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GROTRIAN DIAGRAMS FOR HIGHLY IONIZED MOLYBDENUM MO VI THROUGH MO XLII

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July 1997

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Japan Atomic Energy Research Institute

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Grotrian Diagrams for Highly Ionized Molybdenum
Mo VI through Mo XLII

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(Received June 17, 1997)

Grotrian diagrams are presented to provide graphical overviews for 1,930 spectral lines of highly ionized molybdenum, Mo VI through Mo XLII. In the usual diagram display such as that by Bashkin and Stoner[North-Holland, Amsterdam, 1975], the density of transitions is often too high to allow each transition to be drawn separately. Here in our modified diagrams, the transitions are also represented by lines connecting the upper and lower energy levels, but the lower energy levels are extended and repeated for successive configurations as needed. As a sequence, dense packing is avoided and all lines in a multiplet can be accommodated.

Keywords: Energy Levels, Wavelengths, Molybdenum Ions, Grotrian Diagrams

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*National Institute of Standards and Technology

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高電離モリブデン、Mo VI－Mo XLIIのグロトリアン図

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白井　稔三・Jack SUGAR*・Wolfgang L. WIESE*

(1997年6月17日受理)

高電離モリブデン、Mo VI－Mo XLIIの1,930本のスペクトル線をエネルギー準位と遷移の特徴を視覚化するグロトリアン図にまとめた。Bashkin and Stoner[North-Holland, Amsterdam, 1975] による通常のグロトリアン図の表示法では、それぞれの遷移を表す線の密度が高くなり過ぎ、全ての遷移を表示できないことがしばしばある。我々のグロトリアン図でも遷移を線で表すが、しかし、遷移の下位準位を必要なだけ繰り返す方法に変更した。その結果、遷移線の高密度化が回避でき、多重項等全ての遷移を表すことができた。

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1. Introduction

During the last 10 years we have published a series of spectroscopic data table for highly ionized heavy atoms that occur either as impurities in fusion energy devices or which have been injected into these hot plasmas for diagnostic purposes. These spectroscopic data are required both for modelling the energy balance and impurity cooling effects in such plasmas as well as for applying non-perturbing spectroscopic techniques to determine plasma parameters. In addition, spectroscopic data needs for highly ionized atoms exist in astrophysics, especially the physics of the solar corona, and in atomic physics research. A good bit of new spectral analysis work, both observations and calculations, had been done in recent years, and the results had not been tabulated conveniently before. We have thus critically compiled these spectroscopic data into single monographs for each element and have published, in order of nuclear charge, such tables for the spectra of Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Kr, and Mo ions.

Since we have now compiled this series, we are presenting all these data in a single volume [1] to provide users with the convenience of a single source. However, we do not include the extensive Grotrian diagrams to provide graphical overviews because these would make this volume very large and unwidely.

This report contains all Grotrian diagrams for Mo VI through Mo XLII. The Grotrian diagrams show energy levels and the principal transitions. Typical examples of such diagrams are found in the book published by Bashkin and Stoner [2]. In the usual diagram display such as that by Bashkin and Stoner, the density of transitions is often too high to allow each transition to be drawn separately. Here in our modified diagrams, the transitions are also represented by lines connecting the upper and lower energy levels, but the lower energy levels are extended and repeated for successive configurations as needed. As a sequence, dense packing is avoided and all lines in a multiplet can be accommodated. The diagrams thus allow a quick survey of the principal features of the levels and transitions in the various ions.

Acknowledgments

The present research was organized and inspired by Dr. M. Nakagawa, Chairman of the Research Committee on Atomic and Molecular Data of the Japan Atomic Energy Research Institute, to whom the authors owe special thanks. This work was undertaken under the U.S.-Japan Fusion Cooperation Program and partially supported by the Office of Fusion Energy of the U.S. Department of Energy.

References

[1] T. Shirai, J. Sugar and W. L. Wiese, J. Phys. Chem. Ref. Data, Monograph 8 (1997).

[2] S. Bashkin and J. O. Stoner, Jr., *Atomic Energy Levels and Grotrian Diagrams*, Vol. II, *Sulfur I - Titanium XXII* (North-Holland, Amsterdam, 1975).

2. Grotrian Diagrams

2.1. Explanation of Grotrian Diagrams

Mo VI, Mo XLII, etc.

According to spectroscopic convention, Mo I indicates the first spectrum, i.e., the spectrum of neutral atom; Mo II denotes the second spectrum, belonging to the singly ionized atom; and so on.

H-Sequence, C-Sequence, etc.

Indicates that the respective Mo ion has the same number of electrons as neutral hydrogen, neutral carbon, etc.

Abscissa

Energy in the levels in cm^{-1}.

Short vertical lines

Energy levels are indicated as the vertical lines. The electronic configuration (with the parentage in parentheses) and the level energy in cm^{-1} are given to the right of the vertical line, and at the top is the J value. A symbol "?" after the level value indicates level was derived from a tentatively classified line. Theoretical levels are given in square brackets. Energy levels with the same LS label for the upper term are grouped together. The term designation is given at the right of the diagram; the ordering is by increasing multiplicity and orbital angular momentum. For the lower level, the term is adjacent to the configuration.

Horizontal lines

Transitions between levels. The number below each line gives the transition wavelength in Angstrom (10^{-8}cm).

C,T,P,S

Superscripts to the right of a wavelength value have the following meanings:

^{C} wavelength calculated from energy level data using the Ritz combination principle.

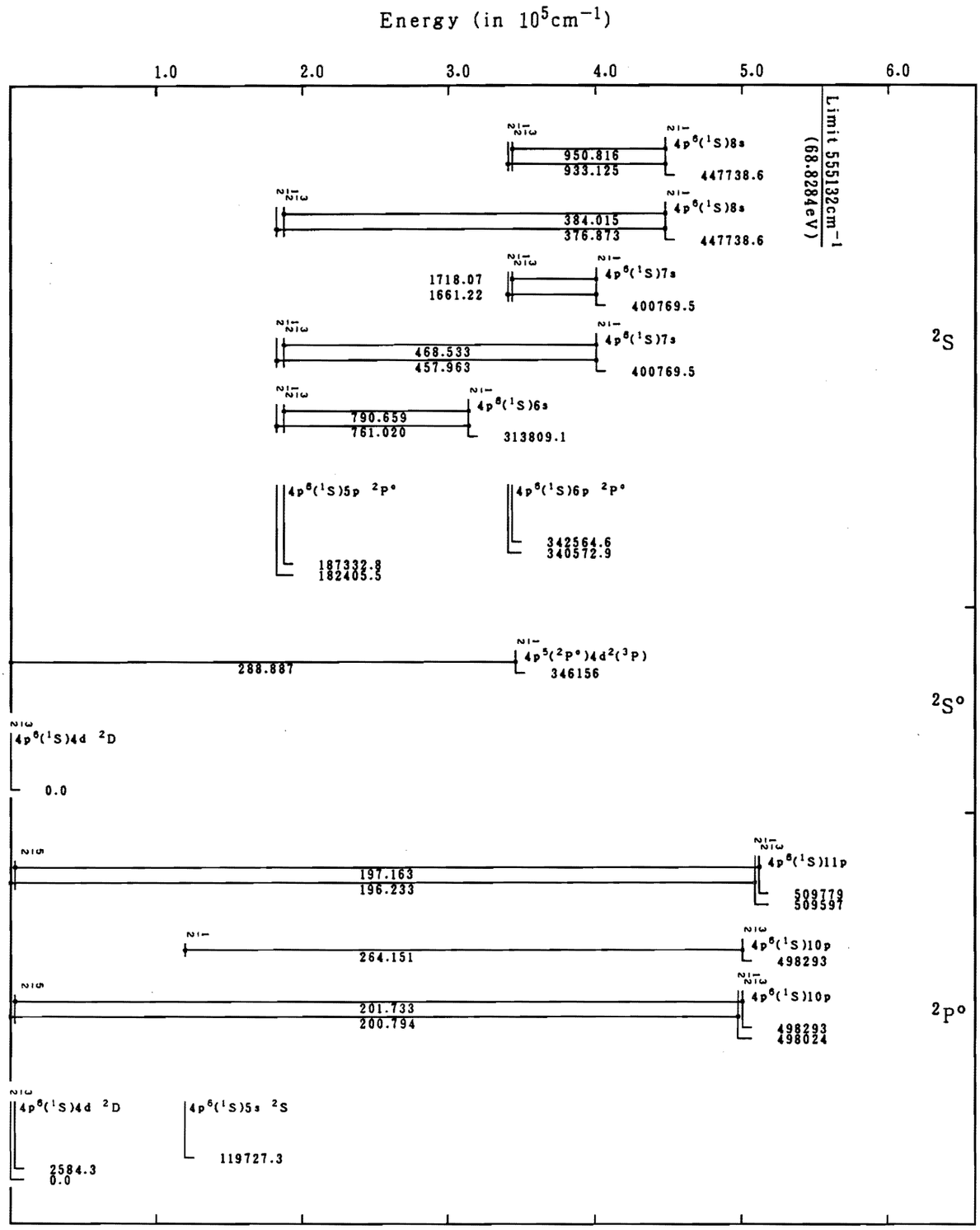
^{T} wavelength tentatively identified.

^{P} wavelength predicted along a isoelectronic sequence.

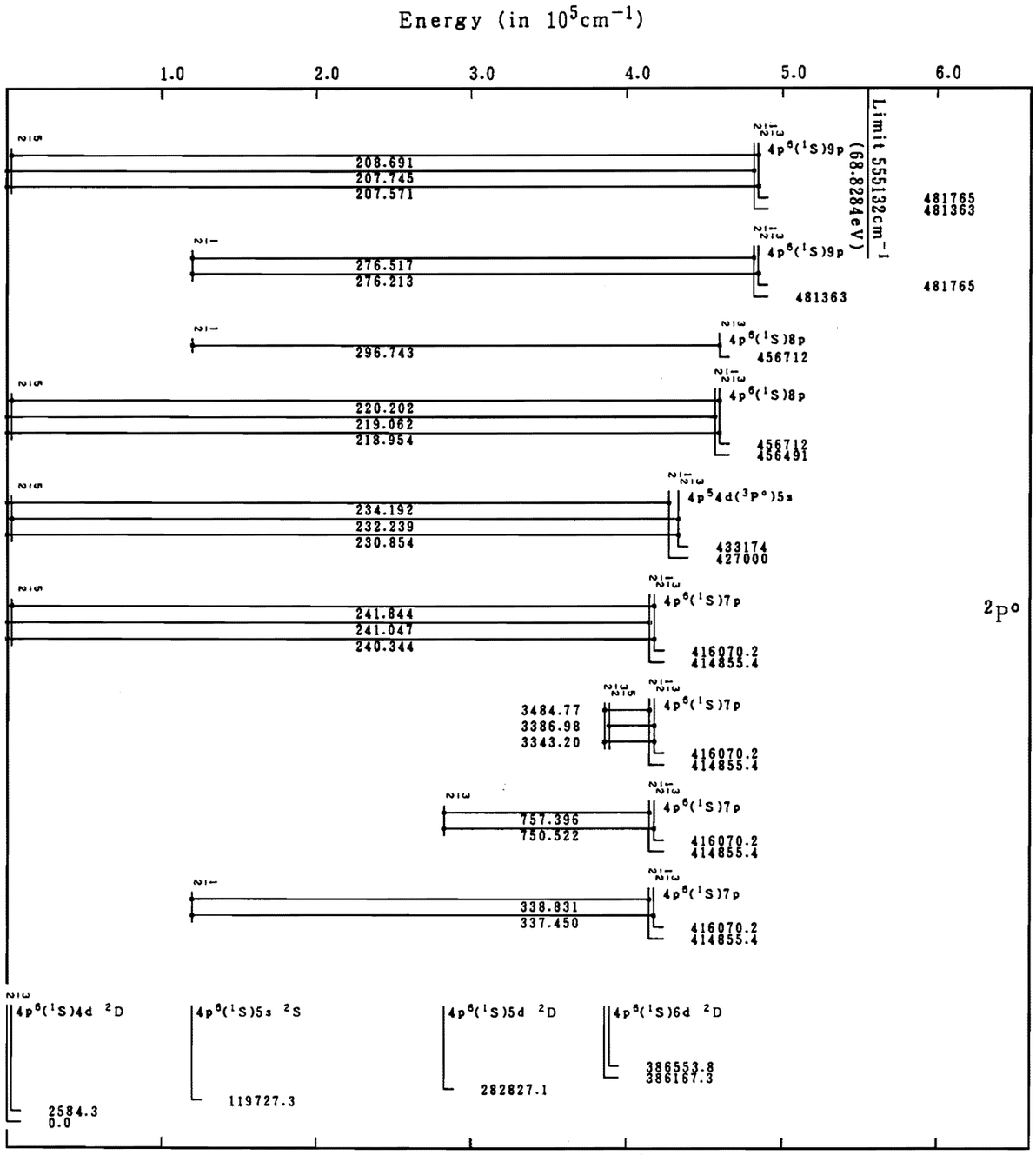
^{S} wavelength smoothed along a isoelectronic sequence.

Limit

Principal ionization limit in cm^{-1} and eV.



Mo VI(Rb−Sequence)



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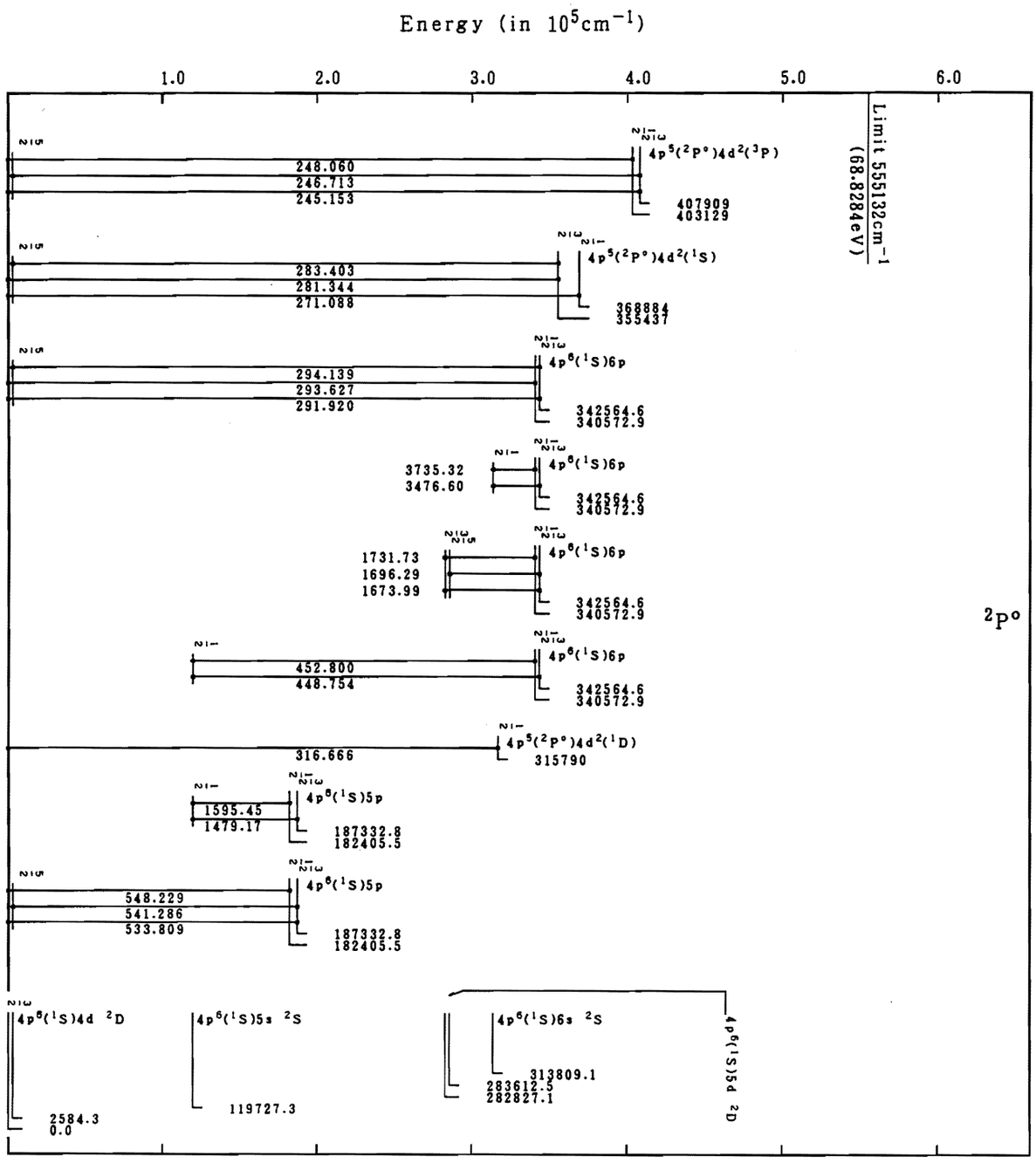

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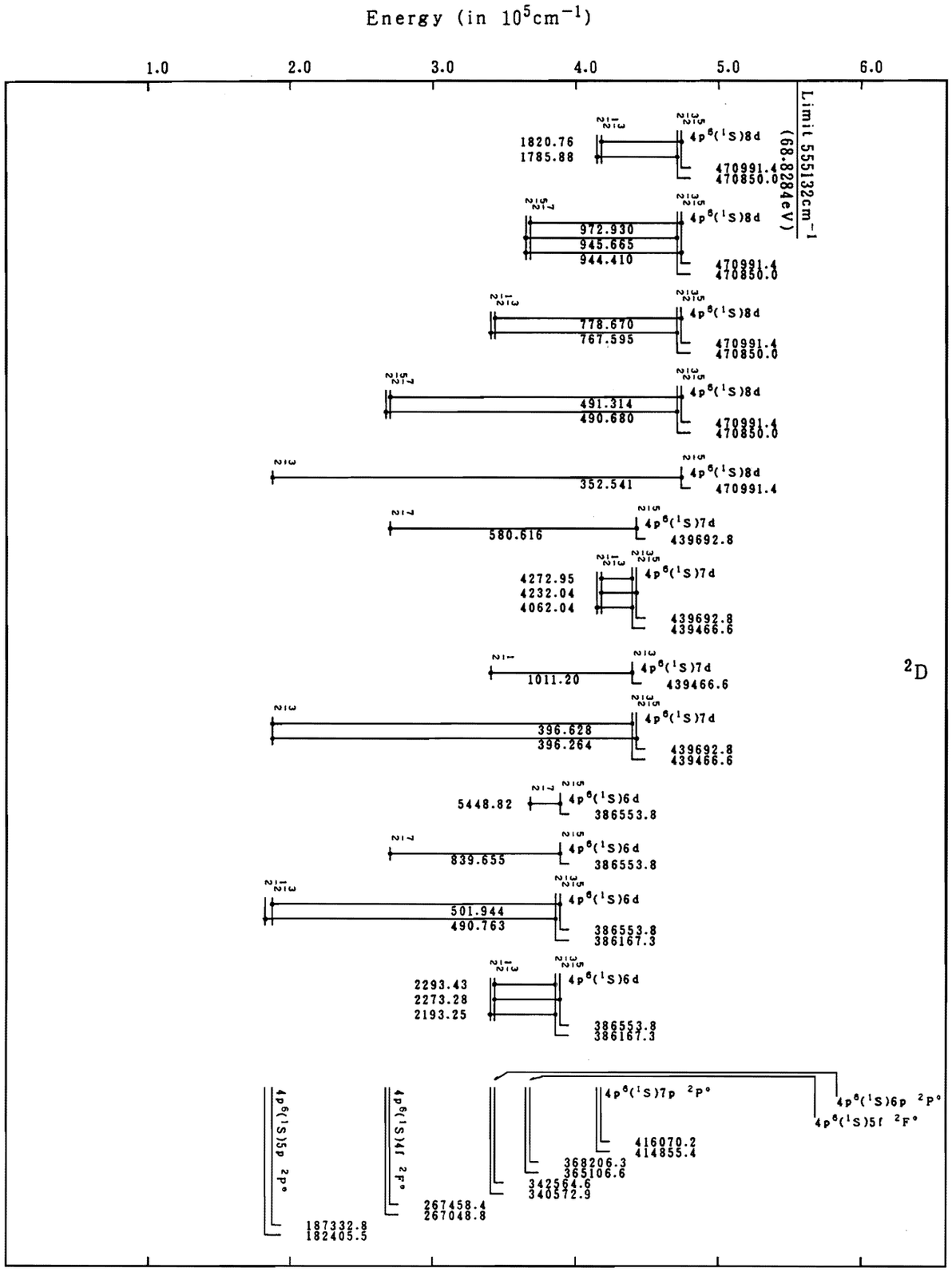

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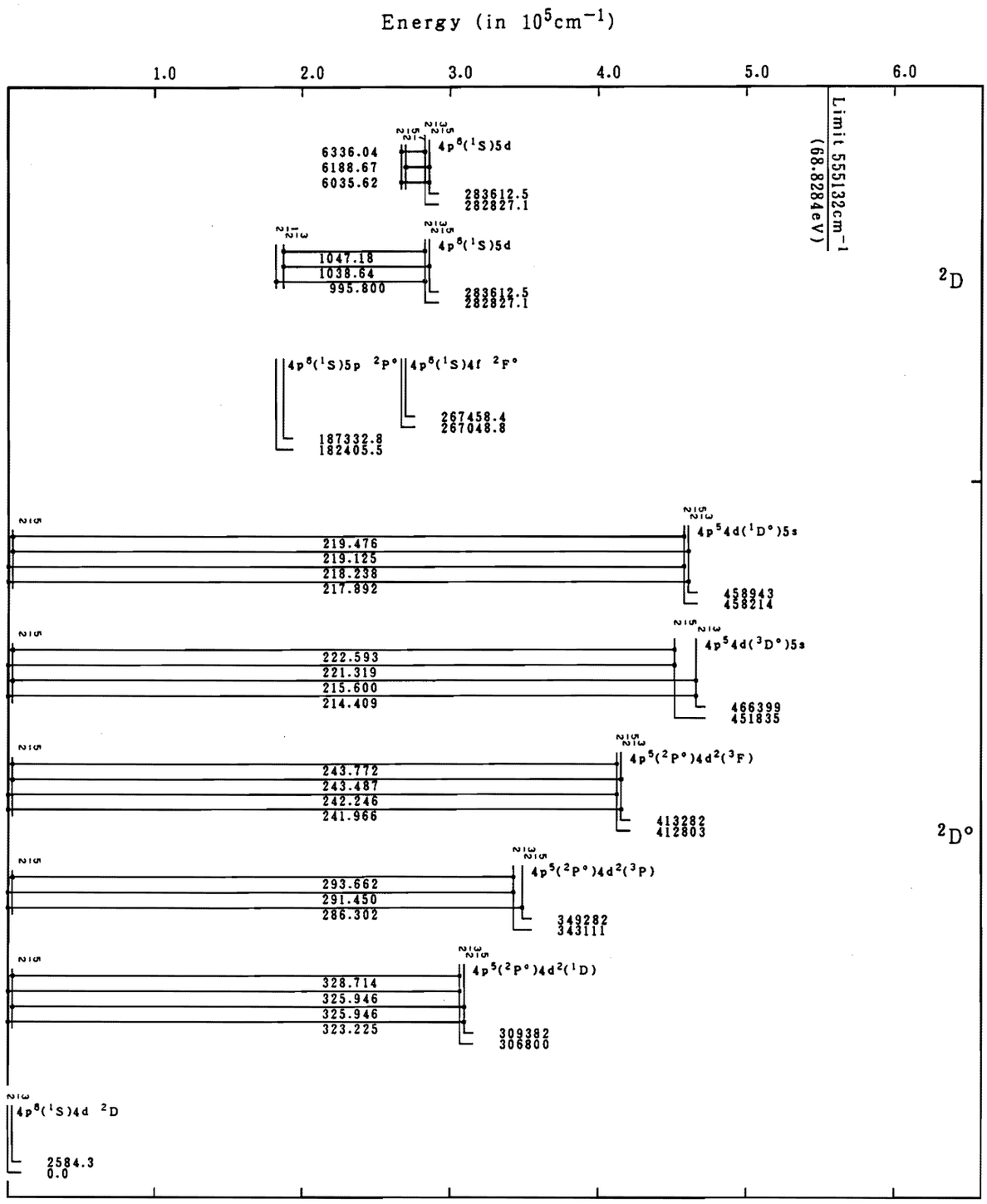

