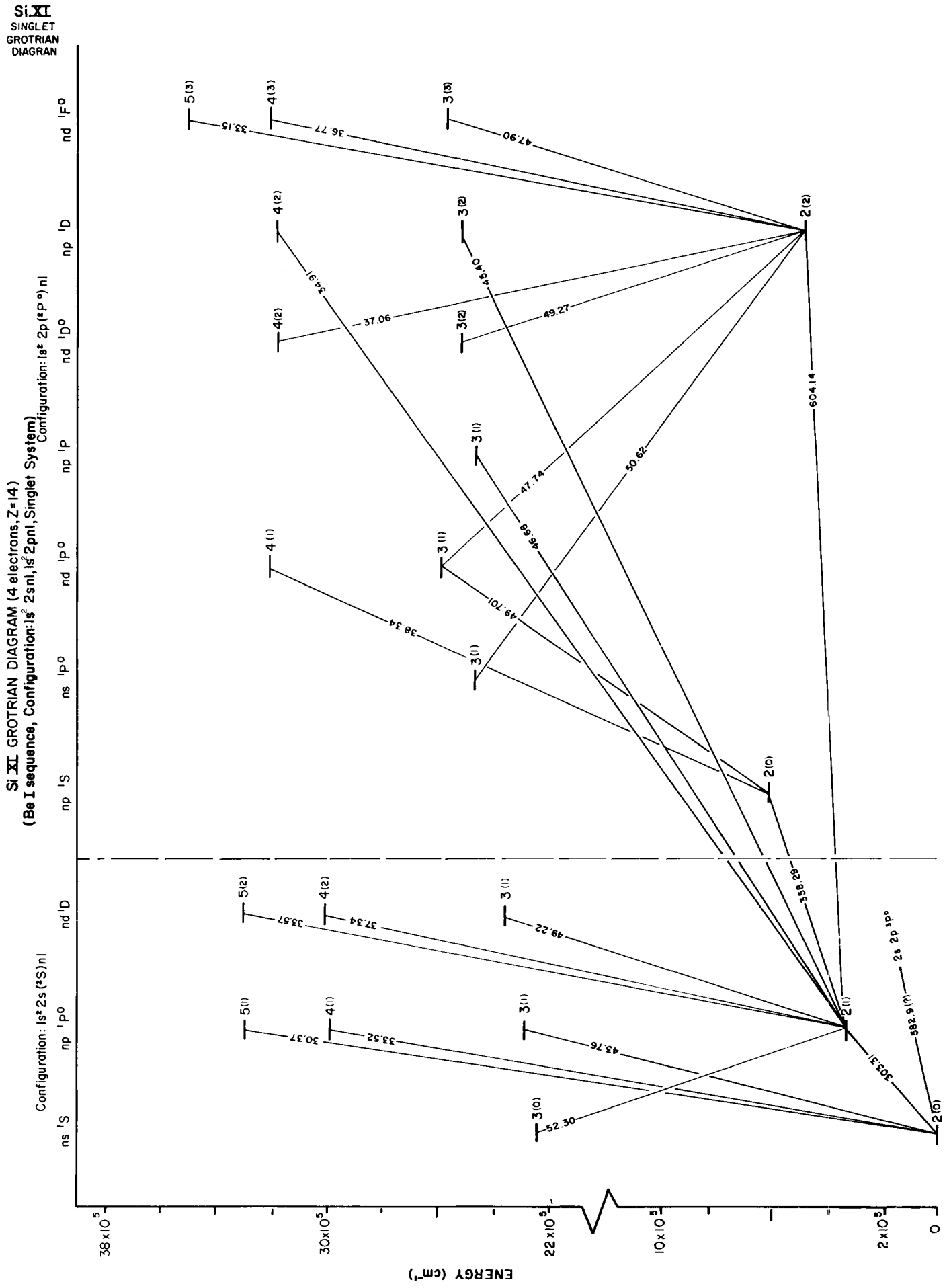


KEY

Ionization Level
3237800 cm^{-1}
(401.43 eV)
$[Si X\ 2s^2 2p\ ^2P^o_{1/2} \rightarrow Si XI\ 2s^2\ ^1S_0]$

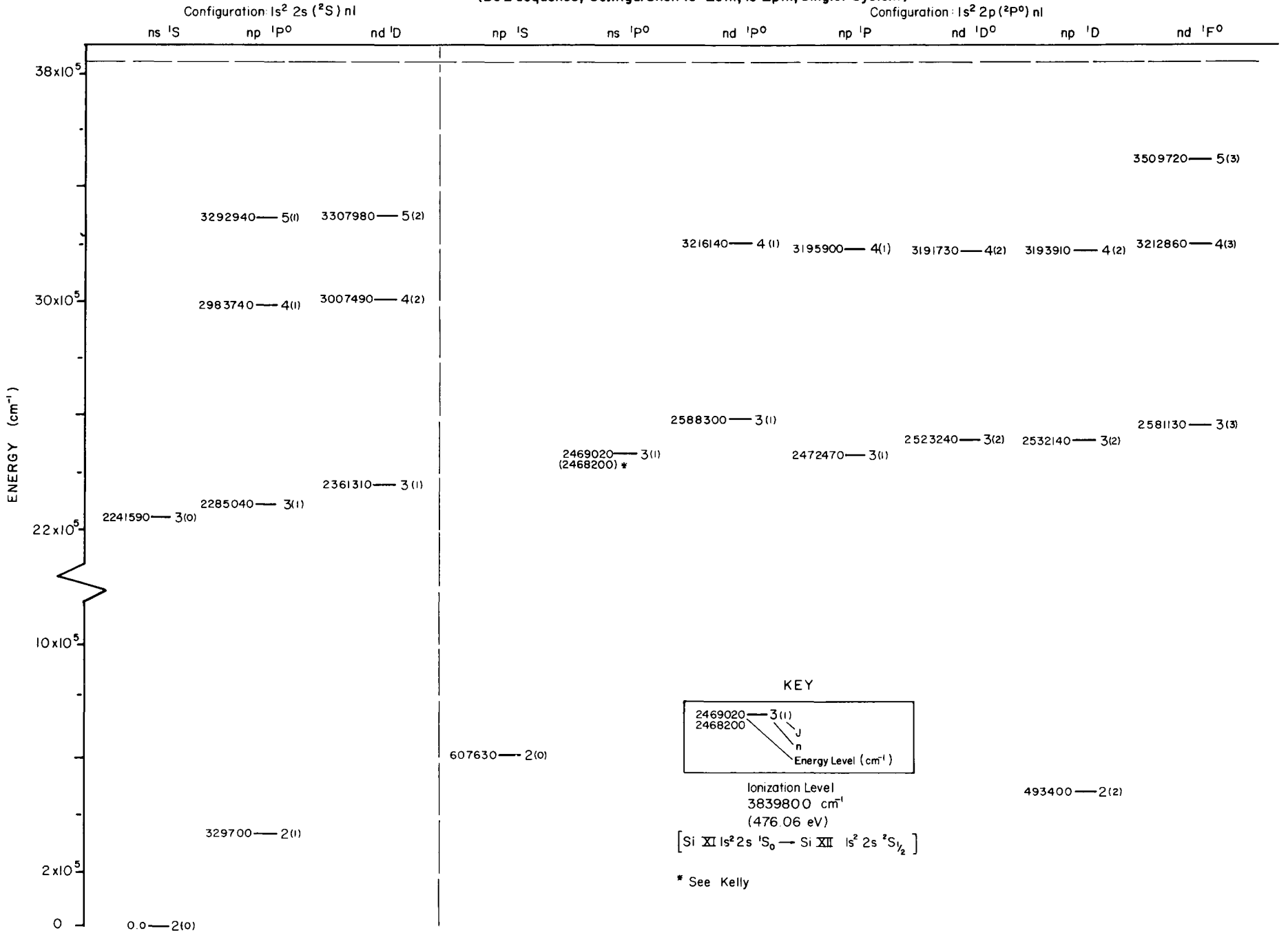
Cores
$nl = 2s2p(^3P^o)$
$n''l'' = 2p^2\ (^3P)$

NOTE: Uncertainty in position, ±x

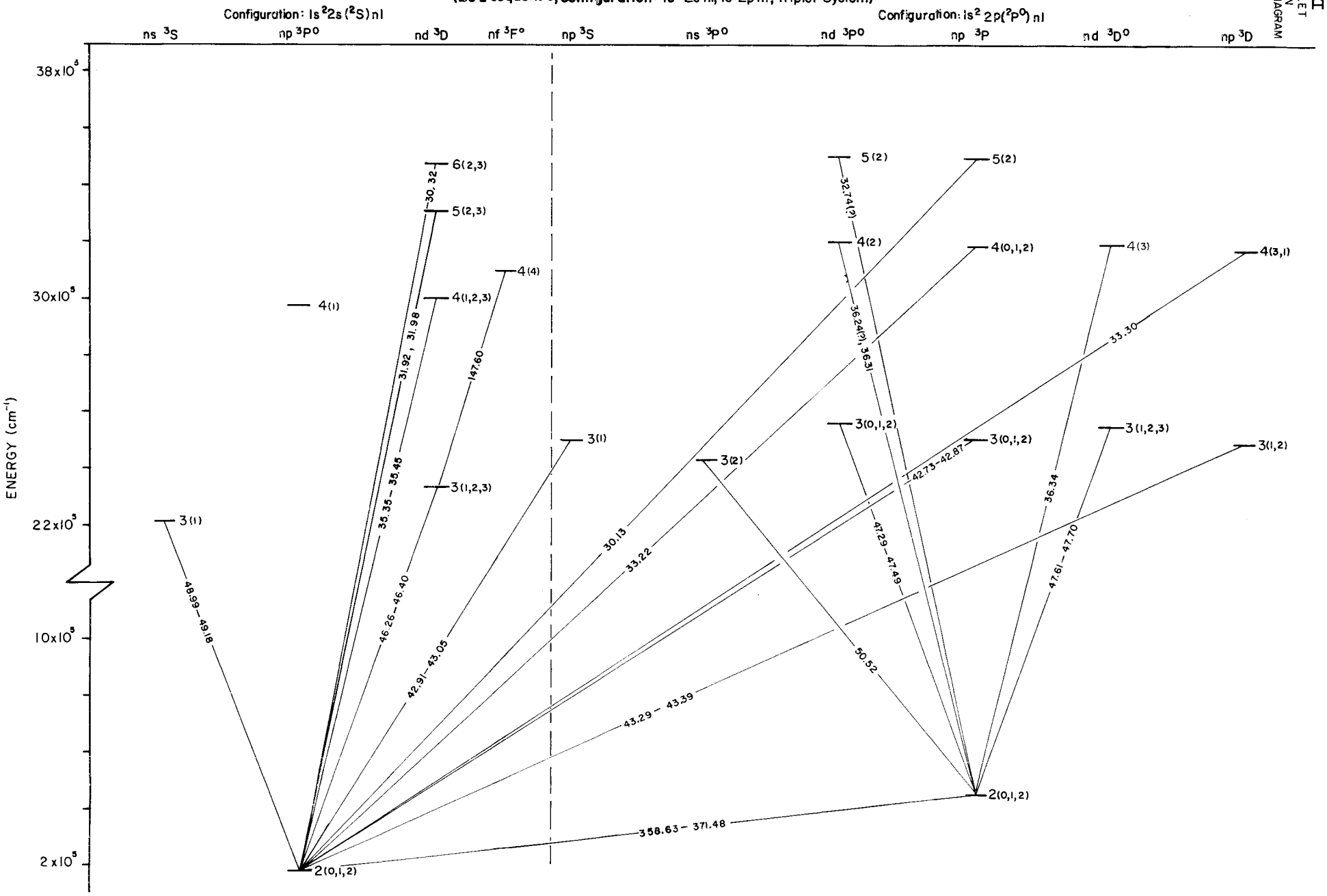

Si XI
SINGLET
GROTRIAN
DIAGRAN
Si XI GROTRIAN DIAGRAM (4 electrons, Z=14)
(Be I sequence, Configuration: 1s² 2snl, 1s² 2pnl, Singlet System)
Configuration: 1s² 2s (²S) nl
Configuration: 1s² 2p (²P°) nl
ns ¹S
np ¹P°
nd ¹D
ns ¹S
np ¹S
nd ¹P°
np ¹P
nd ¹D°
np ¹D
nd ¹F°
ENERGY (cm⁻¹)
38 x 10⁵
30 x 10⁵
22 x 10⁵
10 x 10⁵
2 x 10⁵
0
5(1)
4(1)
3(1)
3(0)
5(2)
4(2)
3(1)
4(1)
3(1)
3(1)
4(2)
4(2)
3(2)
3(2)
5(3)
4(3)
3(3)
2(2)
2(1)
2(0)
2(0)
30.37
33.52
43.76
52.30
33.57
37.34
49.22
38.34
49.70
47.74
48.98
37.06
34.91
45.40
49.27
33.15
36.77
47.90
50.62
604.14
303.31
358.28
582.9(?)
2s 2p ³P°

Si XI ENERGY LEVELS (4 electrons, Z = 14)

(Be I sequence, Configuration: $1s^2 2snl$, $1s^2 2pnl$, Singlet System)

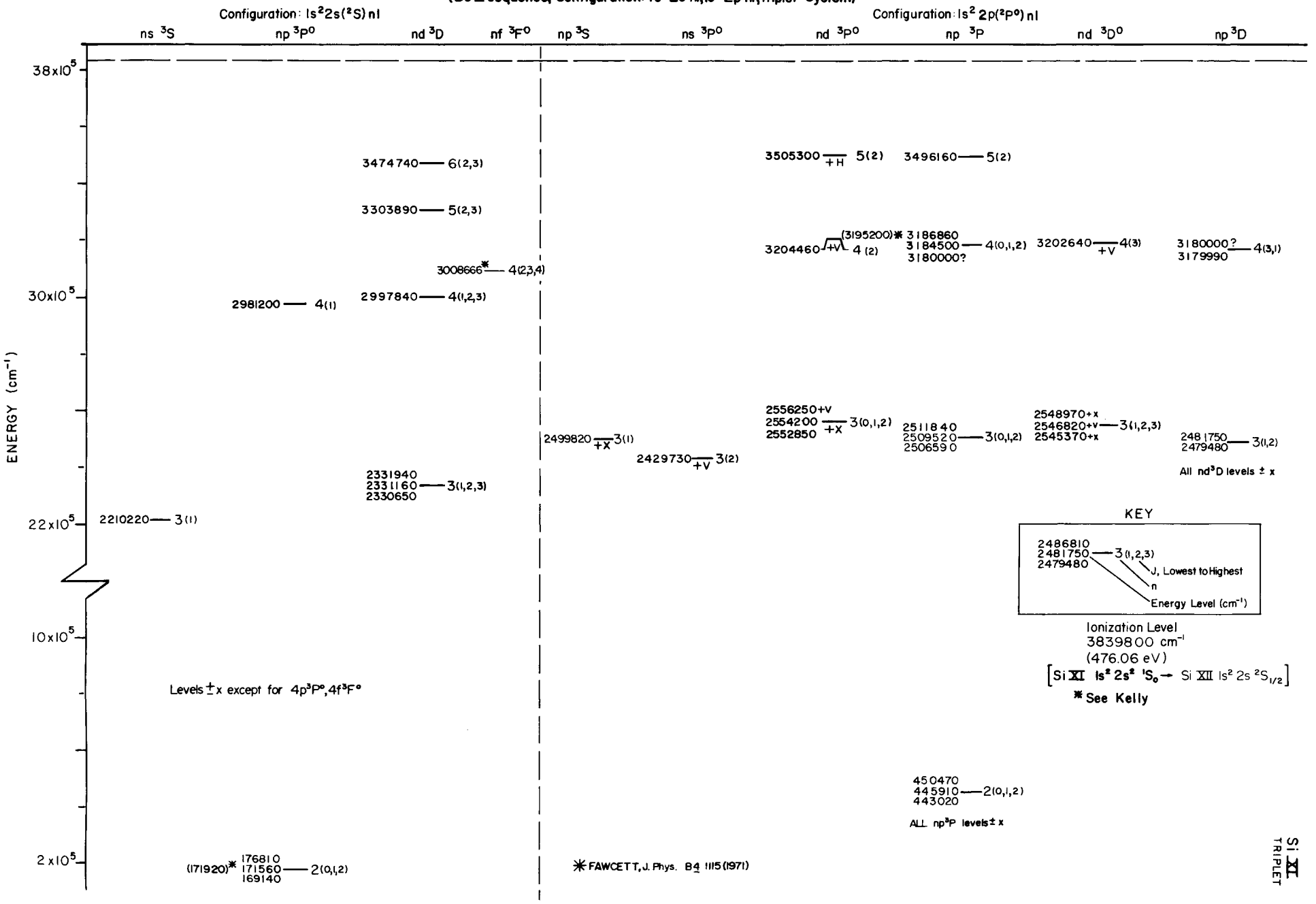


Si XI GROTRIAN DIAGRAM (4 electrons, Z = 14)
(Be I sequence, Configuration: $1s^2 2s\,nl$, $1s^2 2p\,nl$, Triplet System)

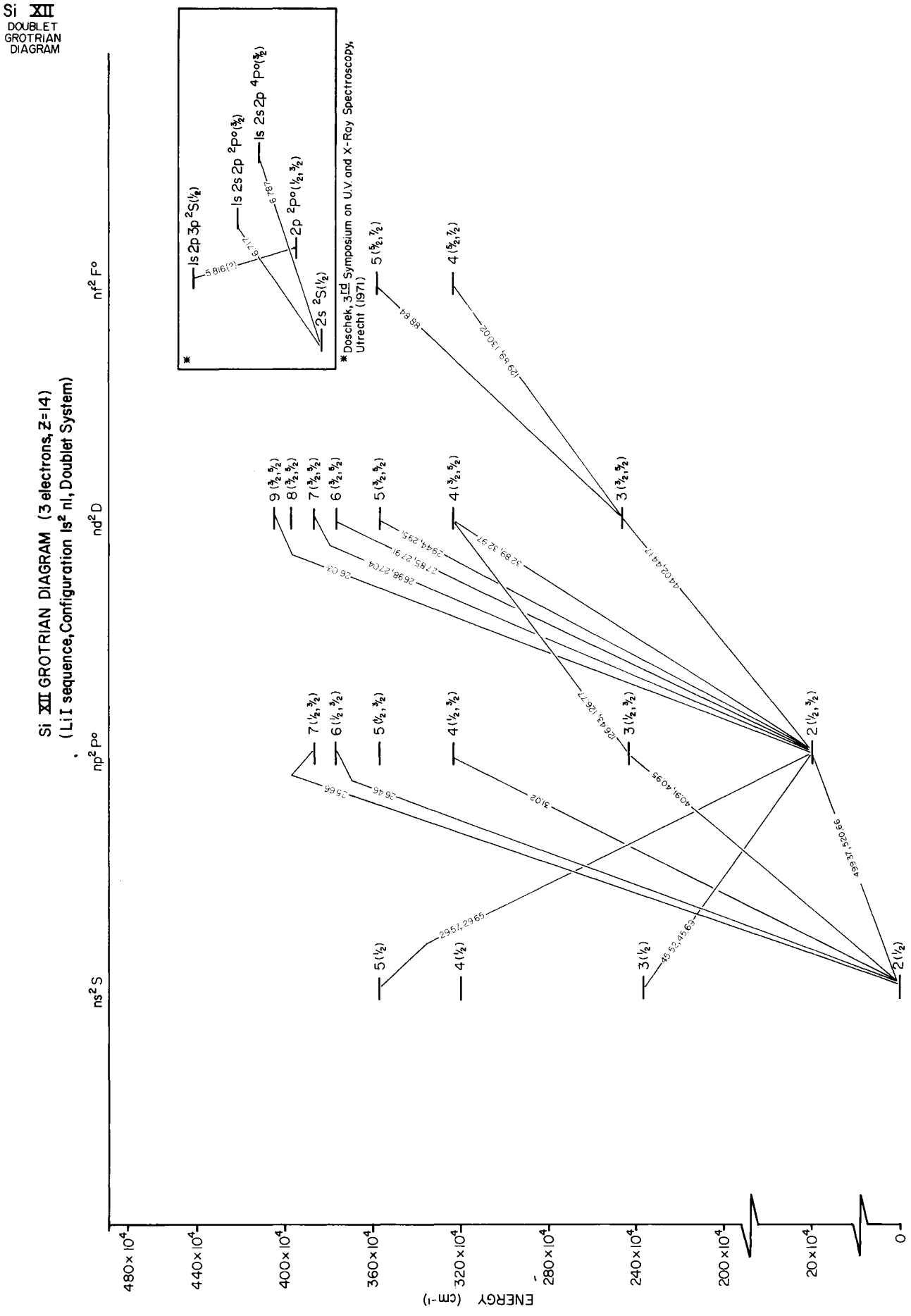


Si XI ENERGY LEVELS (4 electrons, Z=14)

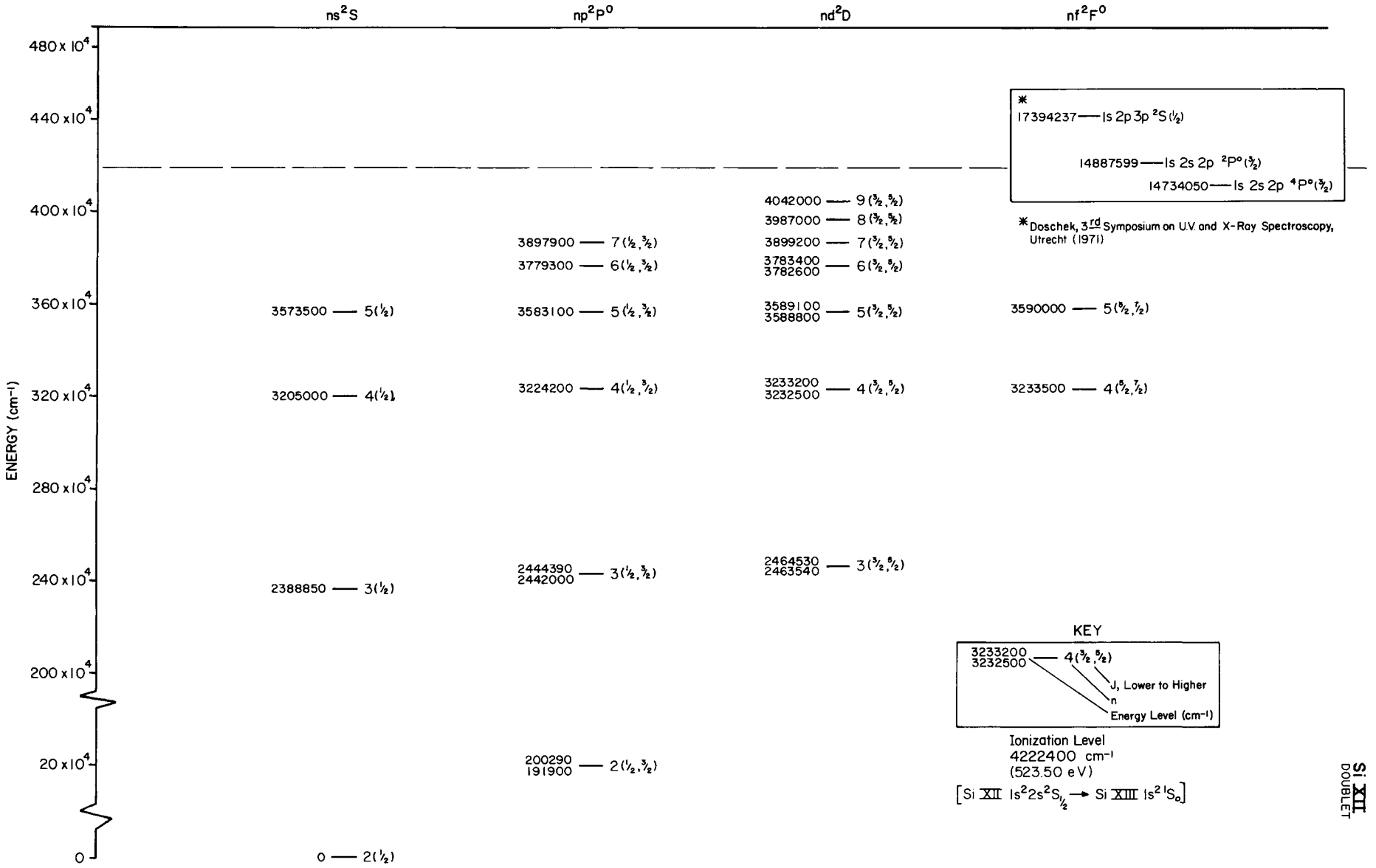
(Be I sequence, Configuration: $1s^2 2s\,nl$, $1s^2 2p\,nl$, Triplet System)



Si XII
DOUBLET
GROTRIAN
DIAGRAM



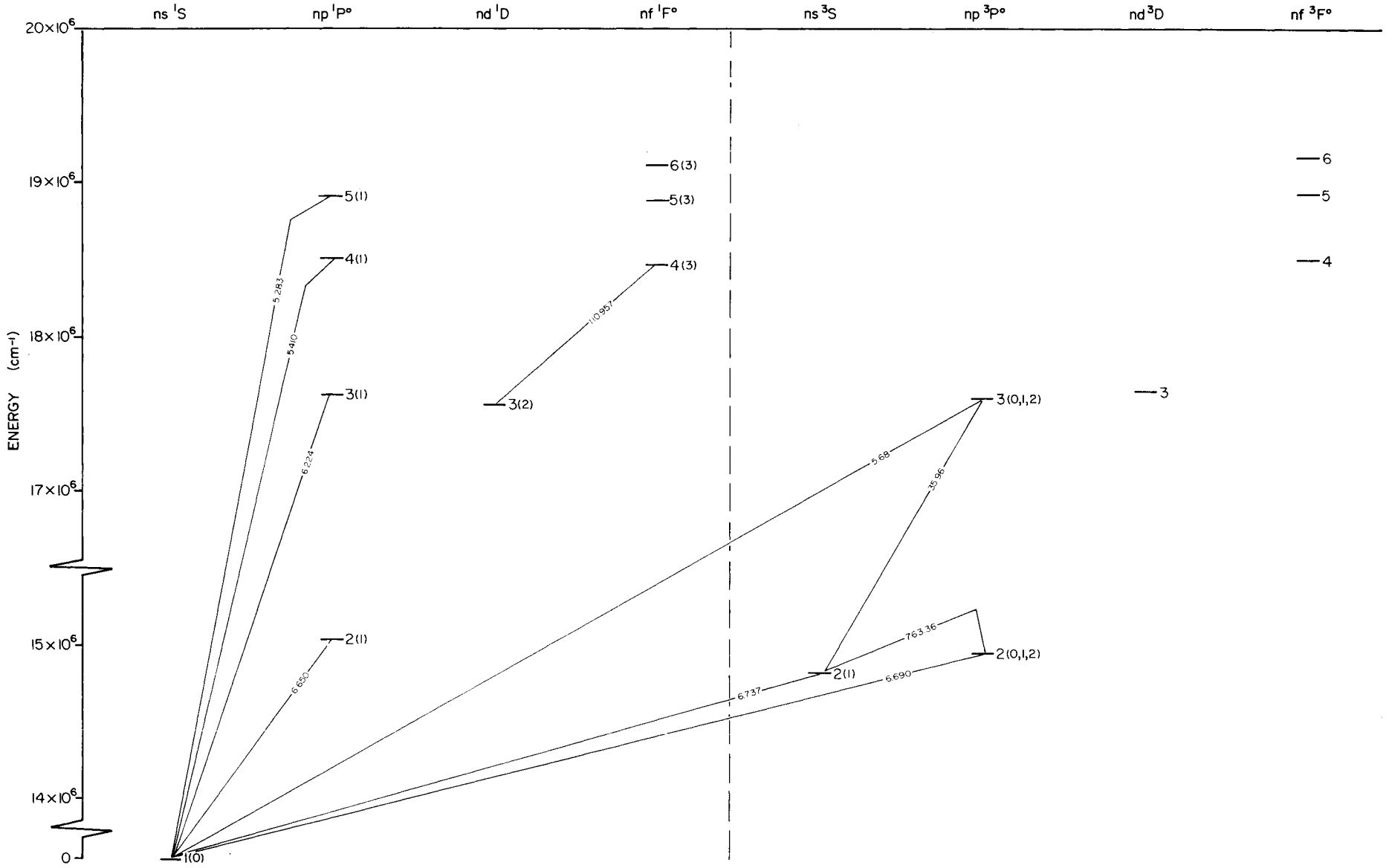
Si XII LEVELS (3 electrons, Z=14)
(Li I sequence, Configuration: $1s^2nl$, Doublet System)



* Doschek, 3rd Symposium on U.V. and X-Ray Spectroscopy, Utrecht (1971)

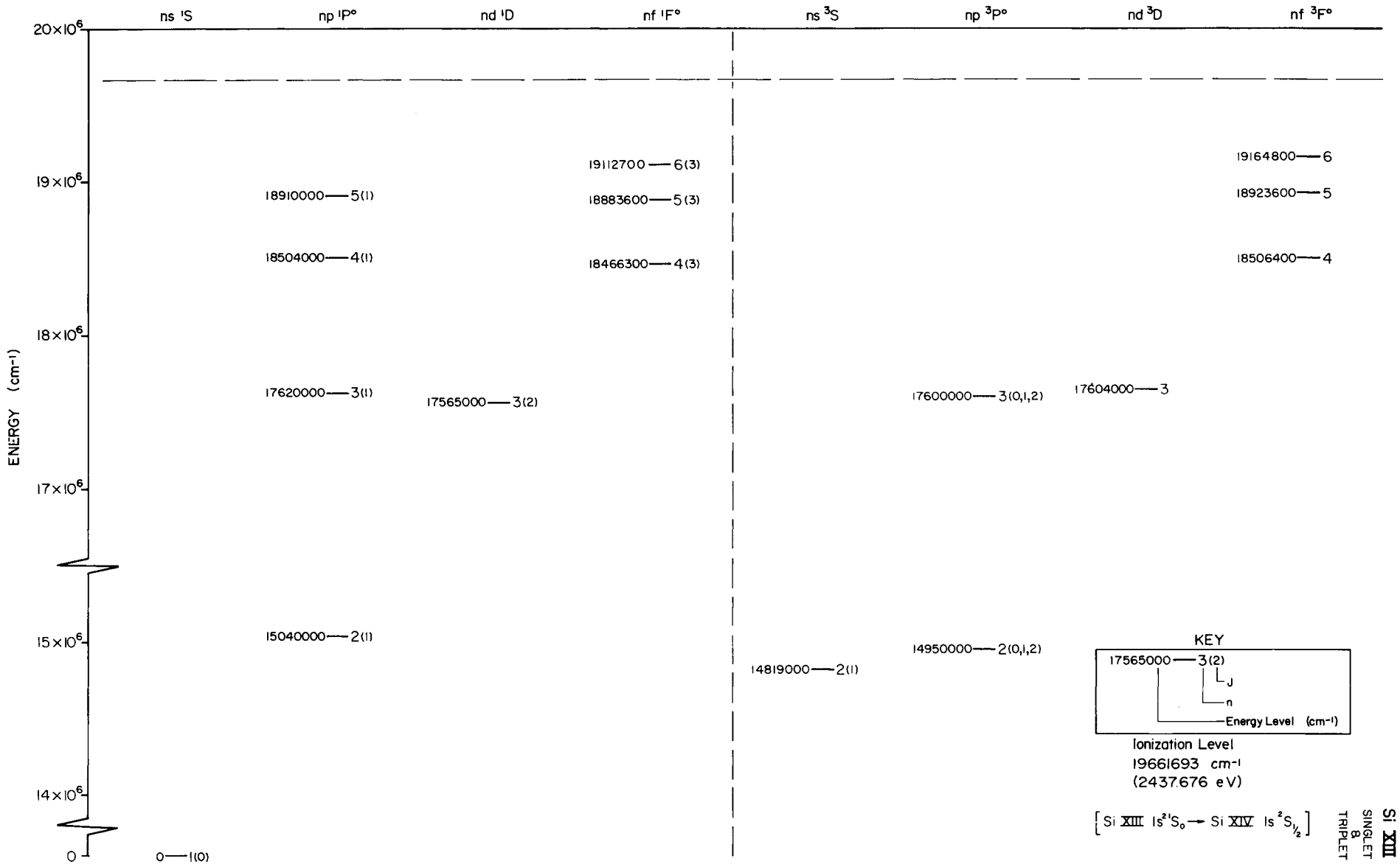
Si XIII GROTRIAN DIAGRAM (2 electrons, Z=14)