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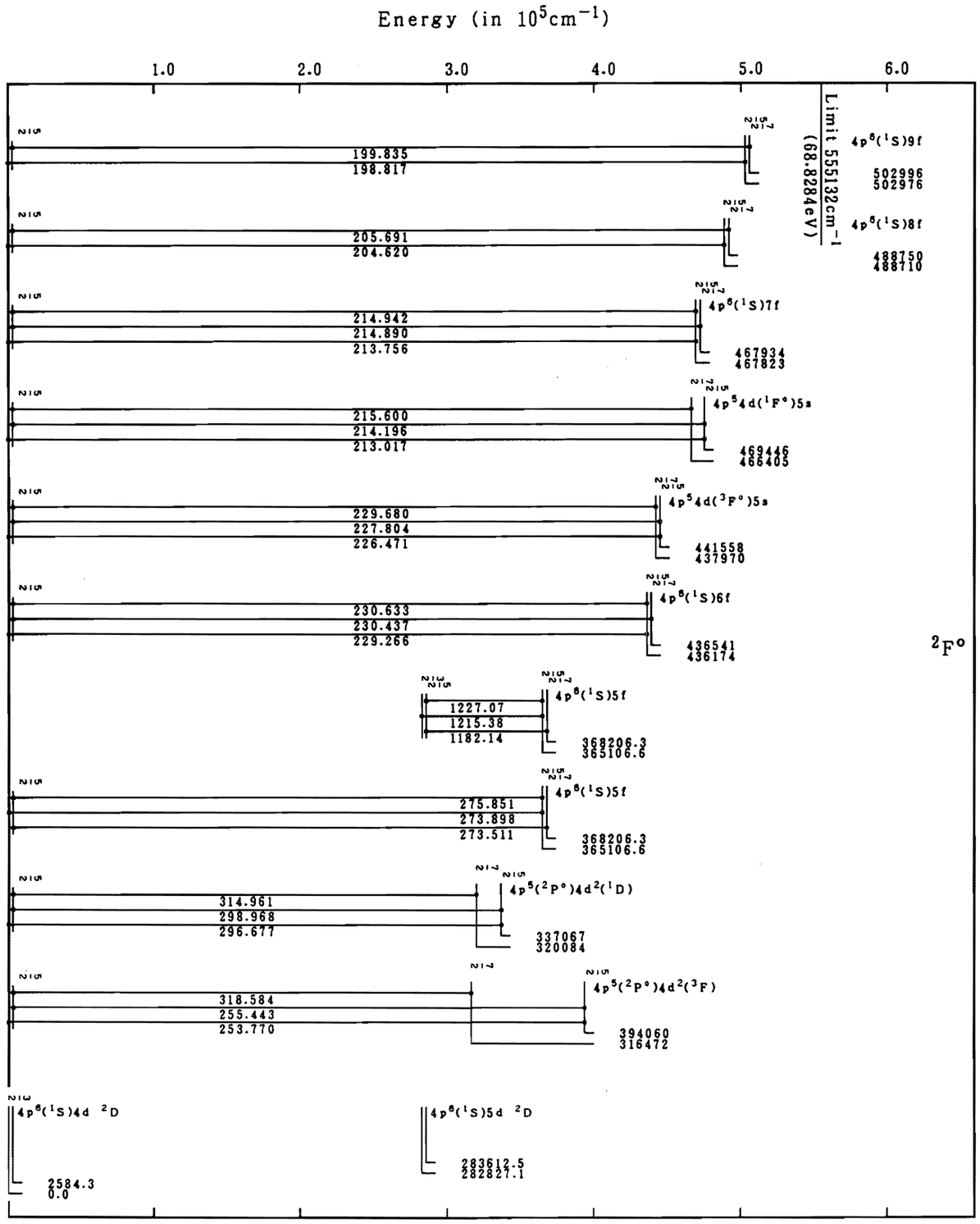

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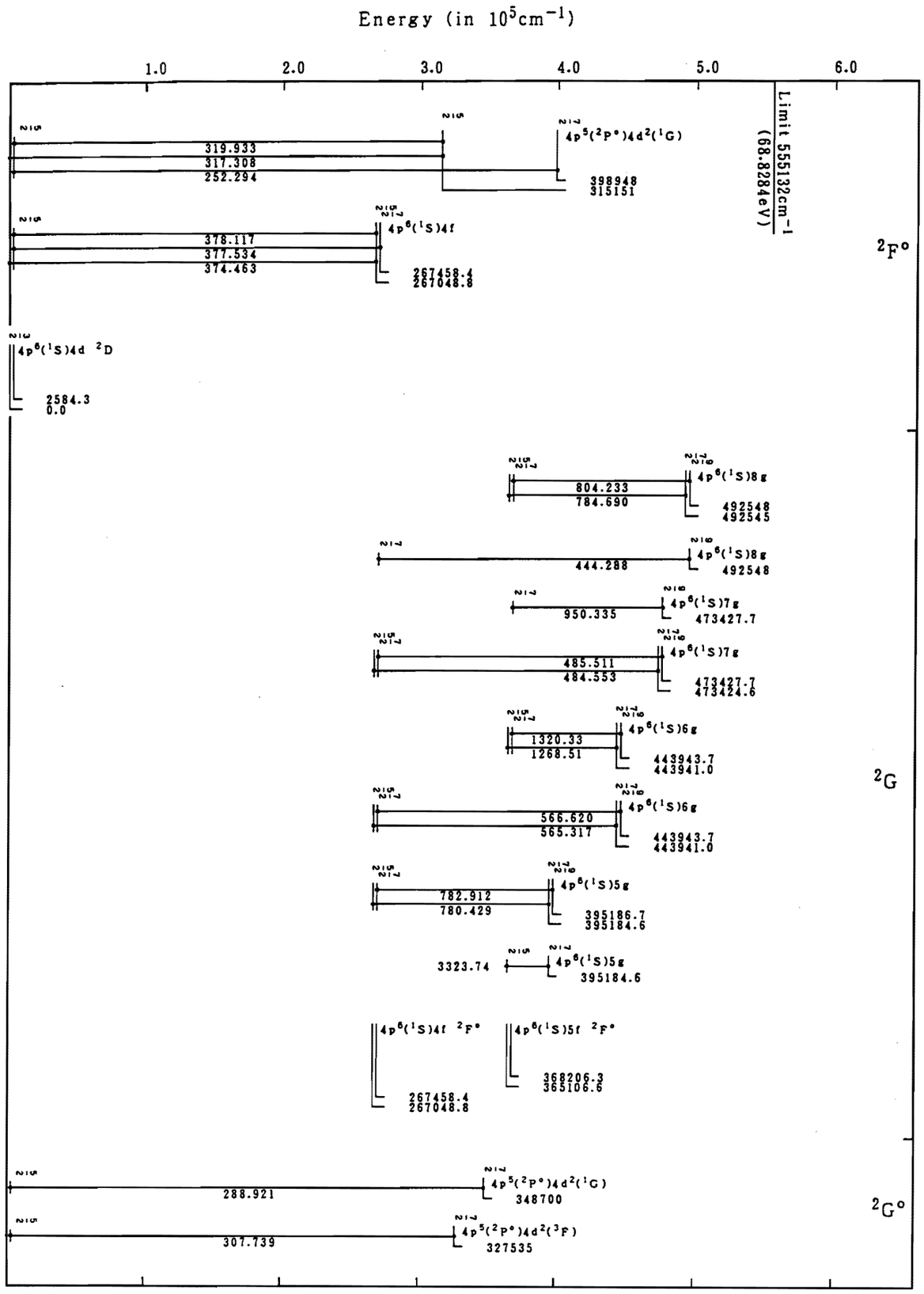

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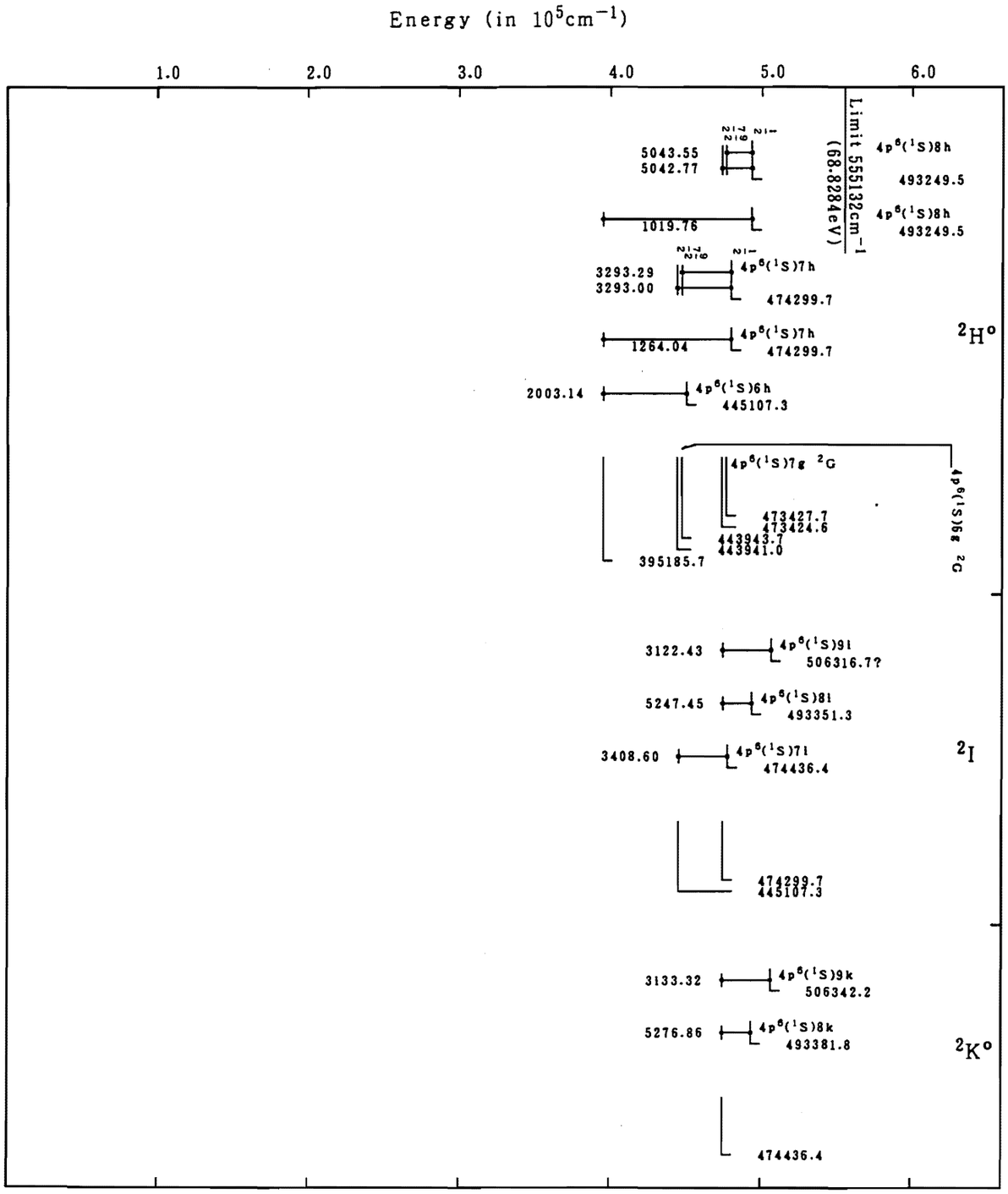

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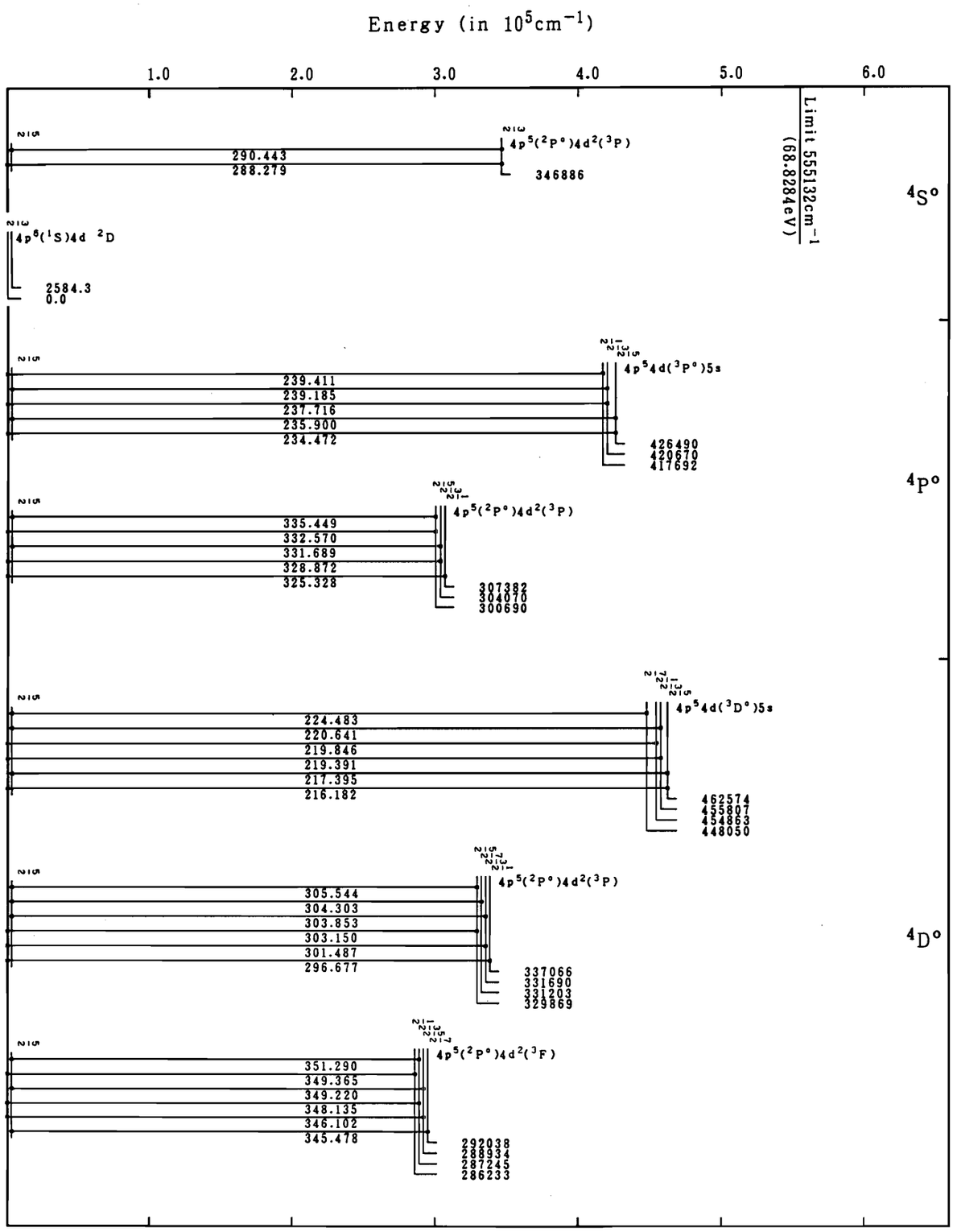

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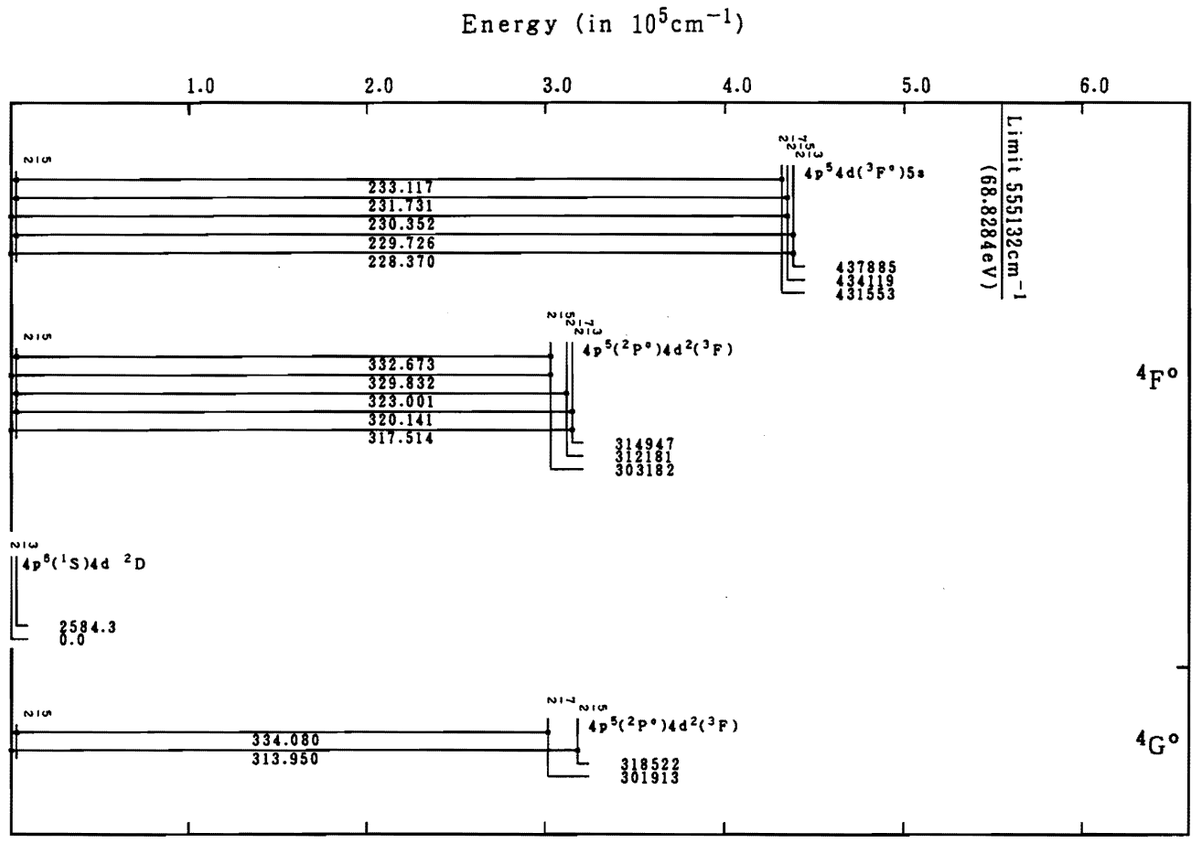

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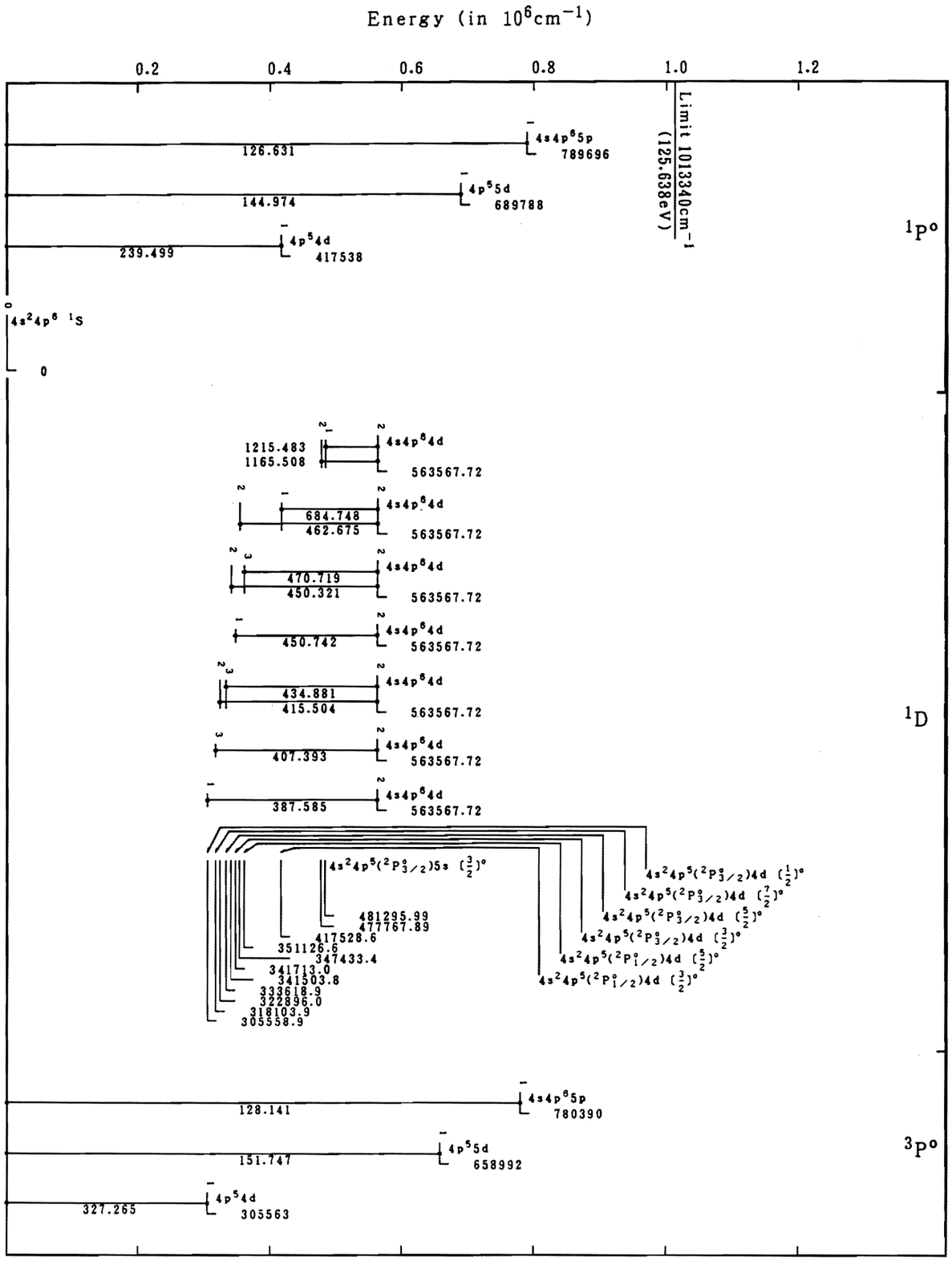

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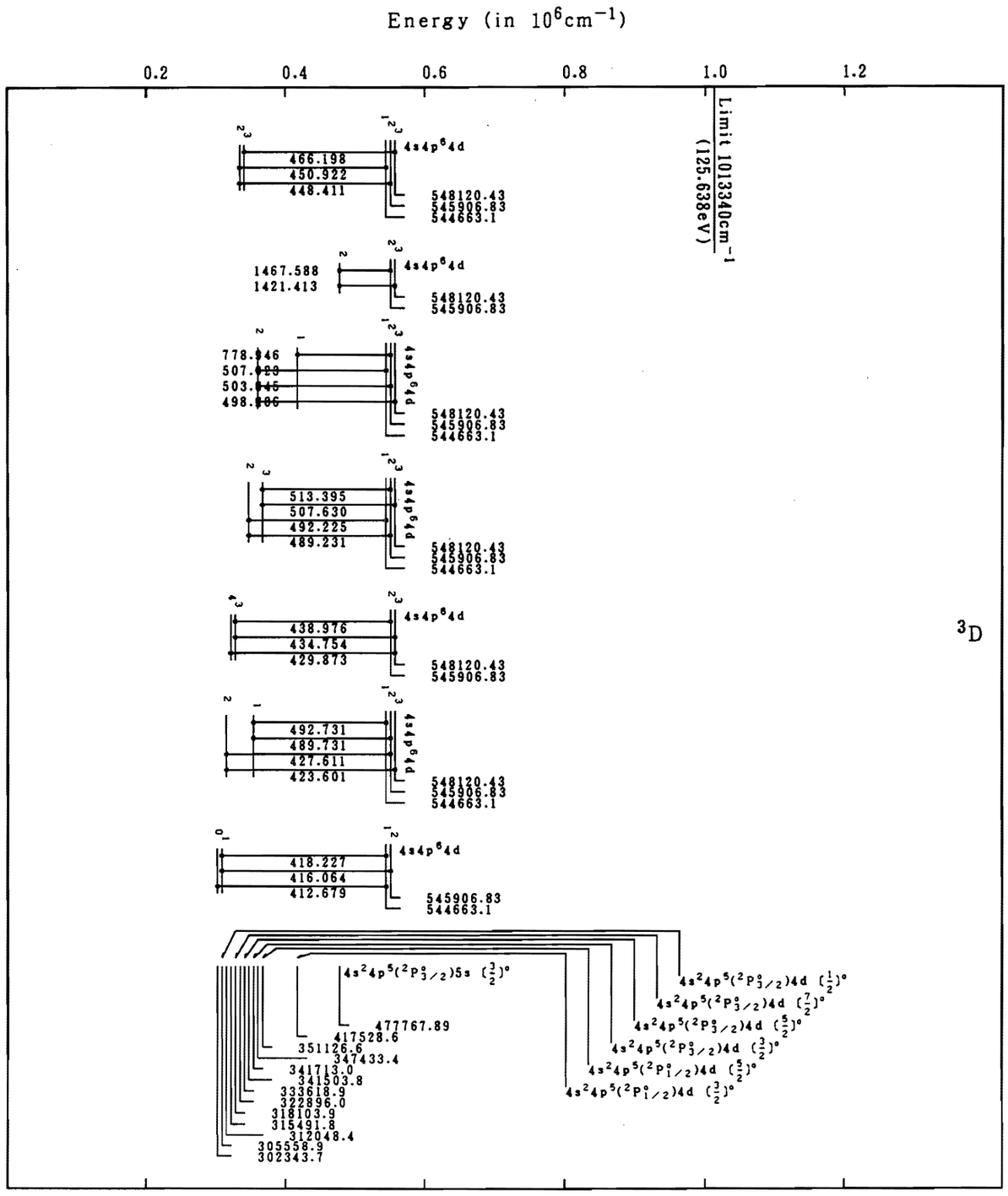

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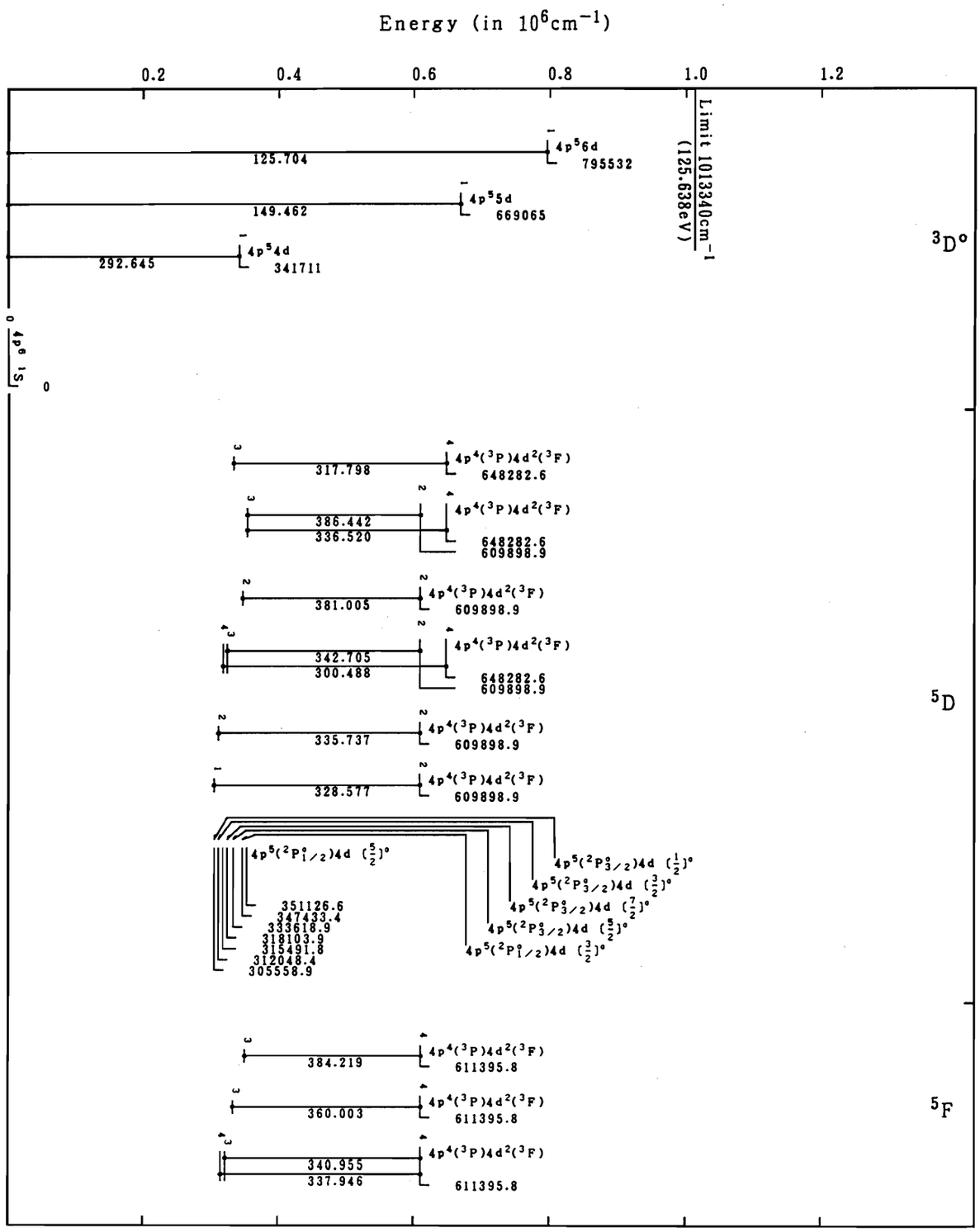

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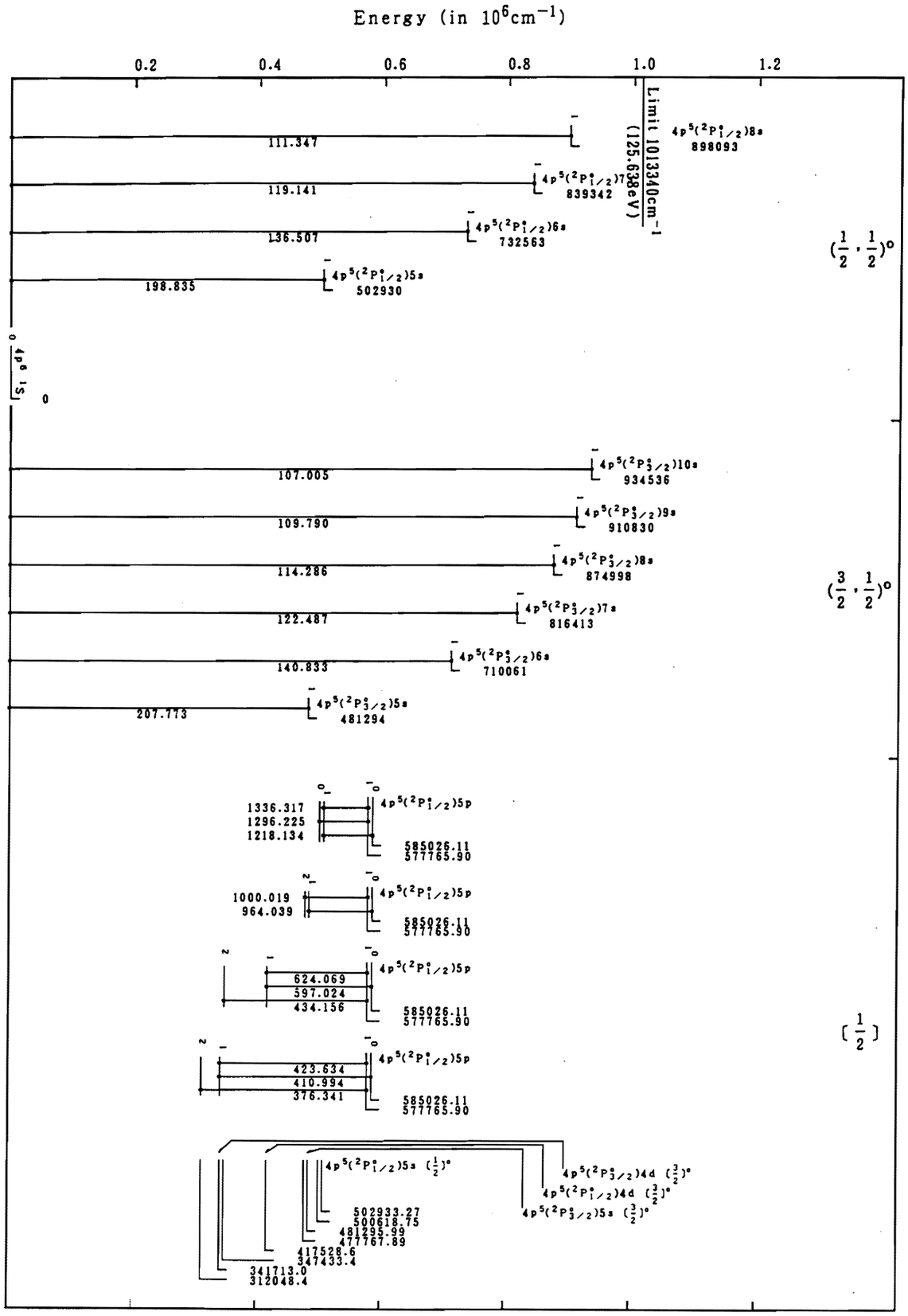

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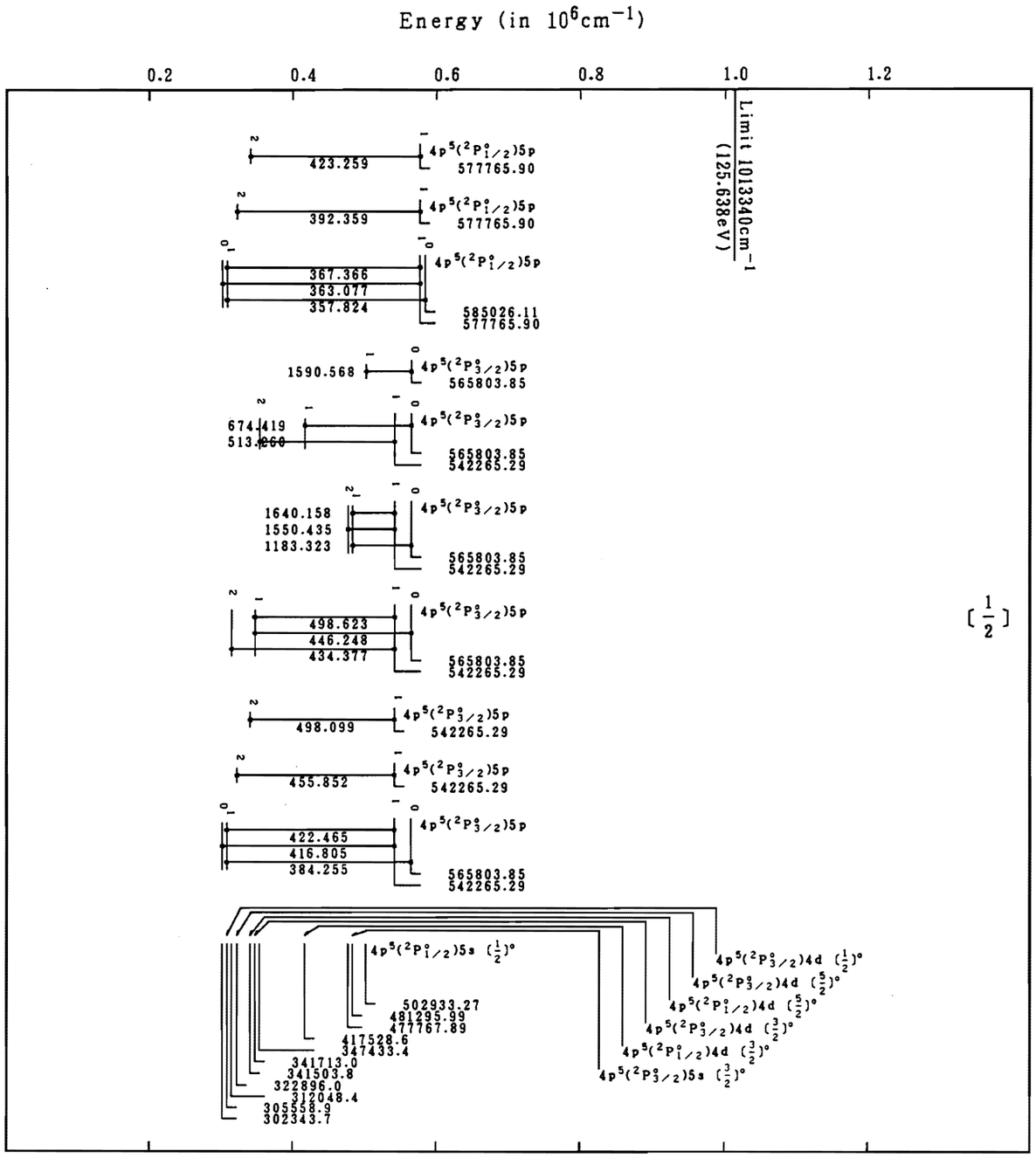

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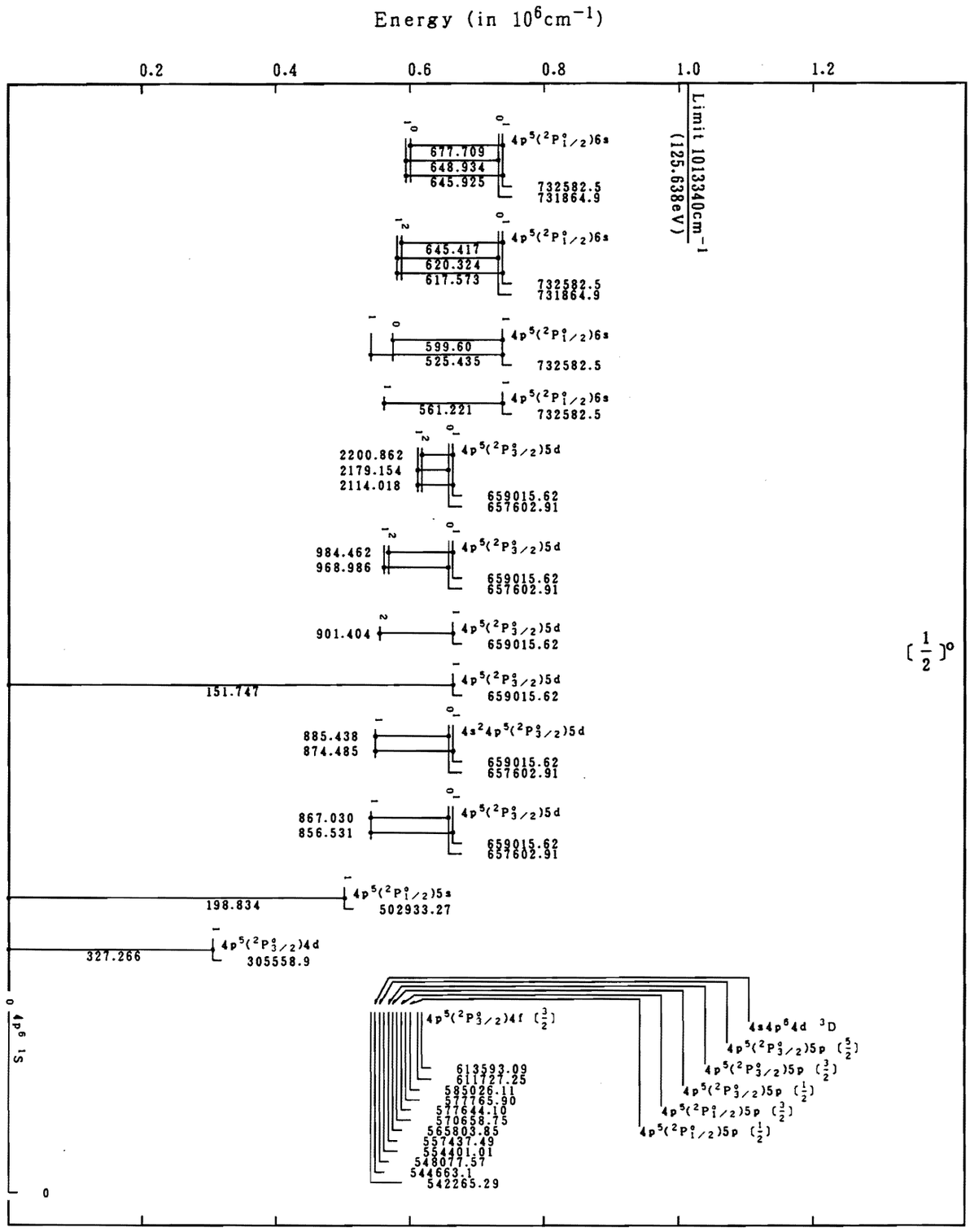

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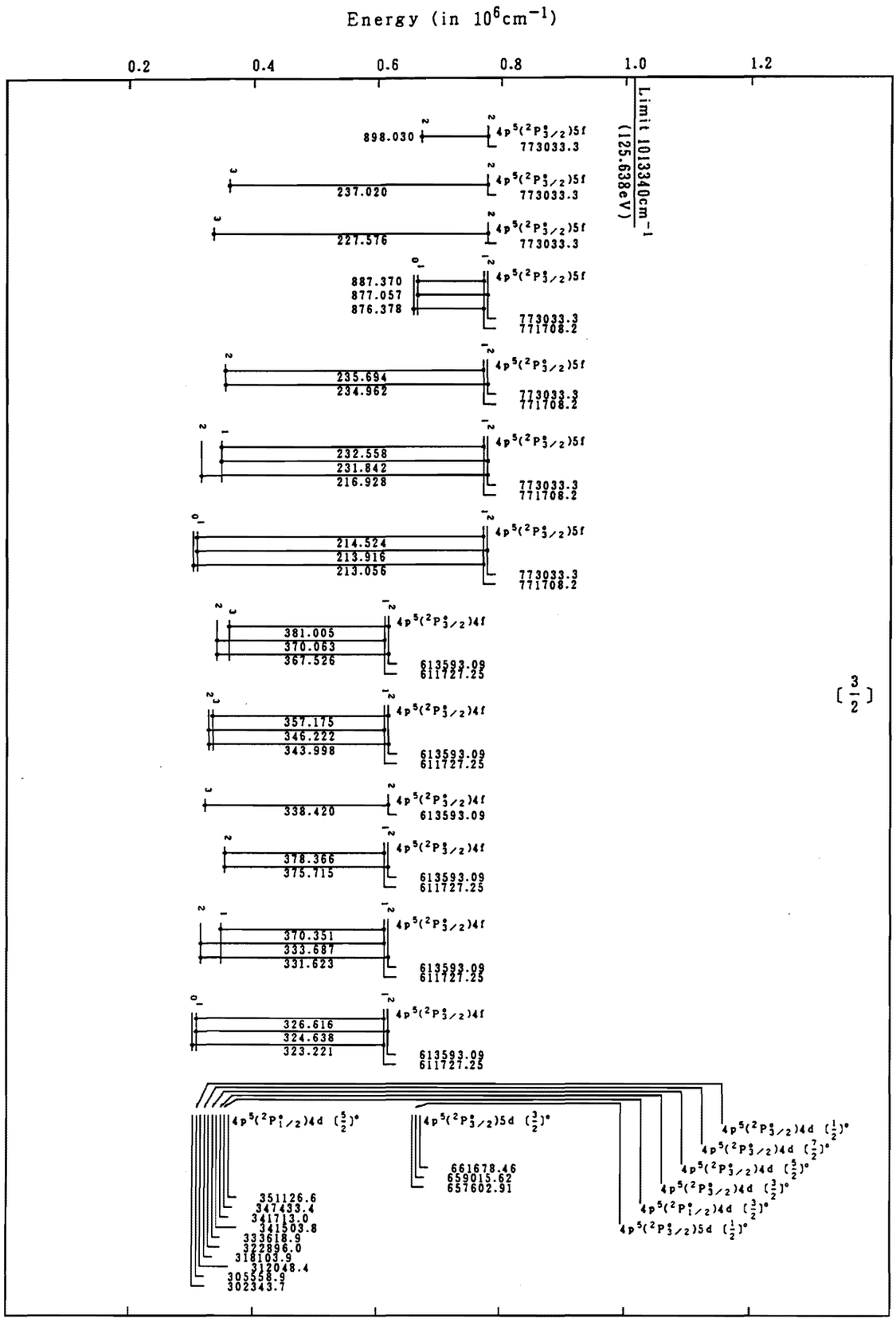

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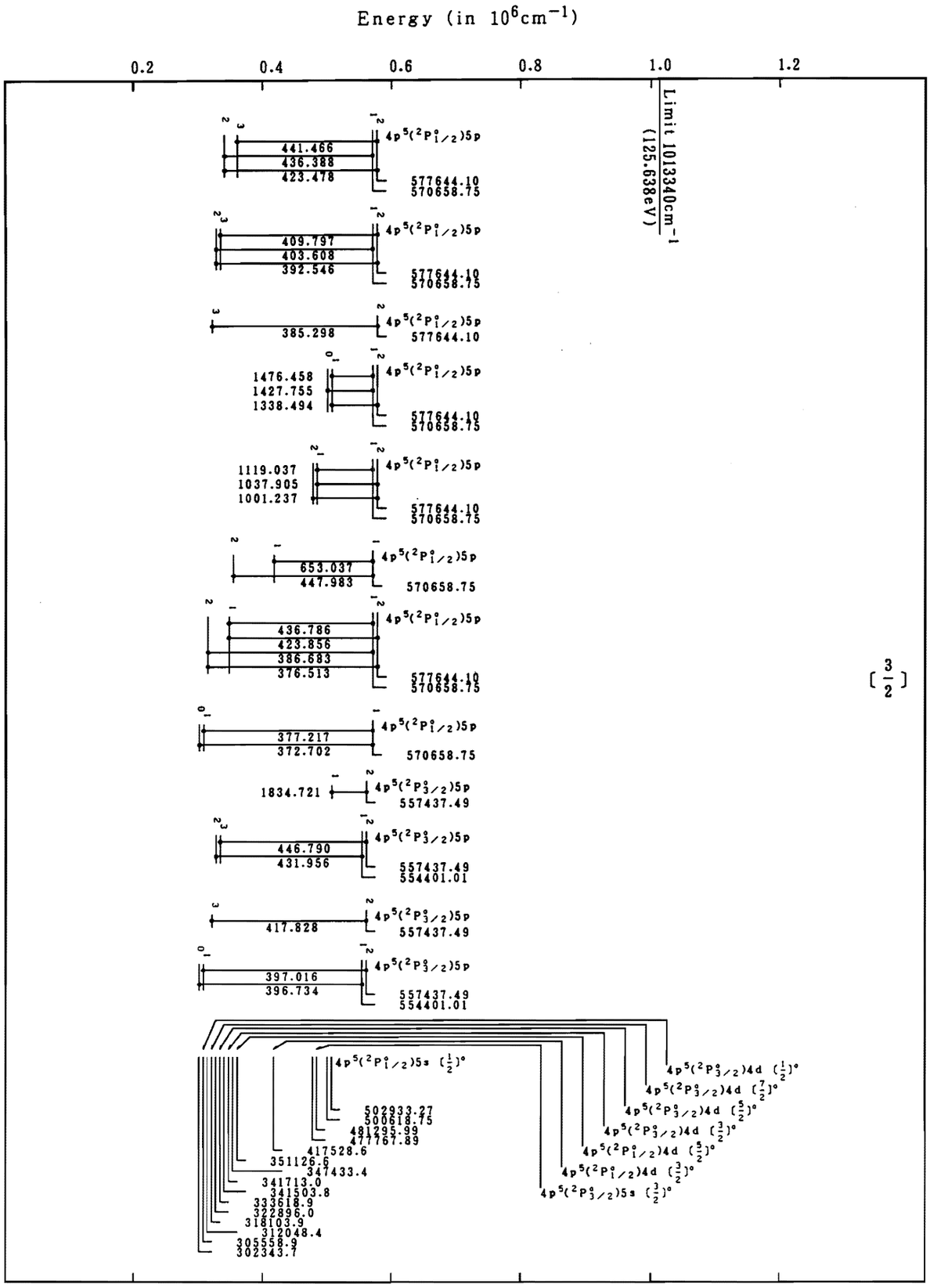