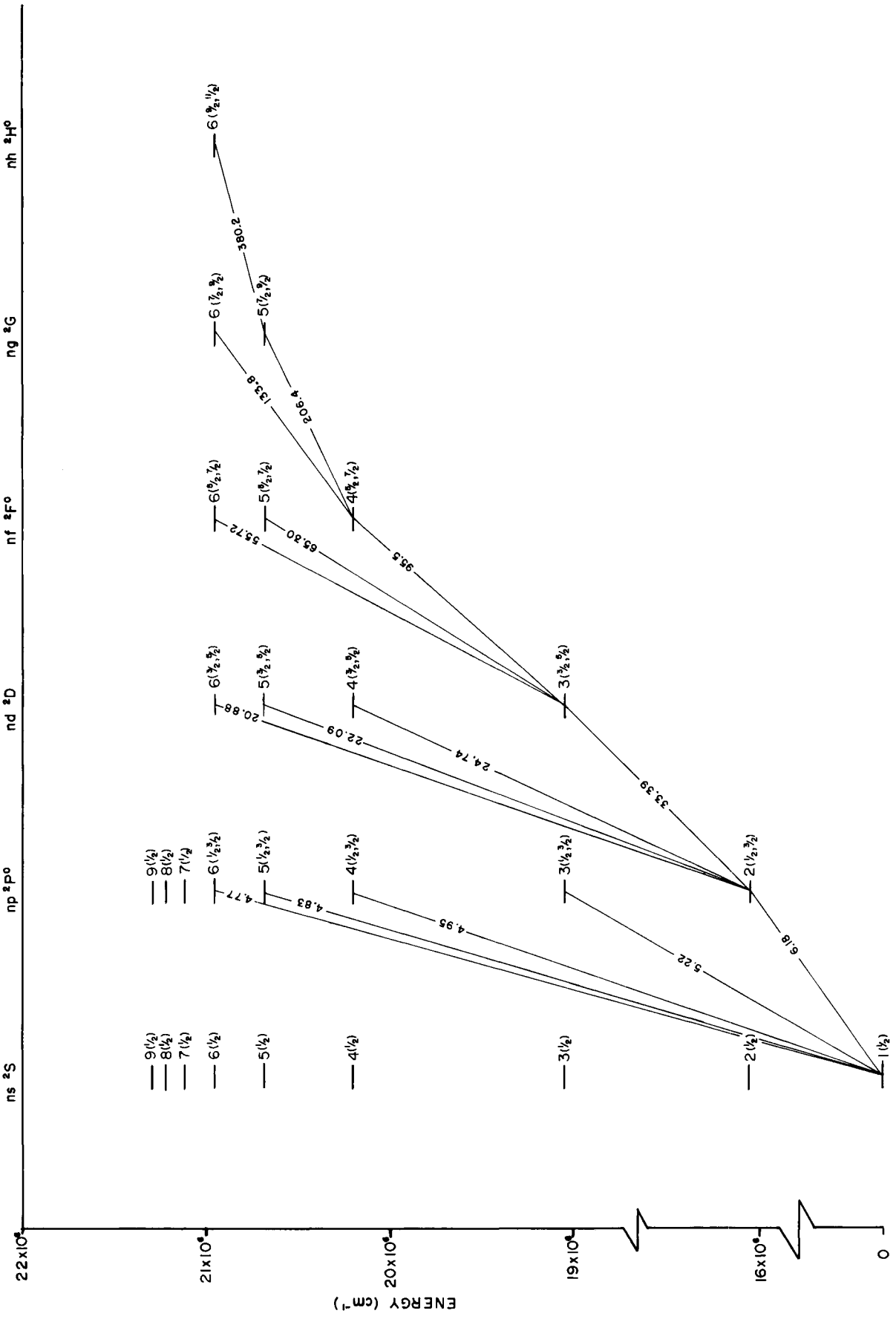
(He I sequence, Configuration: $1s^2$, Singlet & Triplet System)



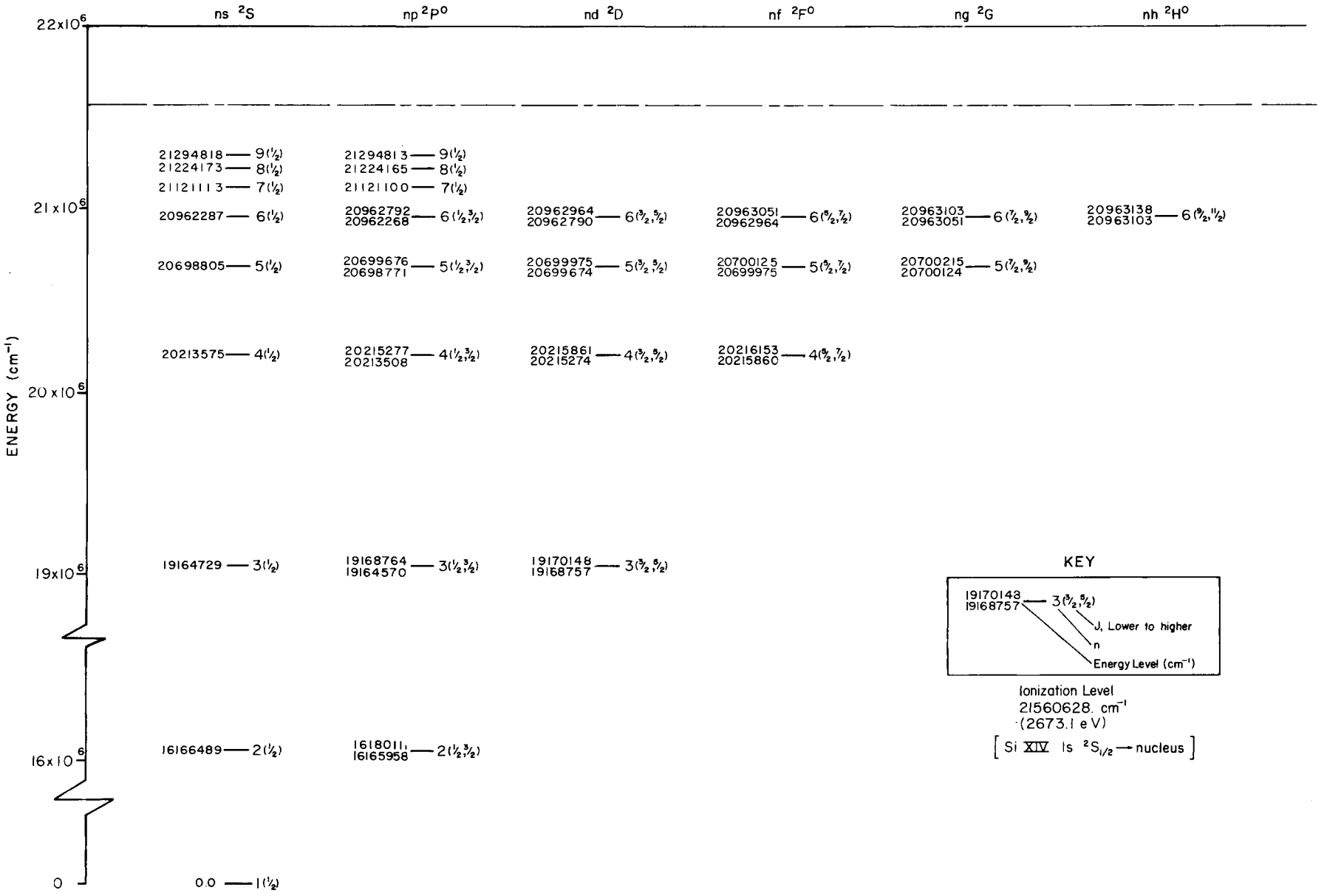
Si XIII ENERGY LEVELS (2 electrons, Z=14)

(He I sequence, Configuration: $1s^2$, Singlet & Triplet System)




Si XIV GROTRIAN DIAGRAM (1 electron, Z=14)
(HI sequence, Configuration: nl, Doublet System)
ns ²S
np ²P°
nd ²D
nf ²F°
ng ²G
nh ²H°
ENERGY (cm⁻¹)
22x10⁶
21x10⁶
20x10⁶
19x10⁶
16x10⁶
0
4.77
4.83
4.95
5.22
6.18
20.88
22.09
24.74
33.39
55.72
65.30
95.5
133.8
206.4
380.2

Si XIV ENERGY LEVELS (1 electron, Z=14)
(HI sequence, Configuration: nl, Doublet System)



Si I $Z = 14$ 14 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line tables for observed lines of forbidden transitions.

D.L. Lambert and B. Warner, Mon. Not. R. Astr. Soc. **138**, 213 (1968).

Authors give line tables for lines observed in the solar spectrum.

D.L. Lambert and B. Warner, Mon. Not. R. Astr. Soc. **139**, 35 (1968).

Authors give line tables of absorption lines predicted and of those affirmed in the solar spectrum in the range 25 578–2935 Å. Energy level tables are included.

U. Litzén, Ark. Fys. **31**, 453 (1966).

Author gives line and energy level tables for lines observed by Litzén, and Radziemski and Andrew.

Wavelength corrections: On the Excited–Excited Triplet–Quintet diagram, for 3p 4p ^{3}S–3s 3p^3 ^{3}P° 13693.85–13711.36, please read 13613.94–13711.36.
The following lines were omitted from the drawings:

3p^2 ^{1}D–3s 3p^3 ^{3}D°	2563.68, 2564.82
3p^2 ^{3}P–3s 3p^3 ^{3}S°	1255.28–1258.80
–3s 3p^3 ^{3}P°	1763.66–1770.92
–3s 3p^3 ^{3}D°	2207.98–2218.91
–3s 3p^3 ^{5}S°	3006.74–3020.00

Correction to key: In brackets ⧫a,b⧫, a denotes j of the core and b denotes electron j.

Si II $Z = 14$ 13 electrons

D.L. Lambert and B. Warner, Mon. Not. R. Astr. Soc. **138**, 213 (1968).

Authors give line tables for lines observed in the solar spectrum.

The following lines were omitted from the drawings:

3p^3 ^{2}D° – 4f ^{4}F	4908.18
3d ^{2}F° – 4f ^{4}G	3977.46, 4016.22

Si III $Z = 14$ 12 electrons

Please see the general references.

The intermediate-coupling designations are taken from Moore, *Atomic Energy Levels*, N.B.S. Circular 467, Vol. I (1949).

Si IV $Z = 14$ 11 electrons

Please see the general references.

Si V $Z = 14$ 10 electrons

Please see the general references.

The intermediate-coupling designations are taken from Moore, *Atomic Energy Levels*, N.B.S. Circular 467, Vol. I (1949).

Si VI $Z = 14$ 9 electrons

Please see the general references.

Si VII $Z = 14$ 8 electrons

B. Edlén, Handbuch der Phys. **27**, 172 (1964).

Author gives corrections to values in C.E. Moore's *Atomic Energy Levels.*

Si VIII $Z = 14$ 7 electrons

Please see the general references.

Si IX $Z = 14$ 6 electrons

Please see the general references.

Si X $Z = 14$ 5 electrons

L.J. Shamey, J. Opt. Soc. Amer. **61**, 942 (1971).

Author gives a line table and a table of calculated energy levels.

Si XI $Z = 14$ 4 electrons

Please see the general references.

Si XII $Z = 14$ 3 electrons

Please see the general references.

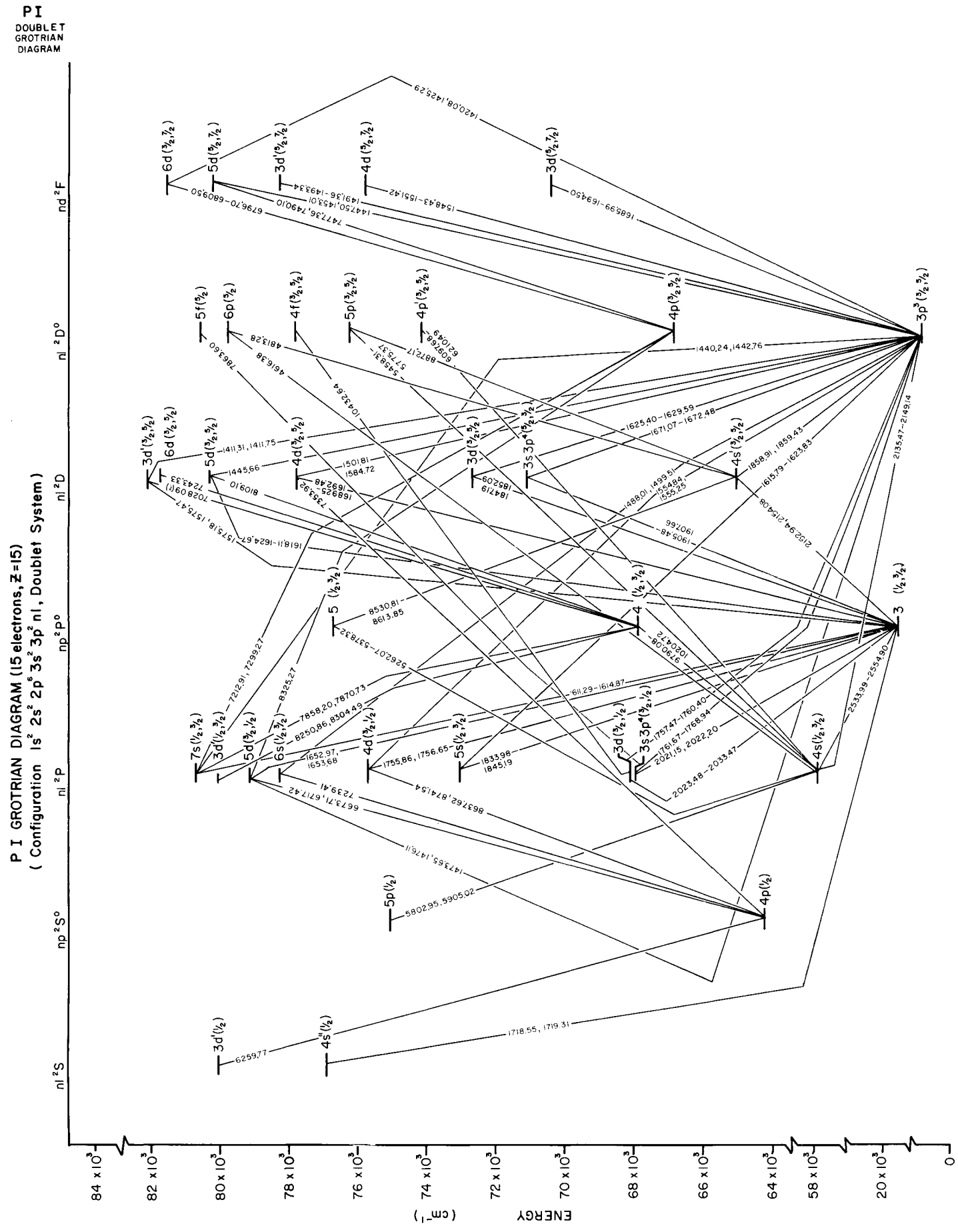
Si XIII $Z = 14$ 2 electrons

Please see the general references.

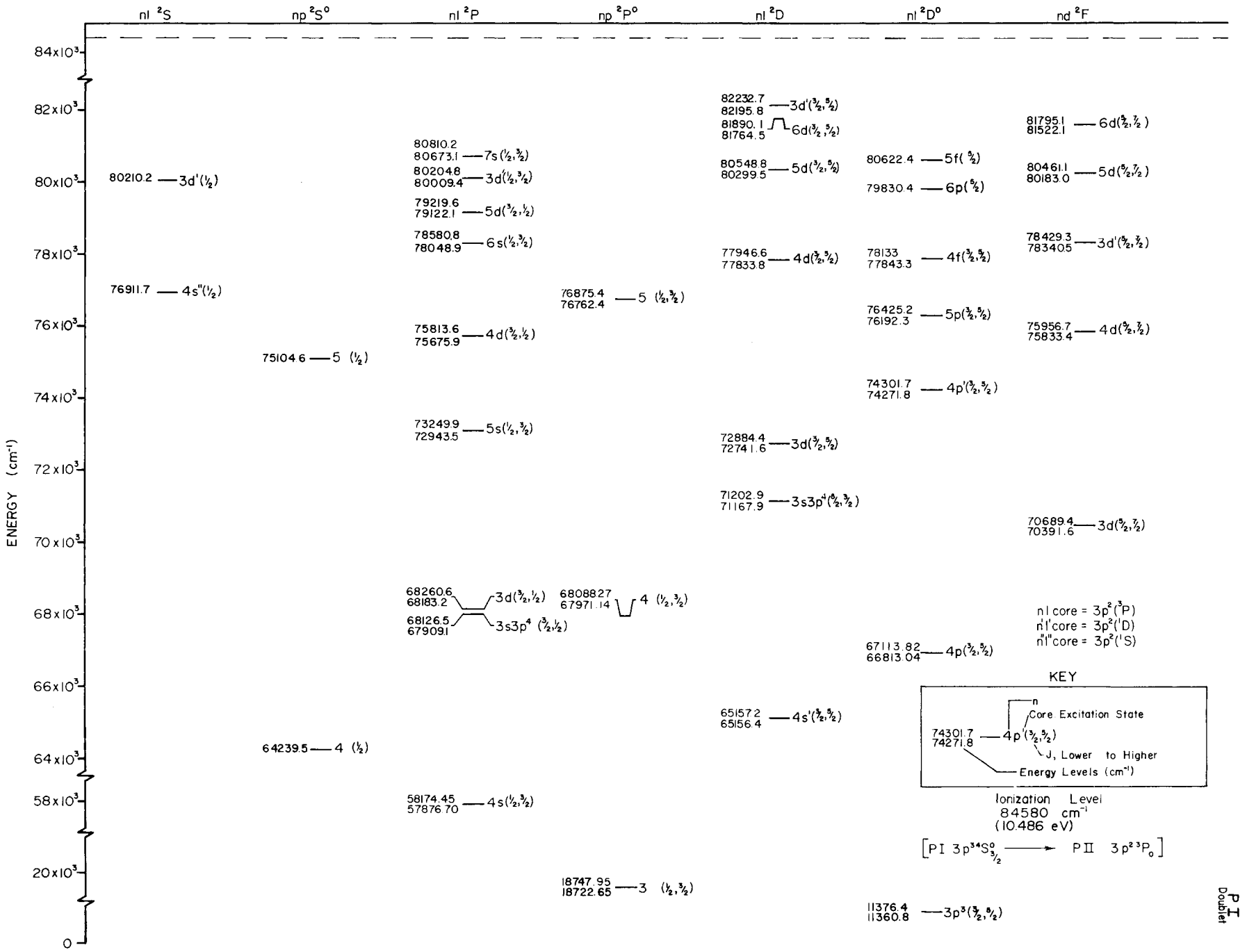
Si XIV $Z = 14$ 1 electron

Please see the general references.

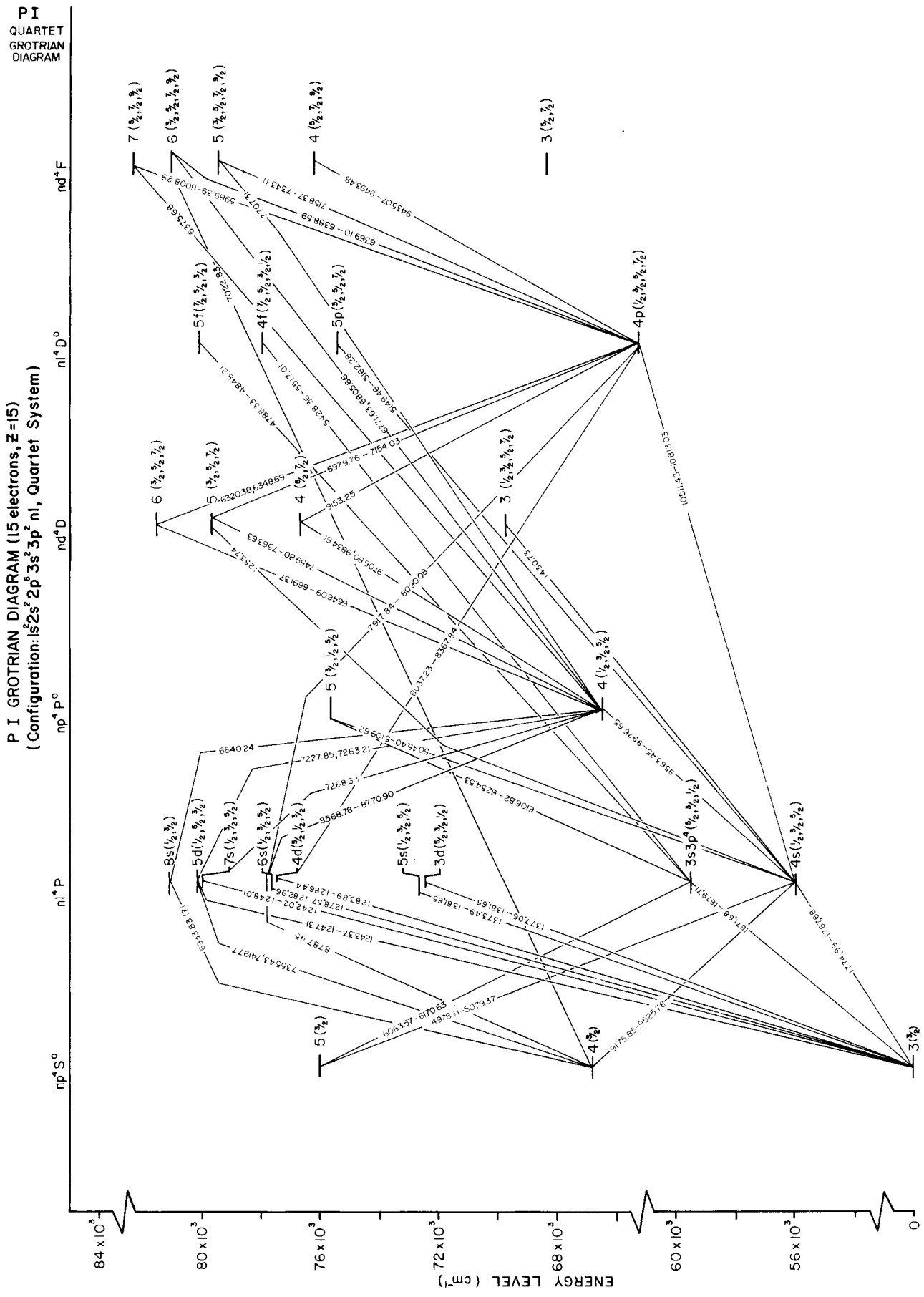
Phosphorus (P)


PI
DOUBLET
GROTRIAN
DIAGRAM
P I GROTRIAN DIAGRAM (15 electrons, Z=15)
(Configuration 1s² 2s² 2p⁶ 3s² 3p² nl , Doublet System)
nl ²S
np ²S°
nl ²P
np ²P°
nl ²D
nl ²D°
nd ²F
ENERGY (cm⁻¹)
84 x10³
82 x10³
80 x10³
78 x10³
76 x10³
74 x10³
72 x10³
70 x10³
68 x10³
66 x10³
64 x10³
58 x10³
20 x10³
0

P I ENERGY LEVELS (15 electrons, Z=15)
(Configuration; $1s^2 2s^2 2p^6 3s^2 3p^2$ nl, Doublet System)

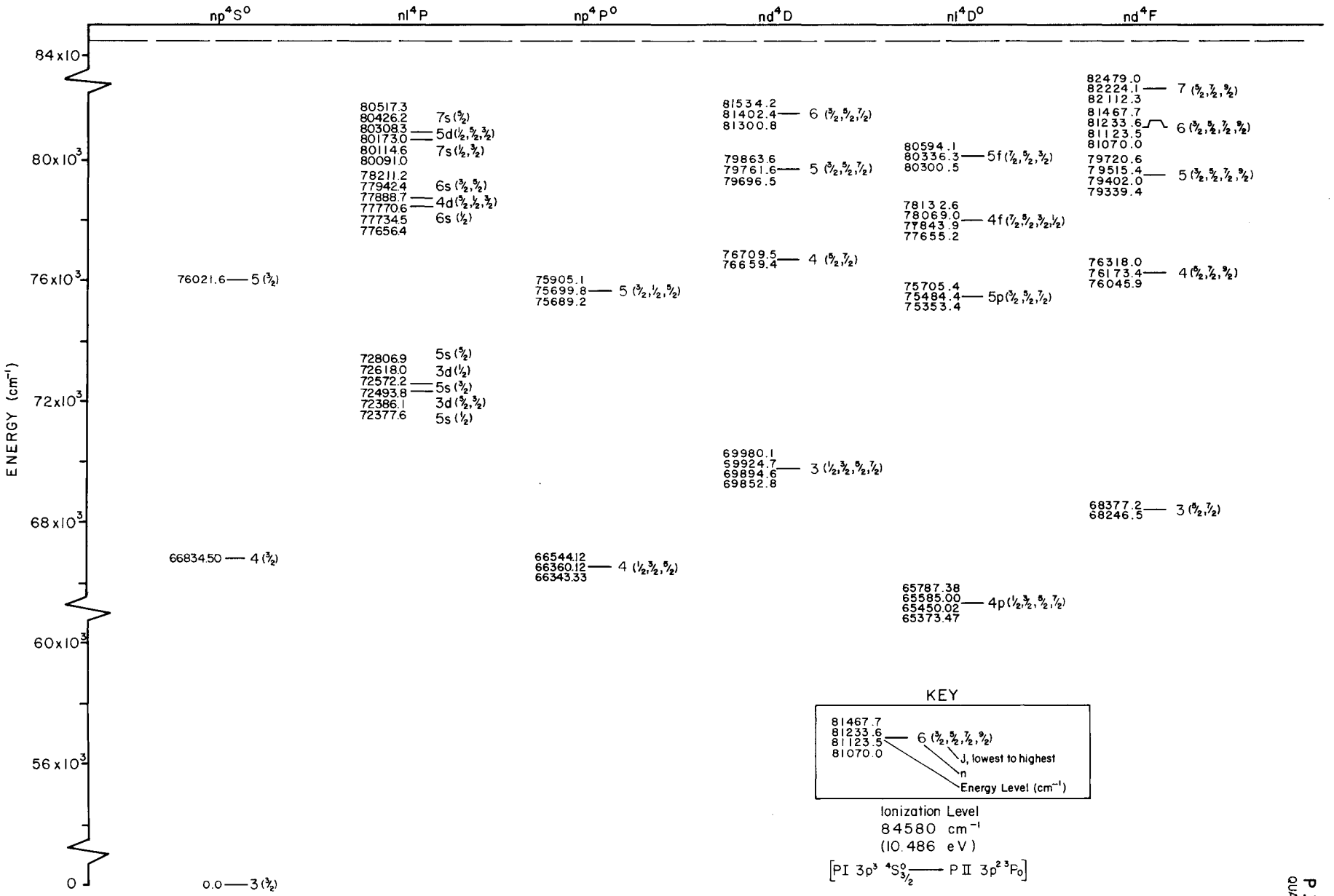


P I
Doublet

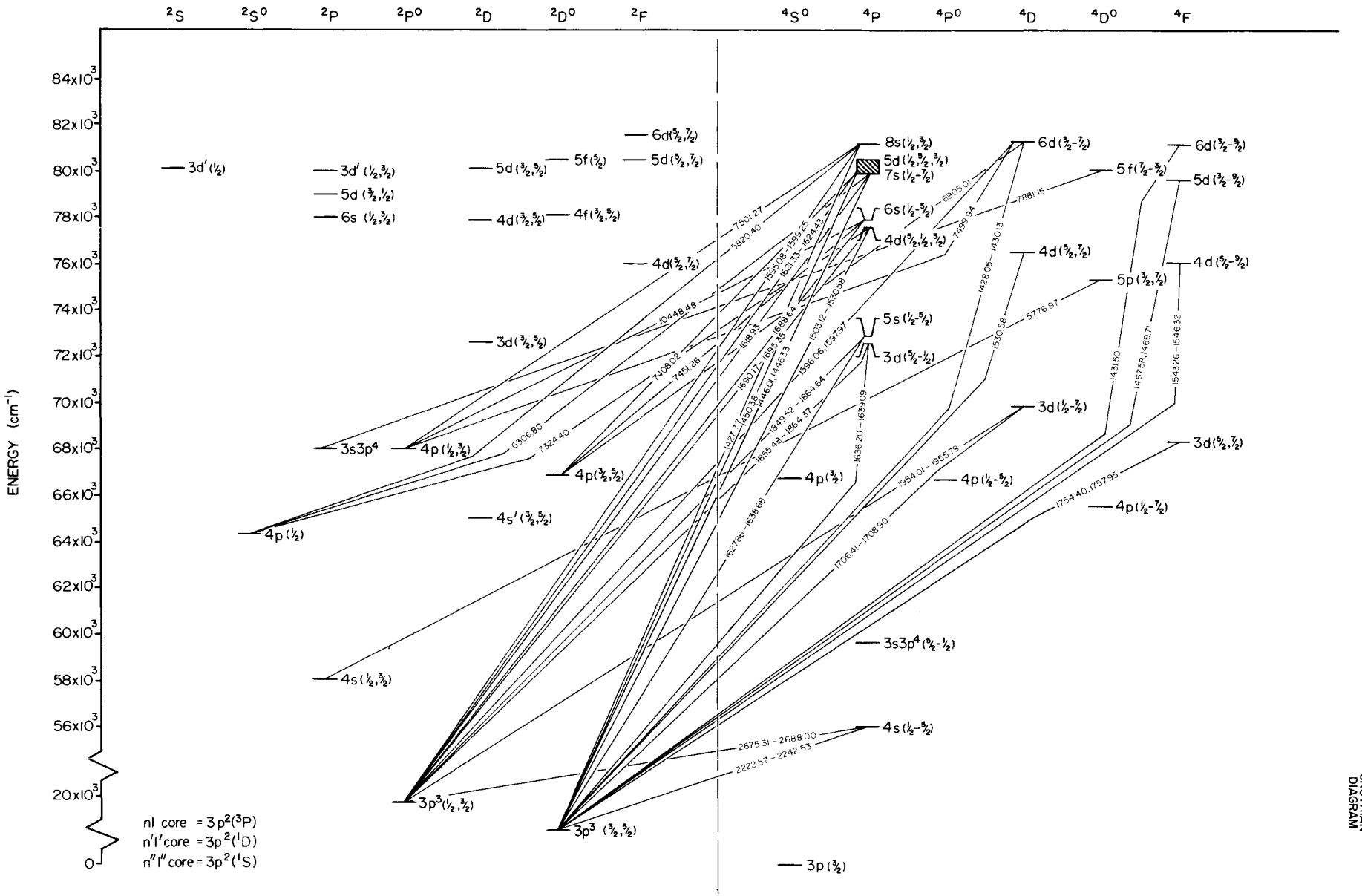

P I
QUARTET
GROTRIAN
DIAGRAM
P I GROTRIAN DIAGRAM (15 electrons, Z=15)
(Configuration: 1s²2s²2p⁶3s²3p² nl, Quartet System)
np⁴S°
nl⁴P
np⁴P°
nd⁴D
nl⁴D°
nd⁴F
ENERGY LEVEL (cm⁻¹)
84 x 10³
80 x 10³
76 x 10³
72 x 10³
68 x 10³
60 x 10³
56 x 10³
0