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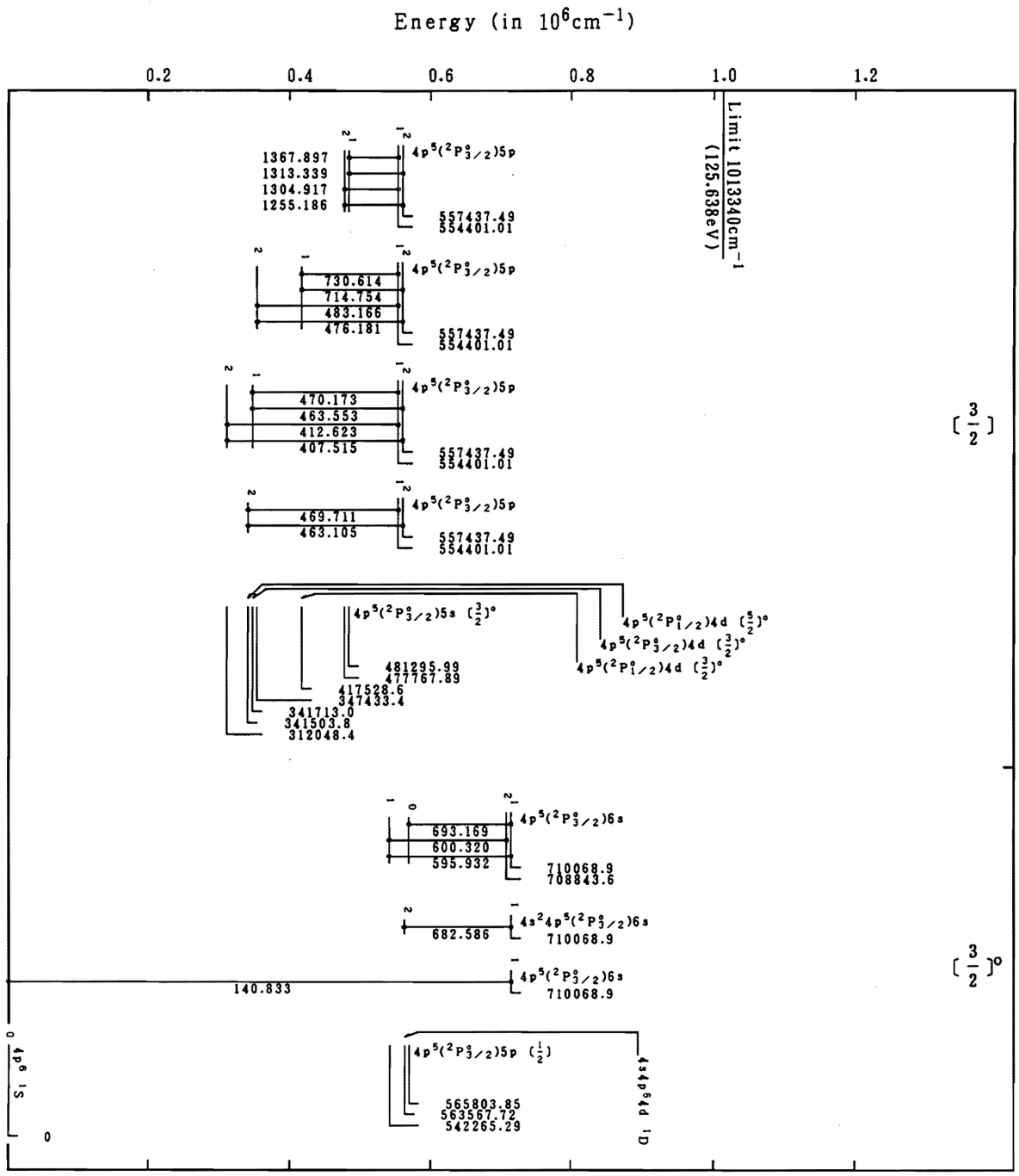

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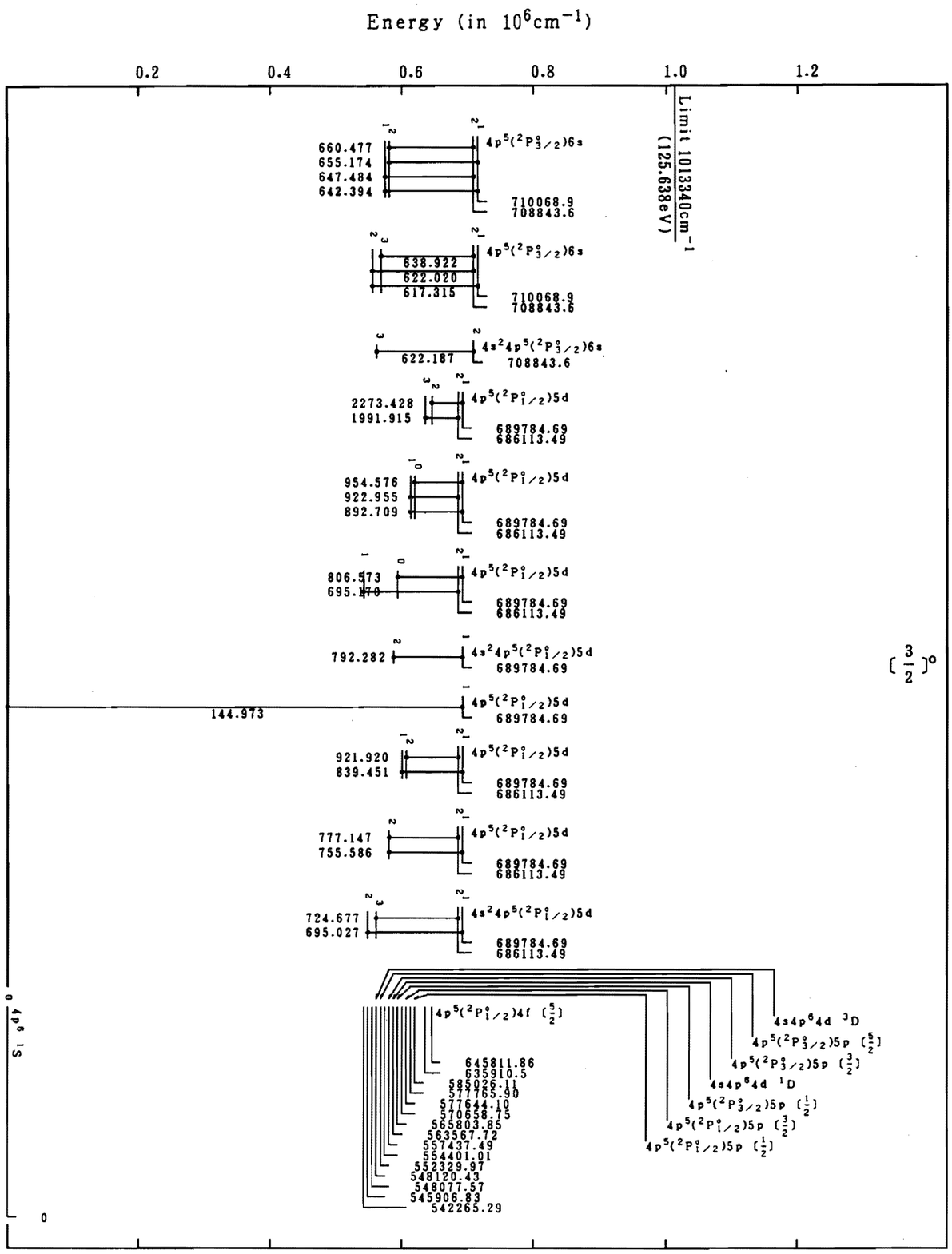

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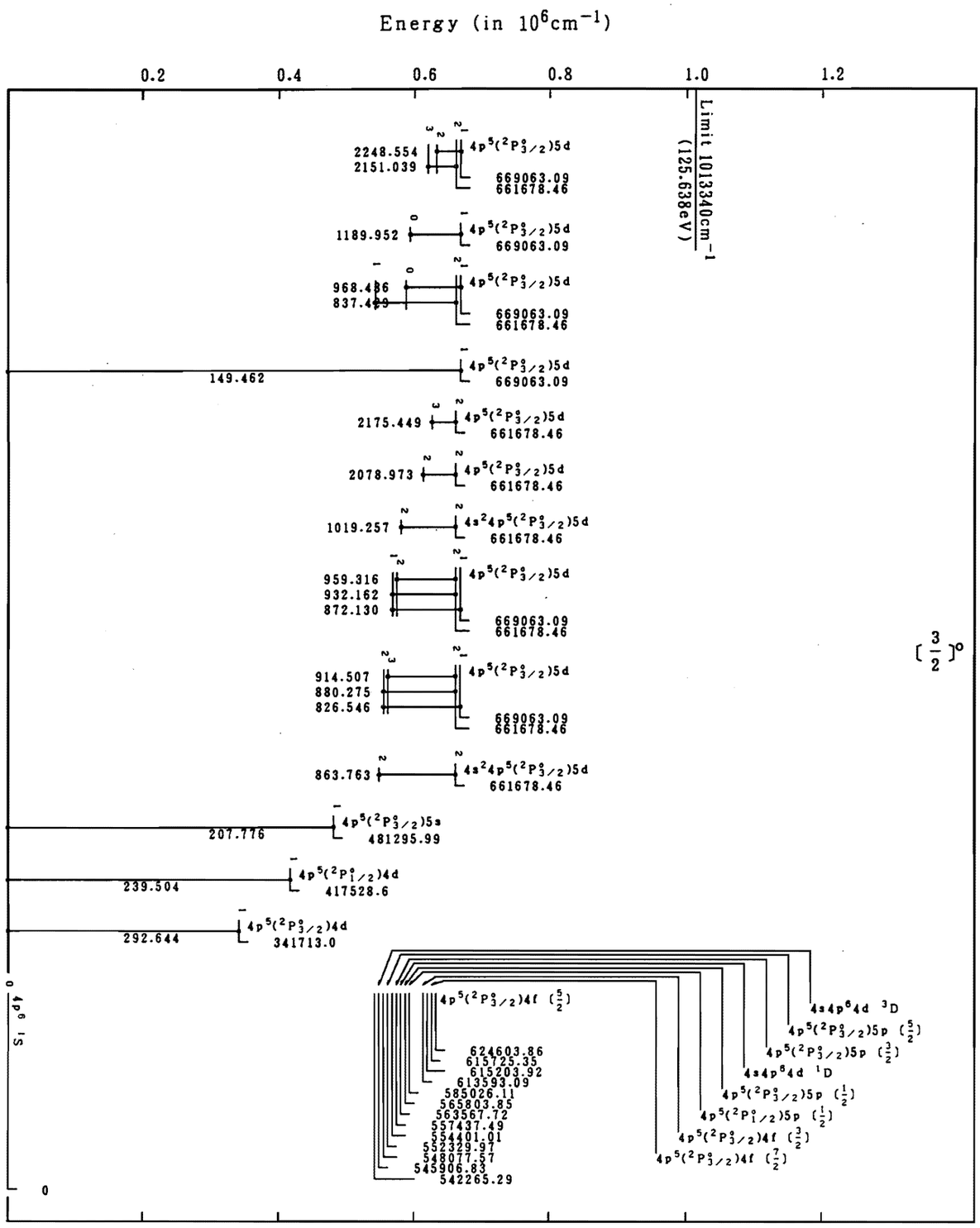

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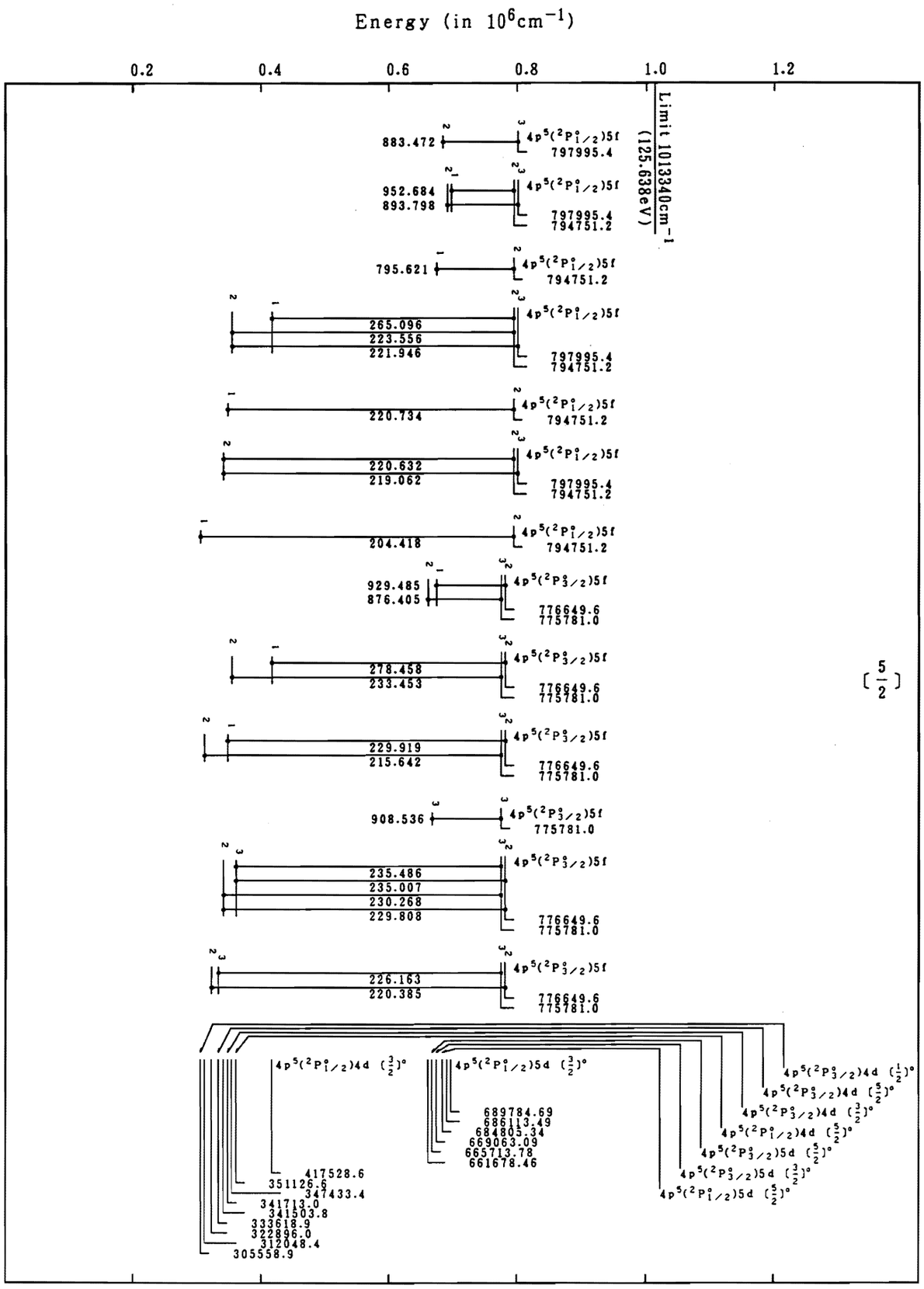

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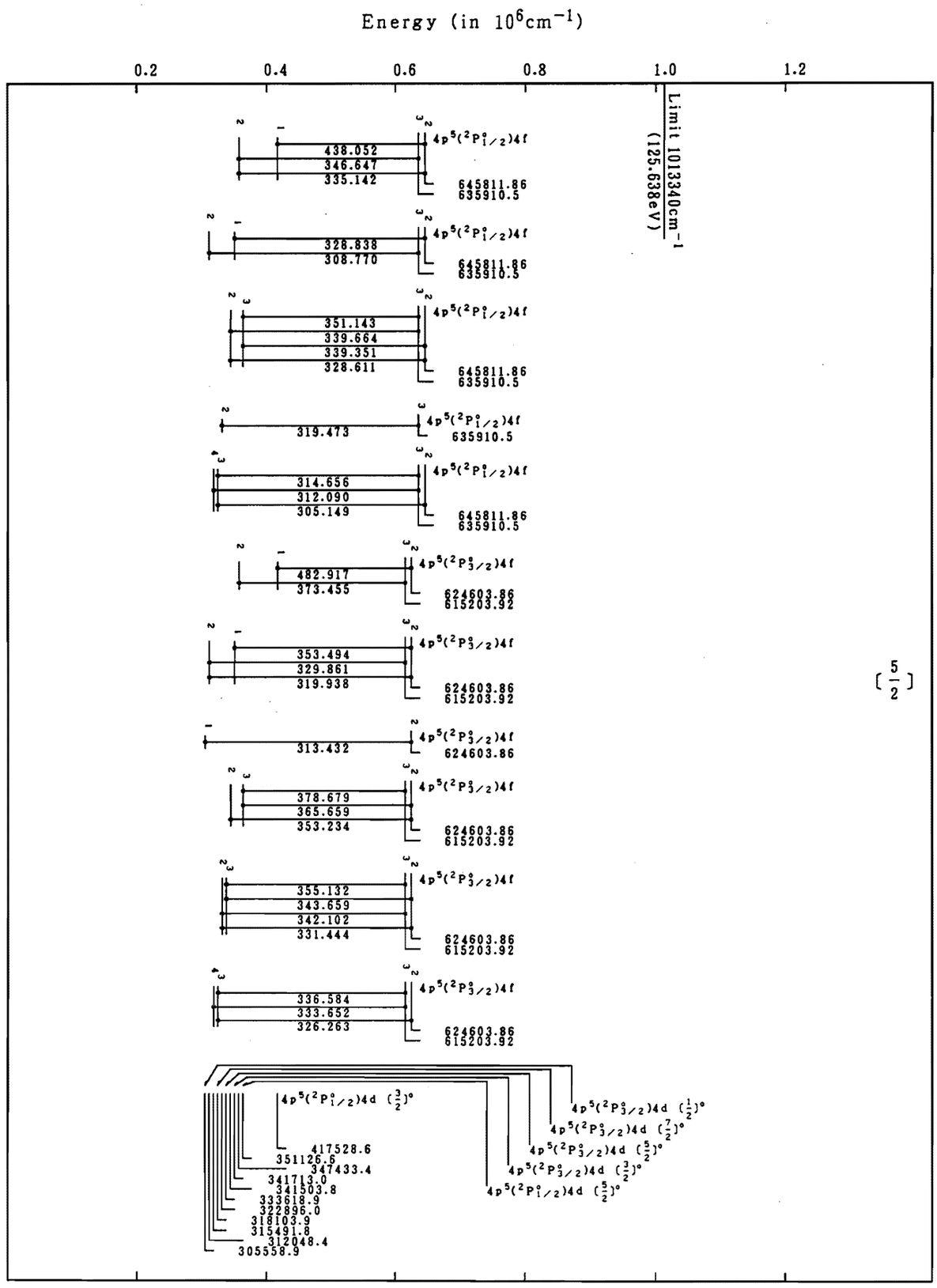

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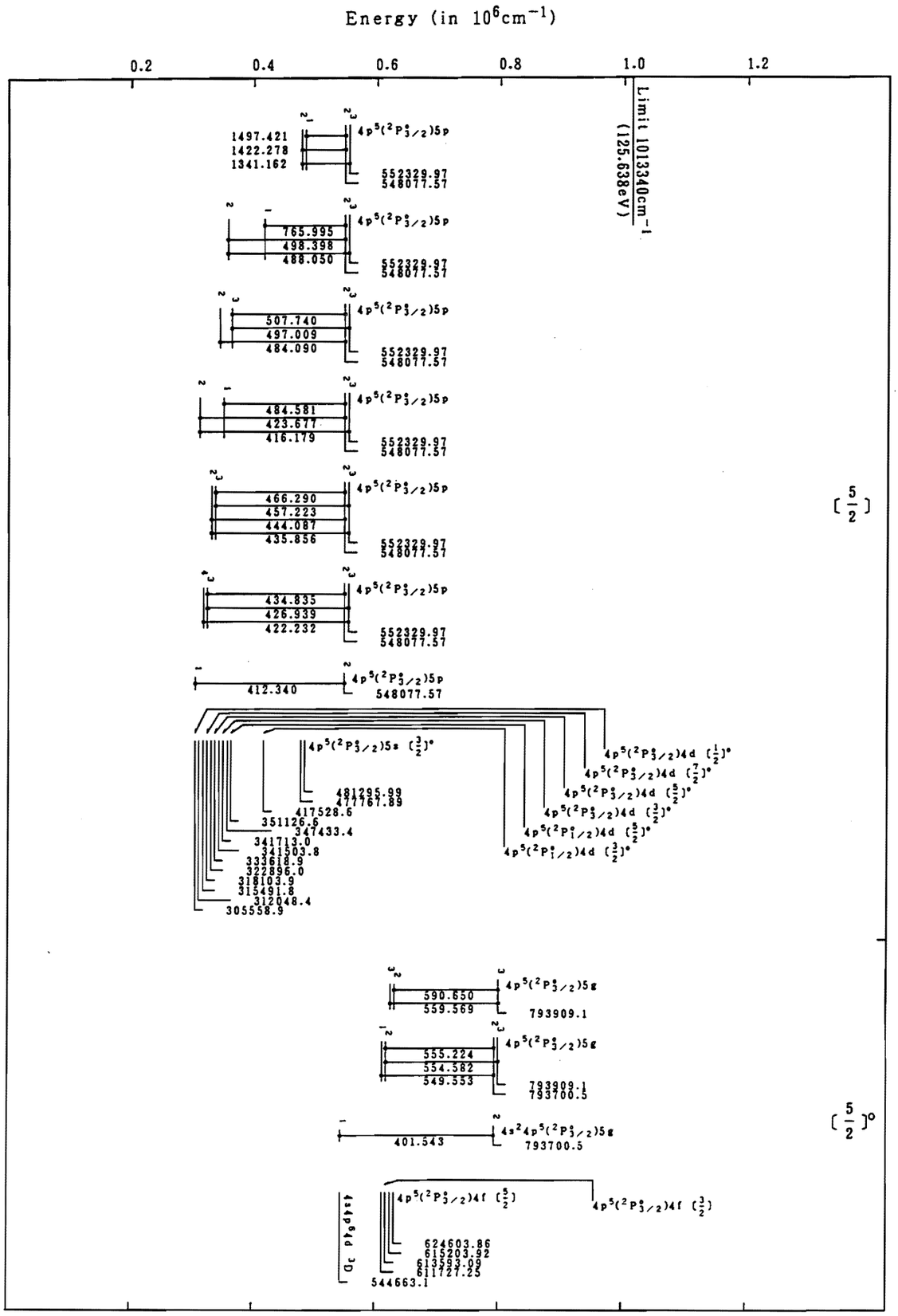

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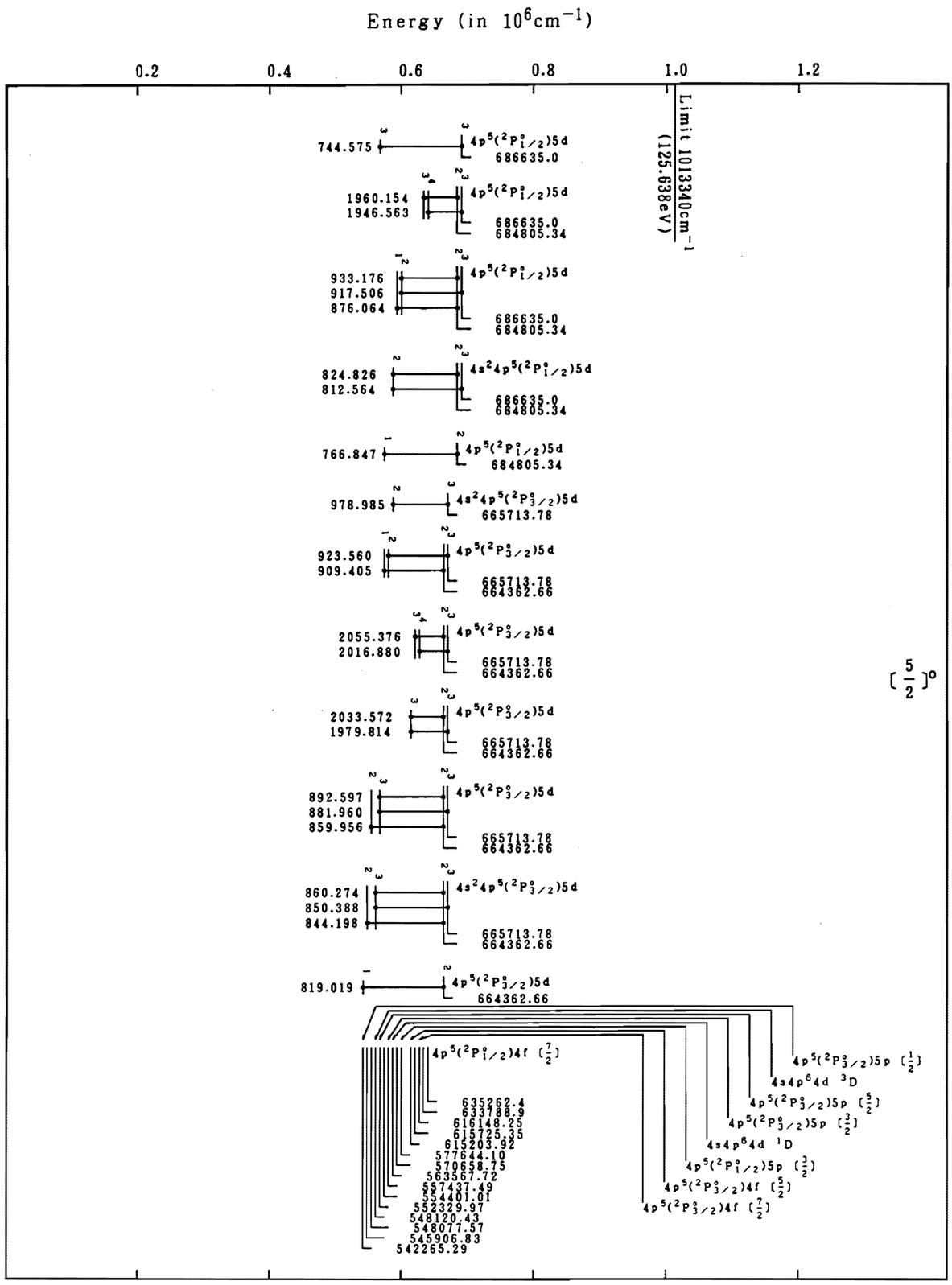

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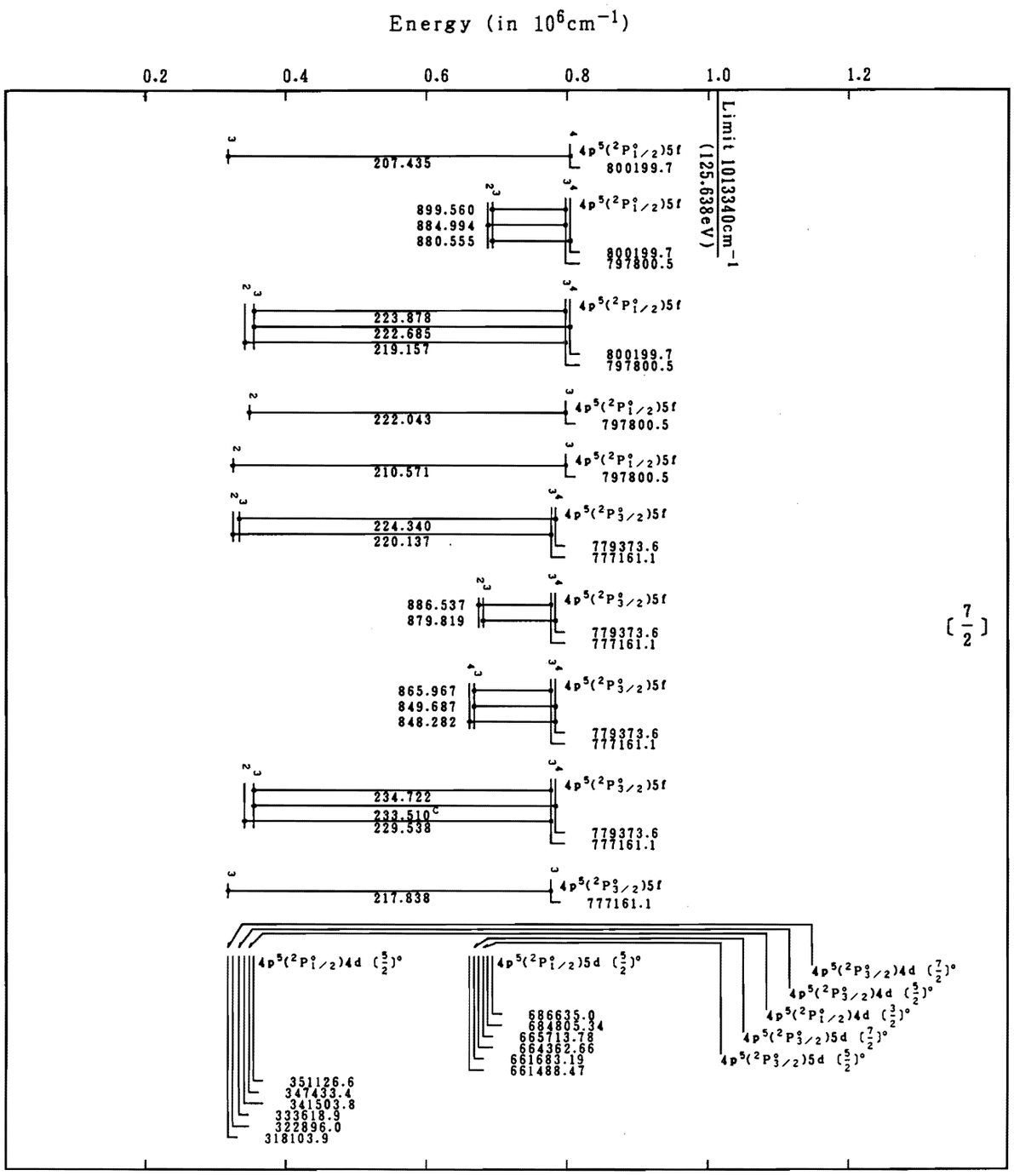

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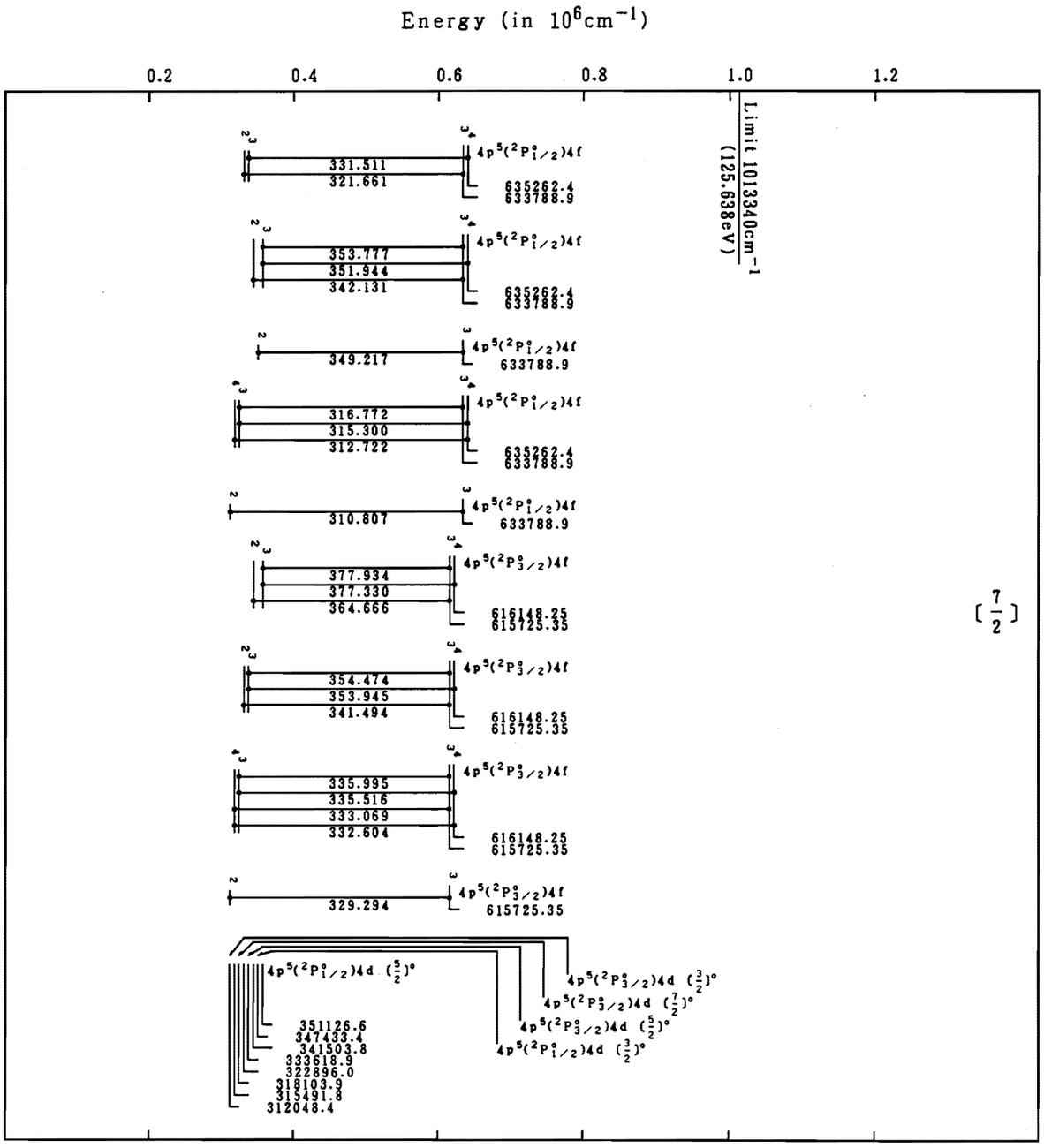

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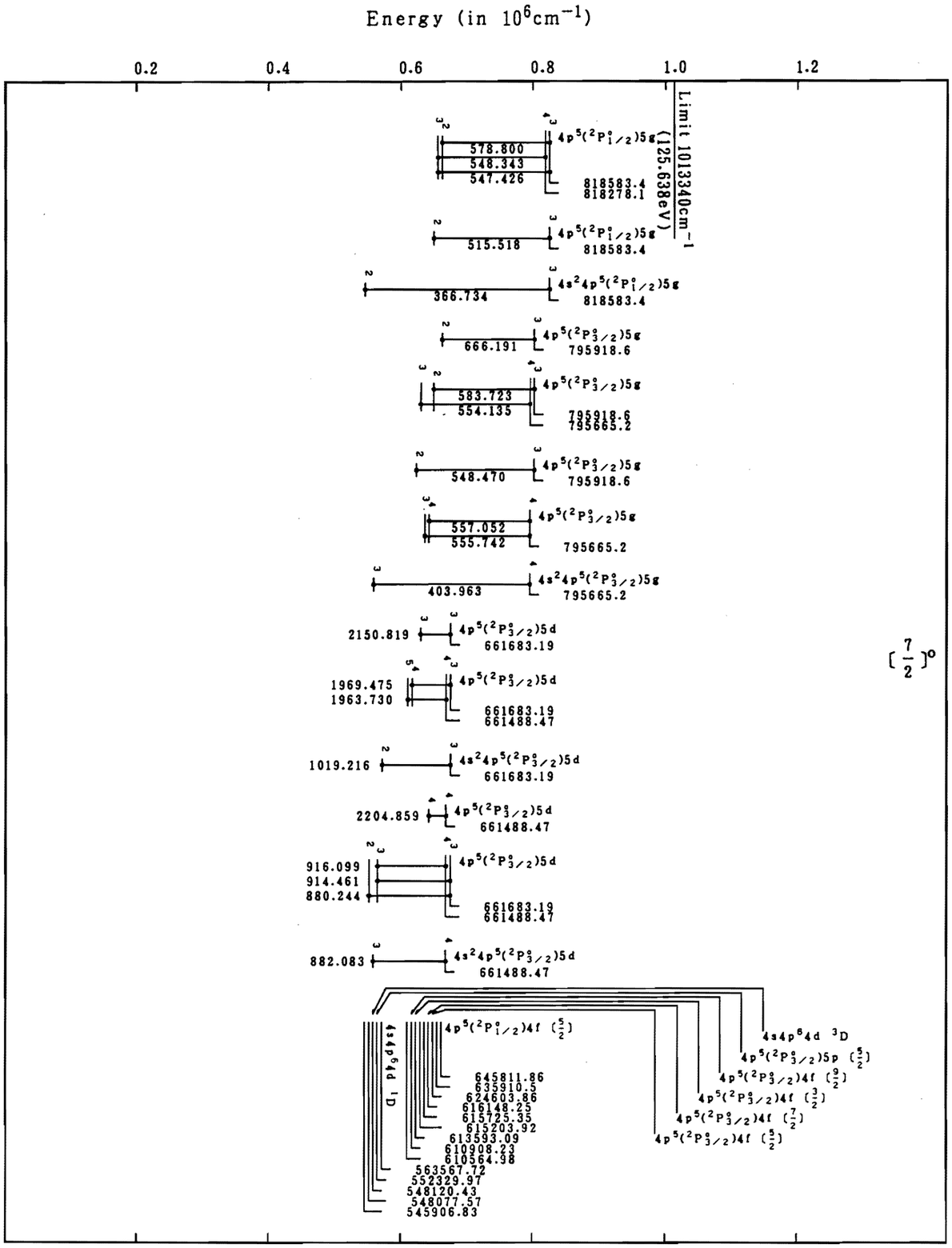

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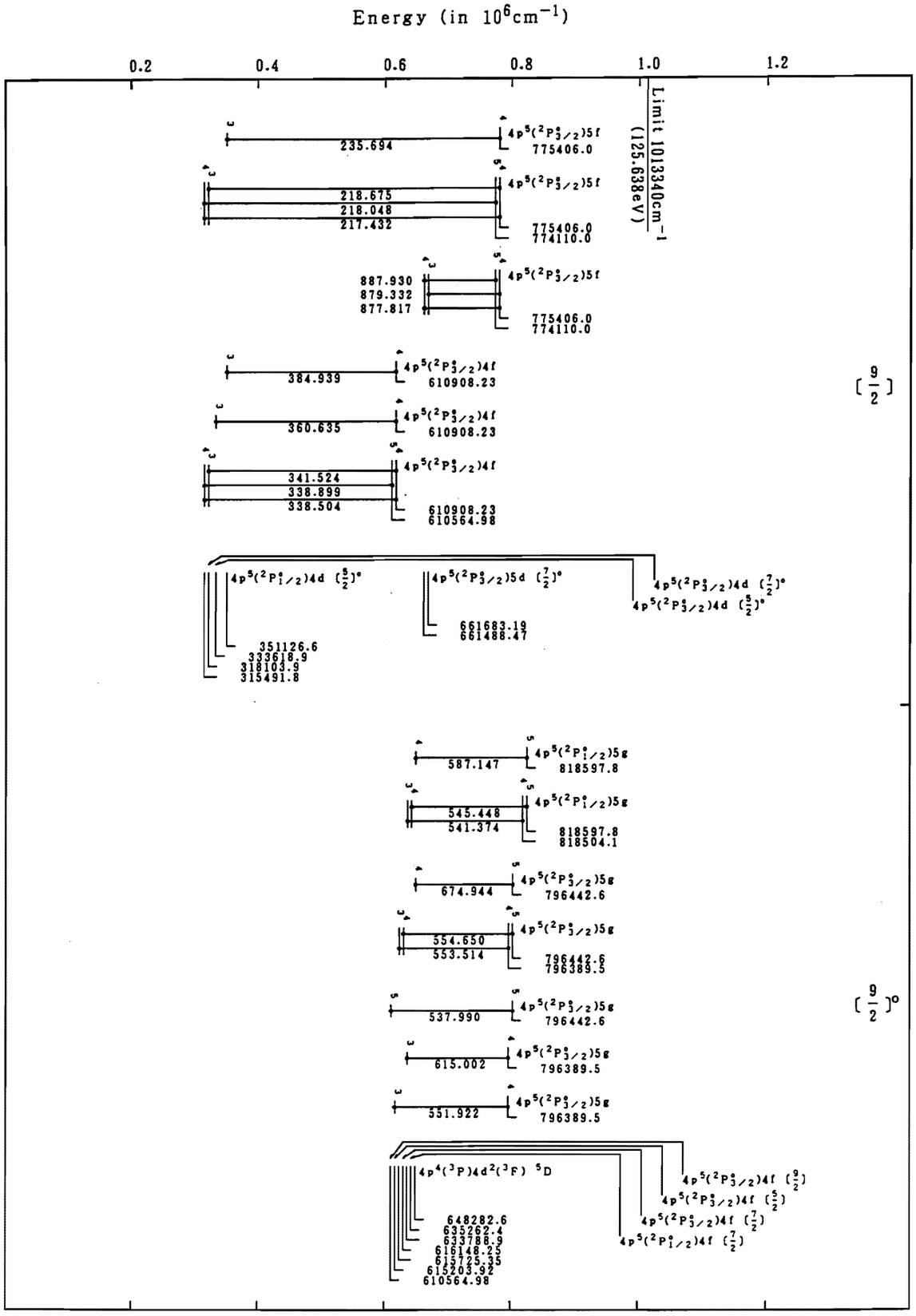

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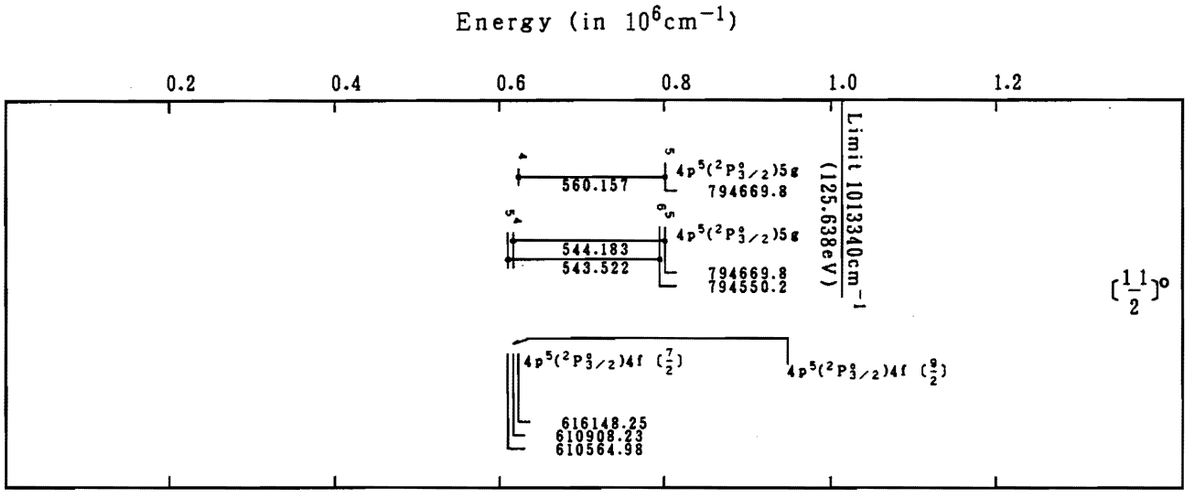

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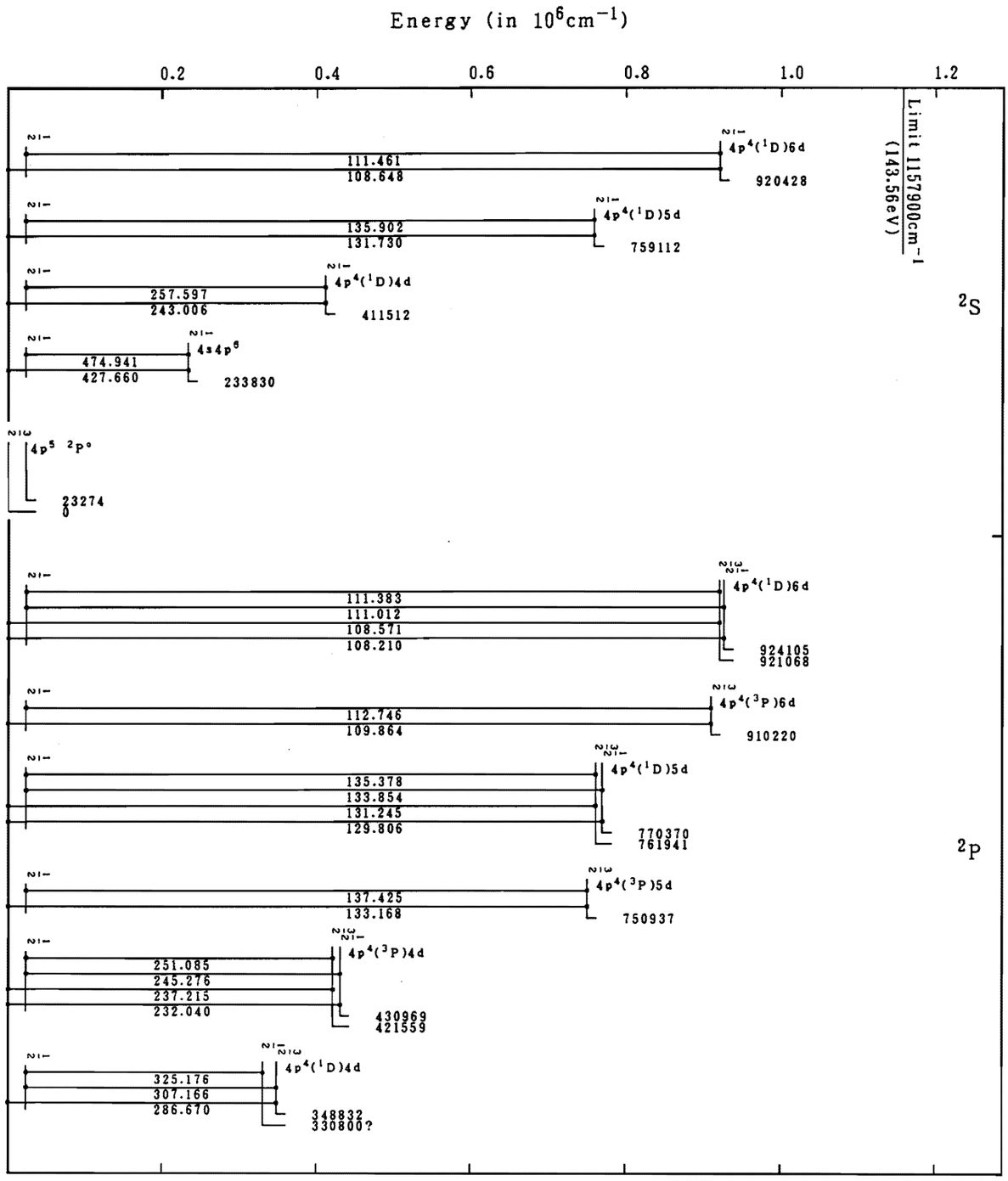

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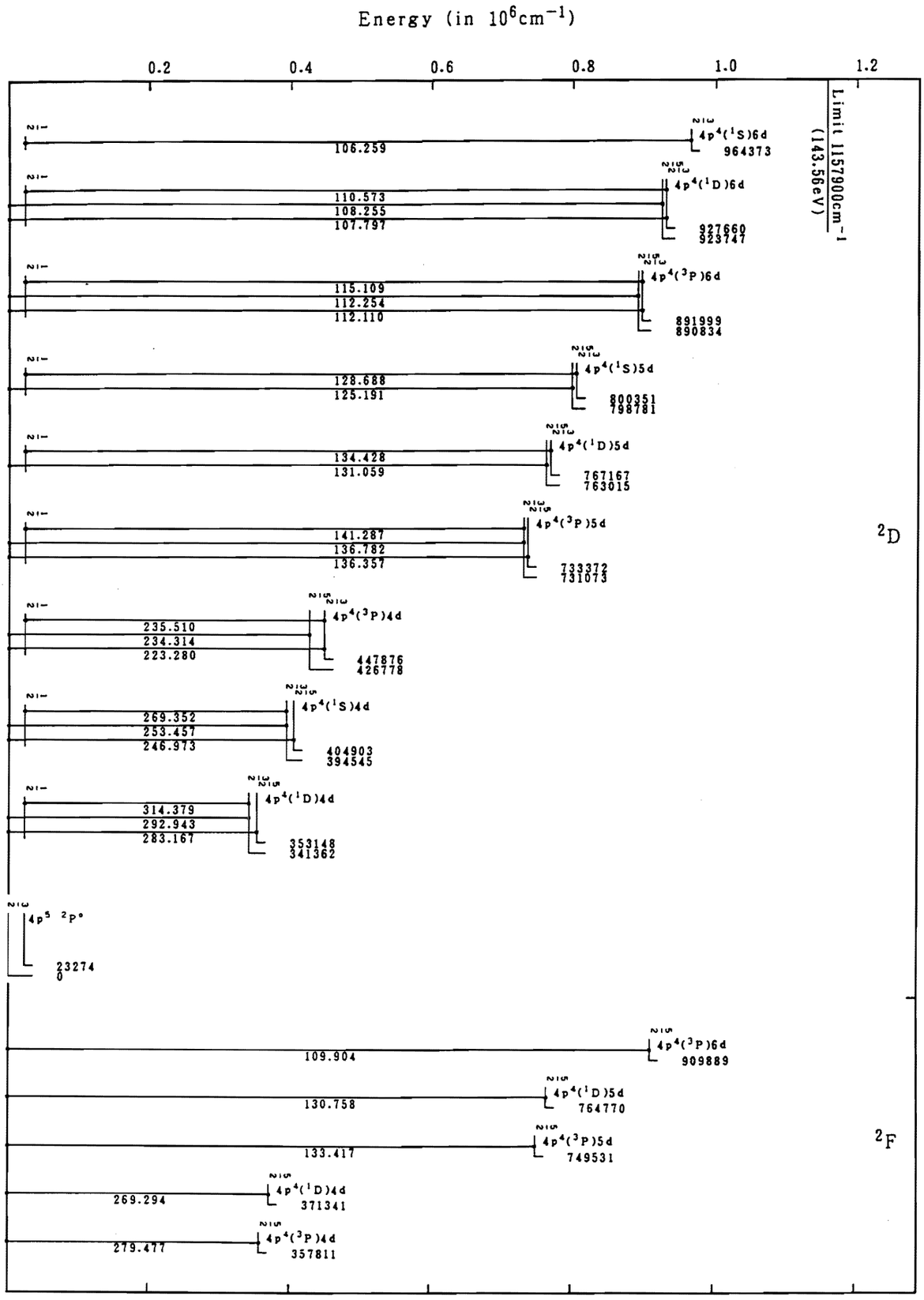