P I ENERGY LEVELS (15 electrons, Z=15)

(Configuration: $1s^2 2s^2 2p^6 3s^2 3p^2 nl$, Quartet System)

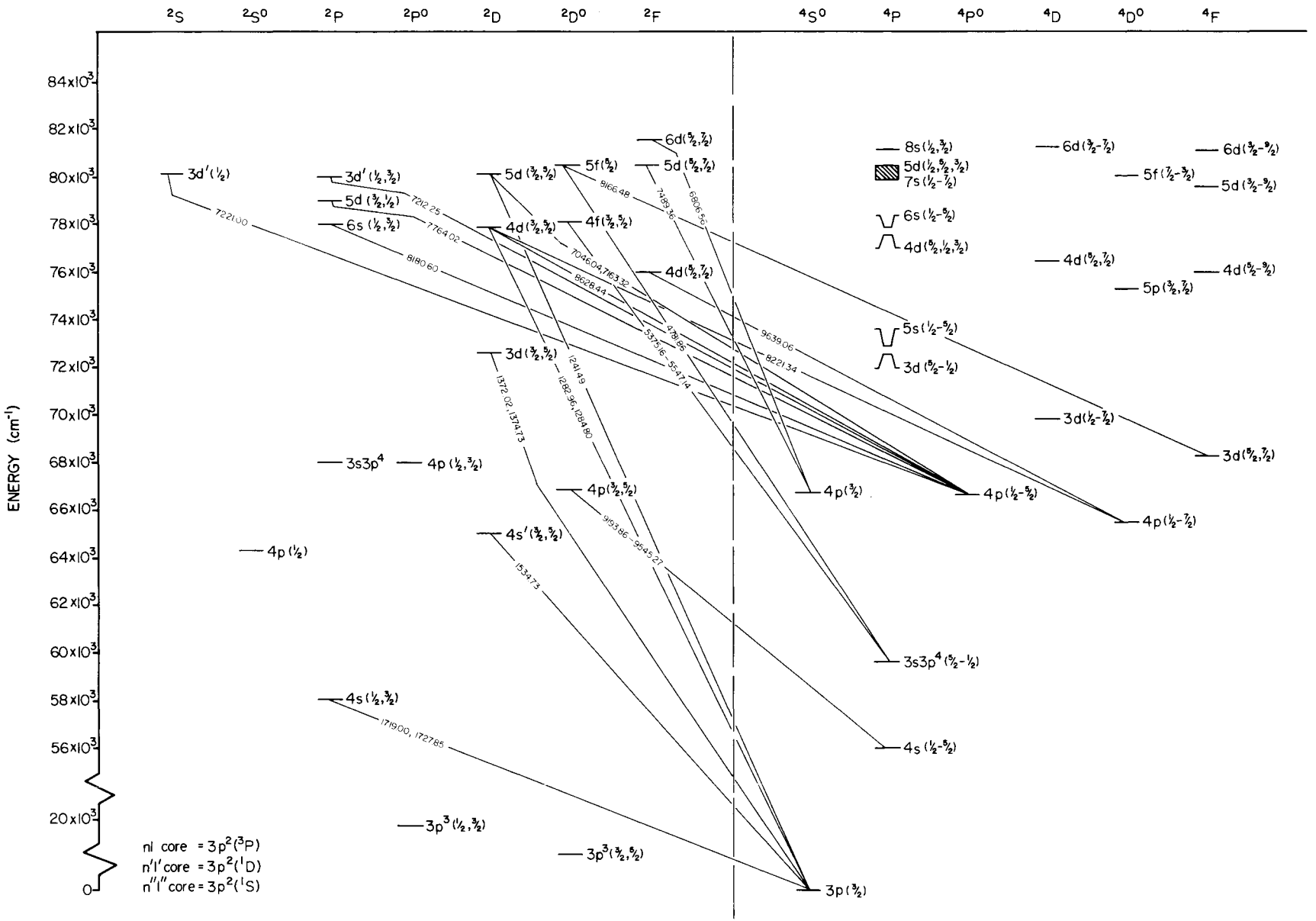


P I INTERCOMBINATION GROTRIAN DIAGRAM (15 electrons, Z = 15)
(Configuration: $1s^2 2s 2p^6 3s^2 3p^2 nl$, Doublet to Quartet System)

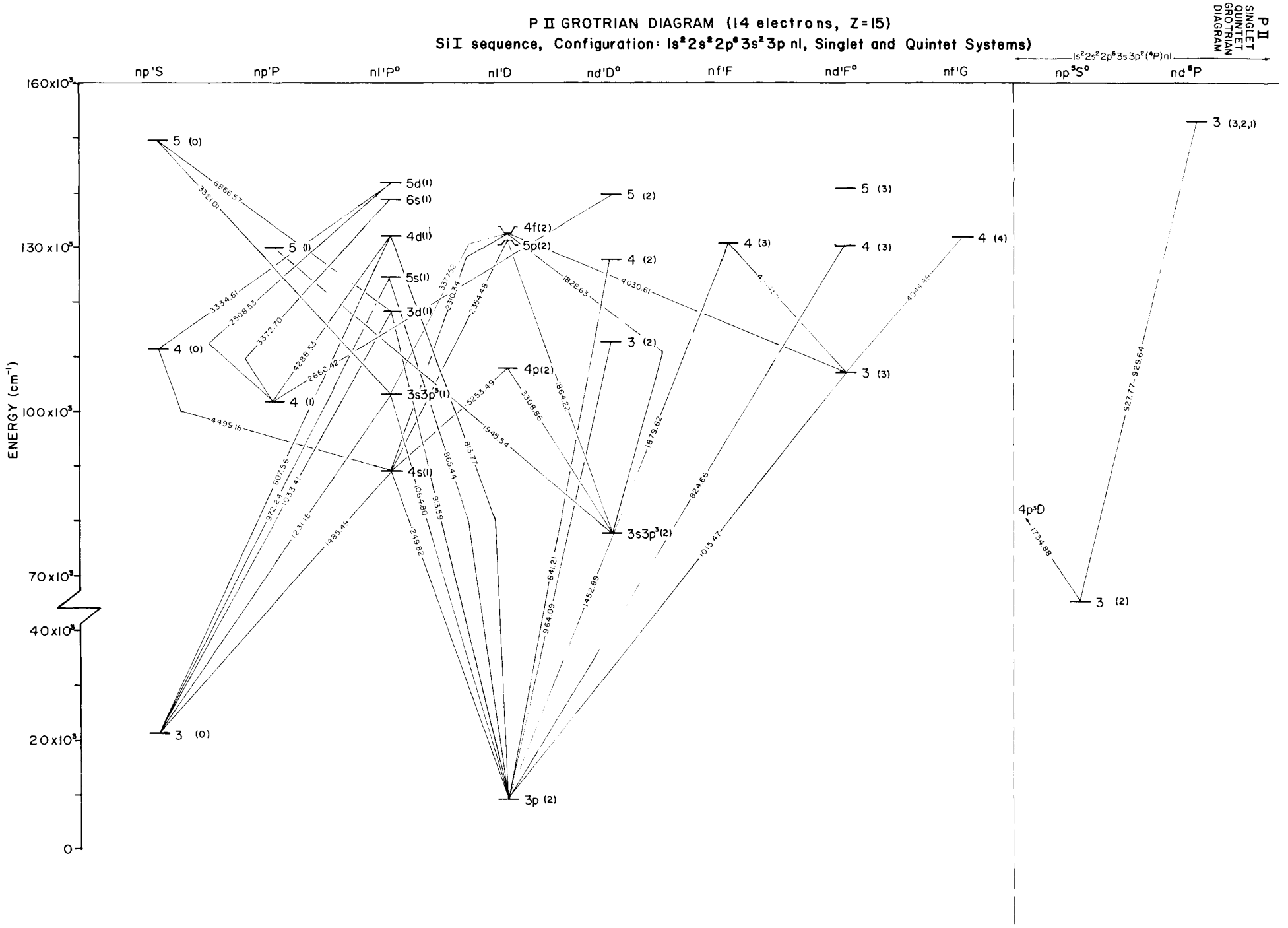


P I
INTERCOMBINATION
DOUBLET to
QUARTET
GROTRIAN
DIAGRAM

P I INTERCOMBINATION GROTRIAN DIAGRAM (15 electrons, Z = 15)
(Configuration: $1s^2 2s 2p^6 3s^2 3p^2 nl$, Quartet to Doublet System)

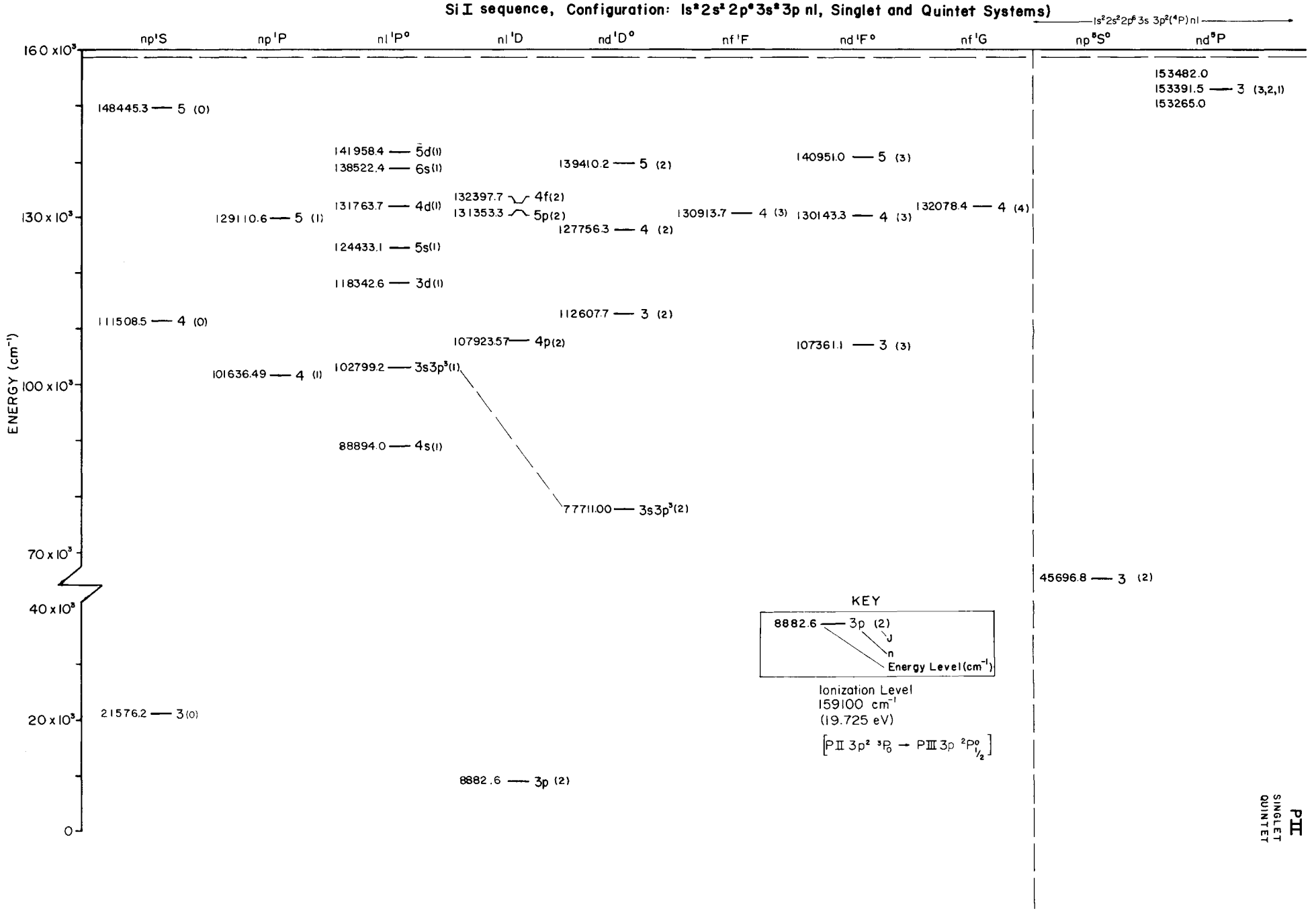


P I
INTERCOMBINATION
QUARTET to
DOUBLET
GROTRIAN
DIAGRAM


P II GROTRIAN DIAGRAM (14 electrons, Z=15)
Si I sequence, Configuration: 1s²2s²2p⁶3s²3p nl, Singlet and Quintet Systems)
P II SINGLET QUINTET GROTRIAN DIAGRAM
1s²2s²2p⁶3s3p²(⁴P)nl
np¹S
np¹P
nl¹P°
nl¹D
nd¹D°
nf¹F
nd¹F°
nf¹G
np³S°
nd³P
ENERGY (cm⁻¹)
160x10³
130x10³
100x10³
70x10³
40x10³
20x10³
0
5 (0)
4 (0)
3 (0)
5 (1)
4 (1)
5d(1)
6s(1)
4d(1)
5s(1)
3d(1)
3s3p³(1)
4s(1)
4f(2)
5p(2)
4p(2)
3p (2)
5 (2)
4 (2)
3 (2)
3s3p³(2)
4 (3)
5 (3)
4 (3)
3 (3)
4 (4)
3 (3,2,1)
4p³D
3 (2)
6866.57
3321.01
3334.61
2508.53
3372.70
4288.53
2660.42
4499.18
907.56
972.24
1033.41
1231.18
1485.49
1064.80
249.82
913.59
865.44
813.77
1945.54
5253.49
3308.86
864.22
841.21
964.09
1452.89
1879.62
824.66
1015.47
1828.63
4030.61
4044.49
927.77-929.64
1734.88

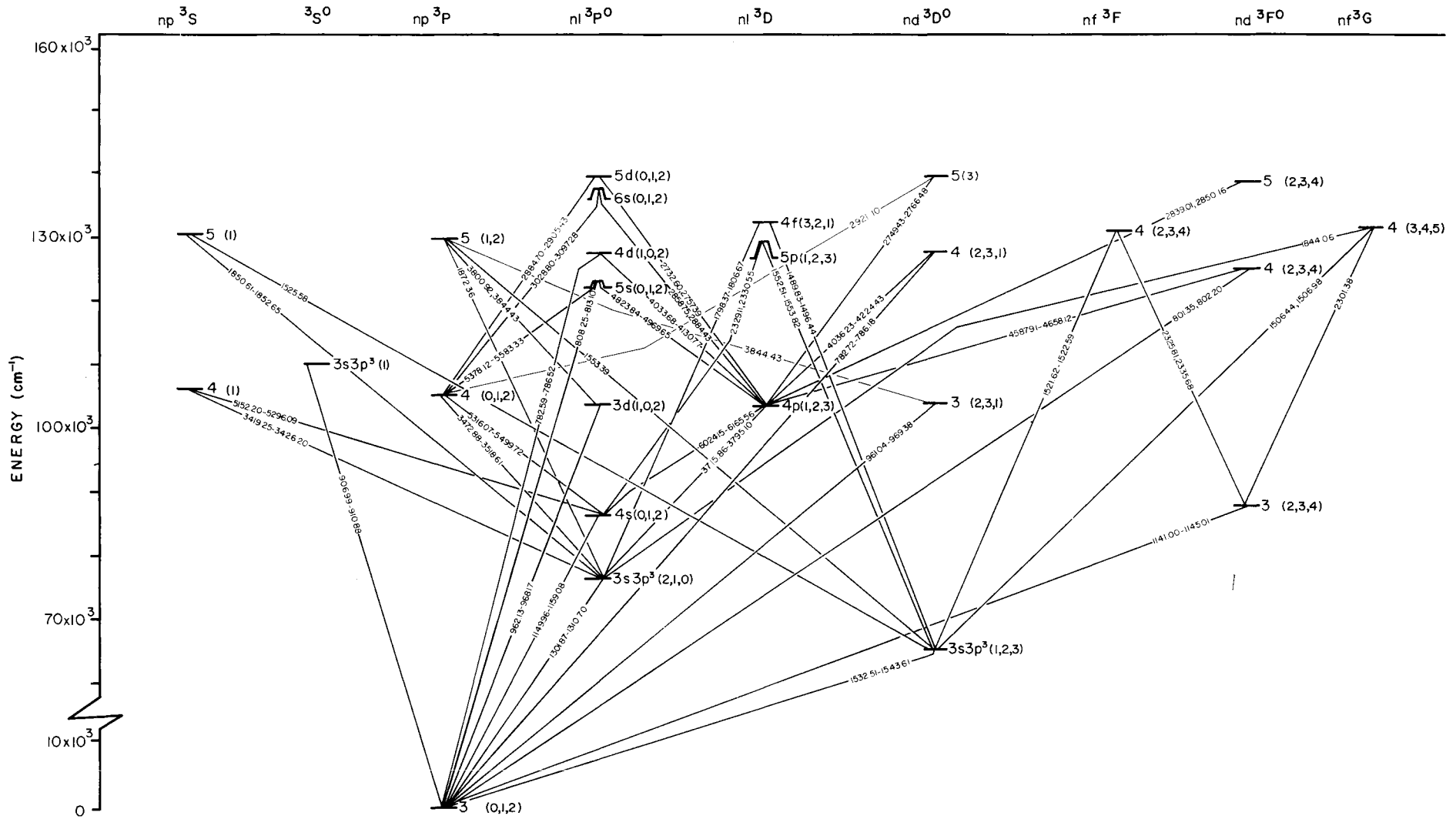
P II ENERGY LEVELS (14 electrons, Z=15)

Si I sequence, Configuration: $1s^2 2s^2 2p^6 3s^2 3p\ nl$, Singlet and Quintet Systems)



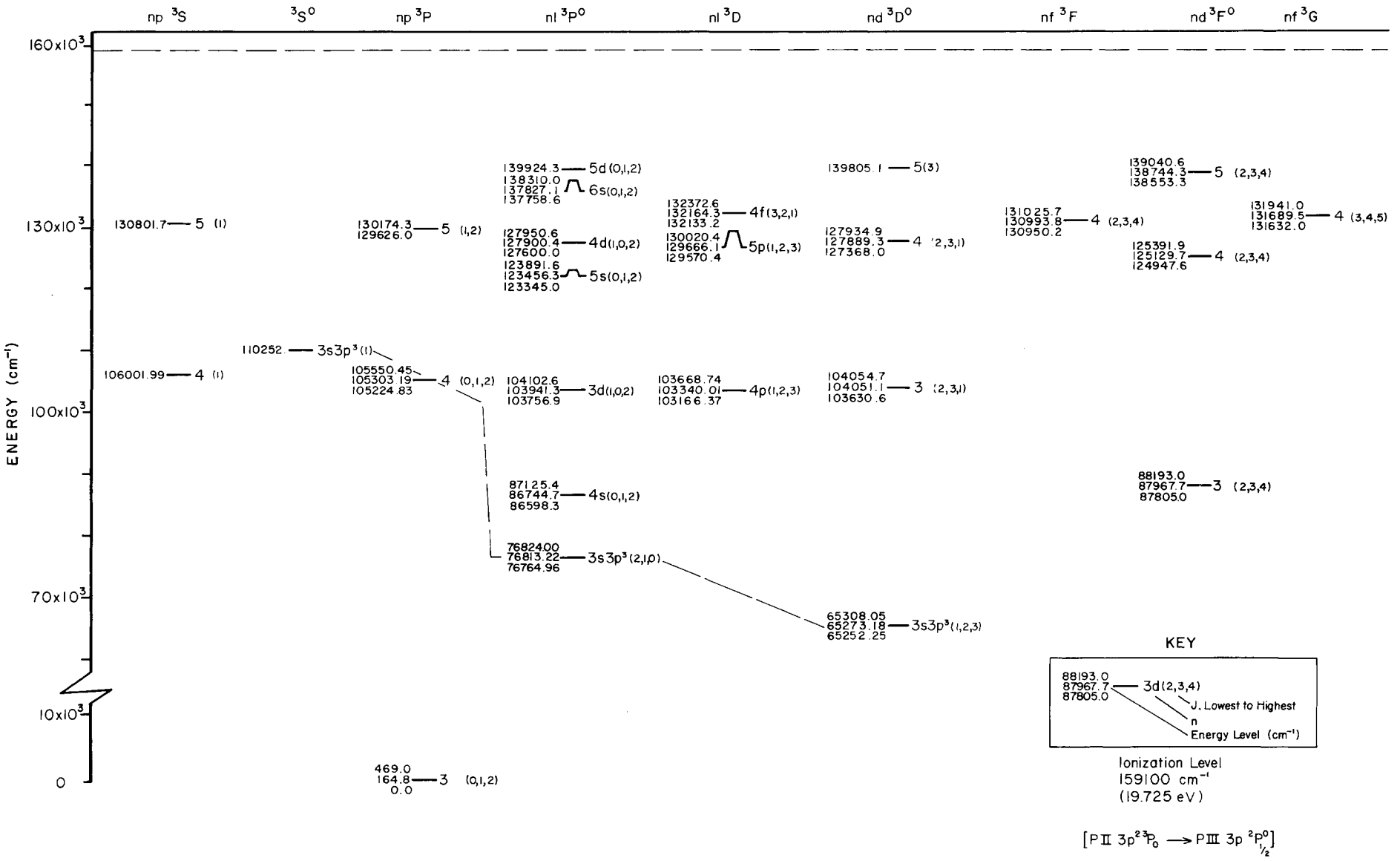
P II
SINGLET
QUINTET

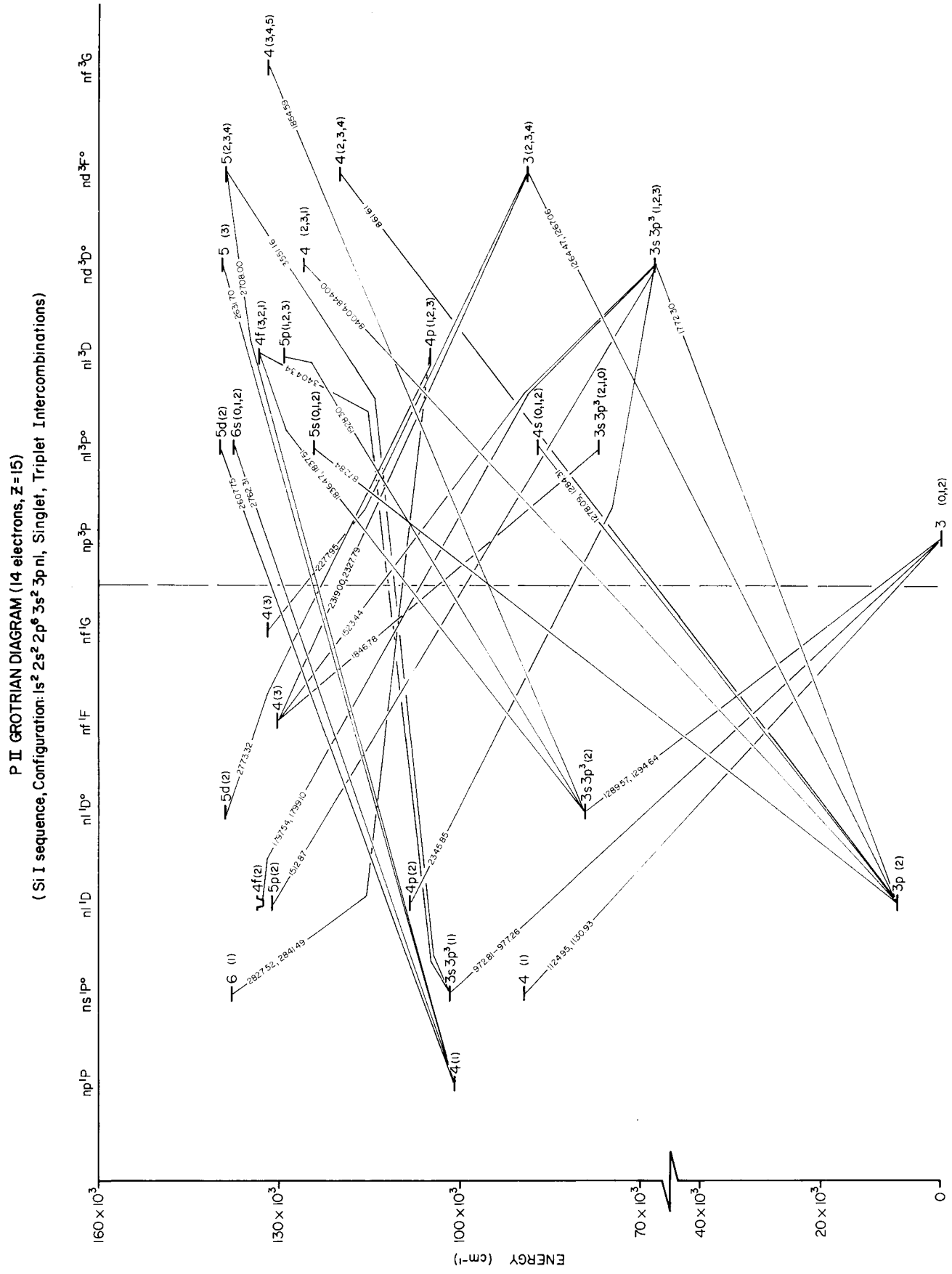
P II GROTRIAN DIAGRAM (14 electrons, Z= 15)
(Si I sequence, Configuration, $1s^2 2s^2 2p^6 3s^2 3p\,nl$, Triplet System)



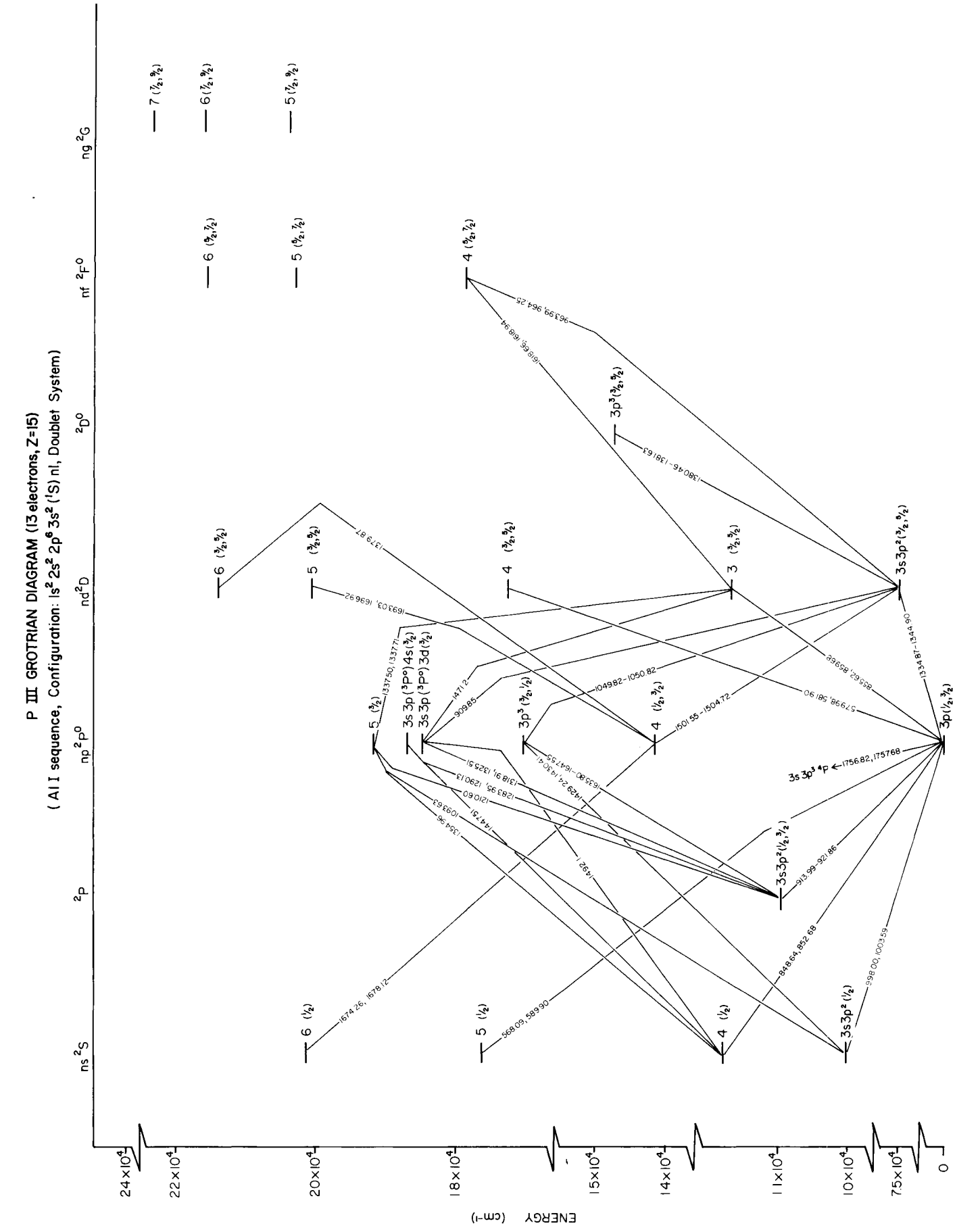
P II ENERGY LEVELS (14 electrons, Z = 15)

(Si I sequence, Configuration; $1s^2 2s^2 2p^6 3s^2 3pnl$, Triplet System)