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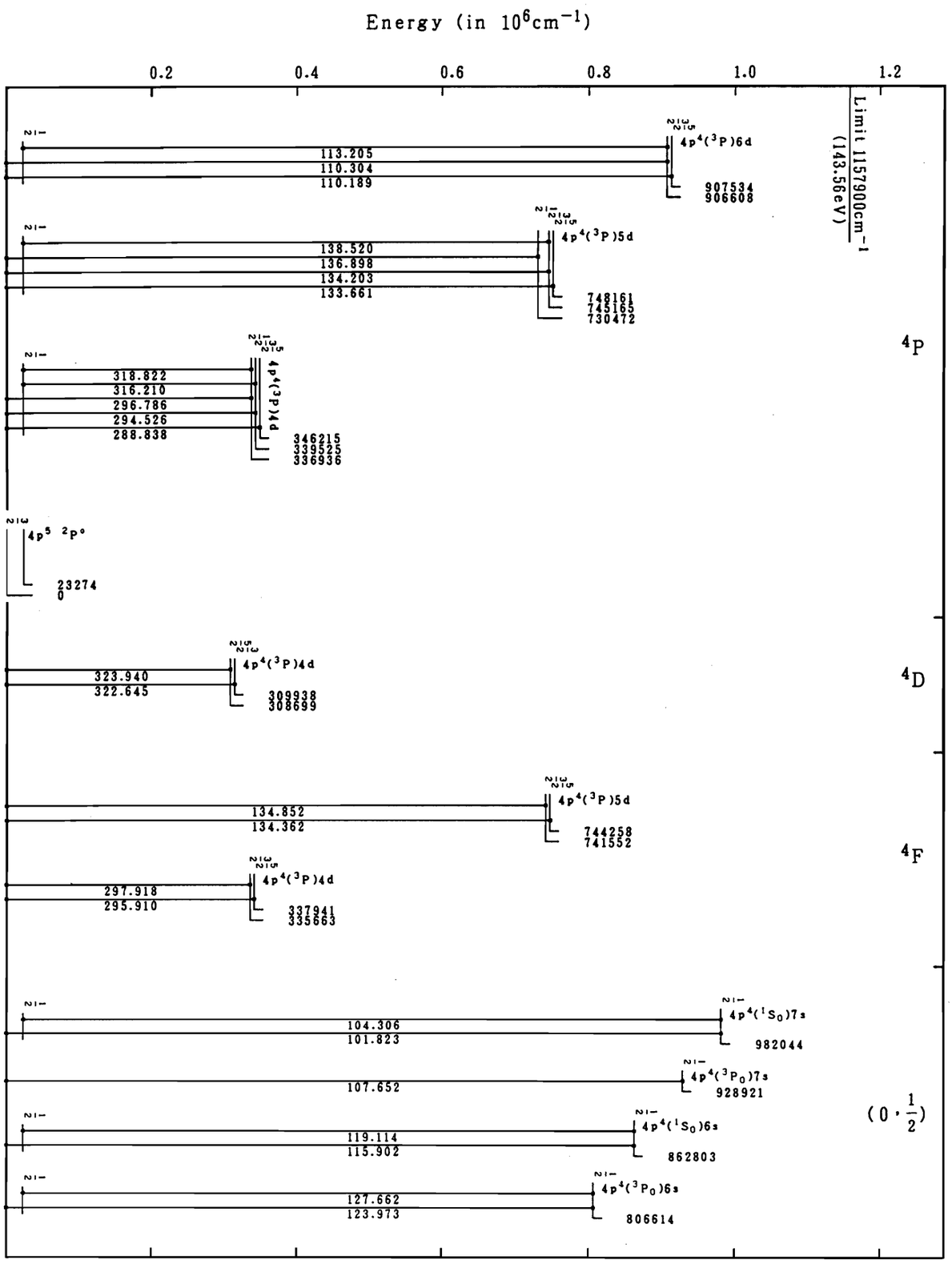

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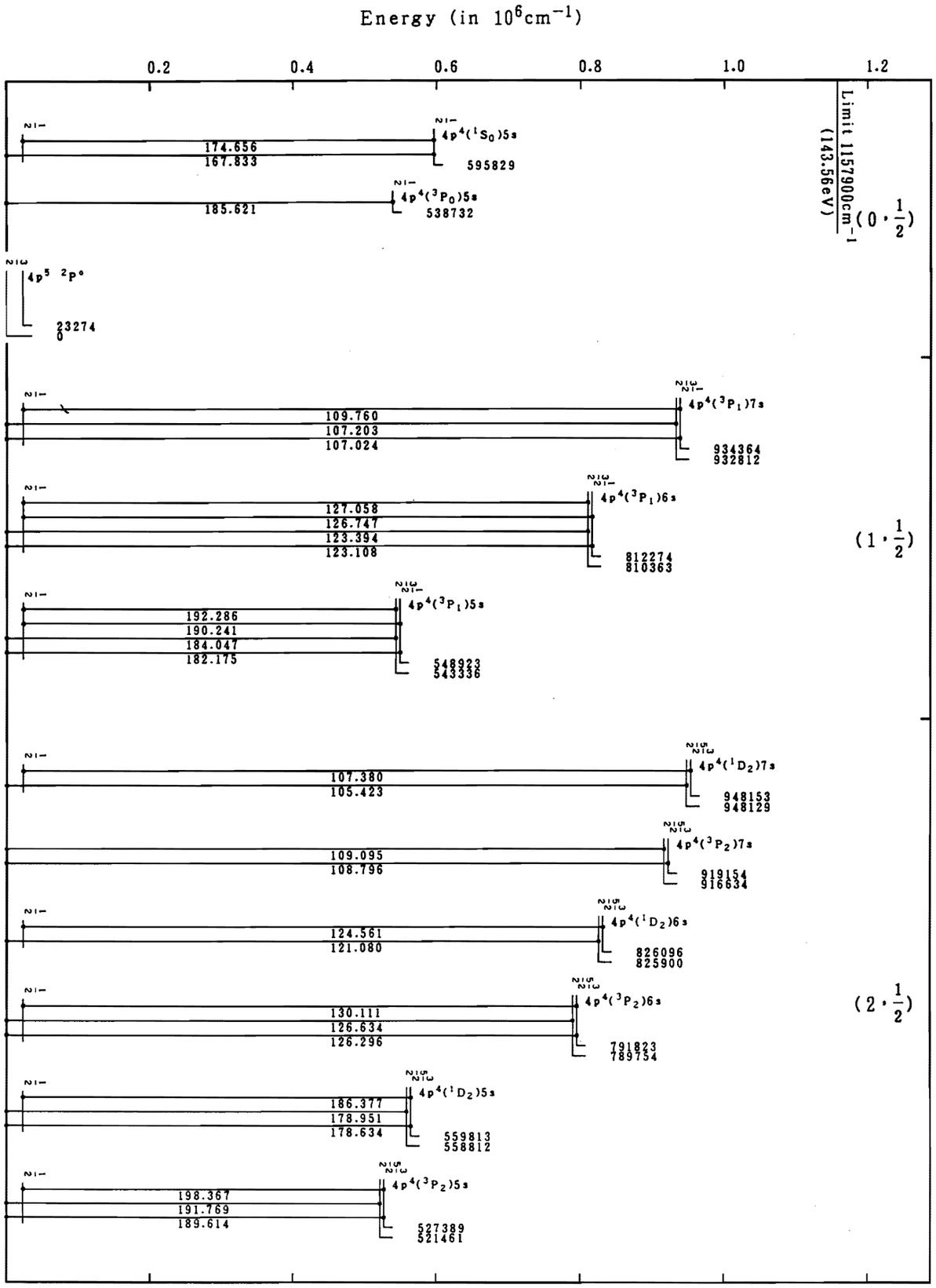

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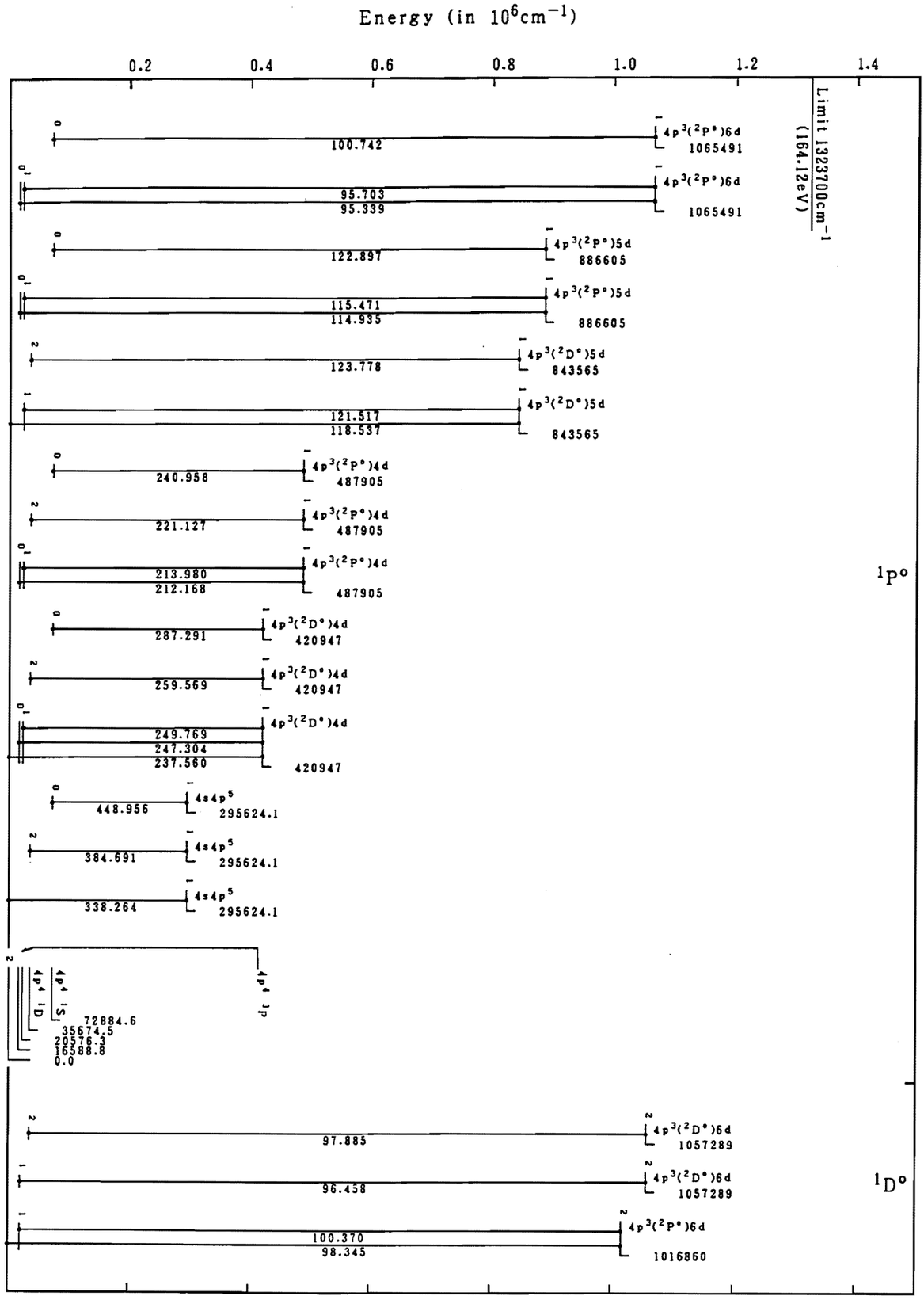

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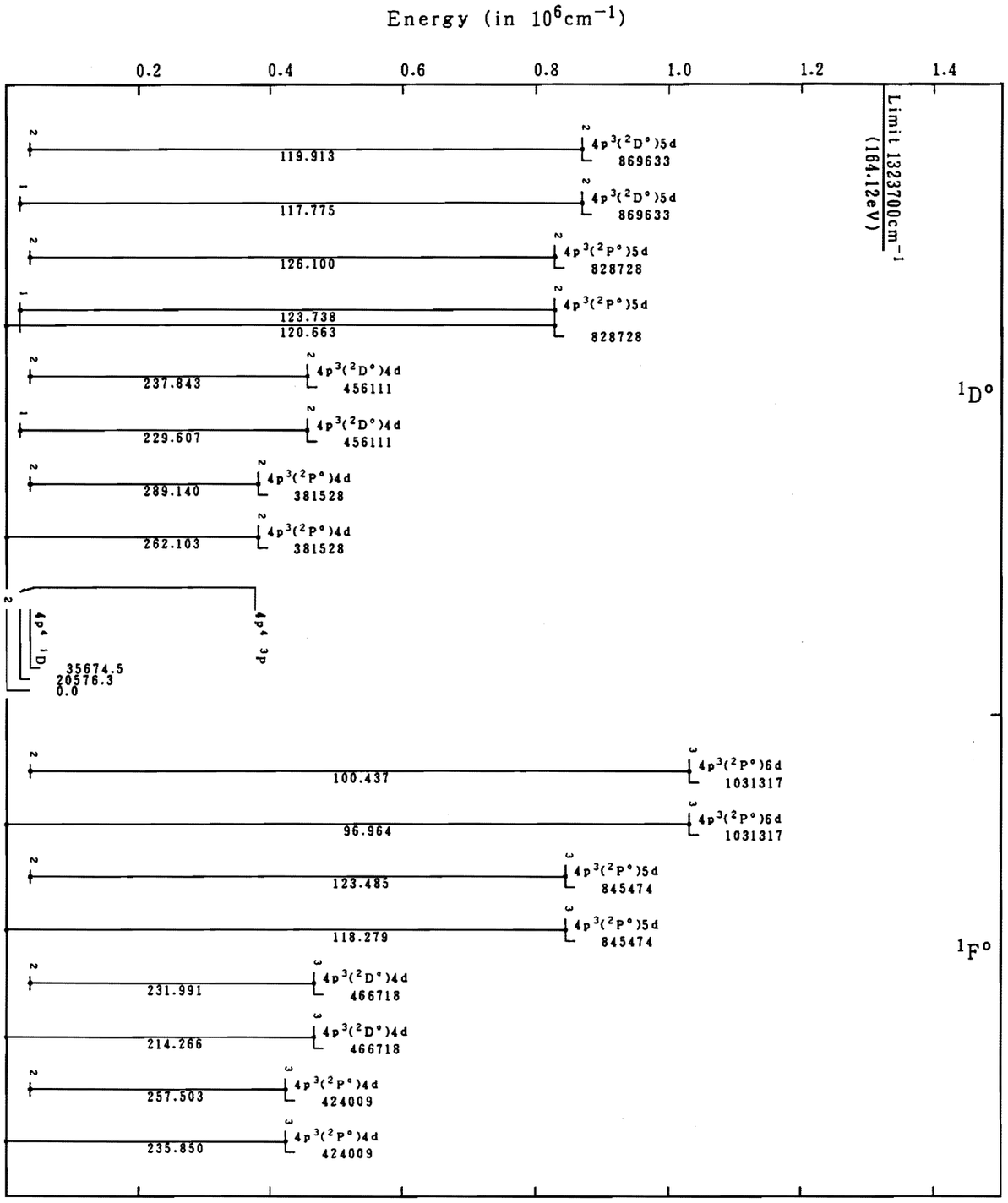

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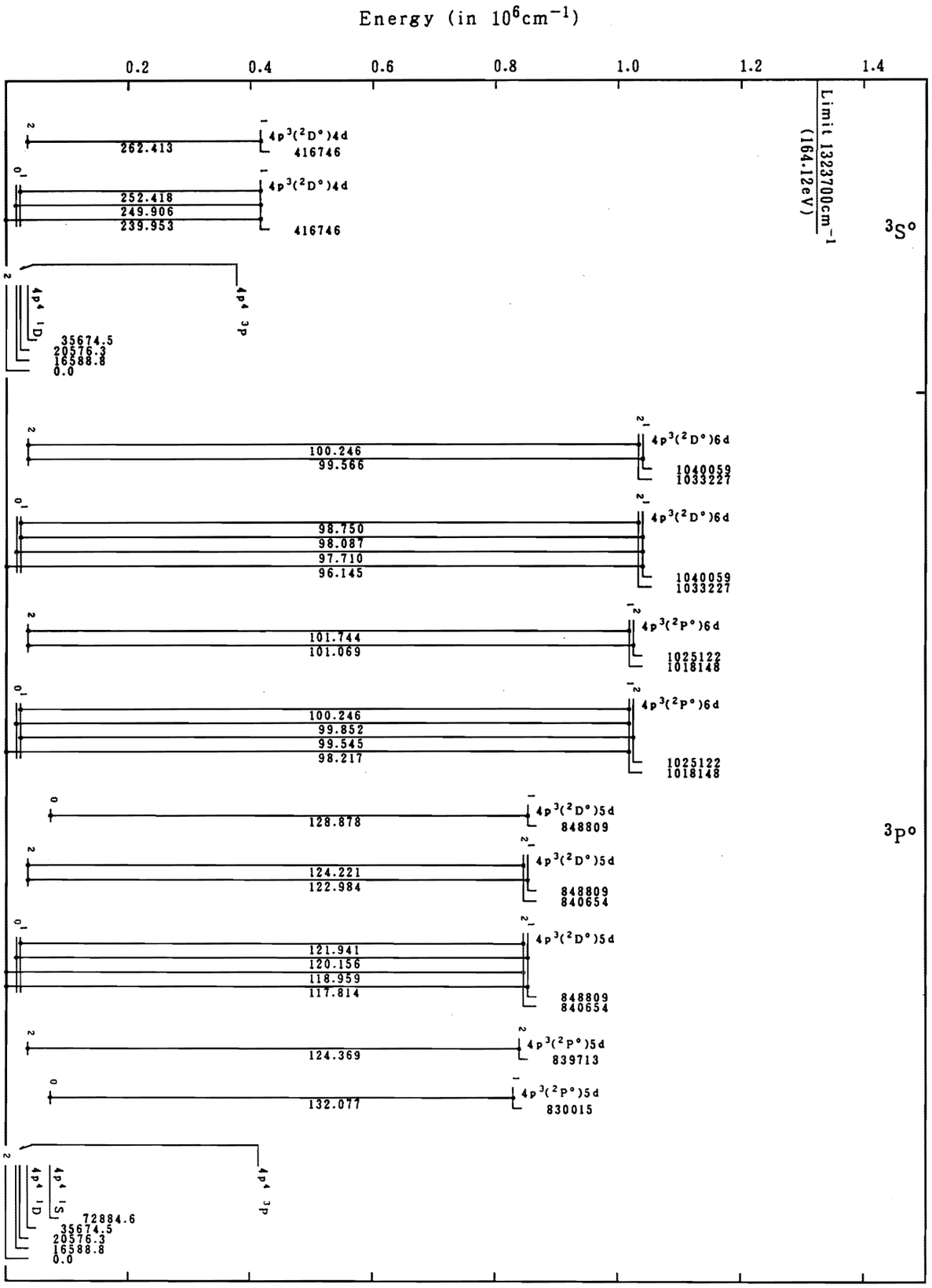

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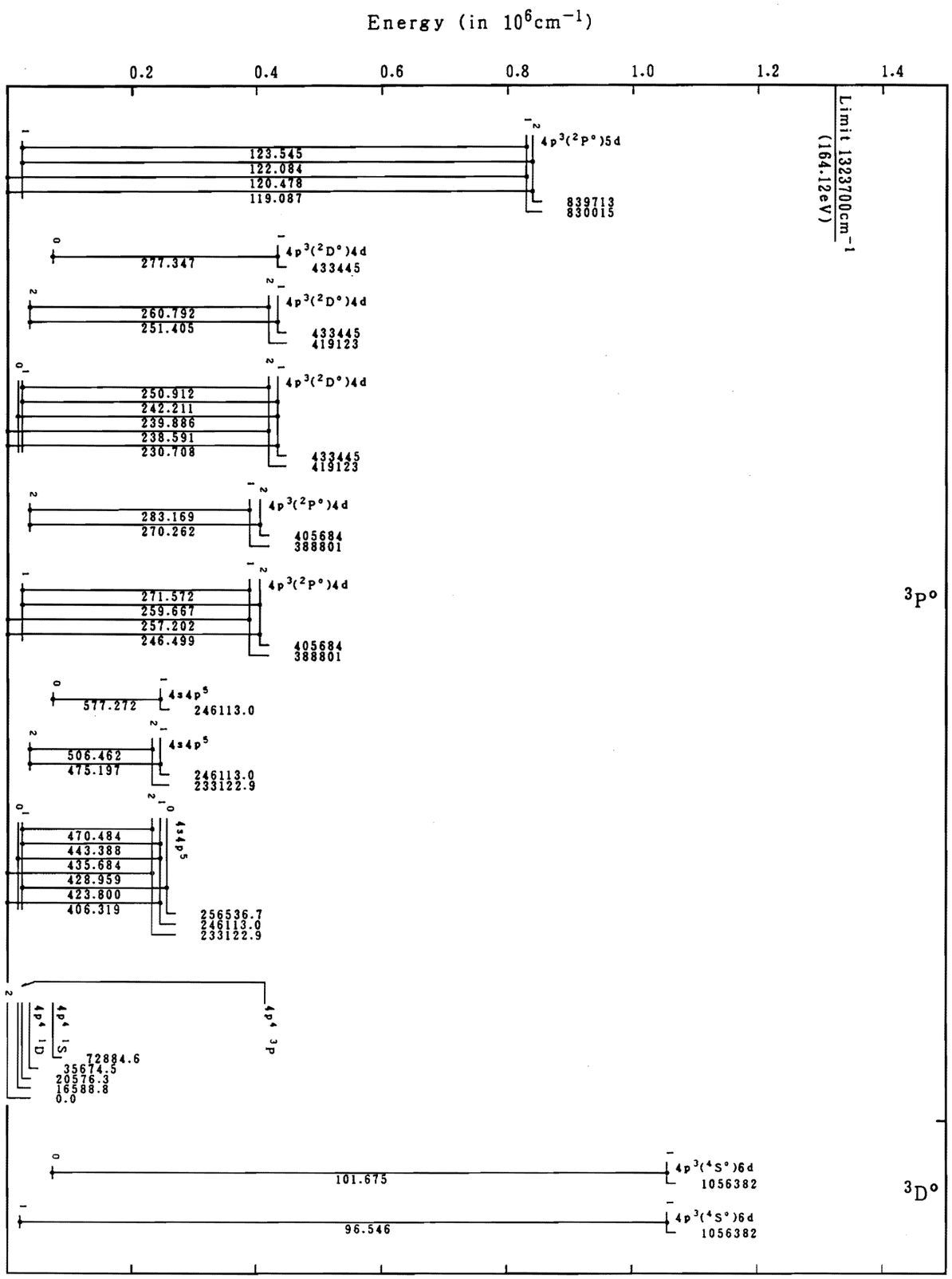