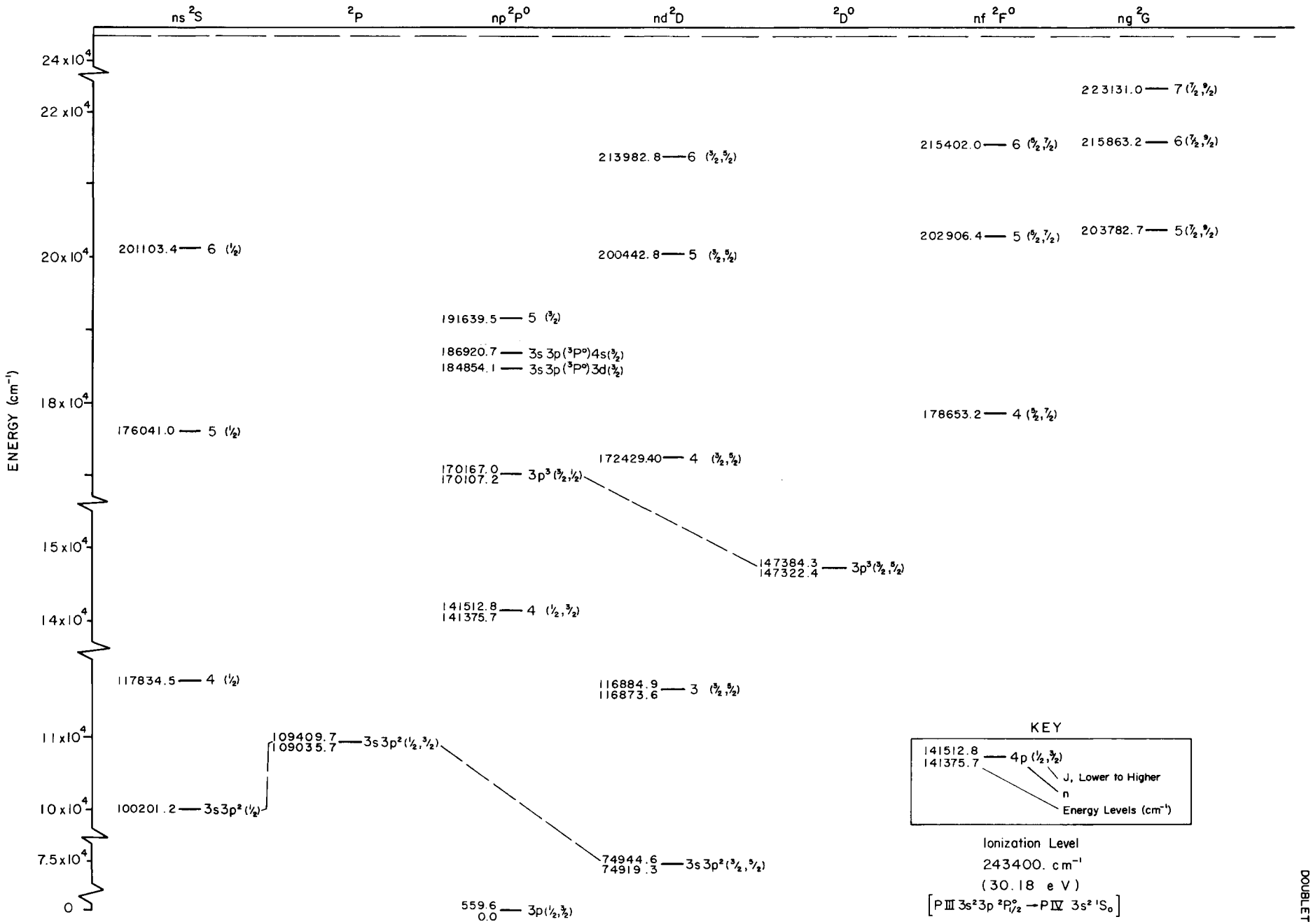

P II GROTRIAN DIAGRAM (14 electrons, Z=15)
(Si I sequence, Configuration: 1s² 2s² 2p⁶ 3s² 3p nl, Singlet, Triplet Intercombinations)
np ¹P
ns ¹P°
nl ¹D
nl ¹D°
nf ¹F
nf ¹G
np ³P
nl ³P°
nl ³D
nd ³D°
nd ³F°
nf ³G
ENERGY (cm⁻¹)
160 × 10³
130 × 10³
100 × 10³
70 × 10³
40 × 10³
20 × 10³
0

P III
DOUBLET
GROTRIAN DIAGRAM



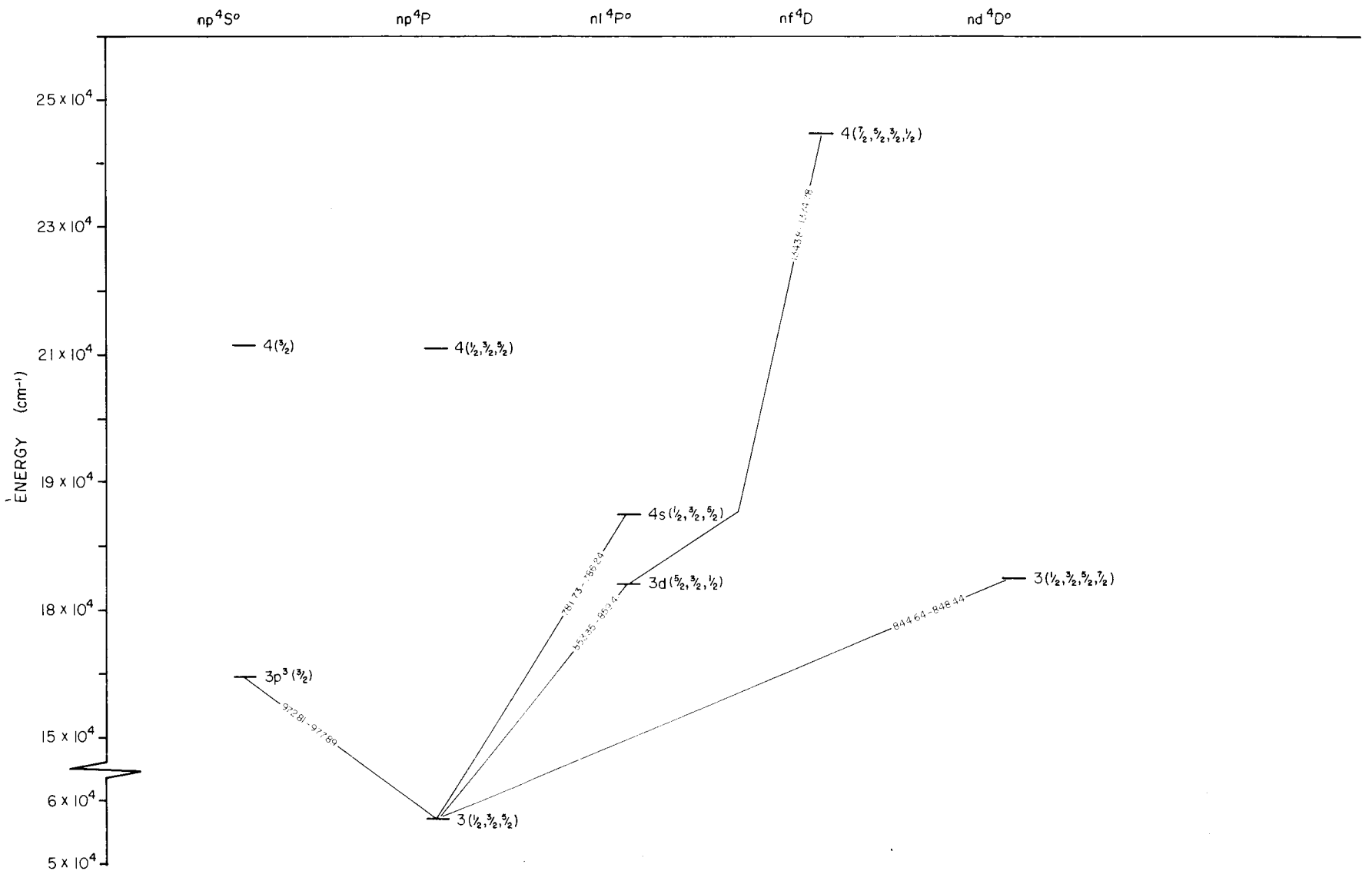
P III ENERGY LEVELS (13 electrons, Z=15)

(Al I sequence, Configuration: $1s^2 2s^2 2p^6 3s^2 (^1S) nl$, Doublet System)



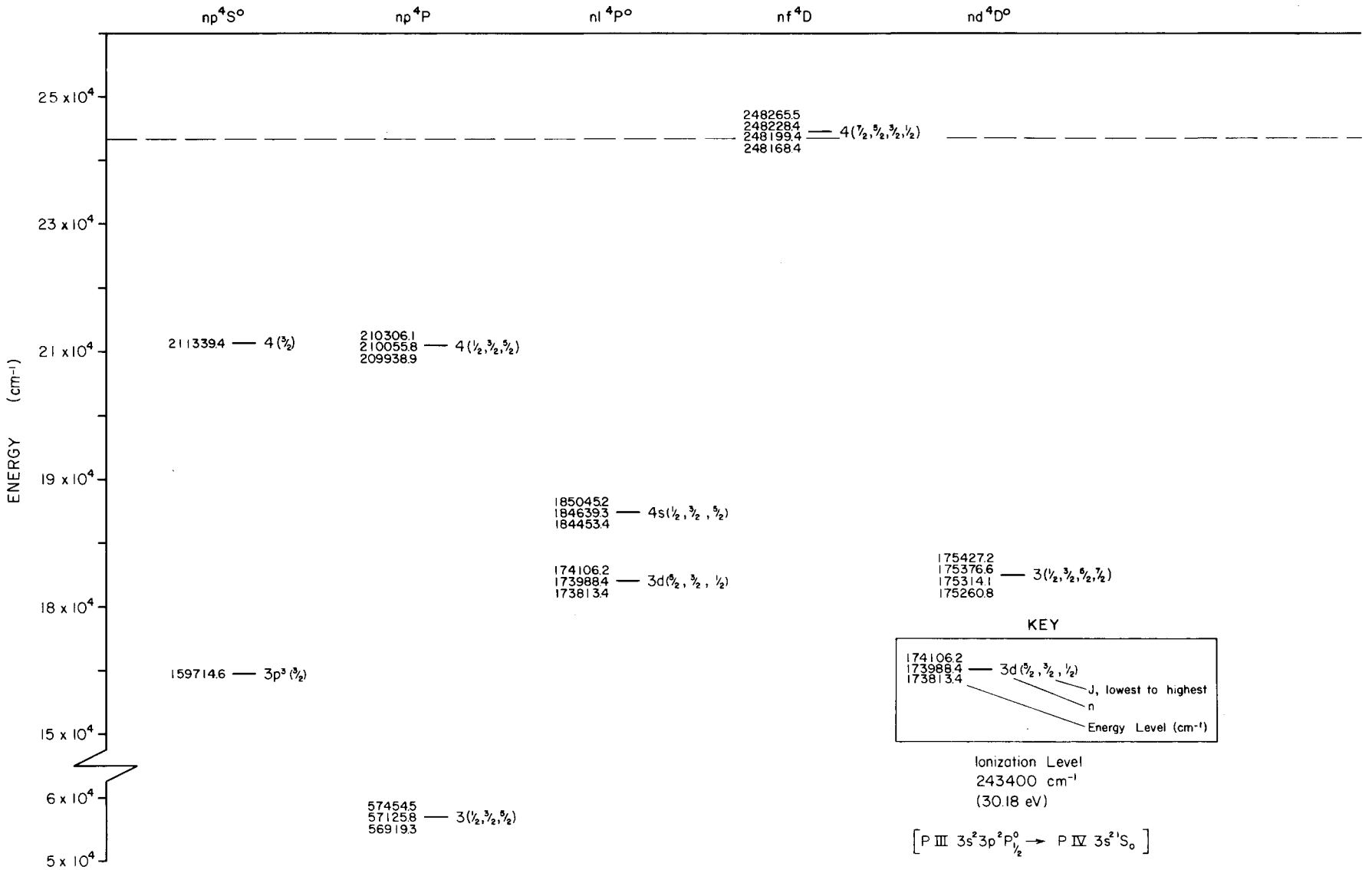
P III GROTRIAN DIAGRAM (13 electrons, Z = 15)

(Al I sequence, Configuration: $1s^2\,2s^2\,2p^6\,3s\,3p\,(^3P^o)nl$, Quartet System and Autoionizing States)

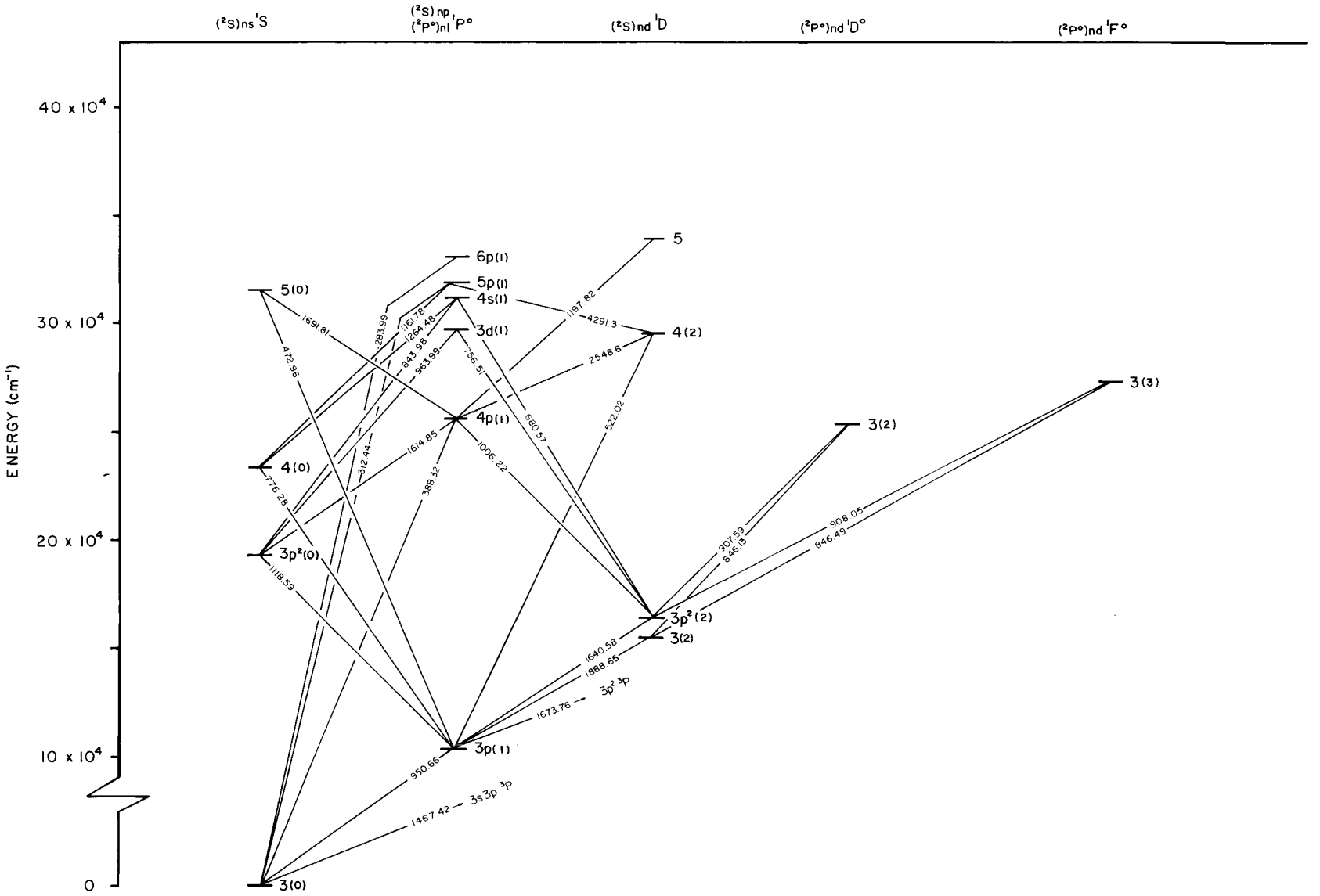


P III ENERGY LEVELS (13 electrons, Z=15)

(Al I Sequence, Configuration: $1s^2 2s^2 2p^6 3s3p(^3P^o)nl$, Quartet Systems and Autoionizing States)

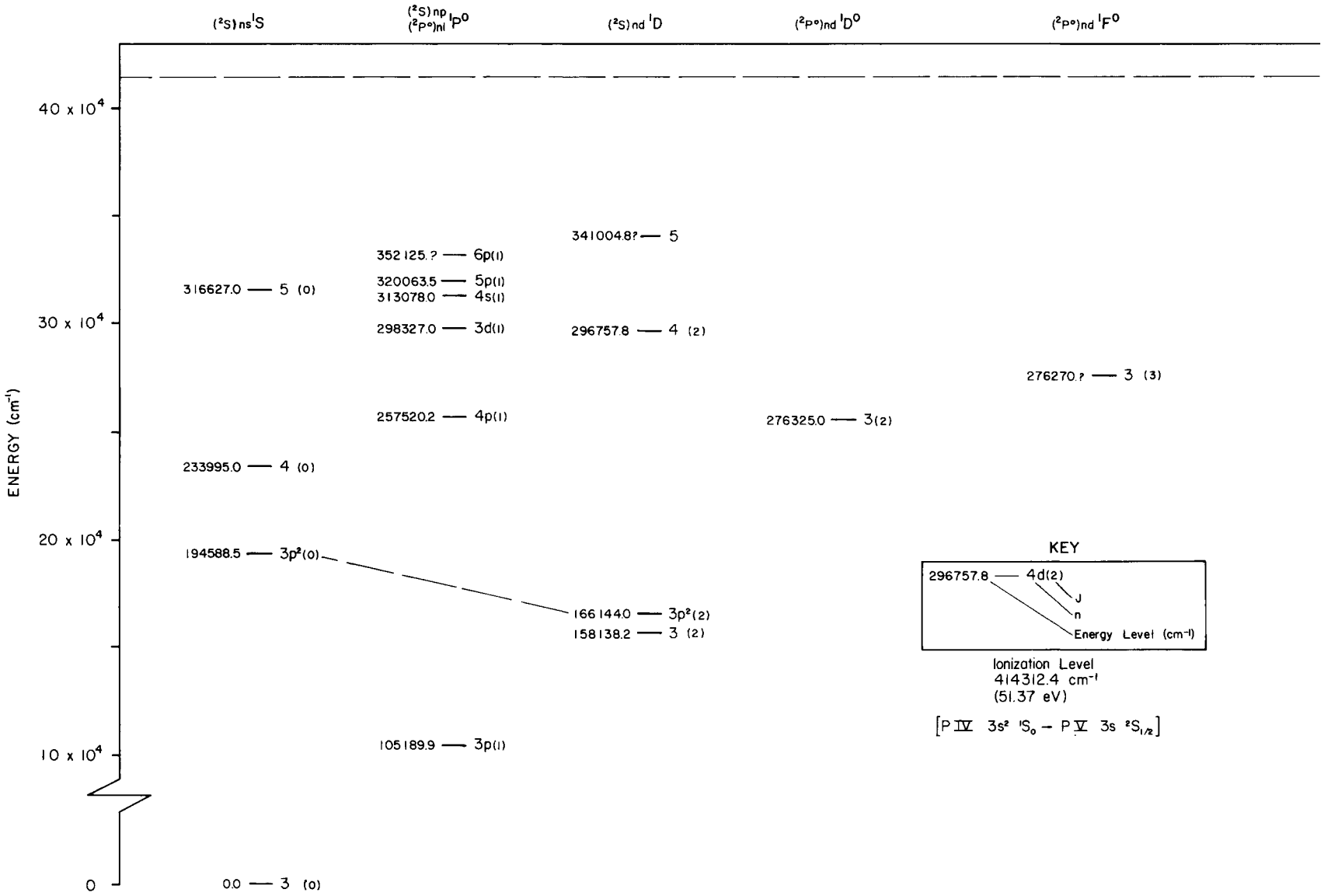


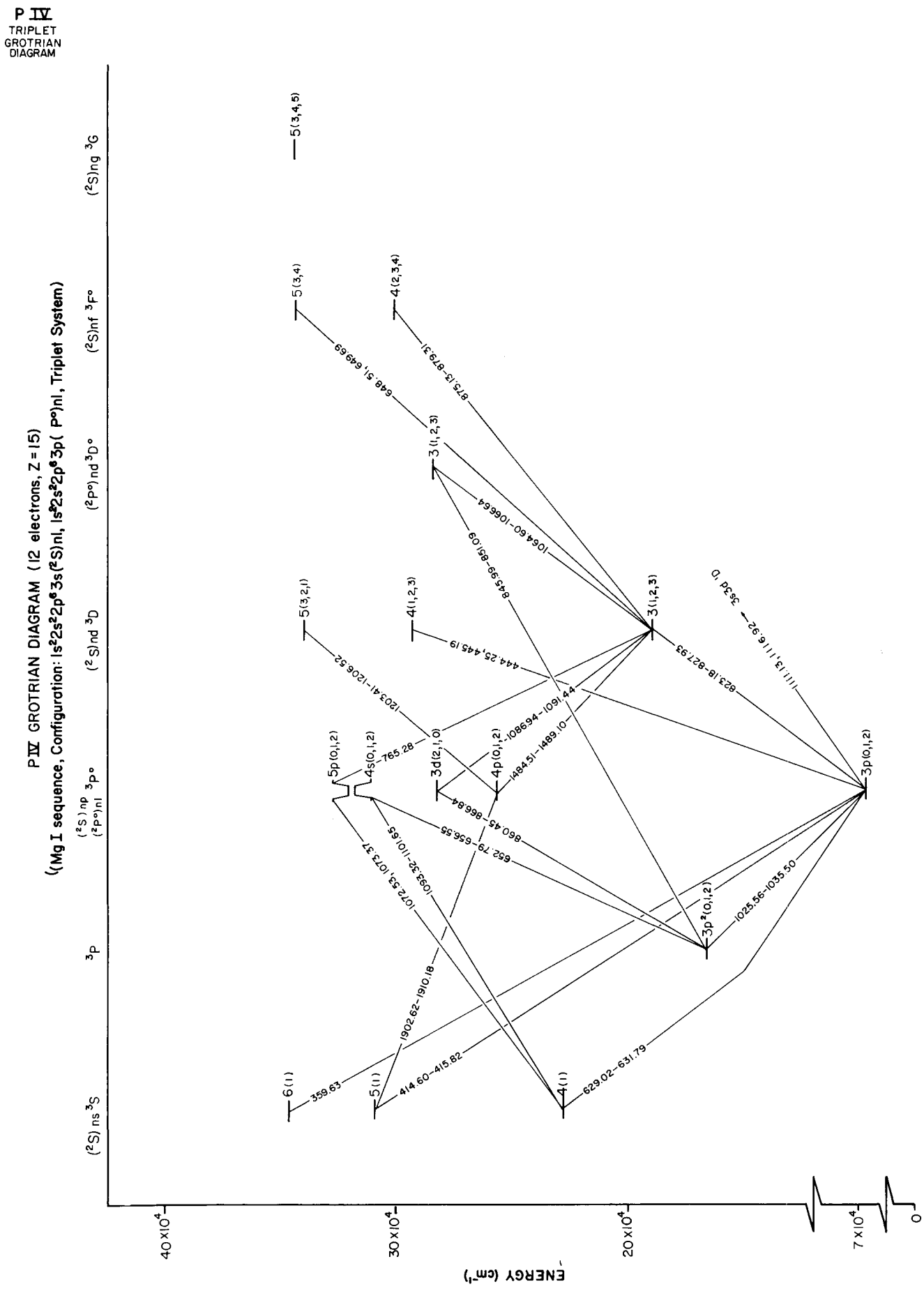
P IV GROTRIAN DIAGRAM (12 electrons, Z = 15)
(Mg I sequence, Configuration: $1s^2\ 2s^2\ 2p^6\ 3l\ (^2L)nl$, Singlet System)



P IV ENERGY LEVELS (12 electrons Z = 15)

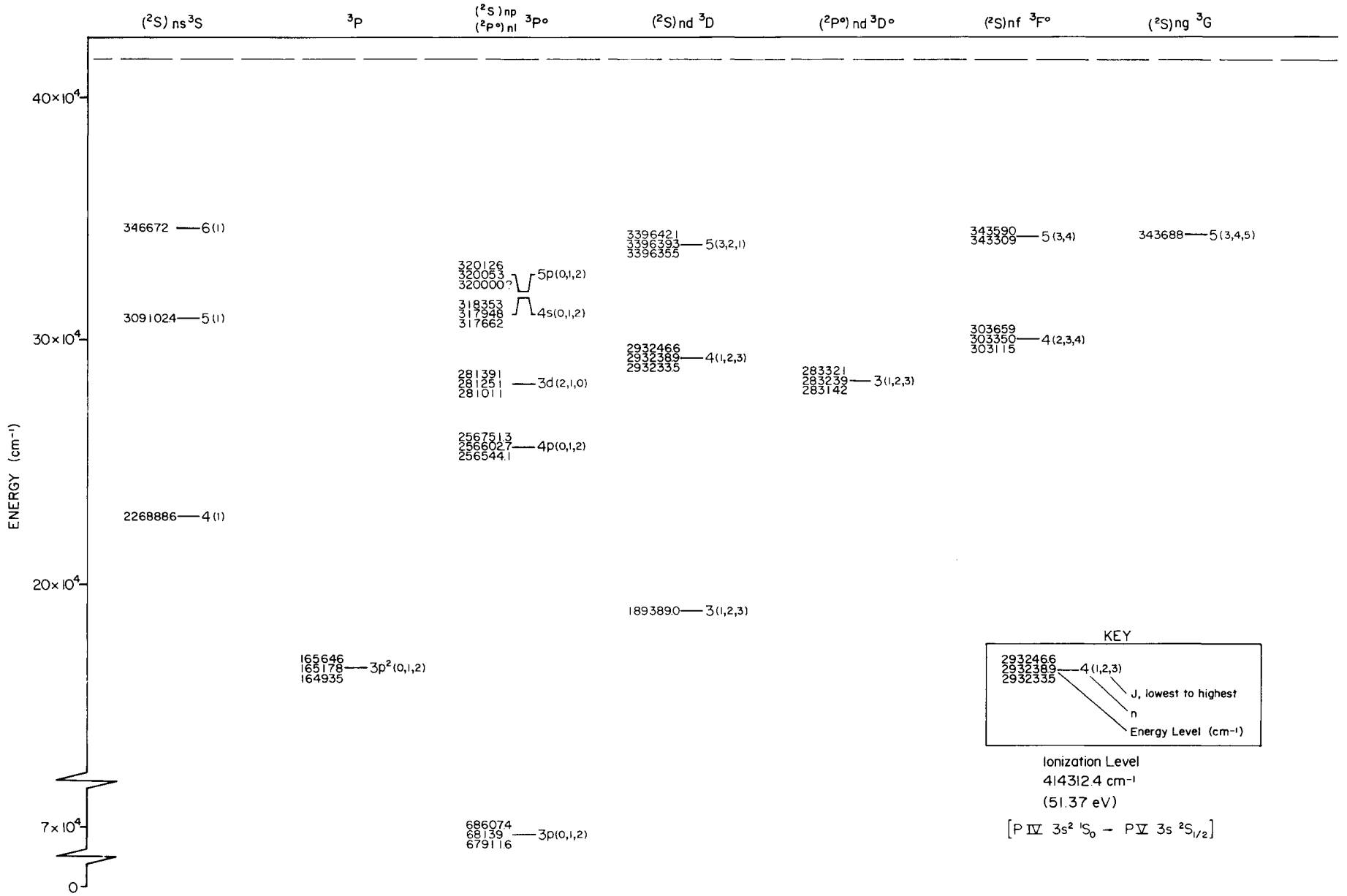
(Mg I Sequence, Configuration: $1s^2\ 2s^2\ 2p^6\ 3l\ (^2L)nl$, Singlet System)



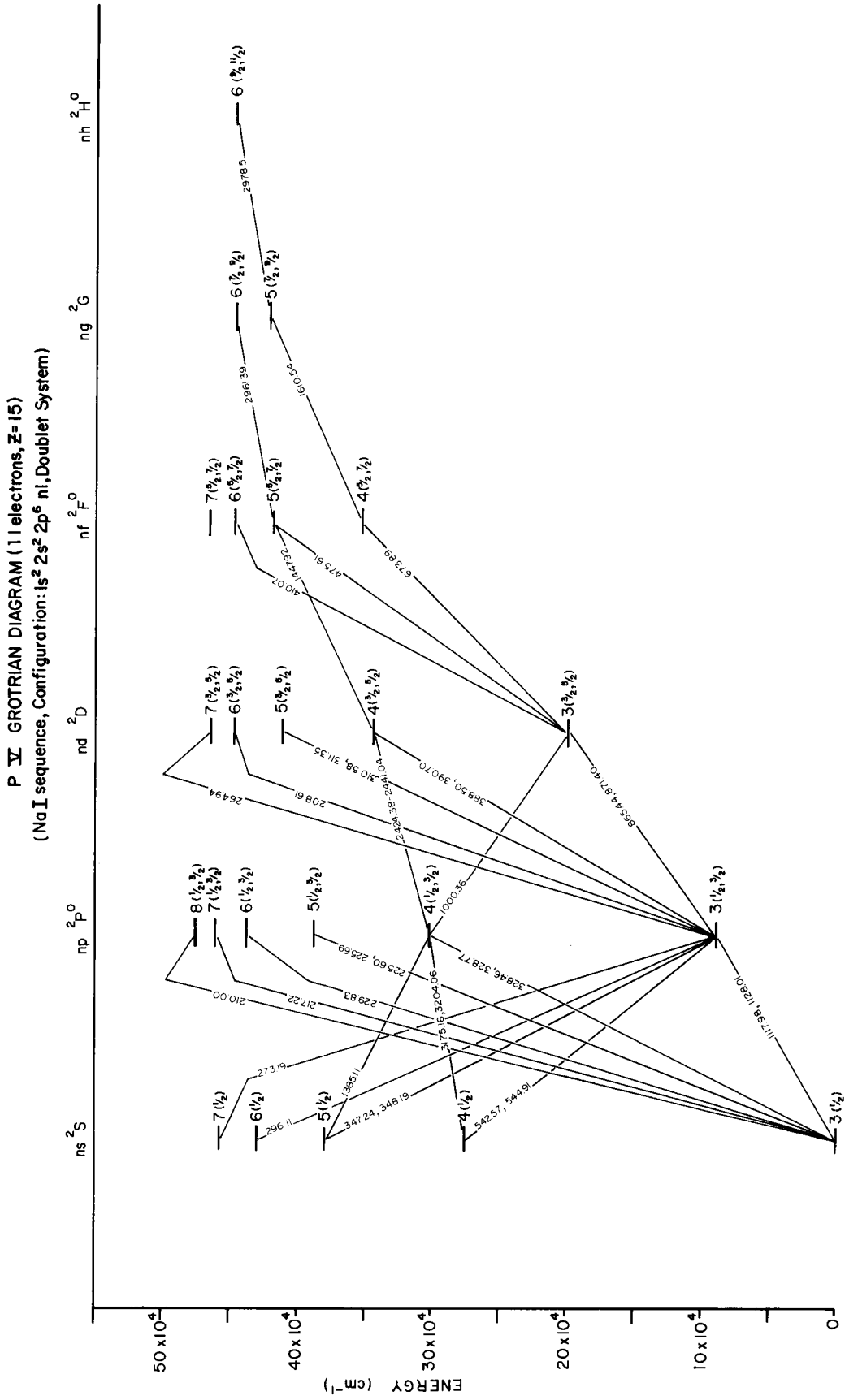

P IV
TRIPLET
GROTRIAN
DIAGRAM
P IV GROTRIAN DIAGRAM (12 electrons, Z = 15)
((Mg I sequence, Configuration: 1s²2s²2p⁶3s(²S)nl, 1s²2s²2p⁶3p(²P°)nl, Triplet System)
(²S) ns ³S
³P
(²S) np ³P°
(²P°)nl
(²S) nd ³D
(²P°) nd ³D°
(²S)nf ³F°
(²S)ng ³G
ENERGY (cm⁻¹)
40×10⁴
30×10⁴
20×10⁴
7×10⁴
0
6(1)
5(1)
4(1)
5p(0,1,2)
4s(0,1,2)
3d(2,1,0)
4p(0,1,2)
3p²(0,1,2)
5(3,2,1)
4(1,2,3)
3(1,2,3)
3p(0,1,2)
5(3,4)
4(2,3,4)
3(1,2,3)
5(3,4,5)
359.63
1902.62-1910.18
414.60-415.82
629.02-631.79
1072.53-1073.37
1093.32-1101.65
652.79-656.55
860.45-866.84
765.28
1484.51-1489.10
1086.94-1091.44
203.41-1206.52
444.25,445.19
1025.56-1035.50
823.18-827.93
1111.13,1116.92 → 3s3d ¹D
843.99-851.09
1064.60-1066.64
875.13-879.31
648.51,649.69