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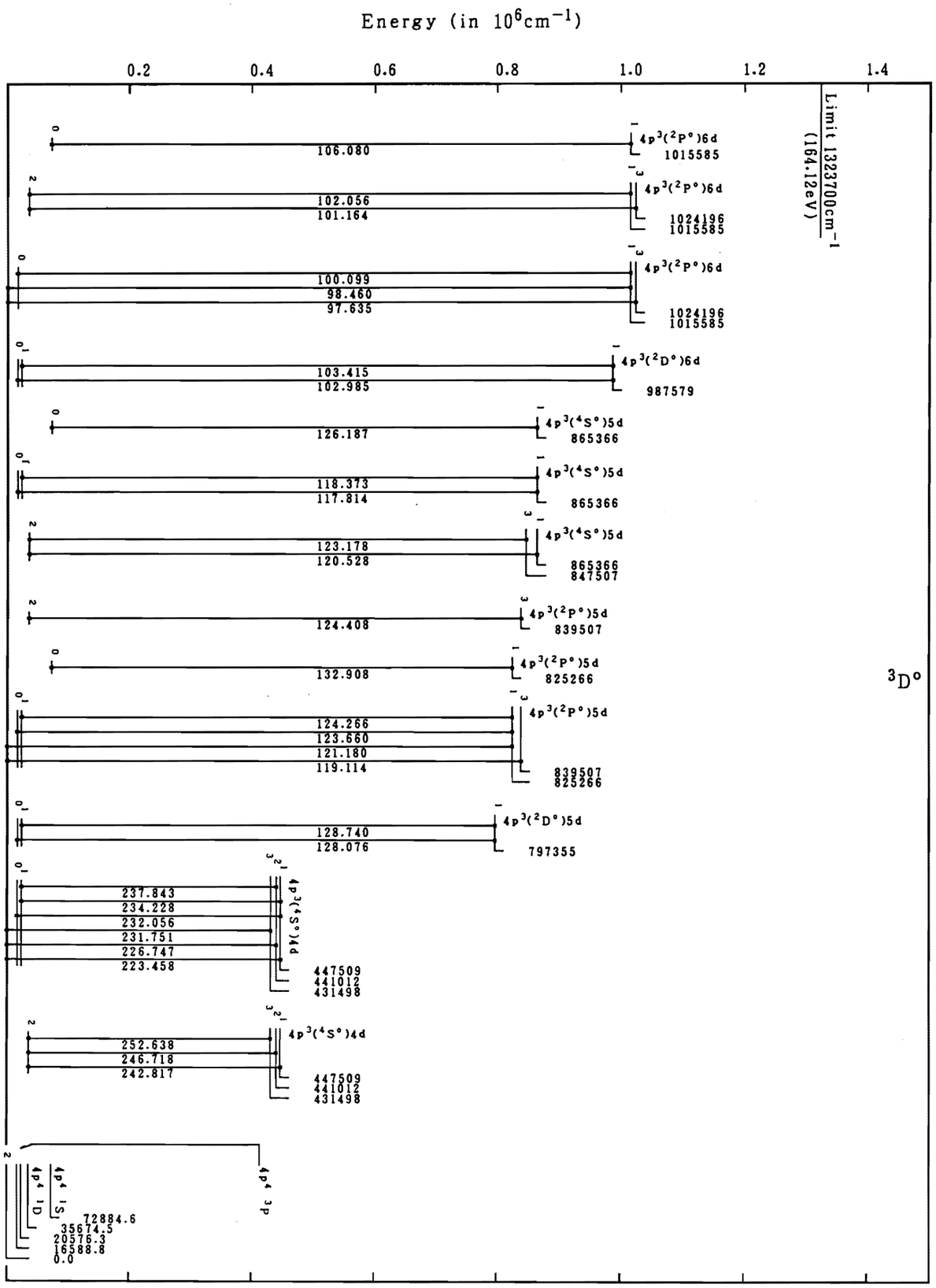

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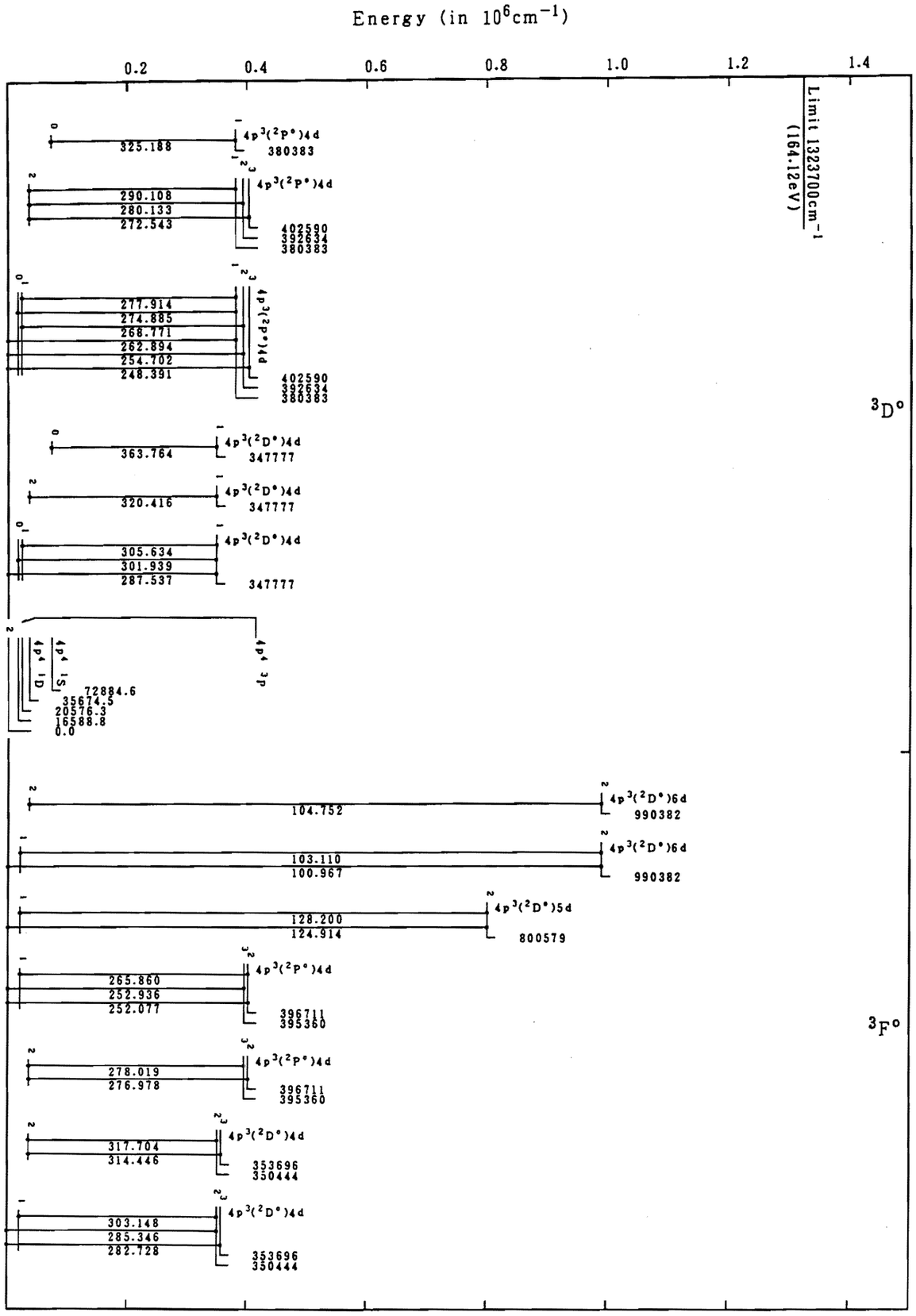

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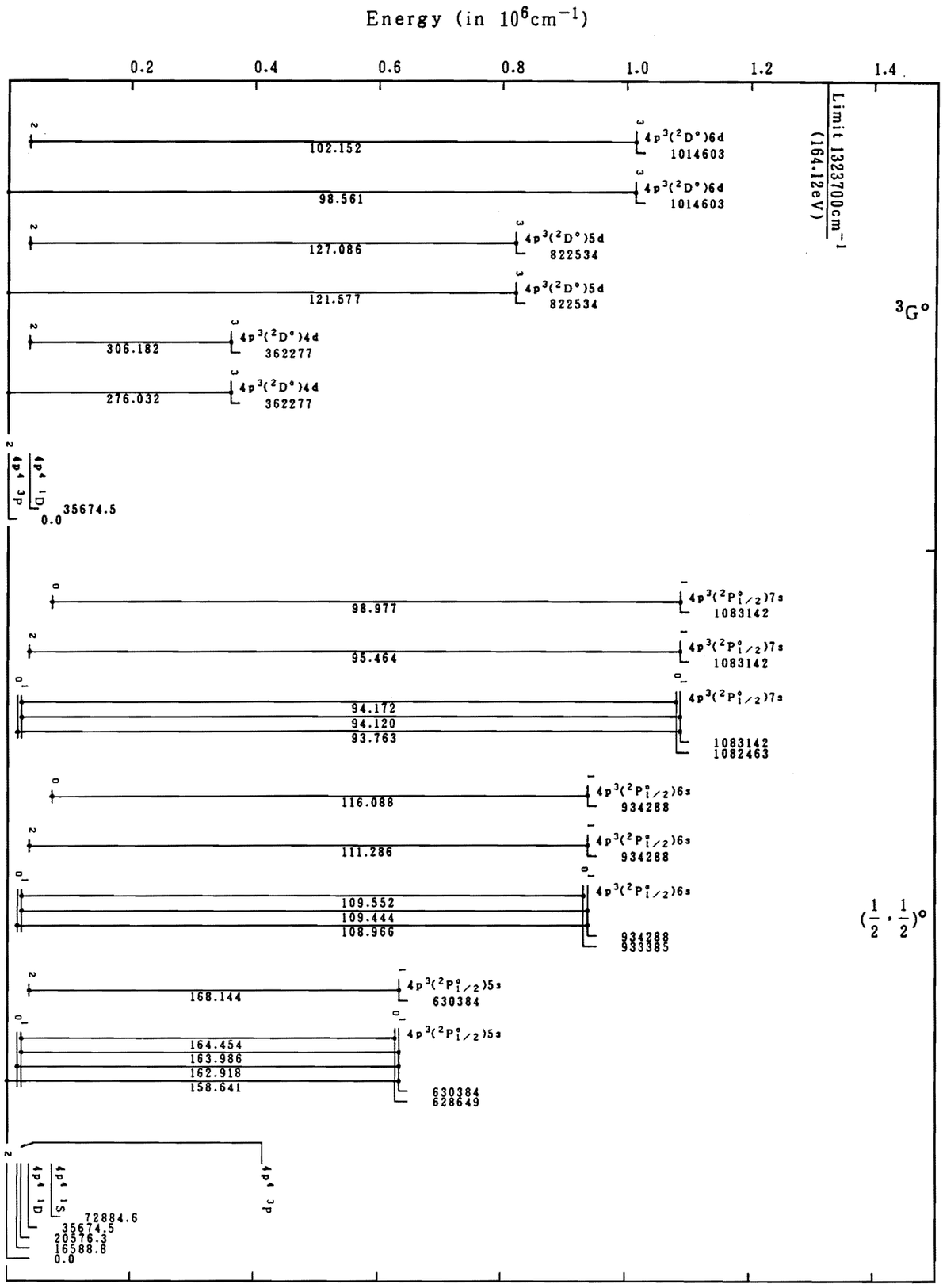

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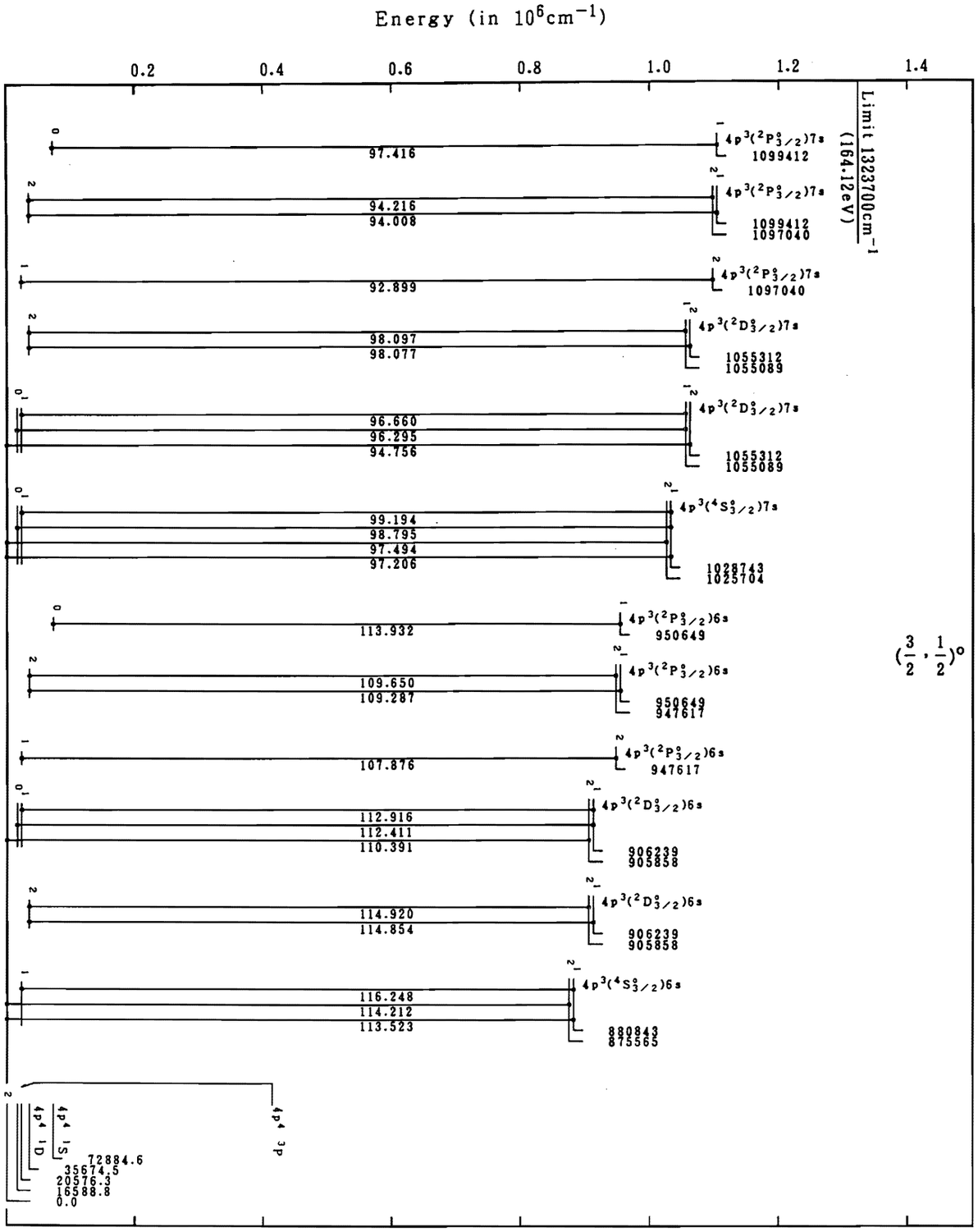
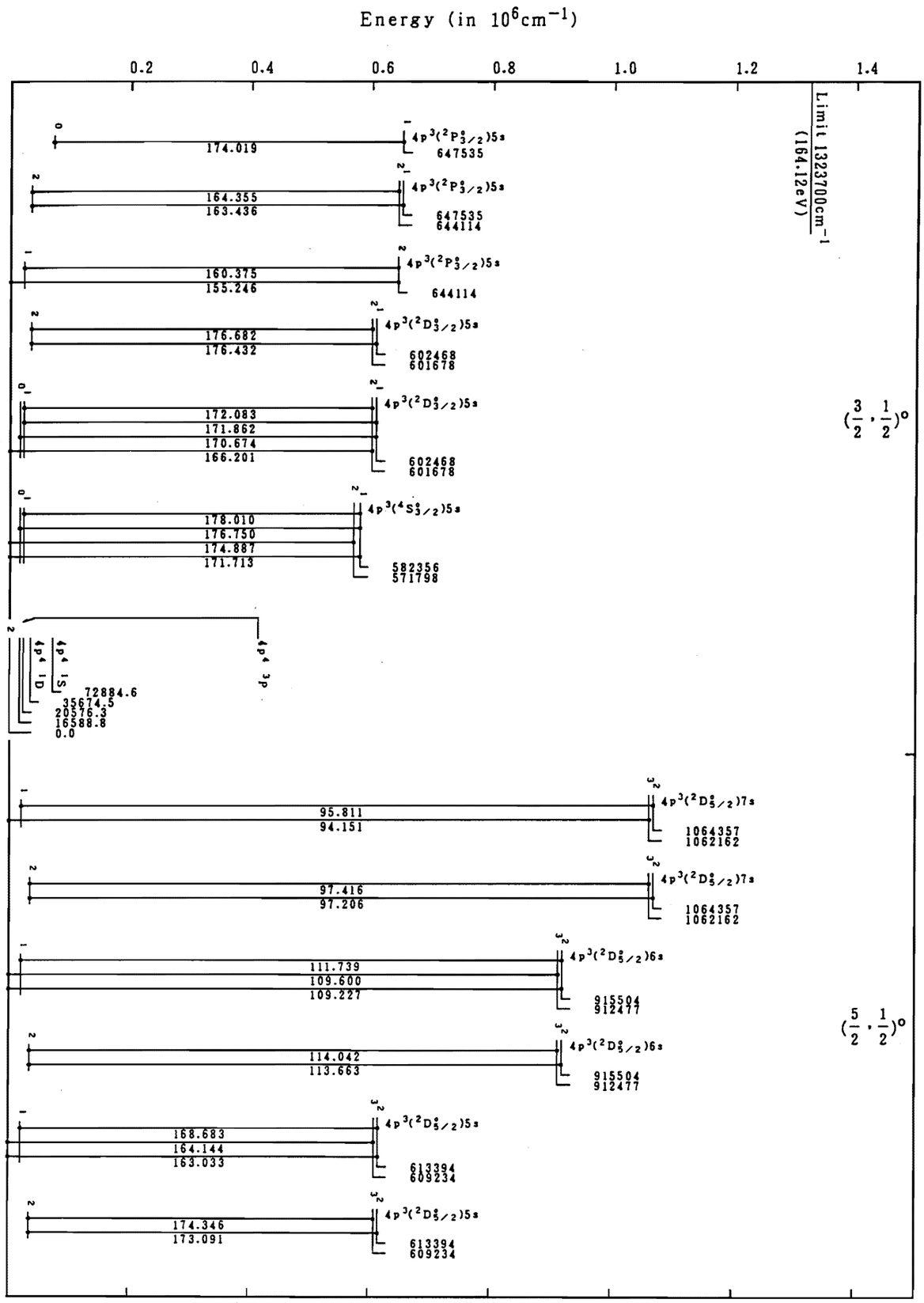
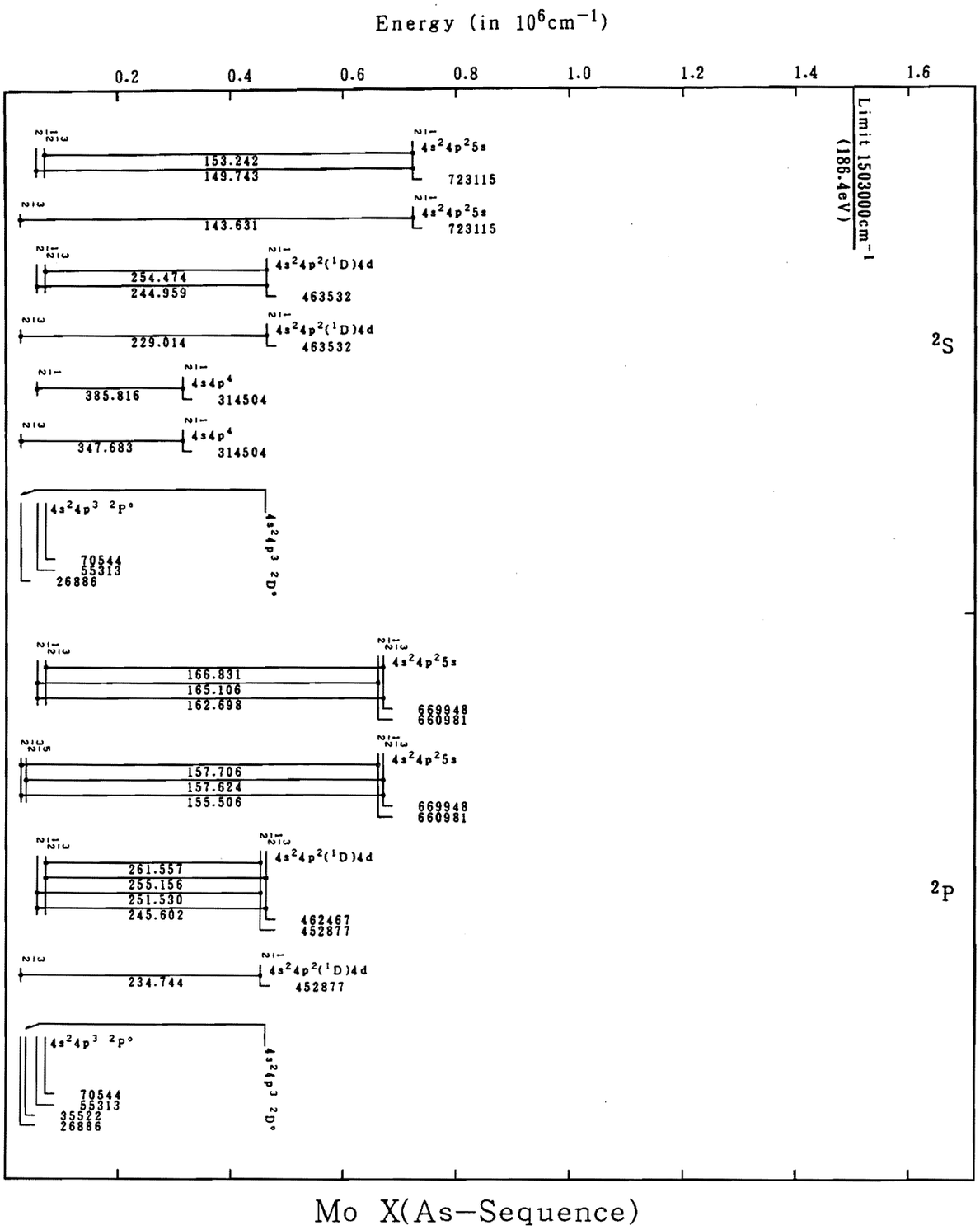


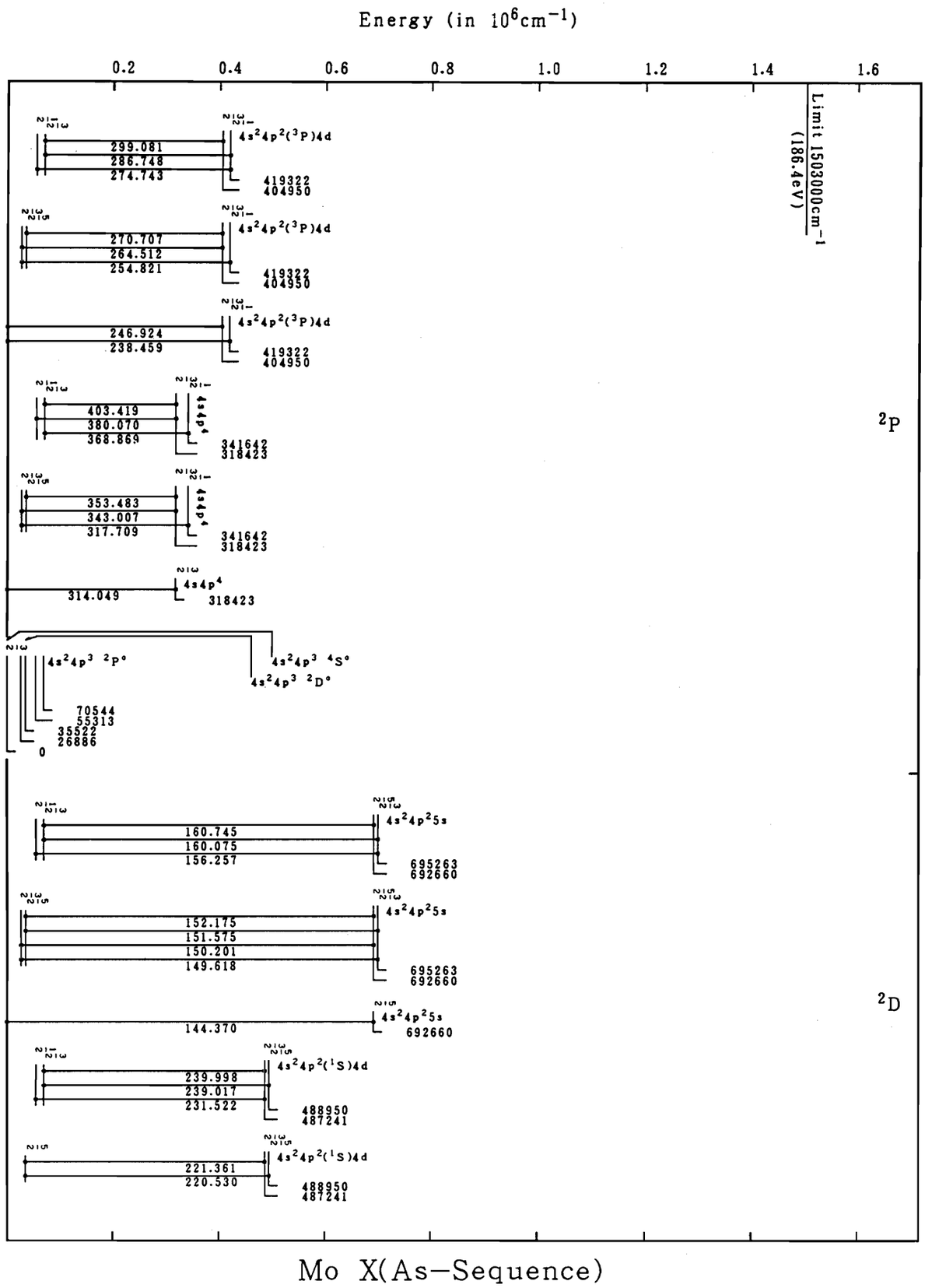
Mo IX(Se−Sequence)