P IV ENERGY LEVELS (12 electrons, Z=15)

(Mg I sequence, Configuration: $1s^2 2s^2 2p^6 3s(^2S)nl$, $1s^2 2s^2 2p^6 3p(^2P^o)nl$, Triplet System)

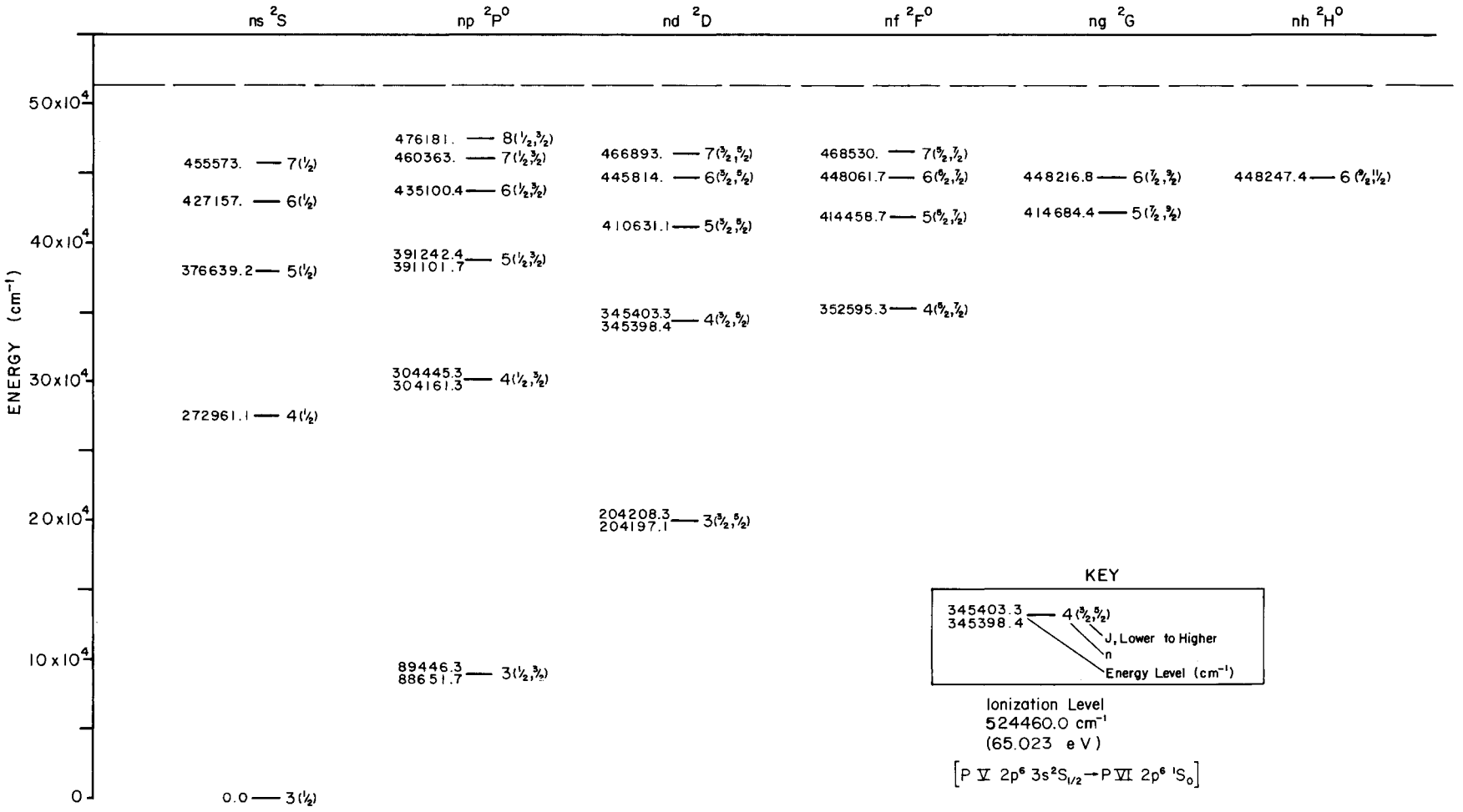


P V
DOUBLET
GROTRIAN
DIAGRAM

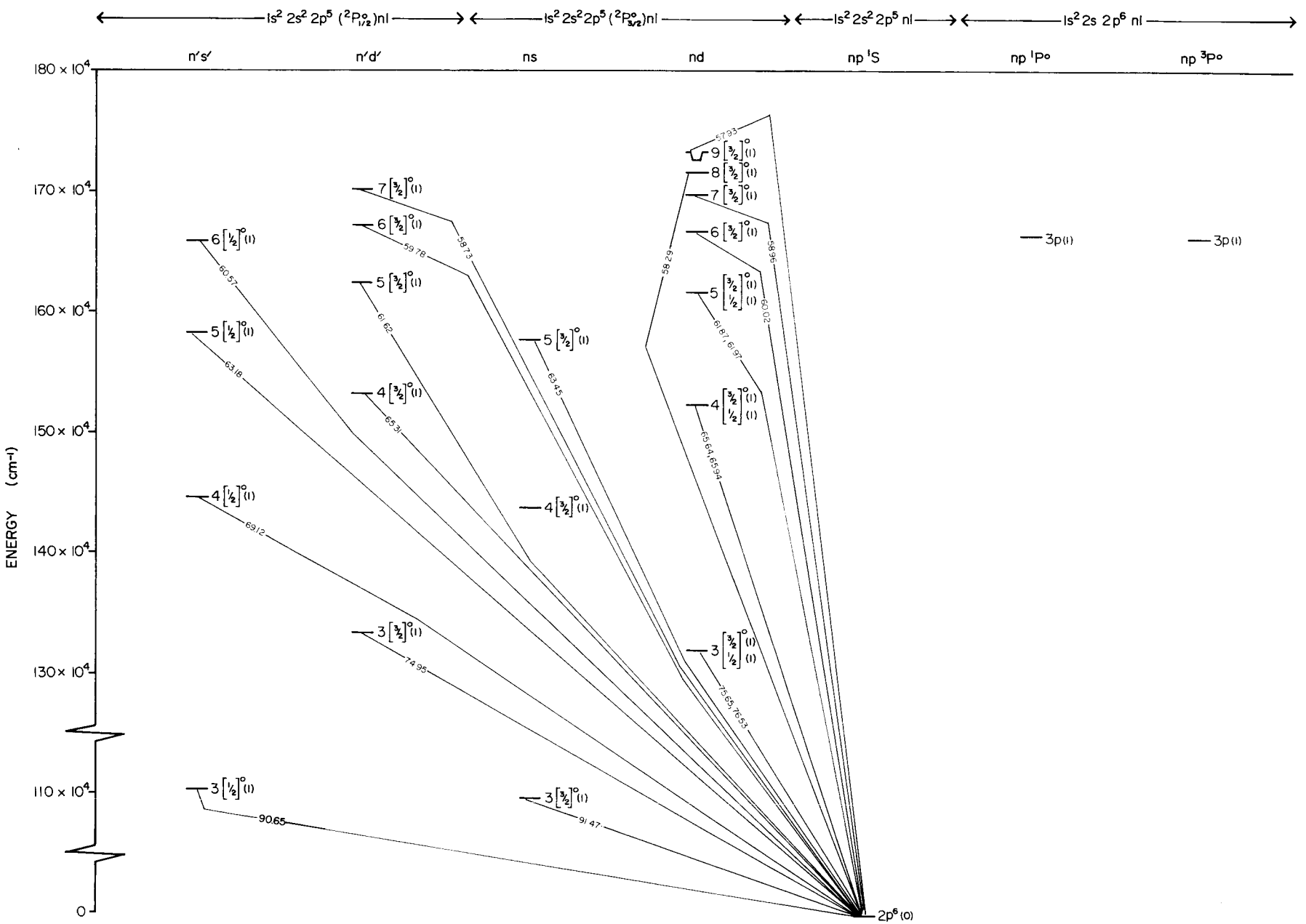


P V ENERGY LEVELS (11 electrons, Z=15)

(Na I sequence, Configuration: $1s^2\,2s^2\,2p^6\,nl$, Doublet System)

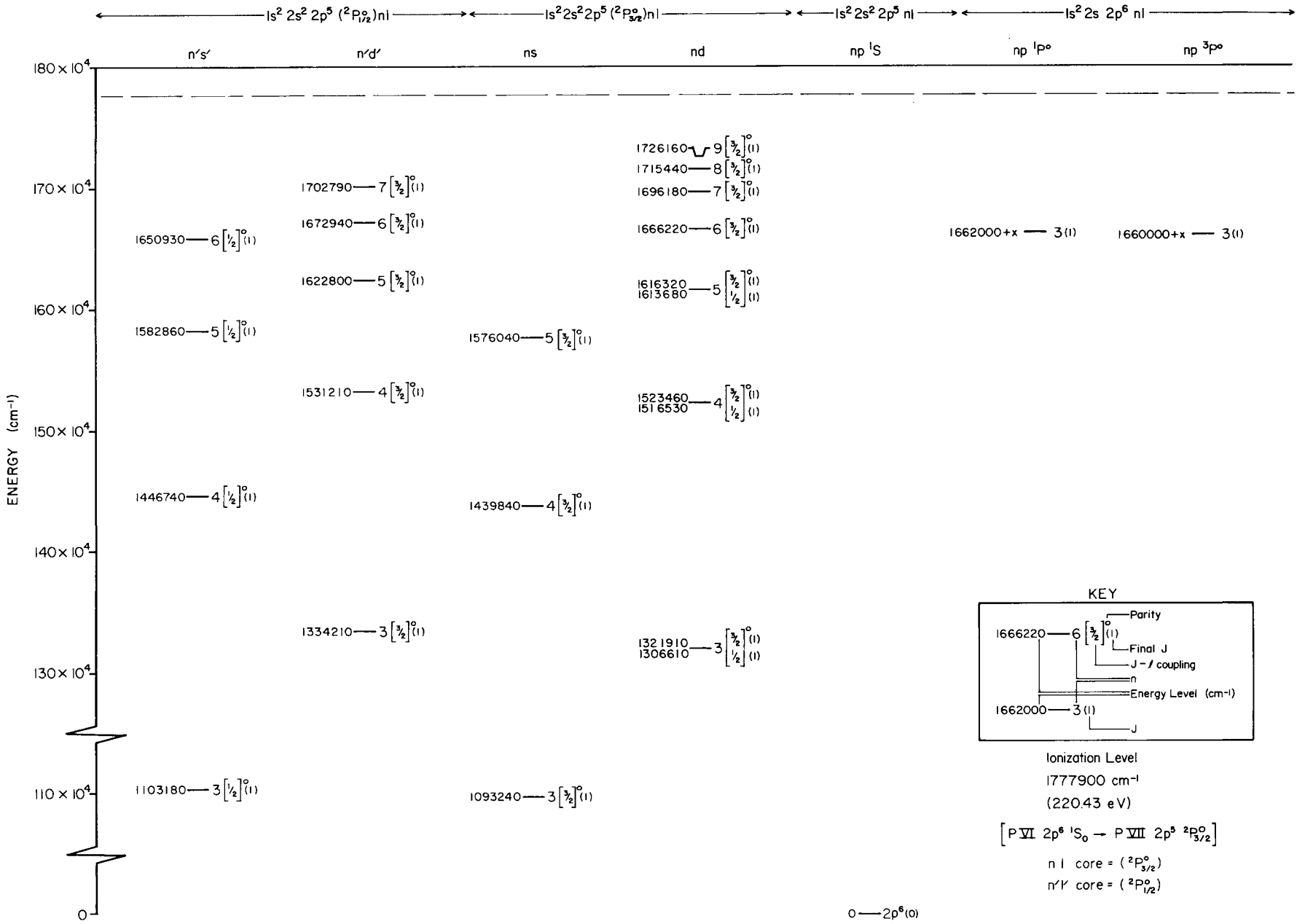


P VI GROTRIAN DIAGRAM (10 electrons, Z=15)
(Ne I sequence, Intermediate Coupling, Singlet, Triplet)



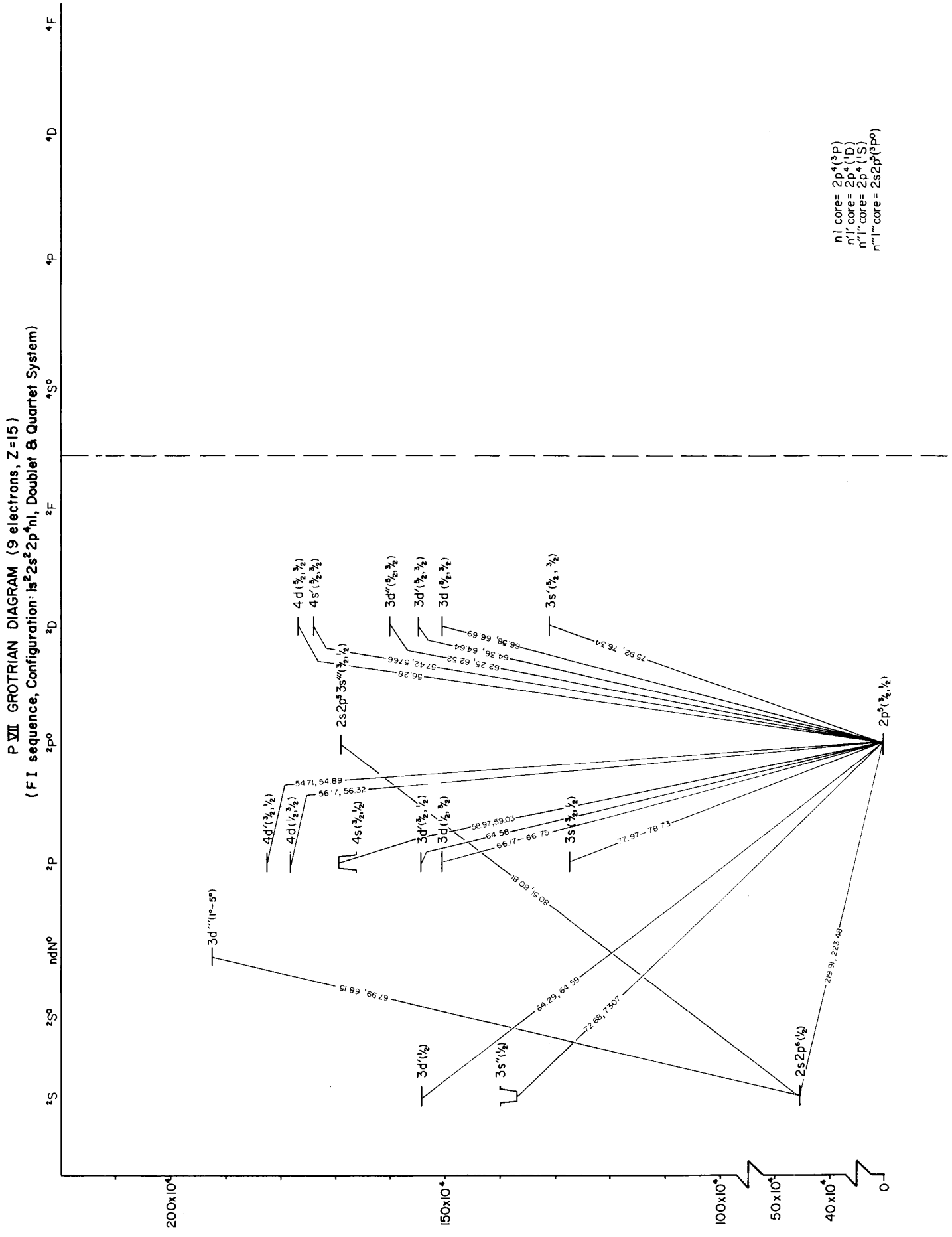
P VI ENERGY LEVELS (10 electrons, Z = 15)

(Ne I sequence, Intermediate Coupling, Singlet, Triplet)



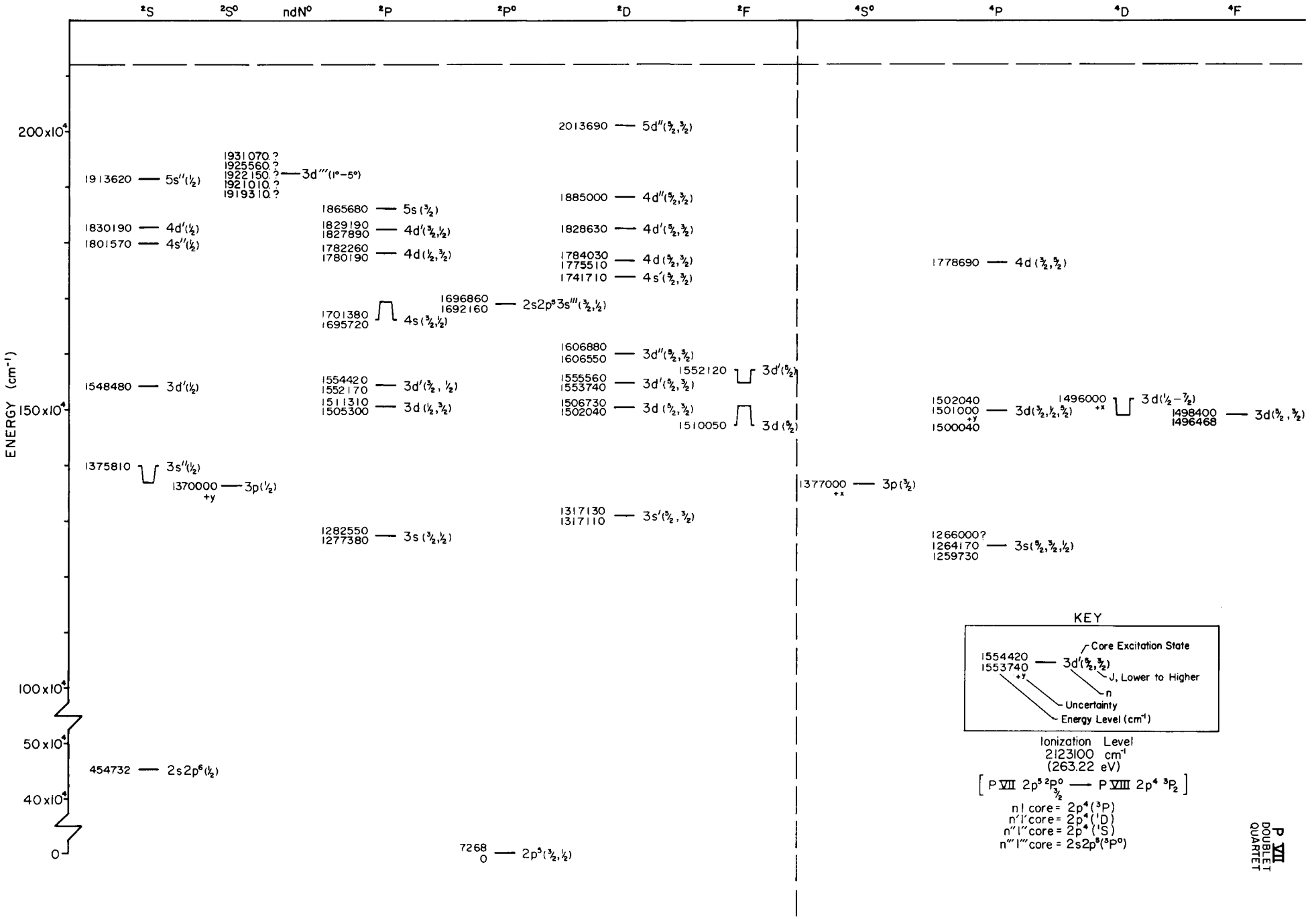
P VI
INTERMEDIATE COUPLING
SINGLET
TRIPLET

P VII
DOUBLET-QUARTET
GROTRIAN DIAGRAM



P VII ENERGY LEVELS (9 electrons, Z = 15)

(F I sequence, Configuration: $1s^2\,2s^2\,2p^4nl$, Doublet & Quartet System)



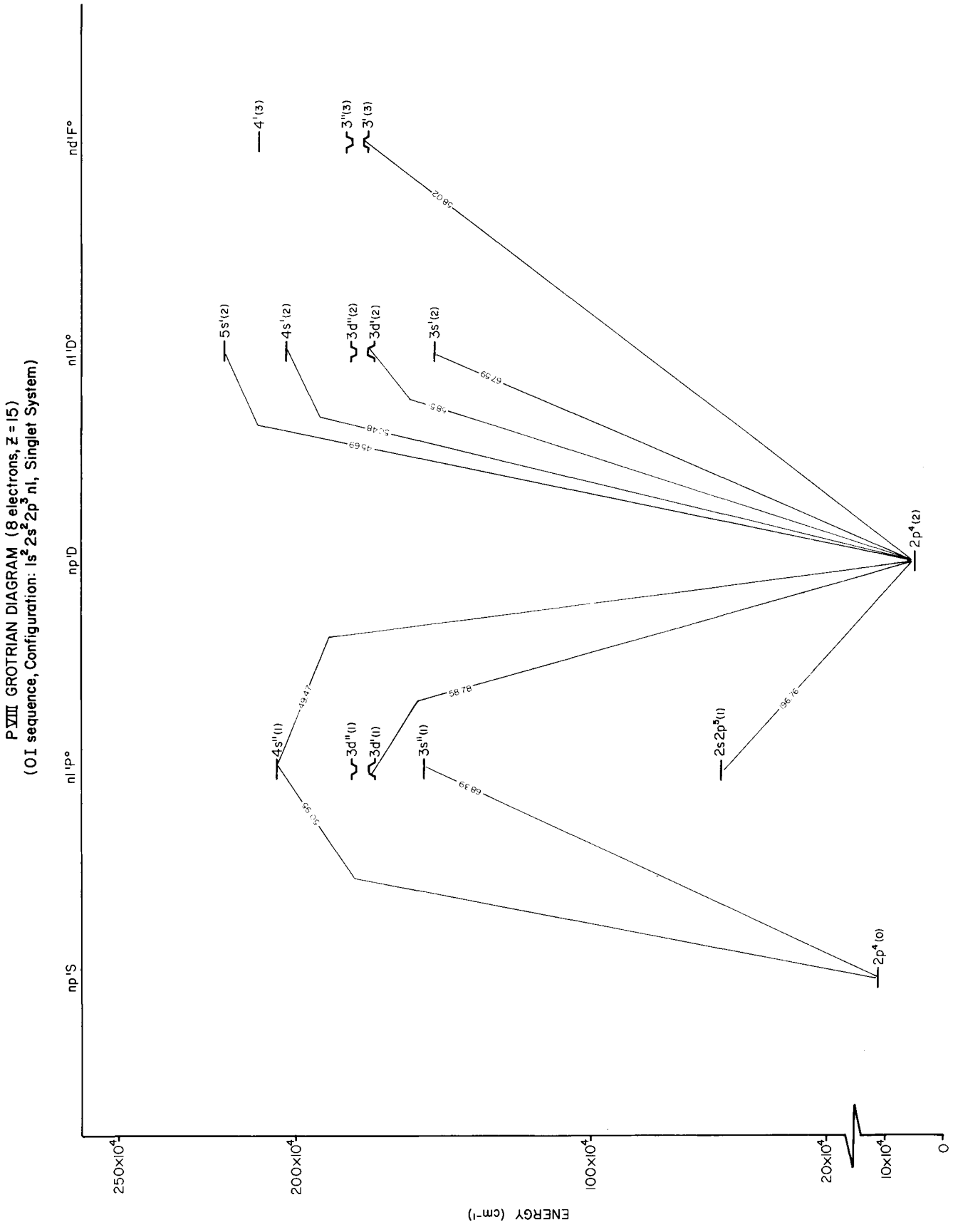
Ionization Level
2123100 cm⁻¹
(263.22 eV)

[P VII $2p^5\,{}^2P^o_{3/2}$ ⟶ P VIII $2p^4\,{}^3P_2$]

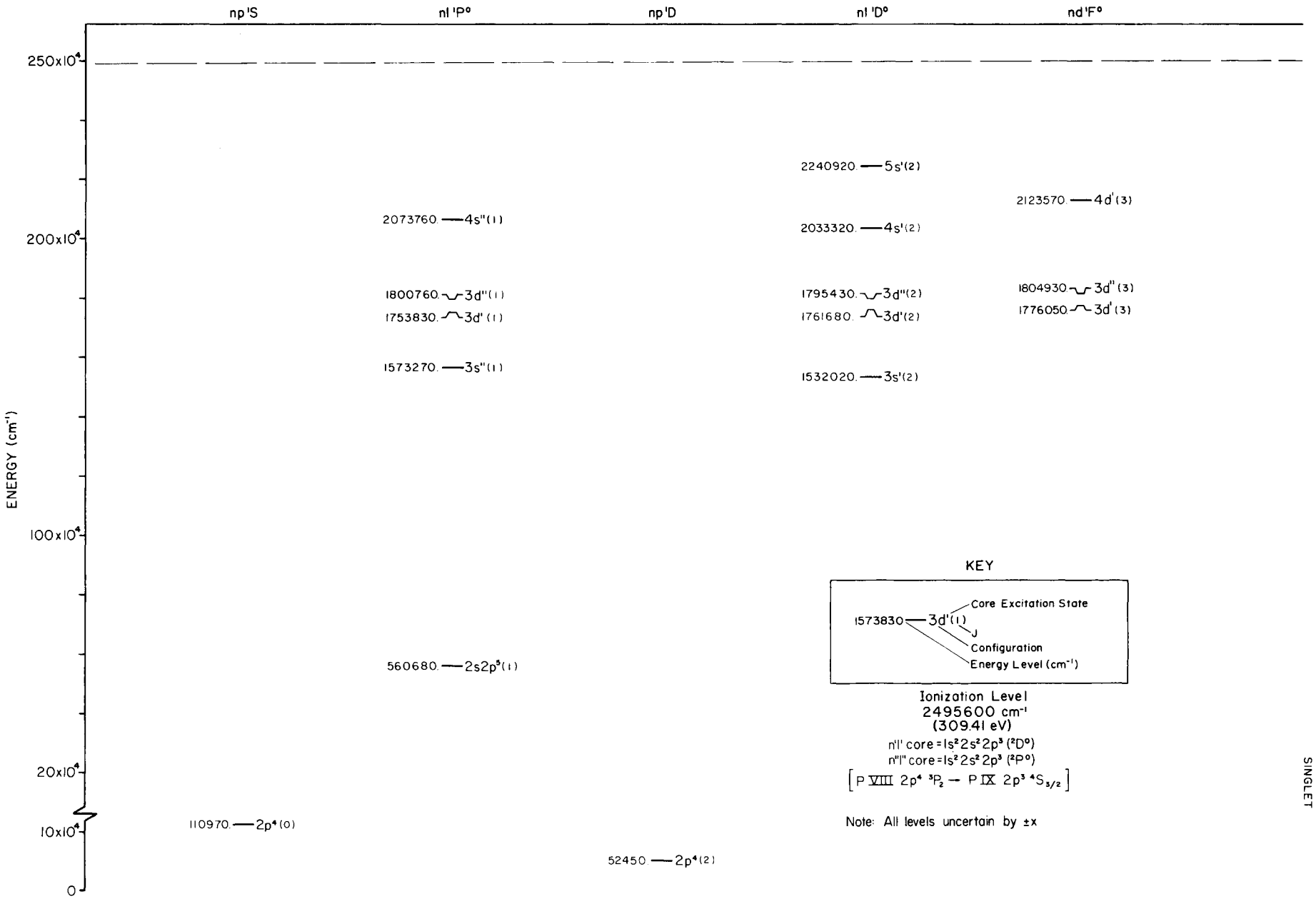
nl core = $2p^4(^3P)$
n'l' core = $2p^4(^1D)$
n''l'' core = $2p^4(^1S)$
n'''l''' core = $2s2p^5(^3P^o)$

P VII
DOUBLET
QUARTET

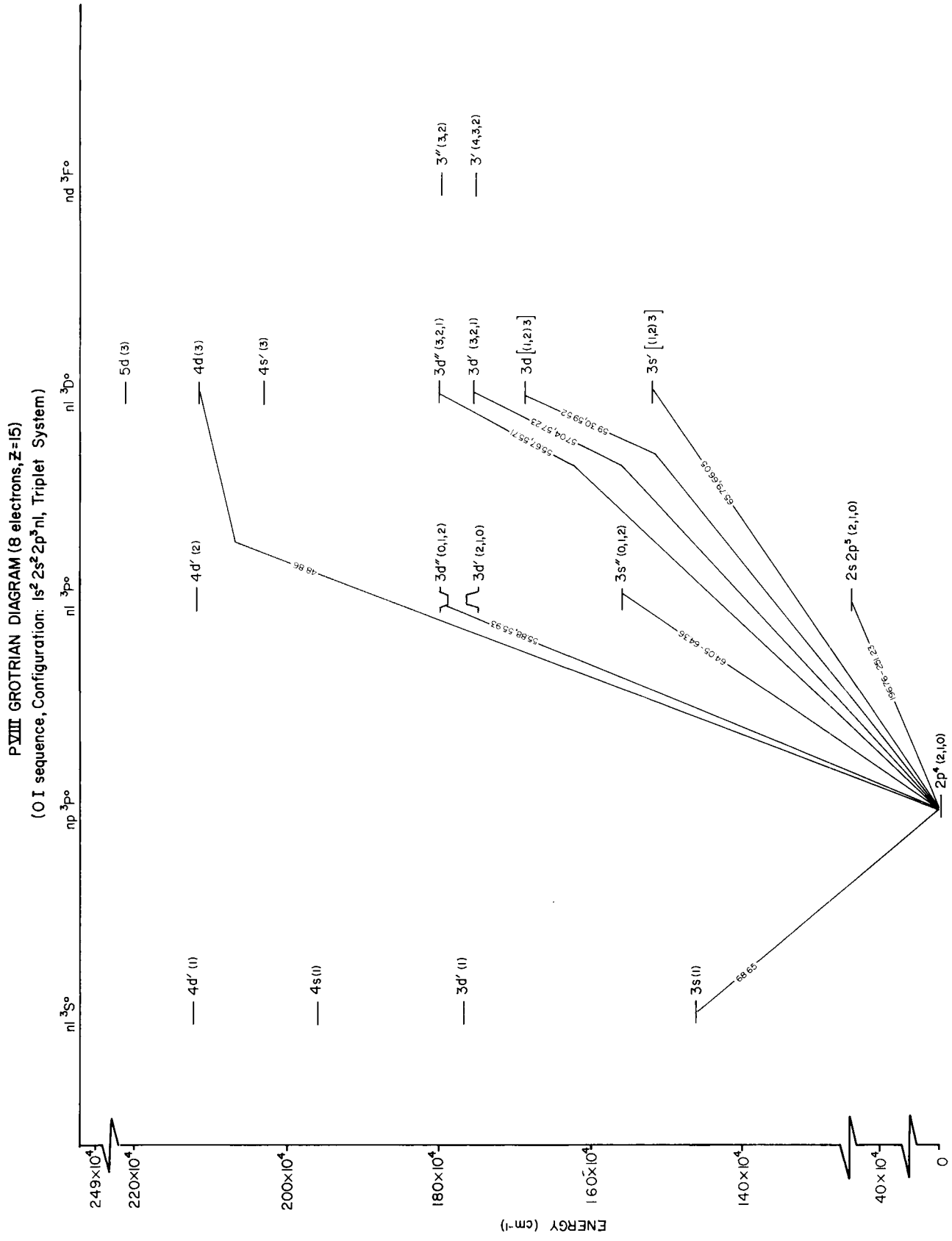
P VIII
SINGLET
GROTRIAN DIAGRAM



P VIII ENERGY LEVELS (8 electrons, Z = 15)
(O I Sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Singlet System)

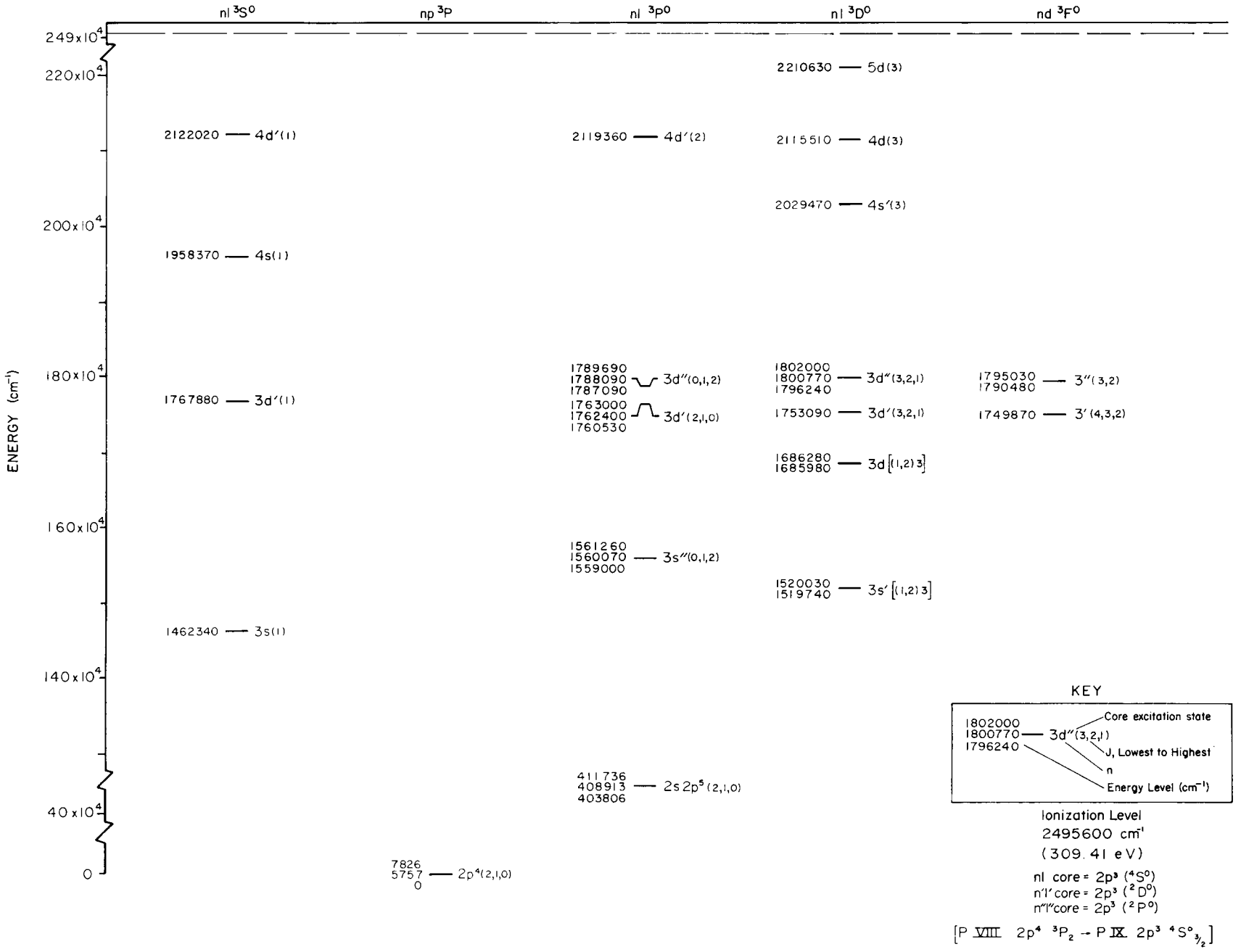


P VIII
TRIPLET
GROTRIAN DIAGRAM

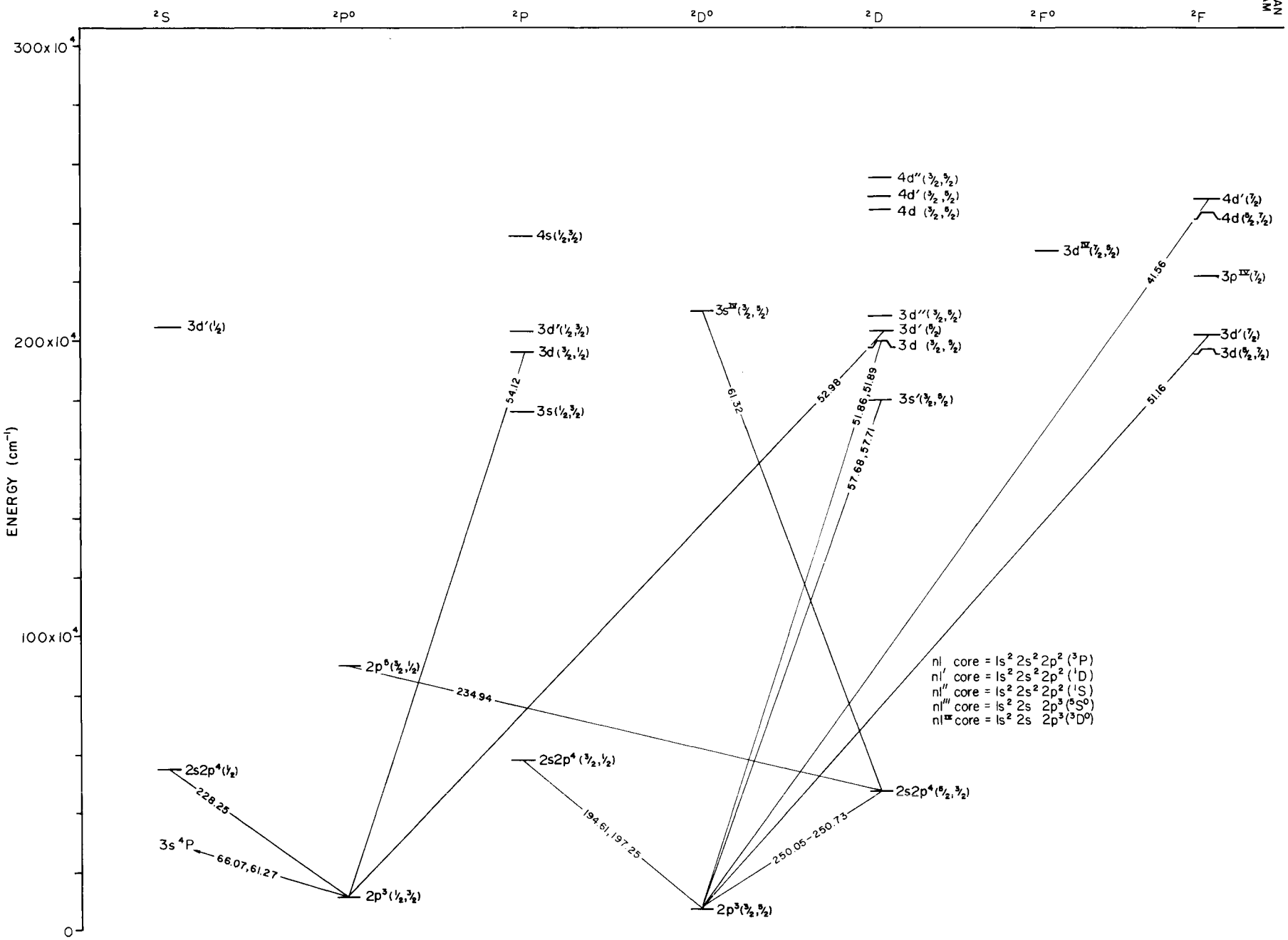


P VIII ENERGY LEVELS (8 electrons, Z=15)

(O I sequence, Configuration: $1s^2 2s^2 2p^3 nl$, Triplet System)

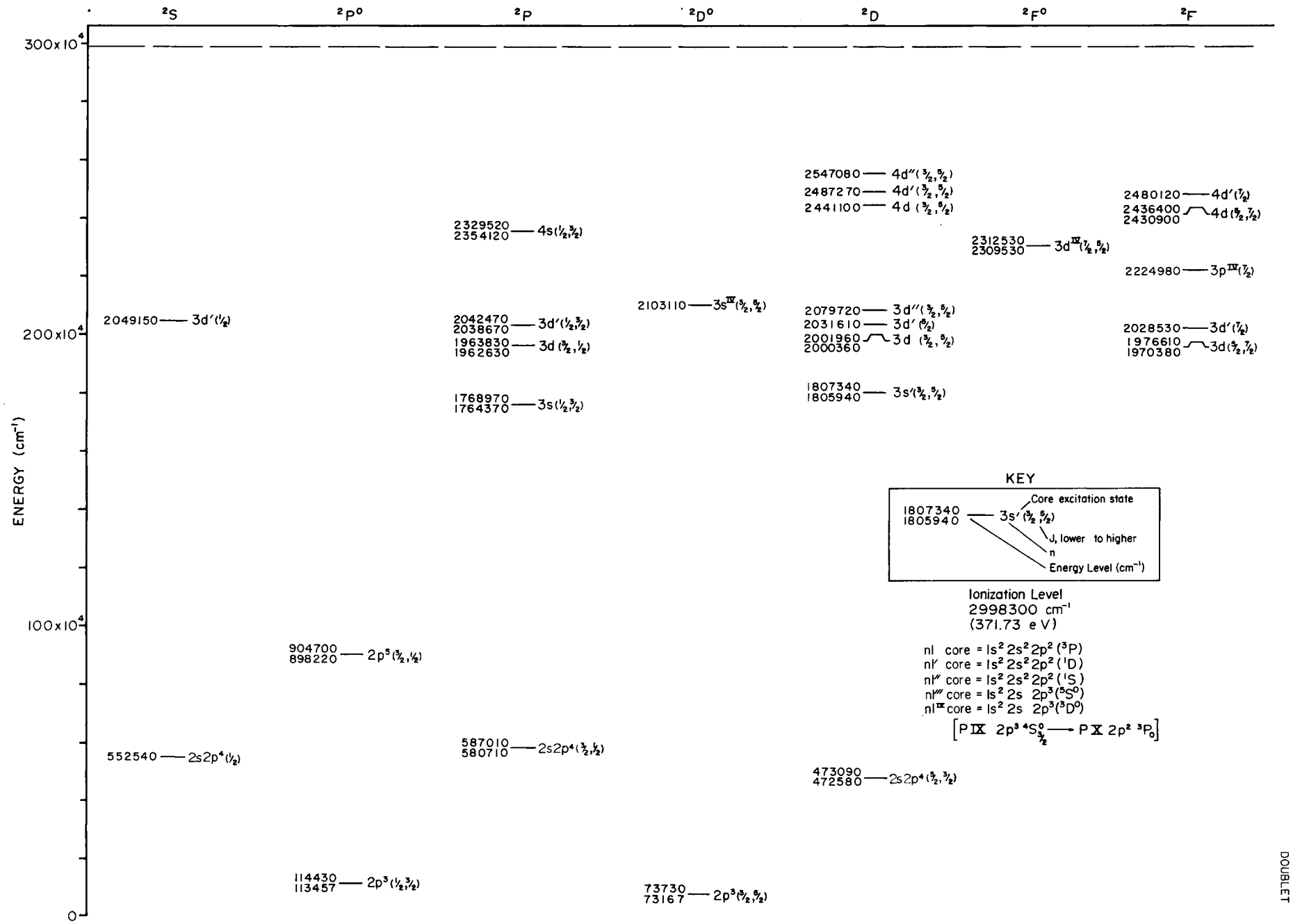


P IX GROTRIAN DIAGRAM (7 electrons, Z=15)
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)

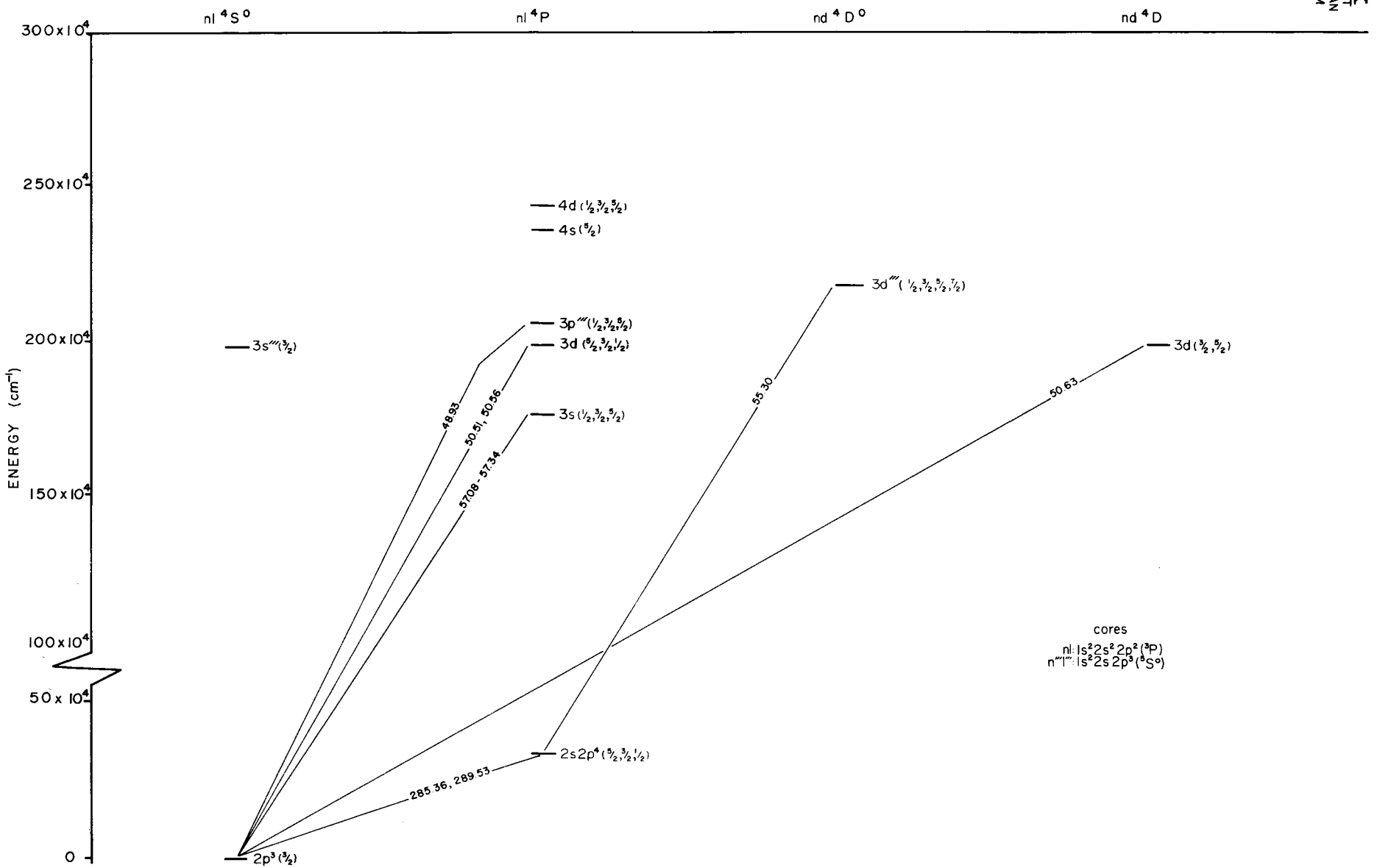


P IX ENERGY LEVELS (7 electrons, Z=15)

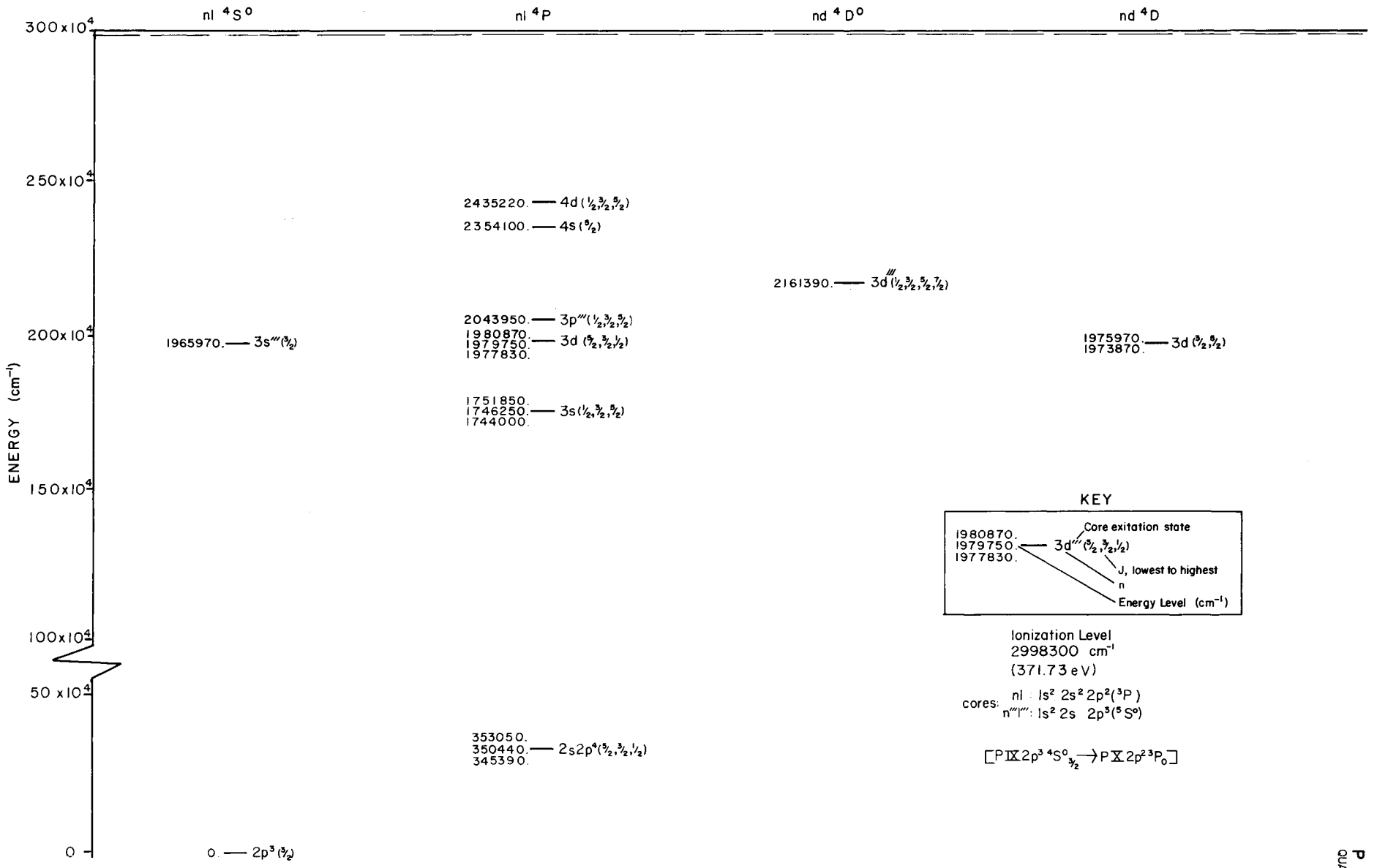
(N I sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Doublet System)



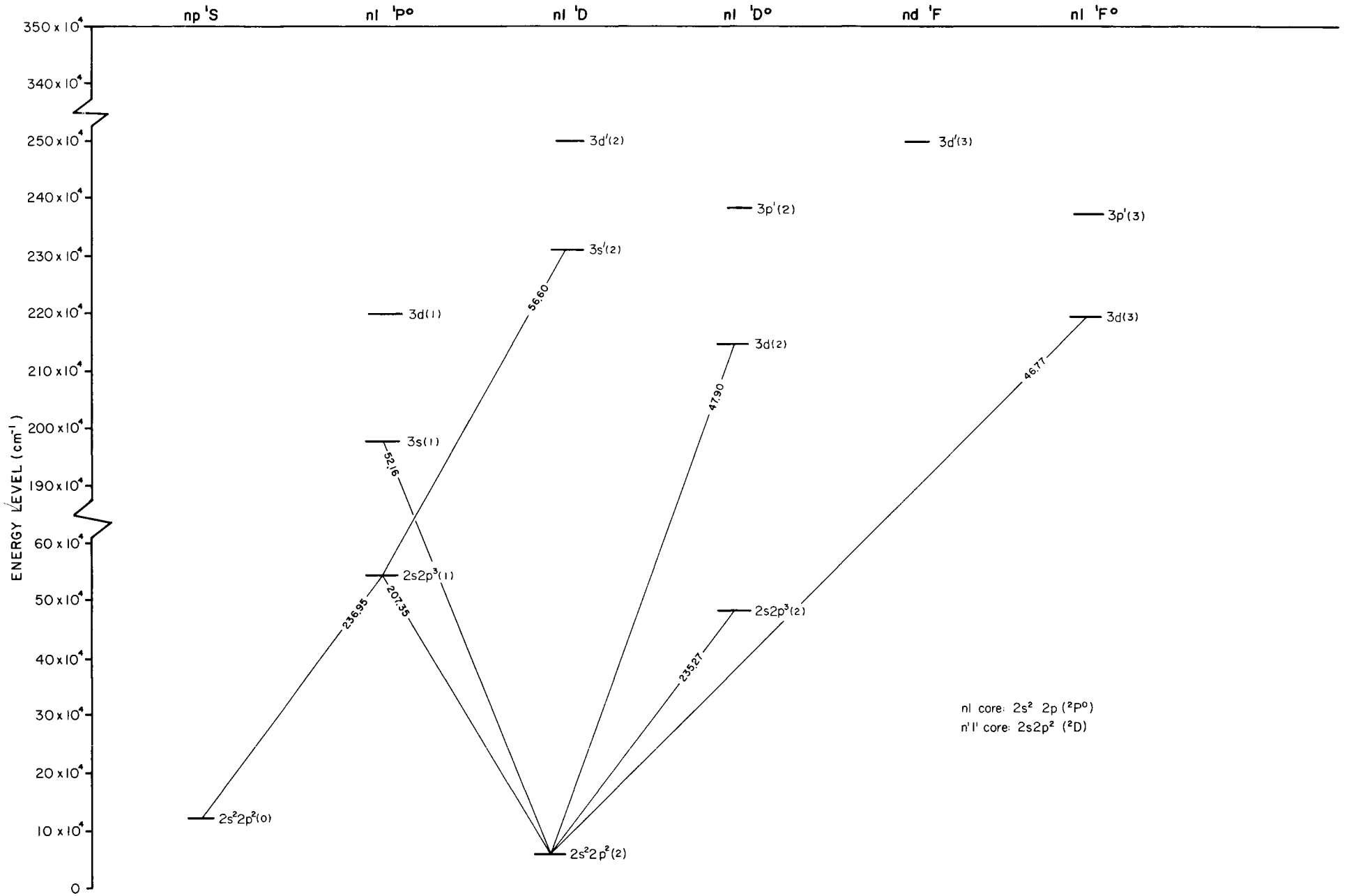
P IX GROTRIAN DIAGRAM (7 electrons, Z=15)
(N I sequence, Configuration: $1s^2\,2s^2\,2p^2nl$, Quartet System)



P IX ENERGY LEVELS (7 electrons, Z=15)
(NI sequence, Configuration: $1s^2 2s^2 2p^2 nl$, Quartet System)

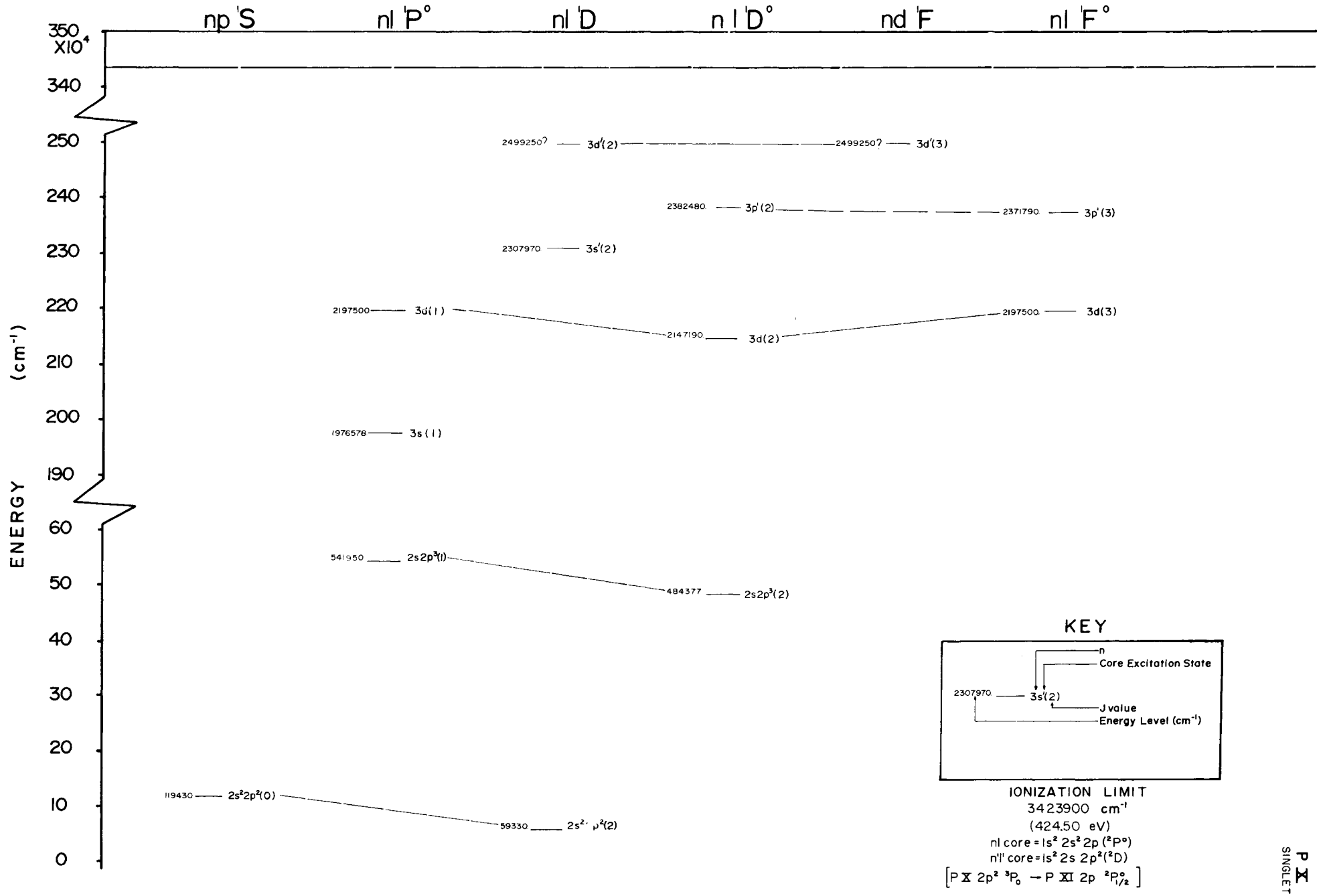


P X GROTRIAN DIAGRAM (6 electrons, Z = 15)
(C I Sequence, Configuration $1s^2\,2s^2 2p(^2P^o)nl$, $1s^2 2s2p^2(^2D)n'l'$, Singlet System)



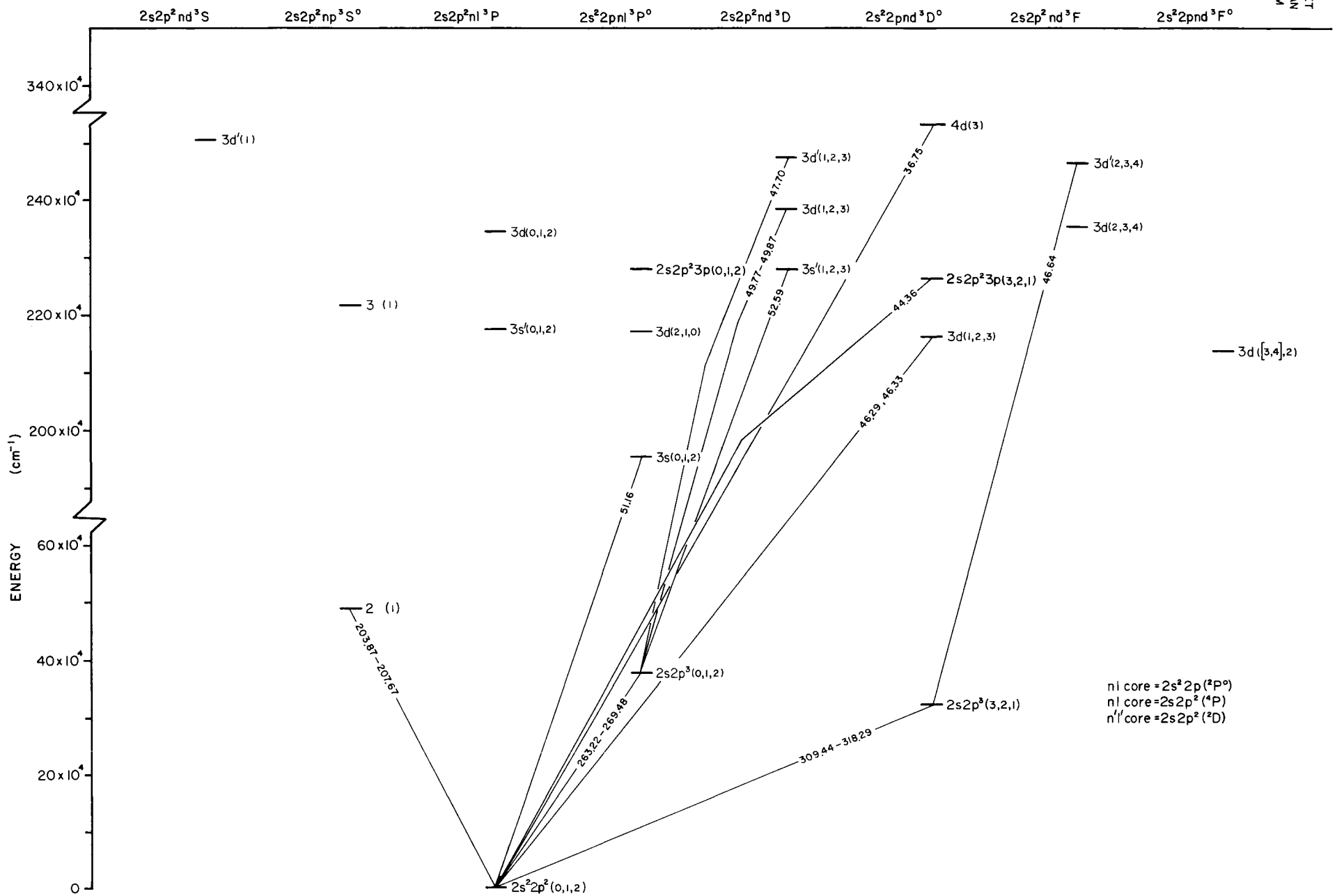
P X ENERGY LEVELS (6 electrons, Z = 15)

(C I Sequence, Configuration: $1s^2 2s^2 2p(^2P^o)nl$, $1s^2 2s2p^2(^2D)n'l'$, Singlet System)



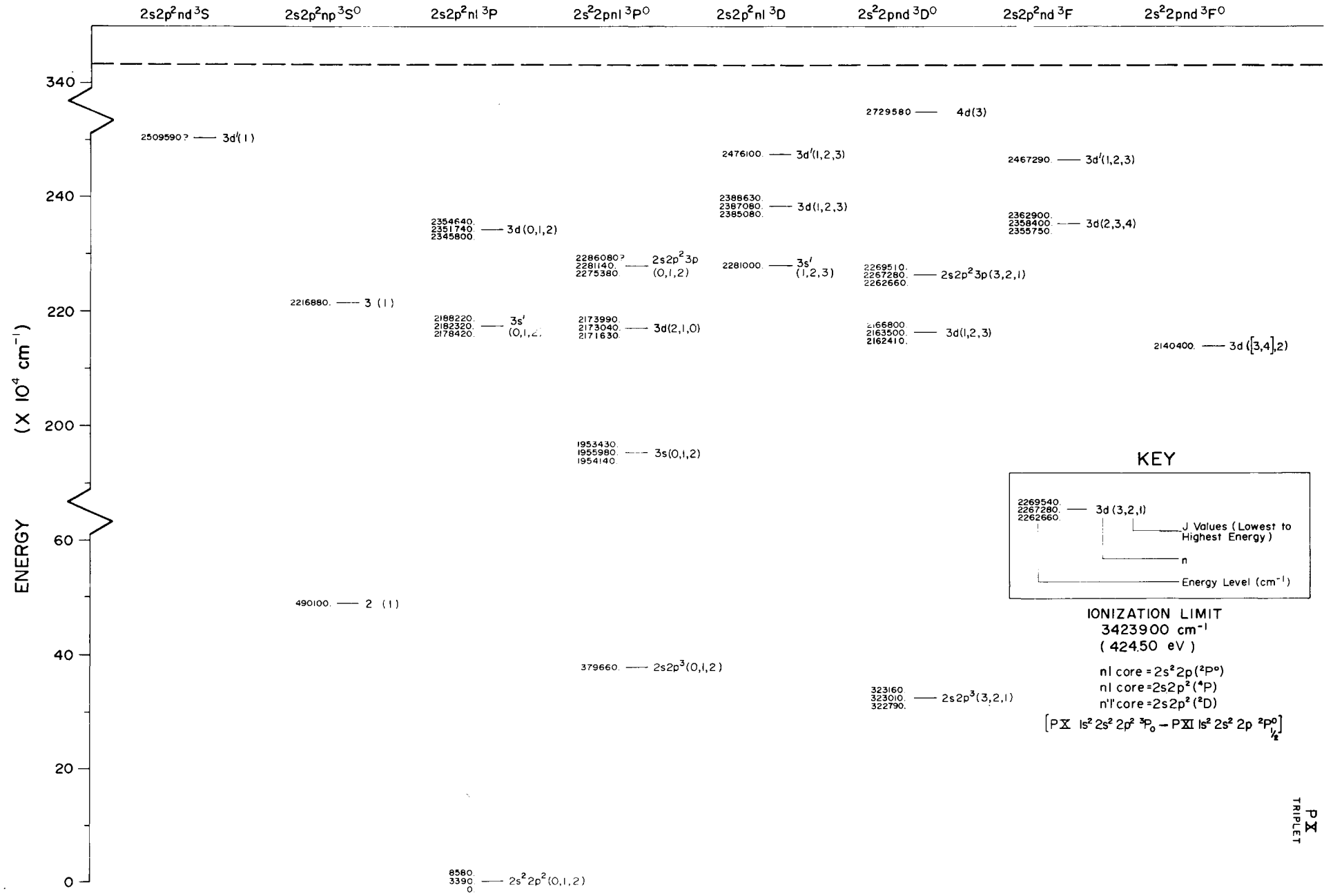
P X GROTRIAN DIAGRAM (6 electrons , Z = 15)

(C I Sequence , Configuration: $1s^2 2s^2 2pnl$, $2s2p^2nl$, Triplet System)

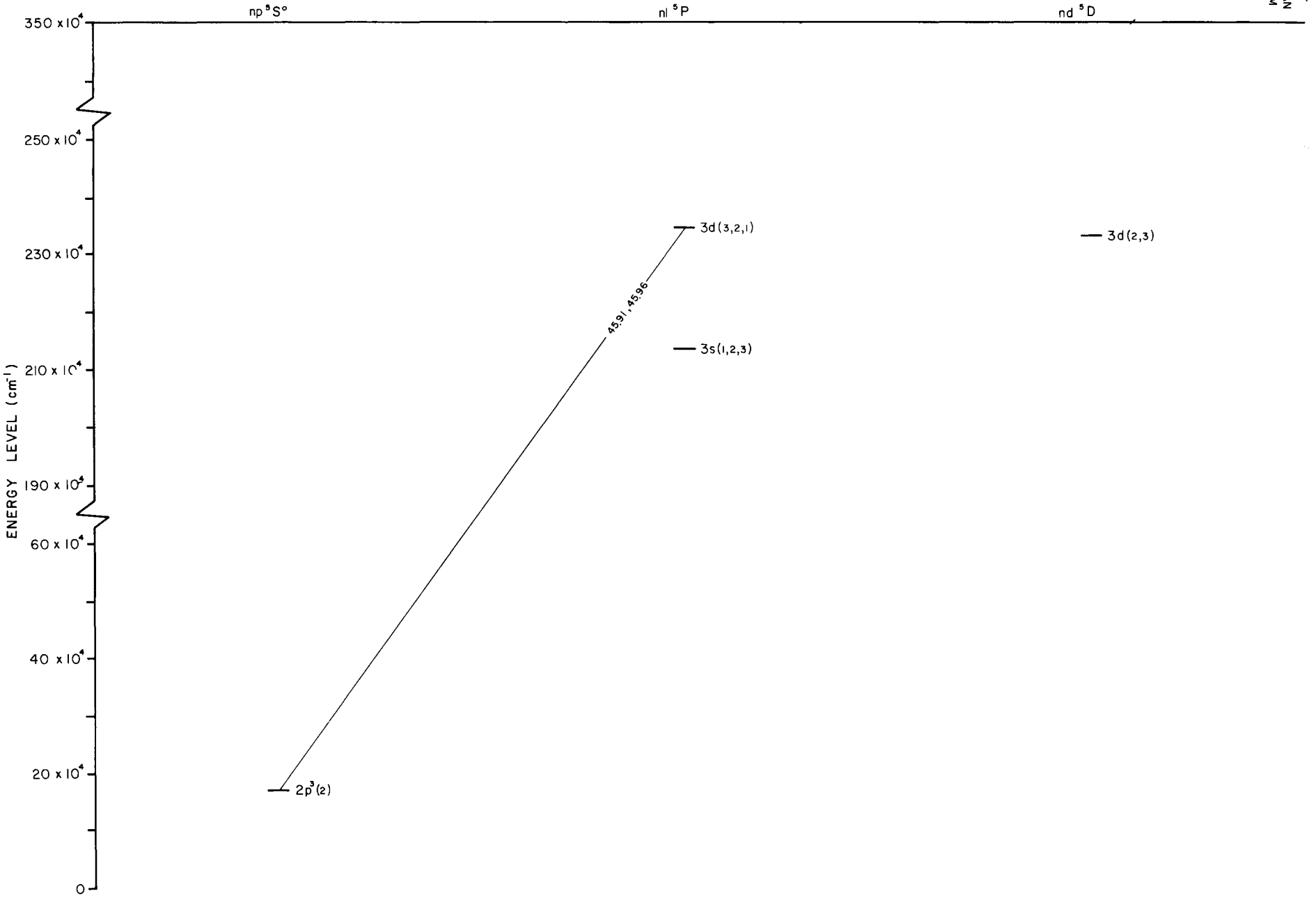


P X ENERGY LEVELS (6 electrons, Z=15)

(C I Sequence, Configuration: $1s^2 2s^2 2p\,nl$, $2s2p^2 nl$, Triplet System)

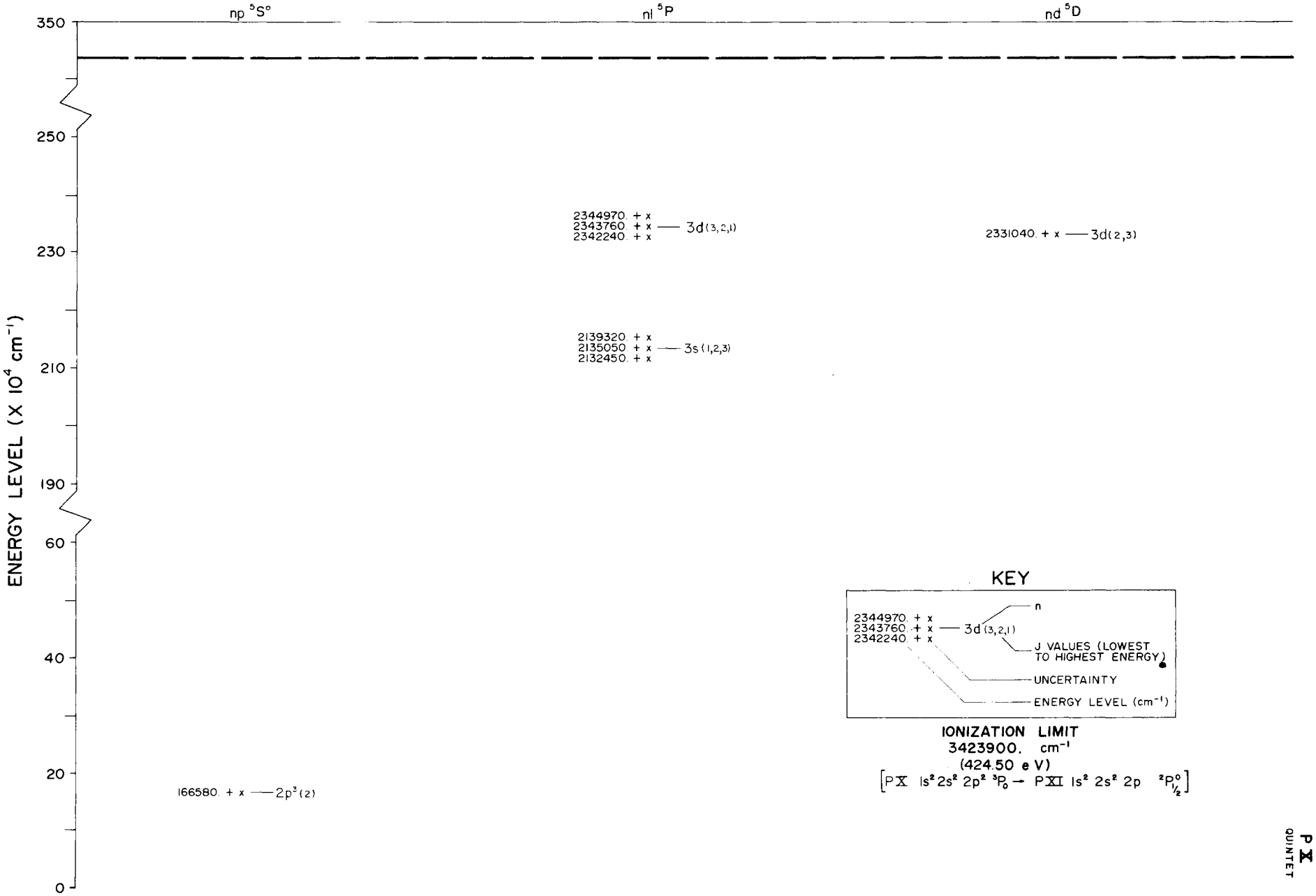


P X GROTRIAN DIAGRAM (6 electrons, Z = 15)
(CI Sequence, Configuration $1s^2\,2s\,2p^2\,nl$, Quintet Term System)



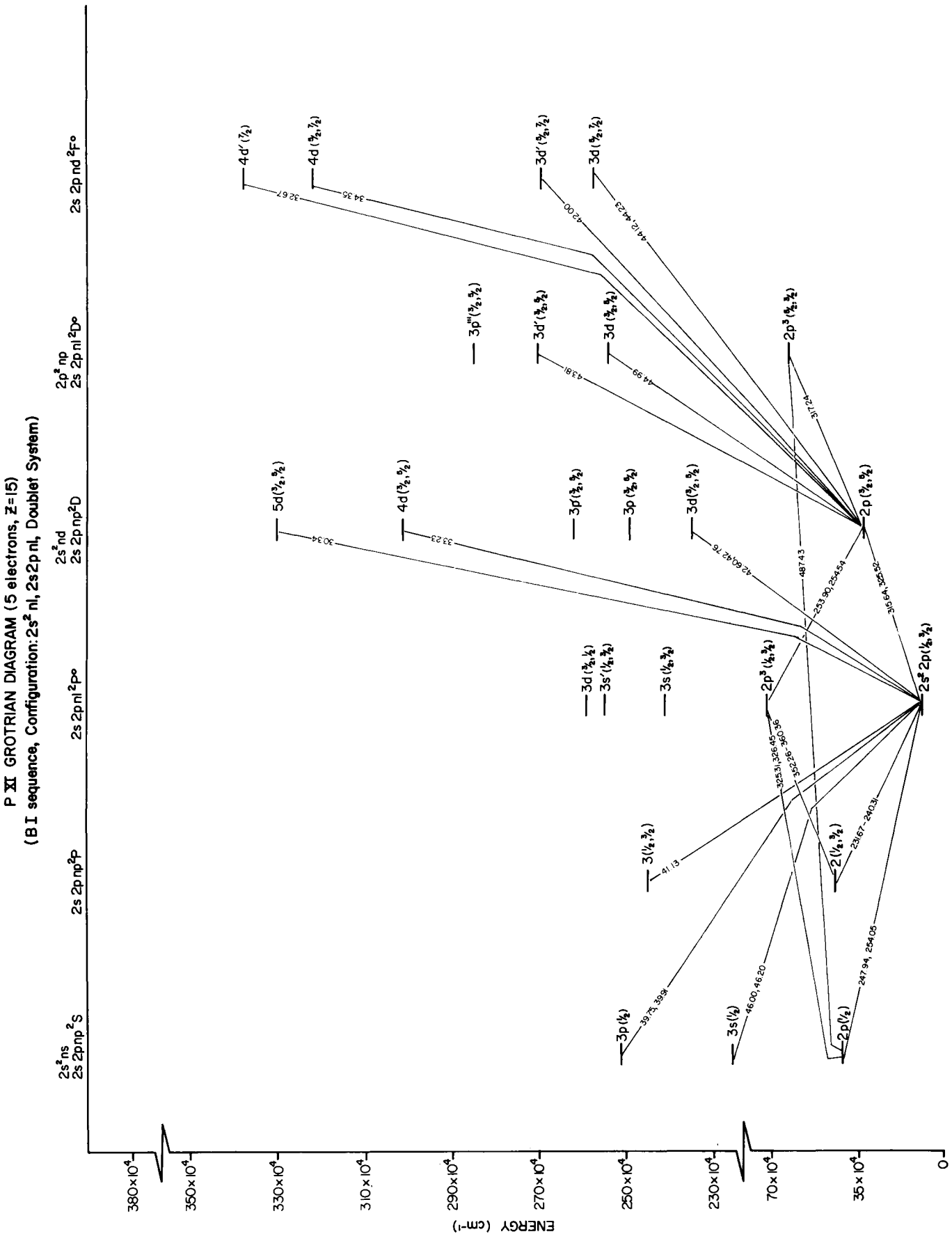
P X ENERGY LEVELS (6 electrons, Z=15)

(C I Sequence, Configuration $1s^2 2s 2p^2\ nl$, Quintet Term System)



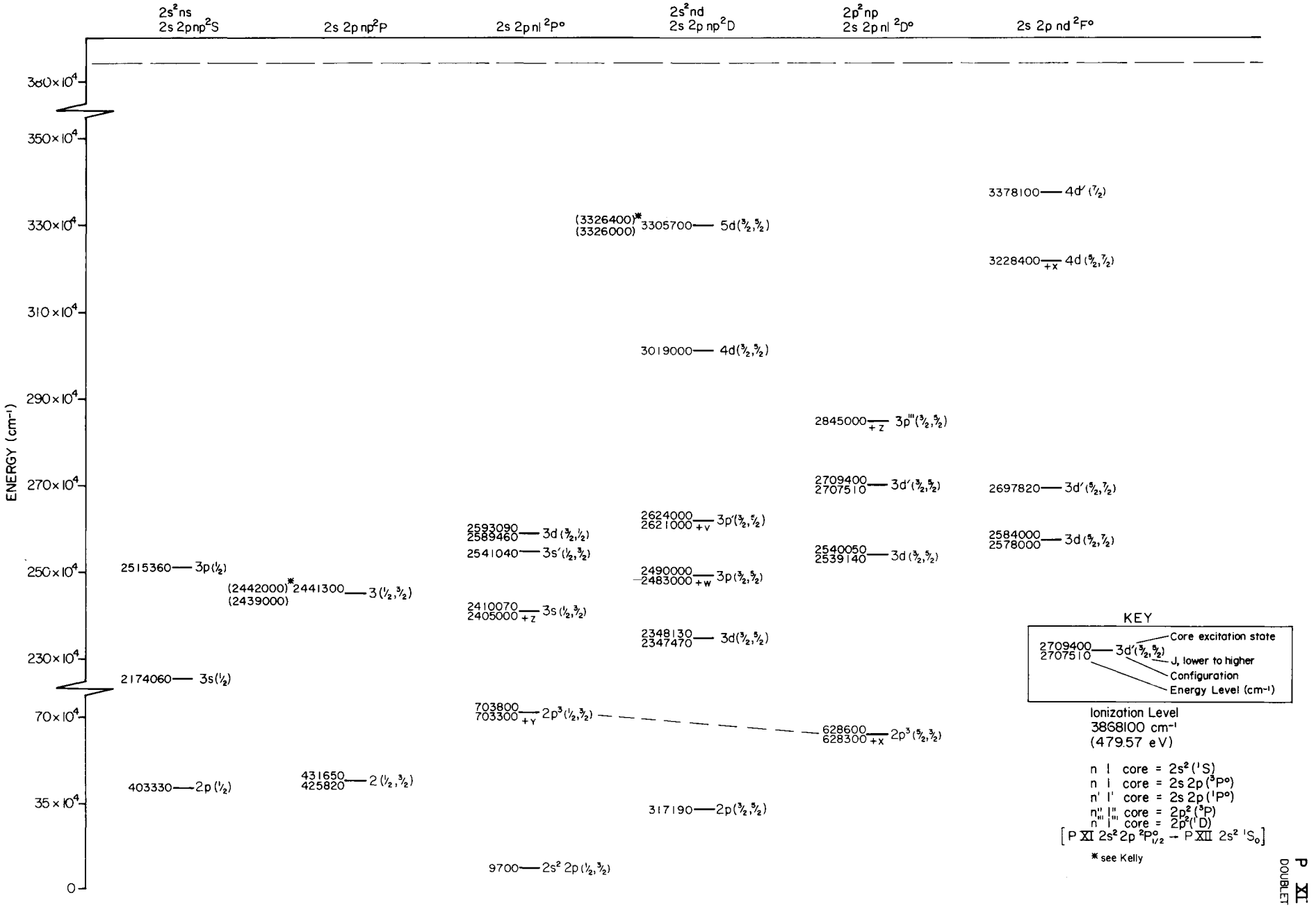
P X
QUINTET

P XI
DOUBLET
GROTRIAN DIAGRAM

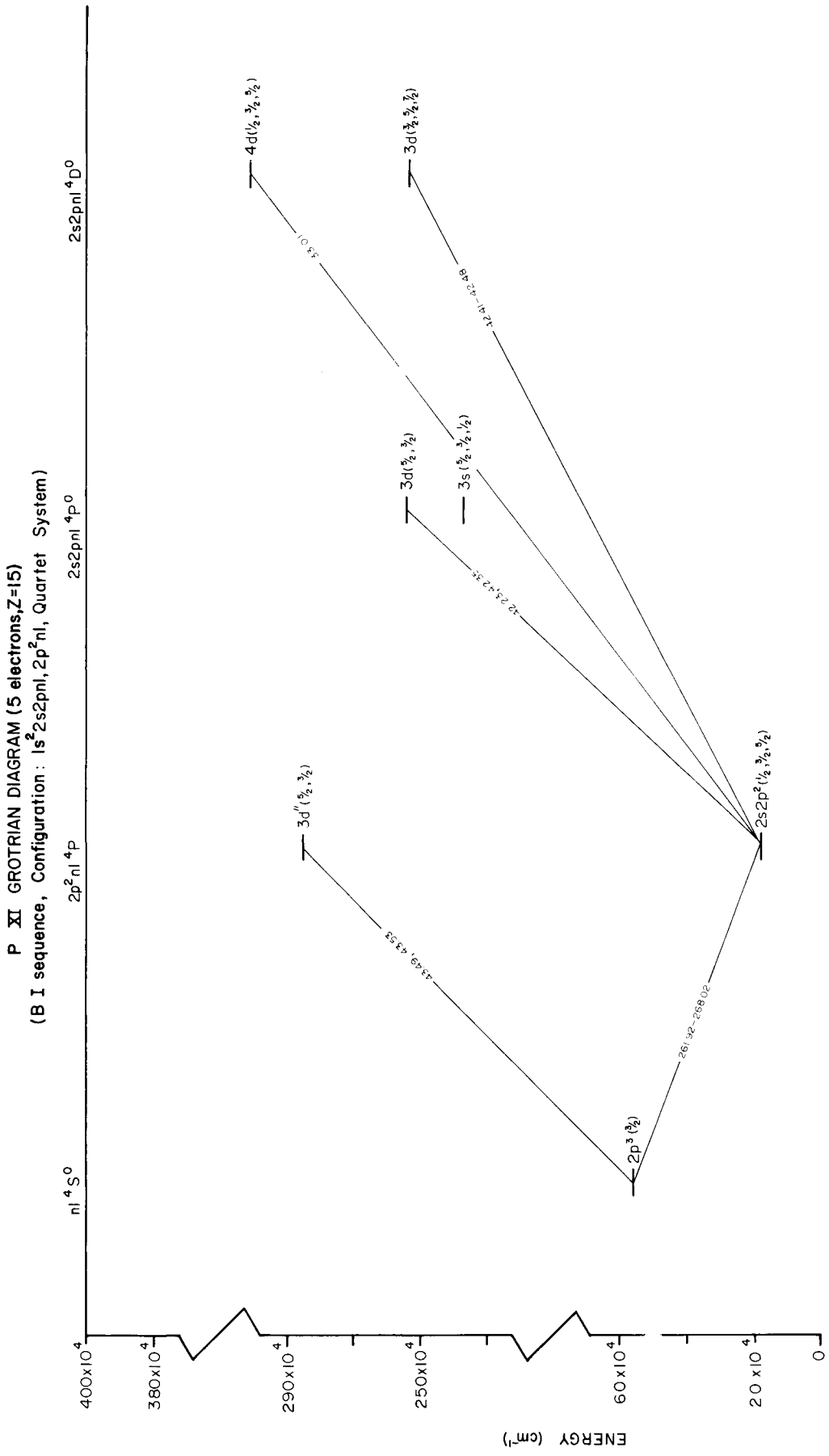


P XI ENERGY LEVELS (5 electrons, Z = 15)

(B I sequence, Configuration: $2s^2nl$, $2s2pnl$, Doublet System)

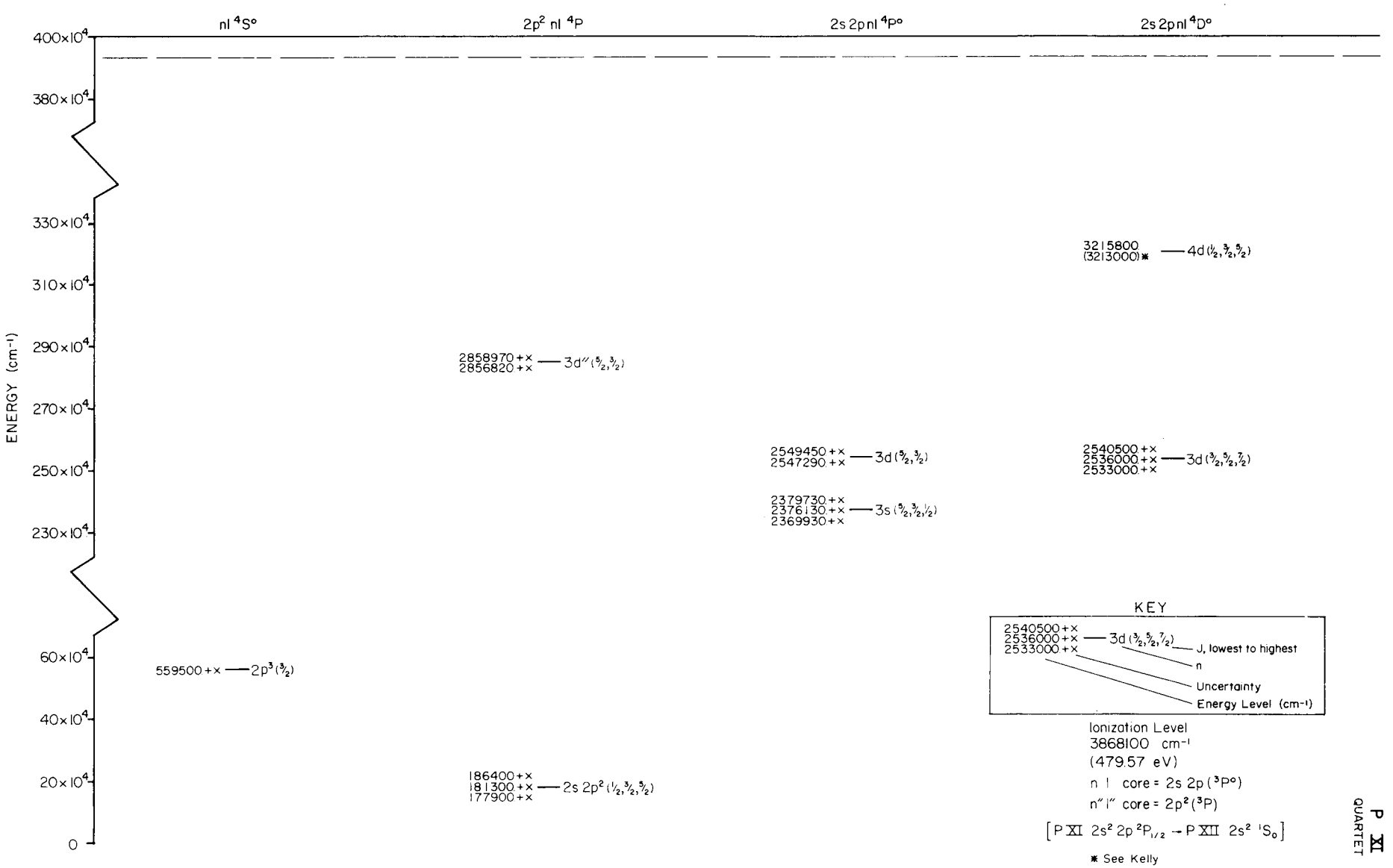


P XI
DOUBLET


P XI GROTRIAN DIAGRAM (5 electrons, Z=15)
(B I sequence, Configuration: $1s^2 2s2pnl$, $2p^2nl$, Quartet System)
$nl\,^4S^o$
$2p^2nl\,^4P$
$2s2pnl\,^4P^o$
$2s2pnl\,^4D^o$
$4d(\frac{1}{2},\frac{3}{2},\frac{5}{2},\frac{7}{2})$
$3d(\frac{3}{2},\frac{5}{2},\frac{7}{2},\frac{1}{2})$
$3d(\frac{5}{2},\frac{3}{2})$
$3s(\frac{5}{2},\frac{3}{2},\frac{1}{2})$
$3d''(\frac{5}{2},\frac{3}{2})$
$2s2p^2(\frac{1}{2},\frac{3}{2},\frac{5}{2},\frac{7}{2})$
$2p^3(\frac{3}{2})$
53.01
42.41-42.48
42.23-42.35
43.49-43.53
261.92-268.02
400x10^4
380x10^4
290x10^4
250x10^4
60x10^4
20x10^4
0
ENERGY (cm^-1)

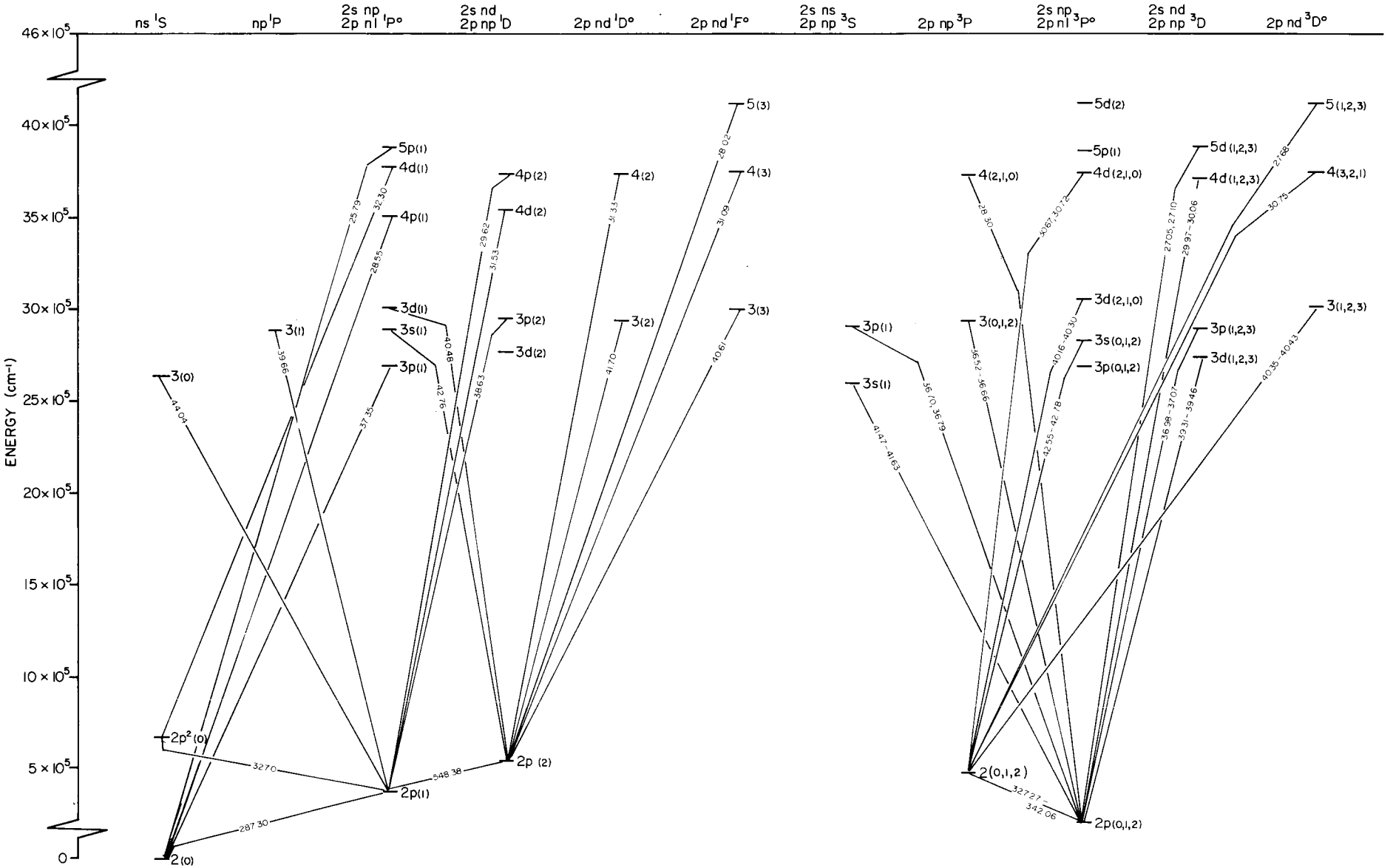
P XI ENERGY LEVELS (5 electrons, Z = 15)

(B I sequence, Configuration: $1s^2\,2s\,2p\,nl$, Quartet System)



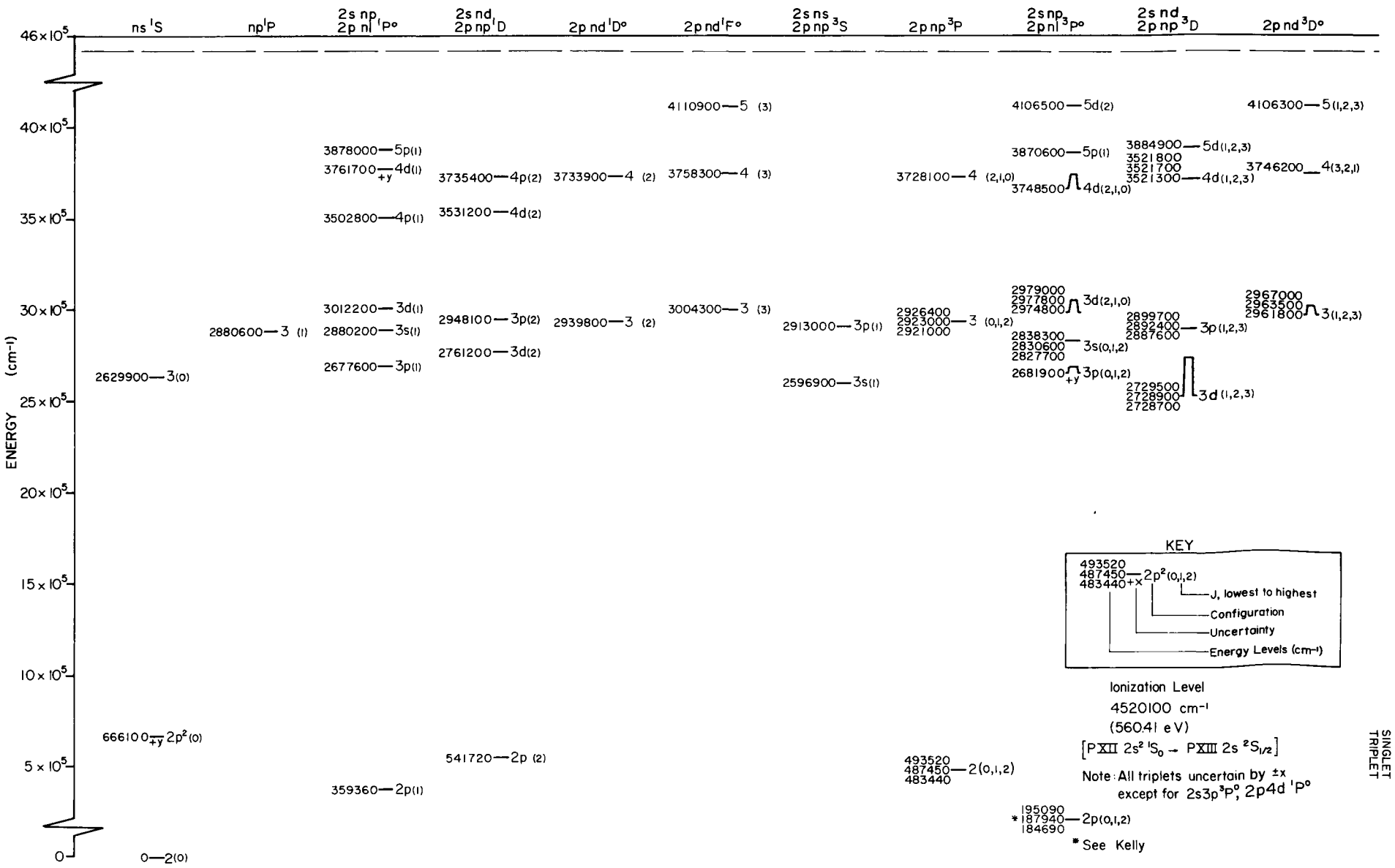
P XII GROTRIAN DIAGRAM (4 electrons, Z = 15)

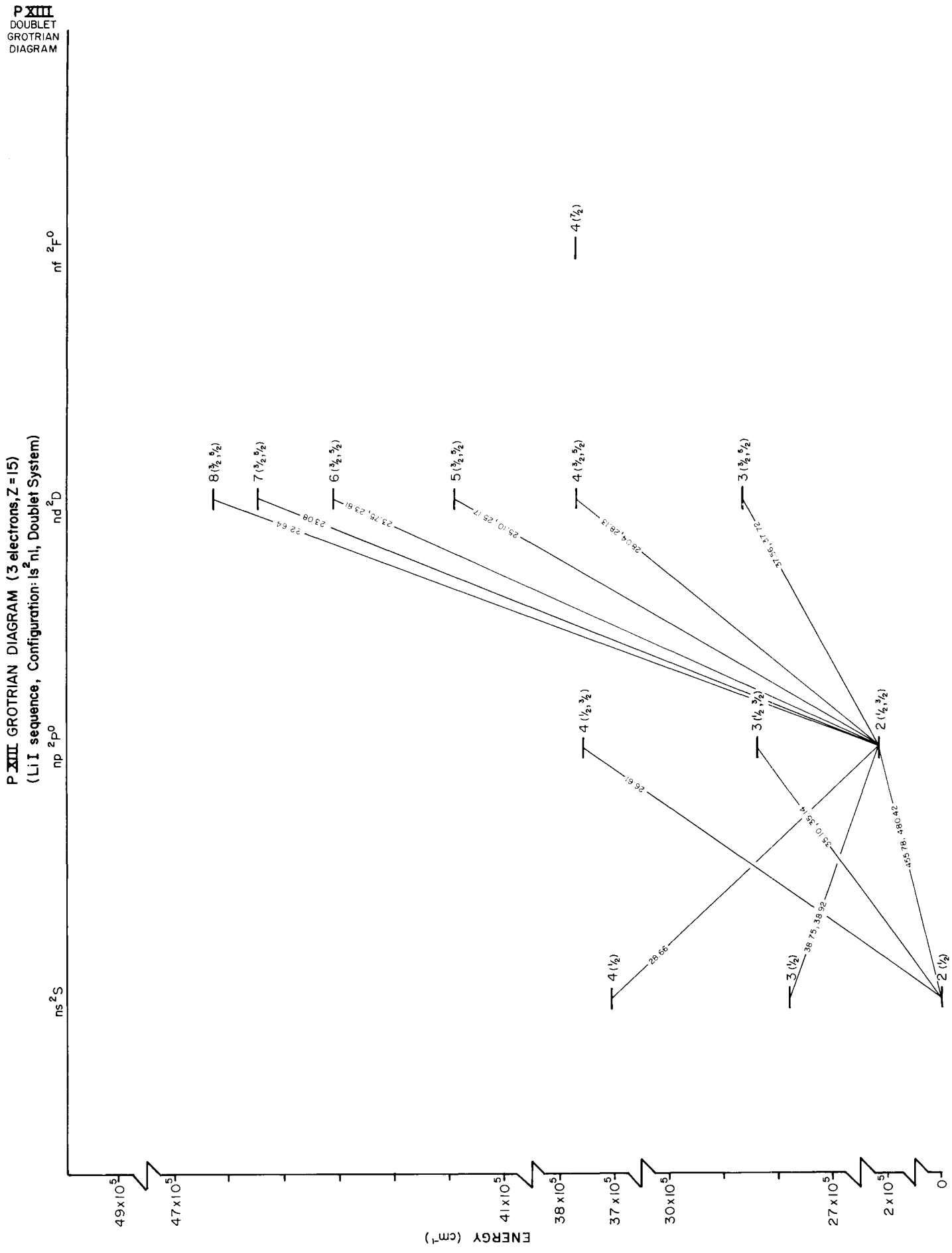
(Be I sequence, Configuration: $1s^2 nl\, n'l'$, Singlet & Triplet System)



P XII ENERGY LEVELS (4 electrons, Z=15)

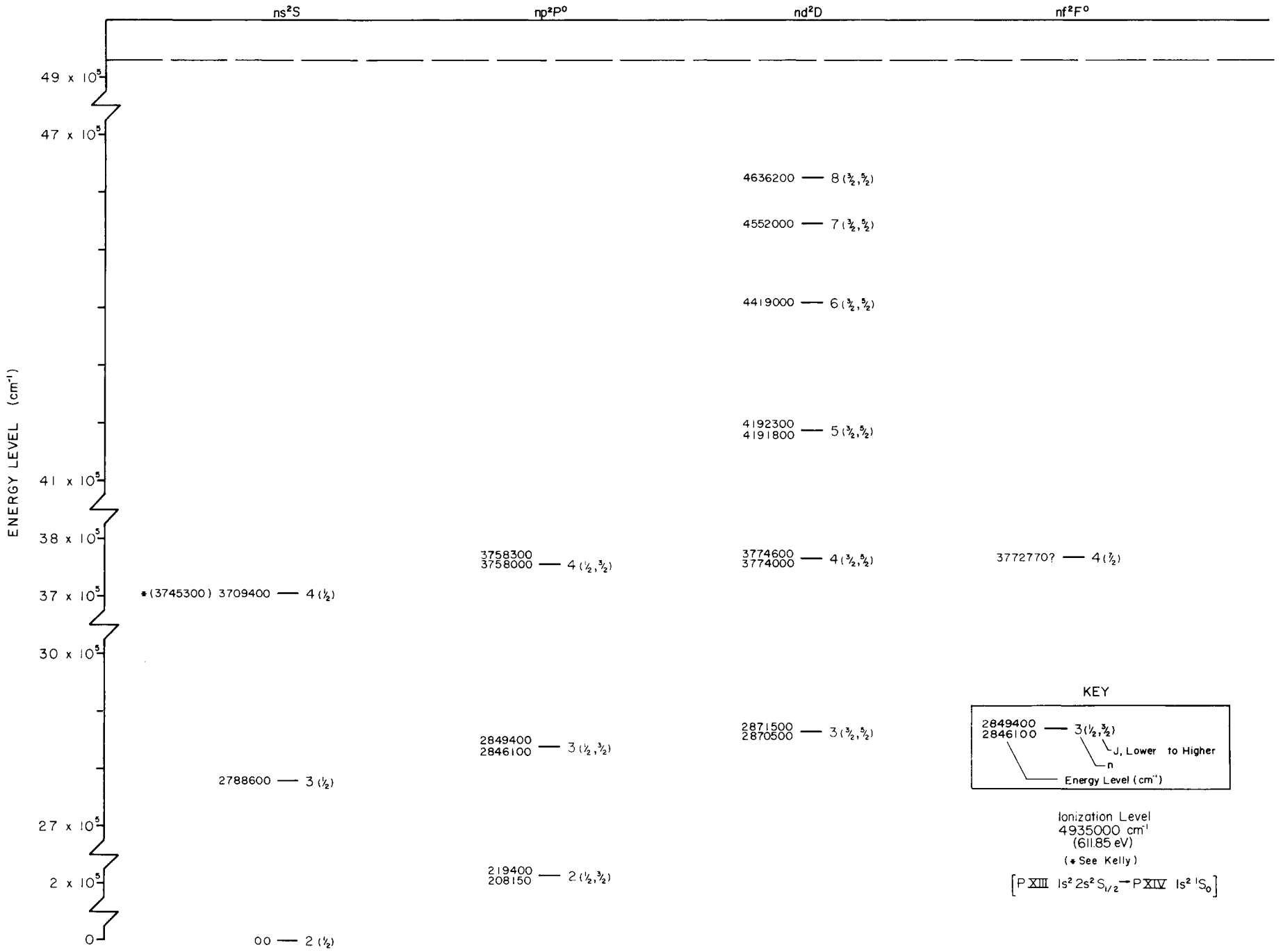
(Be I sequence, Configuration: $1s^2\,nl\,n'l'$, Singlet & Triplet System)



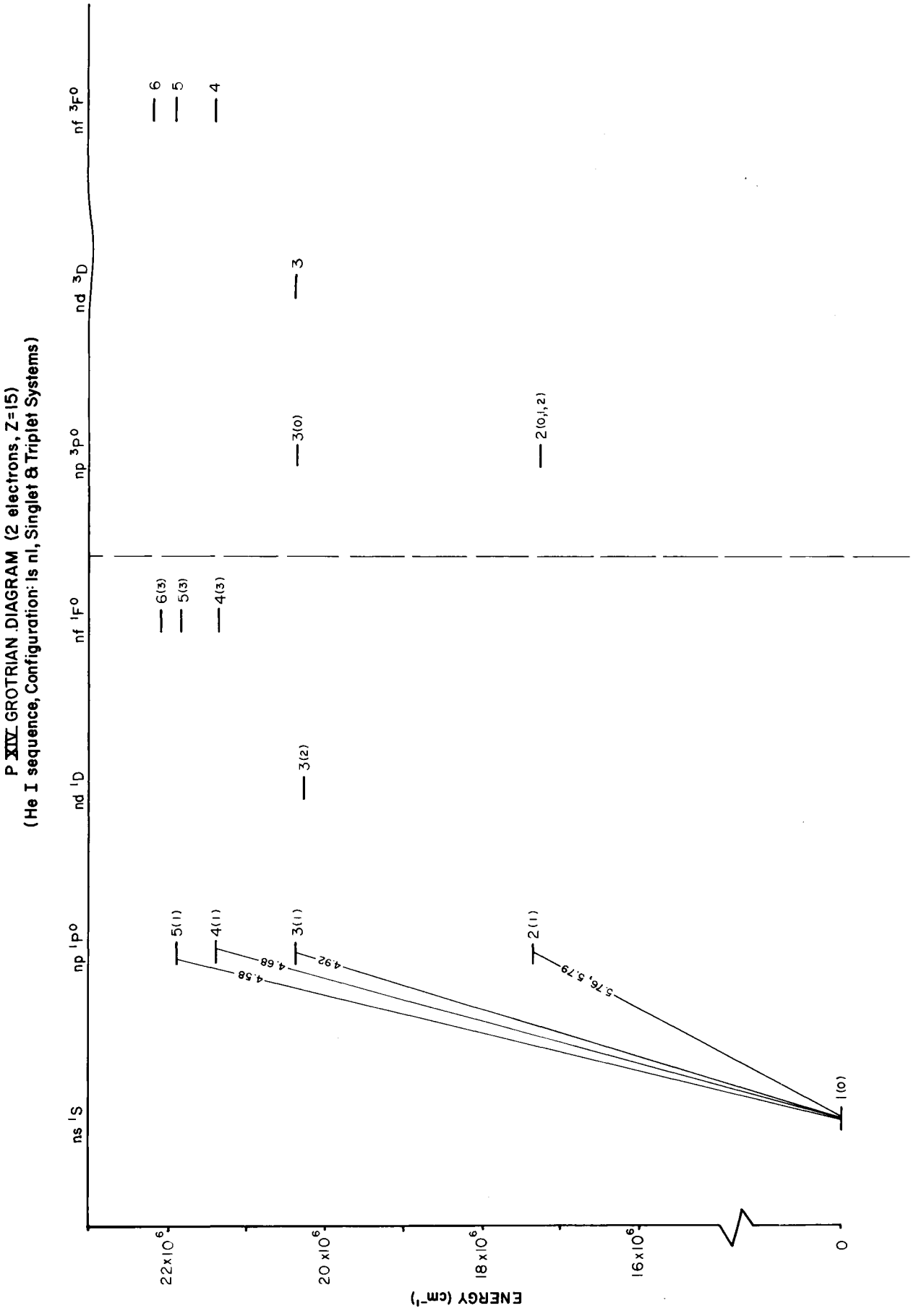

P XIII
DOUBLET
GROTRIAN
DIAGRAM
P XIII GROTRIAN DIAGRAM (3 electrons, Z = 15)
(Li I sequence, Configuration: 1s²nl, Doublet System)
ns ²S
np ²P°
nd ²D
nf ²F°
ENERGY (cm⁻¹)
49x10⁵
47x10⁵
41x10⁵
38x10⁵
37x10⁵
30x10⁵
27x10⁵
2x10⁵
0
8(3/2,5/2)
7(3/2,5/2)
6(3/2,5/2)
5(3/2,5/2)
4(3/2,5/2)
3(3/2,5/2)
4(7/2)
4(1/2,3/2)
3(1/2,3/2)
2(1/2,3/2)
4(1/2)
3(1/2)
2(1/2)
22.64
23.08
23.75, 23.81
25.10, 25.17
28.04, 28.13
37.56, 37.72
26.61
35.10, 35.14
38.75, 38.92
28.66
455.78, 480.42

P XIII ENERGY LEVELS (3 electrons, Z = 15)

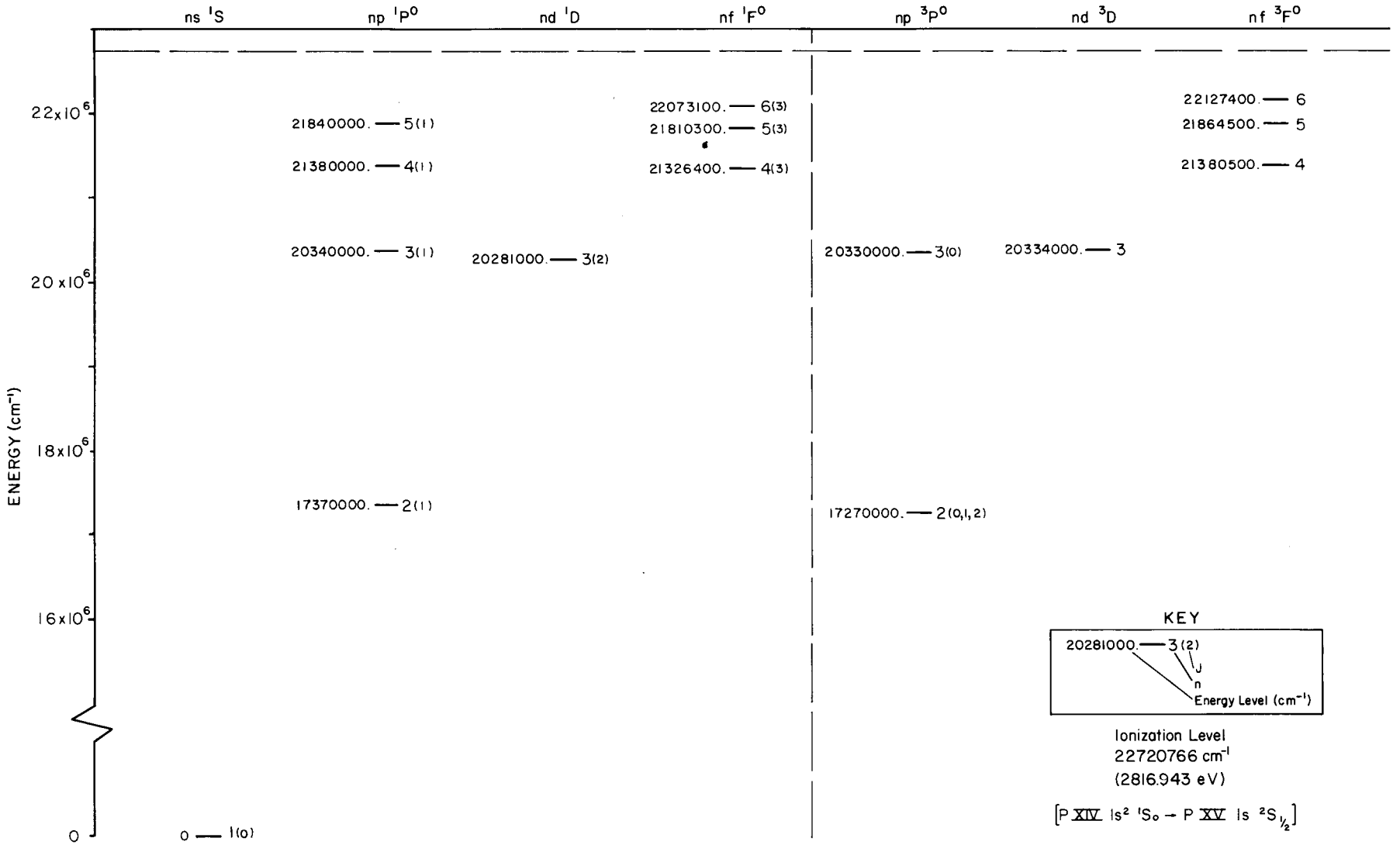
(Li I sequence, Configuration: $1s^2nl$, Doublet System)



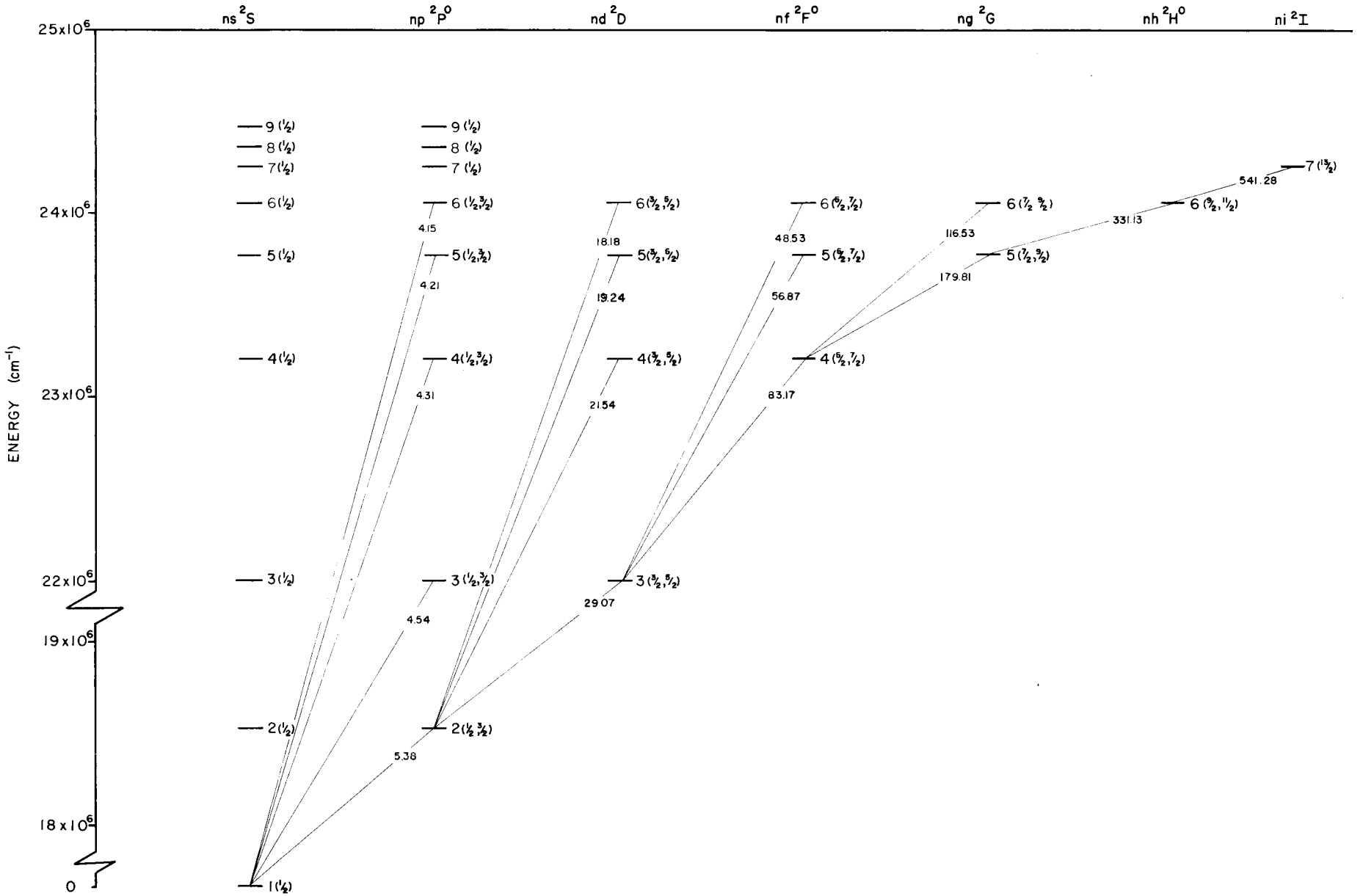
P XIV
SINGLET
TRIPLET
GROTRIAN
DIAGRAM



P XIV ENERGY LEVELS (2 electrons, Z=15)
(He I sequence, Configuration: 1s nl, Singlet & Triplet Systems)

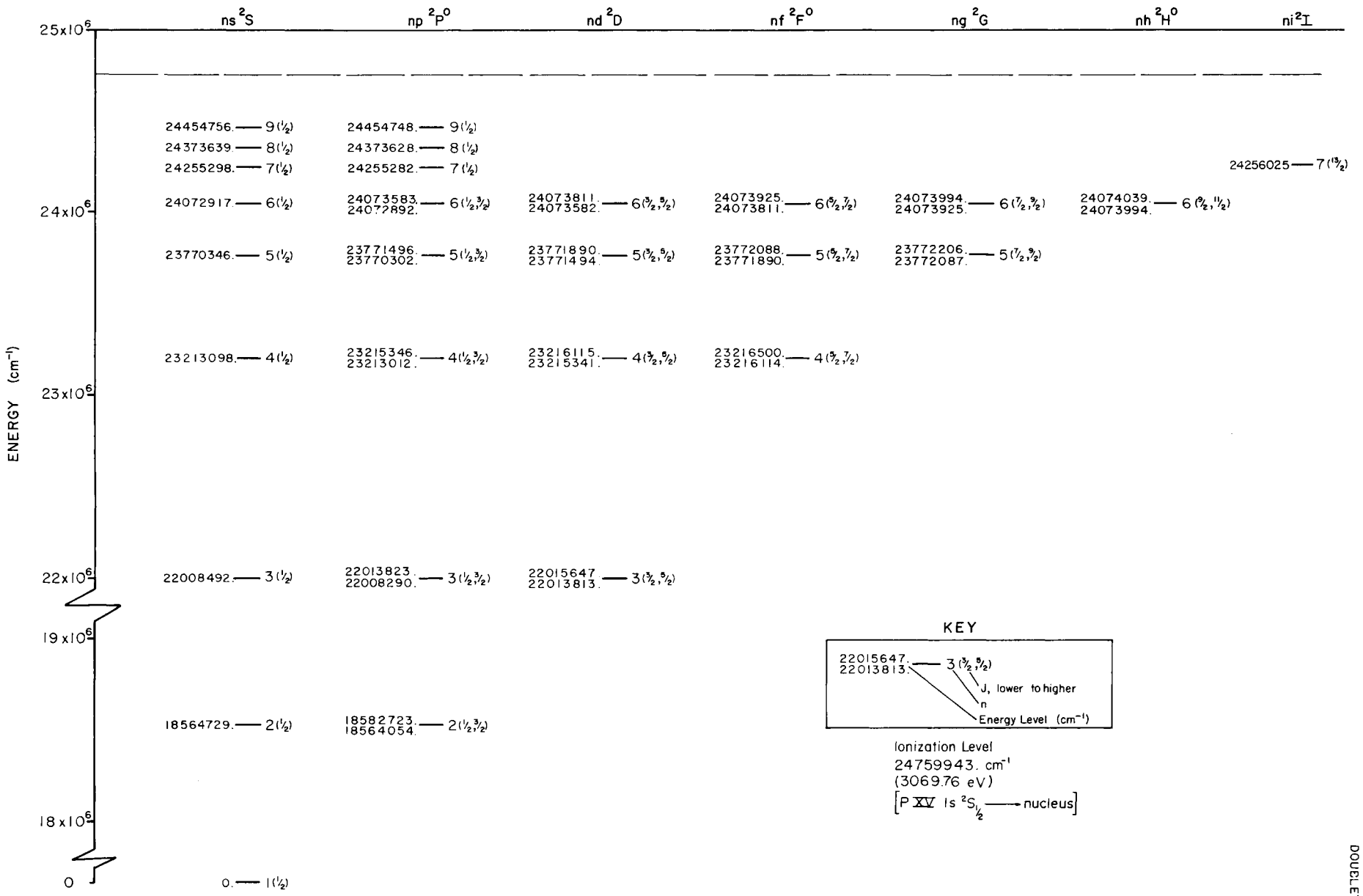


P XV GROTRIAN DIAGRAM(1 electron, Z = 15)
(H I sequence, Configuration : nl, Doublet System)



P XV ENERGY LEVELS (1 electron, Z = 15)

(H I sequence, Configuration : nl, Doublet System)



P I $Z = 15$ 15 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line tables of observed forbidden transitions.

P II $Z = 15$ 14 electrons

I.S. Bowen, Ap. J. **132**, 1 (1960).

Author gives line tables of observed forbidden transitions.

H. Li, J. Opt. Soc. Amer. **62**, 1483 (1972).

Line and energy-level tables for lines from 2285 to 7840 Å.

P III $Z = 15$ 13 electrons

Please see the general references.

P IV $Z = 15$ 12 electrons

Please see the general references.

P V $Z = 15$ 11 electrons

Please see the general references.

P VI $Z = 15$ 10 electrons

Please see the general references.

P VII $Z = 15$ 9 electrons

Please see the general references.

P VIII $Z = 15$ 8 electrons

Please see the general references.

P IX $Z = 15$ 7 electrons

Please see the general references.

P X $Z = 15$ 6 electrons

Please see the general references.

P XI $Z = 15$ 5 electrons

Please see the general references.

P XII $Z = 15$ 4 electrons

Please see the general references.

P XIII $Z = 15$ 3 electrons

Please see the general references.

P XIV $Z = 15$ 2 electrons

Please see the general references.

P XV $Z = 15$ 1 electron

Please see the general references.