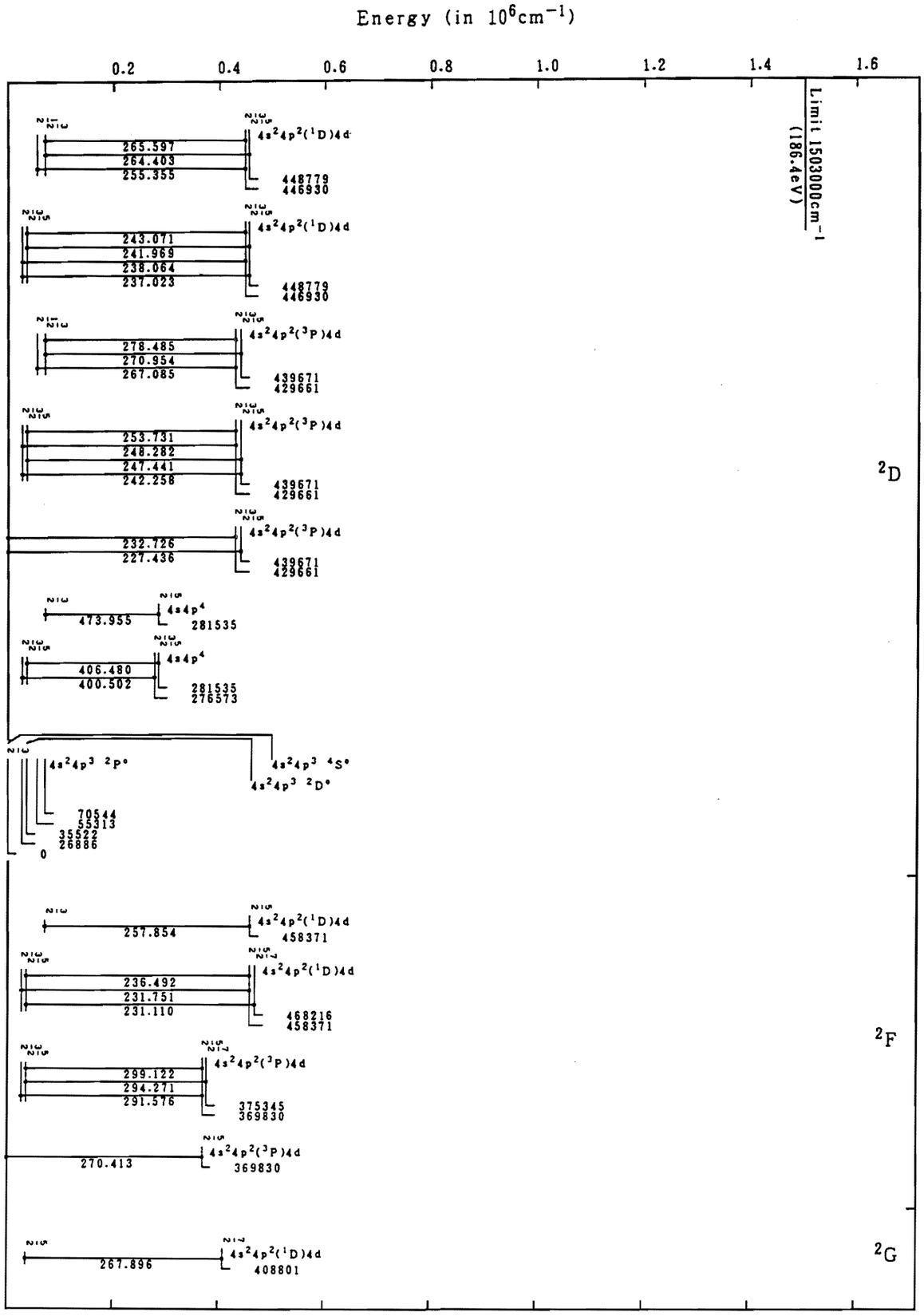


Mo IX(Se–Sequence)

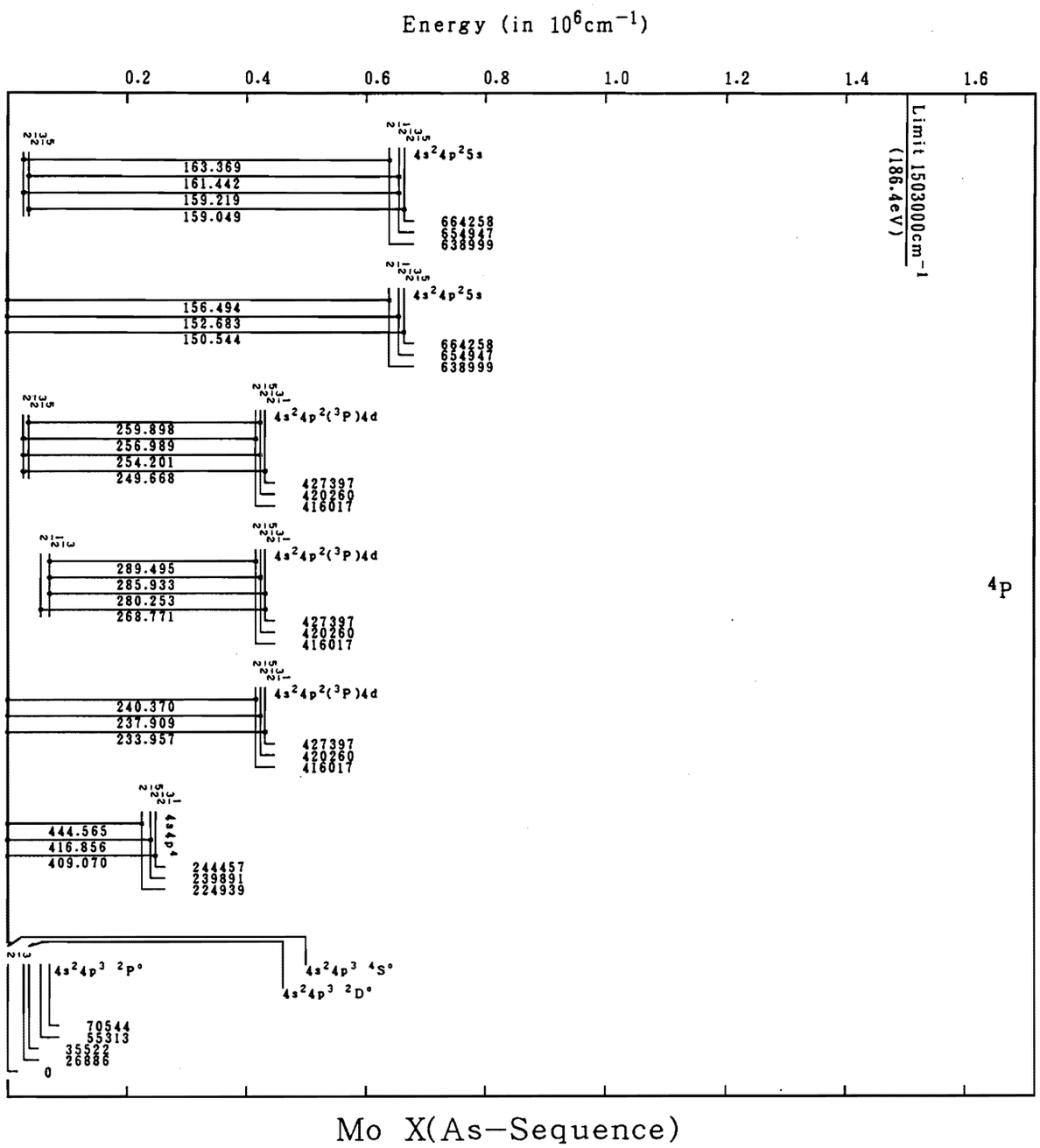


Mo X(As–Sequence)

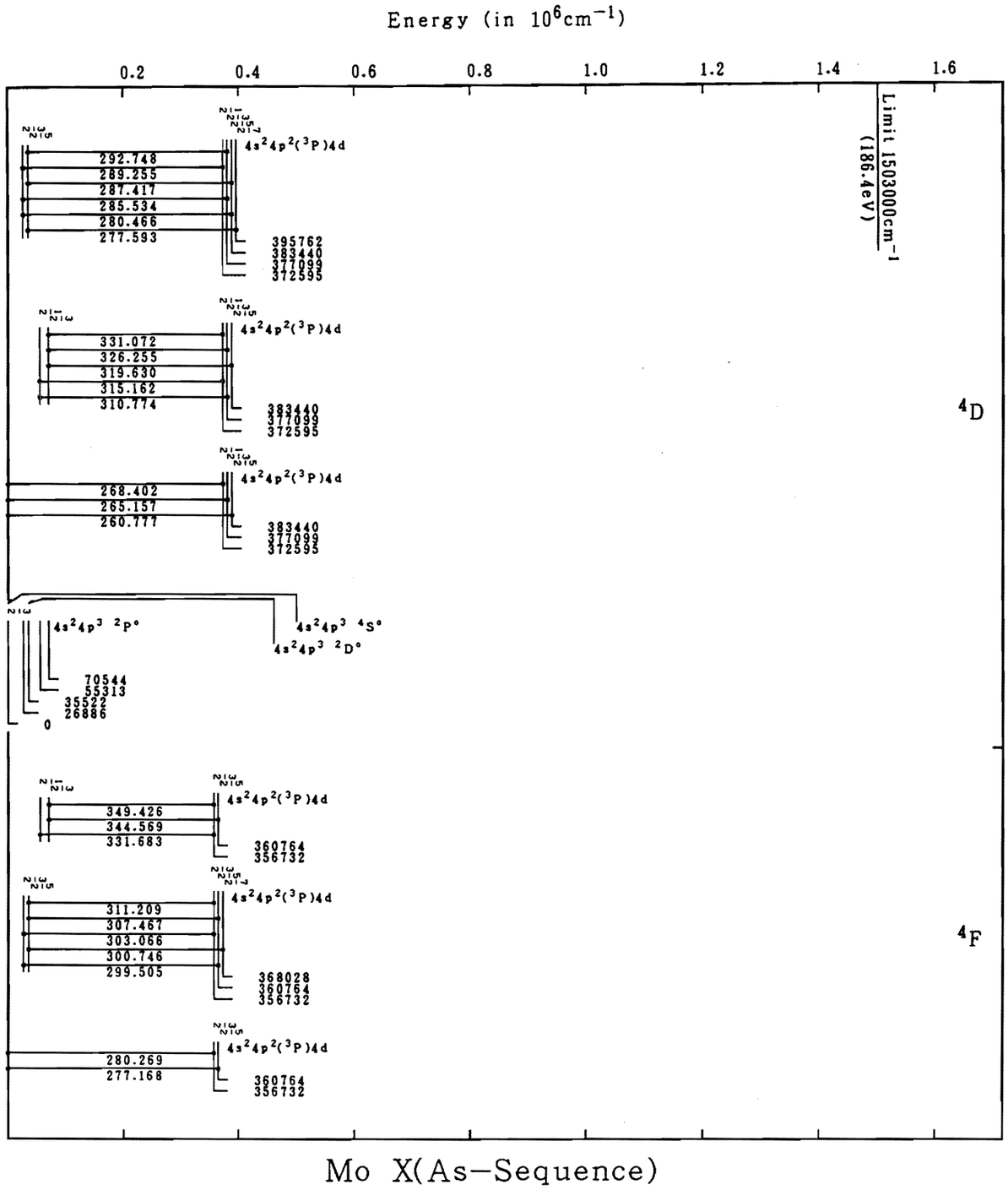

Energy (in $10^6 cm^{-1}$)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Limit 1503000cm^{-1}
(186.4eV)
$4s^24p^2(^3P)4d$
299.081
286.748
274.743
419322
404950
$4s^24p^2(^3P)4d$
270.707
264.512
254.821
419322
404950
$4s^24p^2(^3P)4d$
246.924
238.459
419322
404950
$4s4p^4$
403.419
380.070
368.869
341642
318423
$4s4p^4$
353.483
343.007
317.709
341642
318423
$4s4p^4$
314.049
318423
$4s^24p^3\ ^2P°$
$4s^24p^3\ ^4S°$
$4s^24p^3\ ^2D°$
70544
55313
35522
26886
0
^2P
$4s^24p^25s$
160.745
160.075
156.257
695263
692660
$4s^24p^25s$
152.175
151.575
150.201
149.618
695263
692660
$4s^24p^25s$
144.370
692660
$4s^24p^2(^1S)4d$
239.998
239.017
231.522
488950
487241
$4s^24p^2(^1S)4d$
221.361
220.530
488950
487241
^2D
Mo X(As−Sequence)

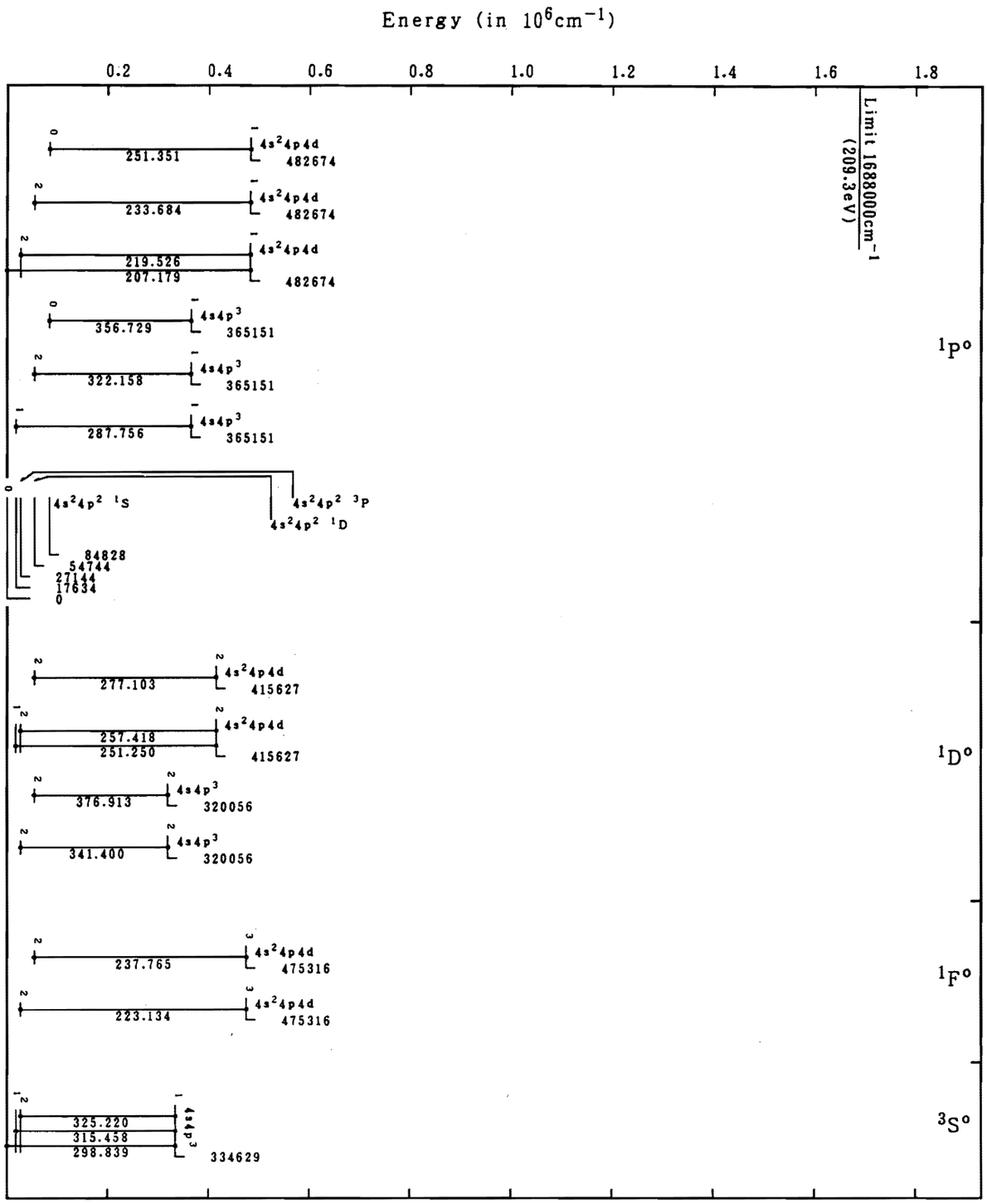


Mo X(As–Sequence)

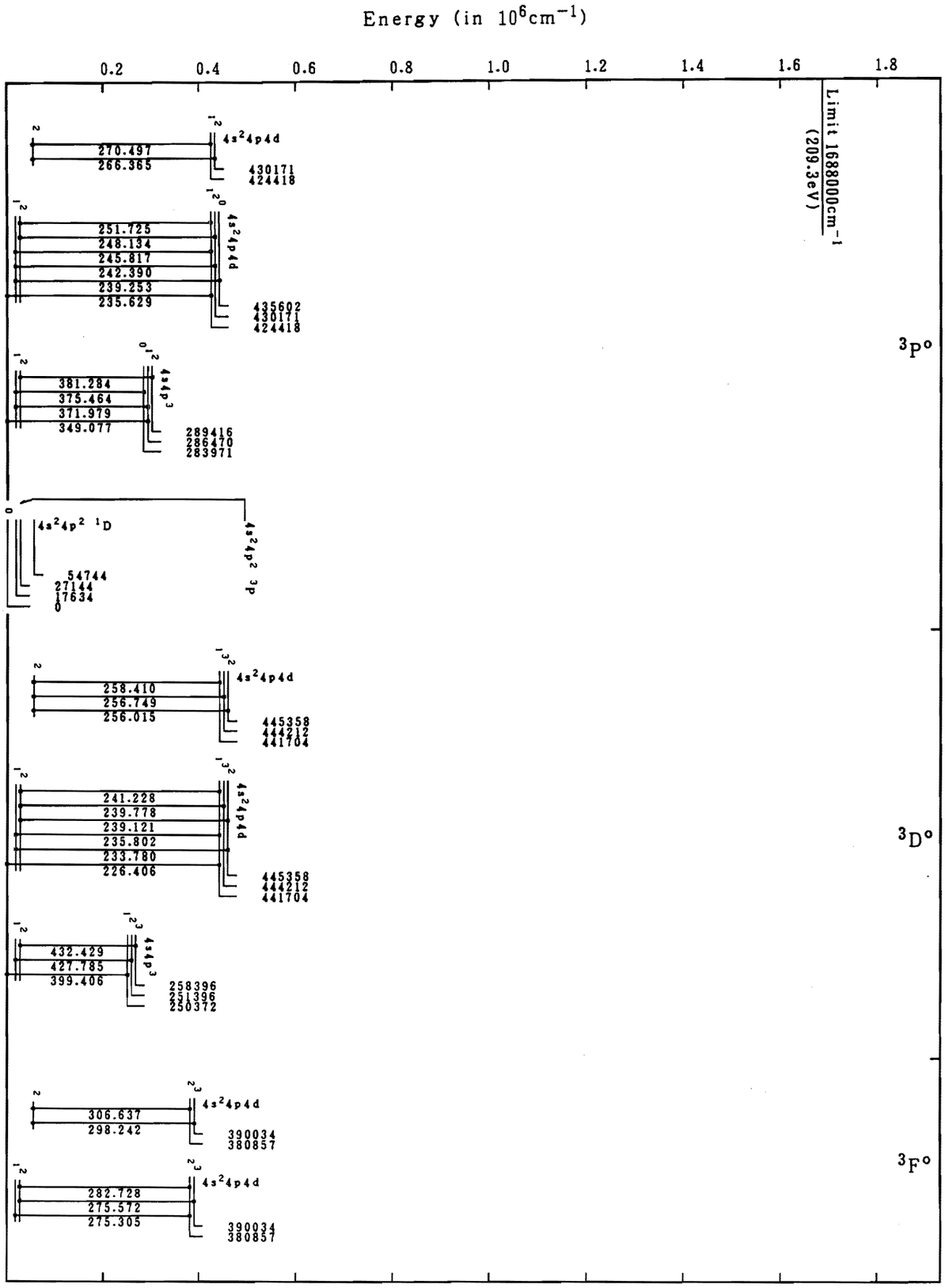


Mo X(As−Sequence)

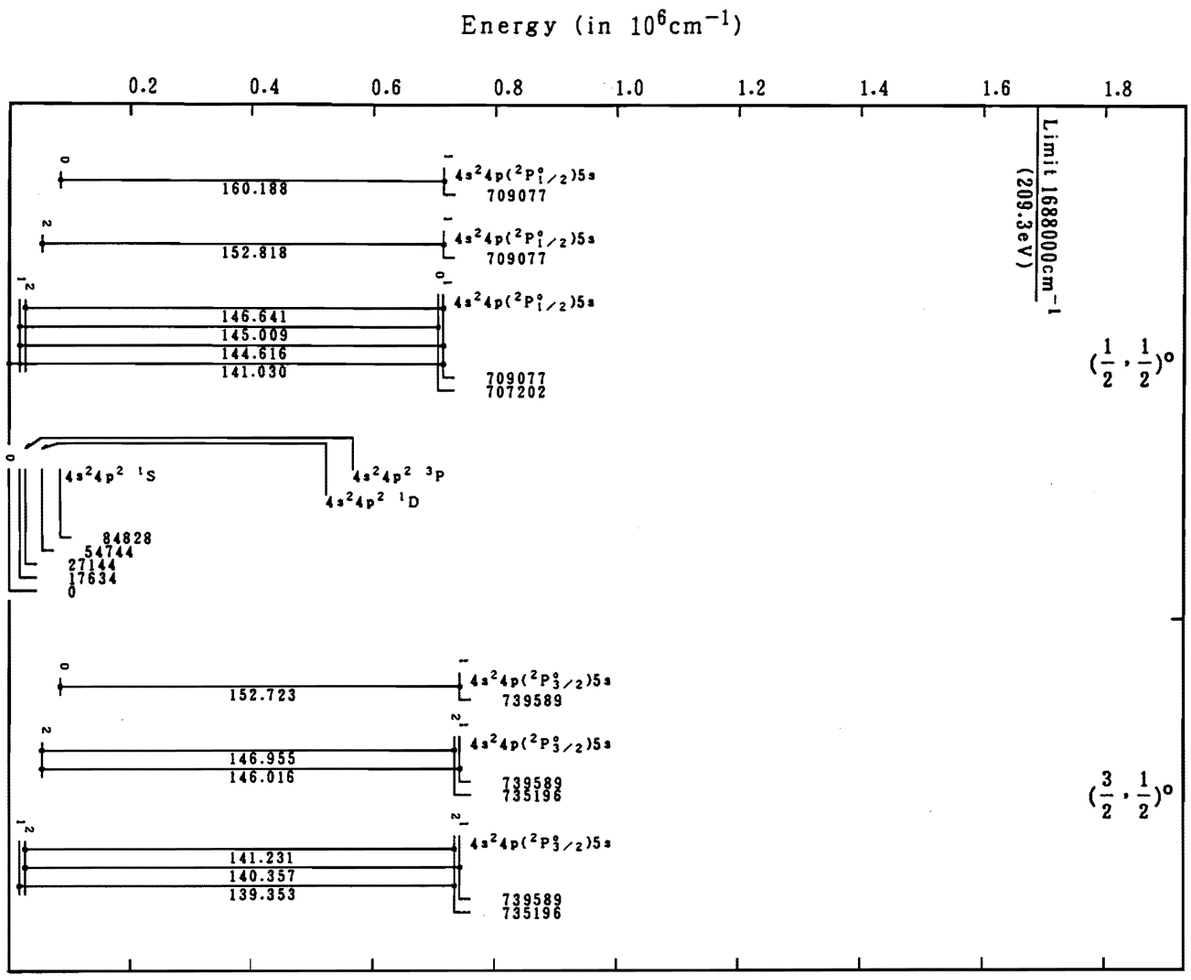

Energy (in $10^6 cm^{-1}$)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Limit 1503000cm^{-1}
(186.4eV)
$4s^24p^2(^3P)4d$
292.748
289.255
287.417
285.534
280.466
277.593
395762
383440
377099
372595
331.072
326.255
319.630
315.162
310.774
383440
377099
372595
268.402
265.157
260.777
383440
377099
372595
$4s^24p^3\ ^2P°$
$4s^24p^3\ ^4S°$
$4s^24p^3\ ^2D°$
70544
55313
35522
26886
0
349.426
344.569
331.683
360764
356732
311.209
307.467
303.066
300.746
299.505
368028
360764
356732
280.269
277.168
360764
356732
^4D
^4F
Mo X(As-Sequence)



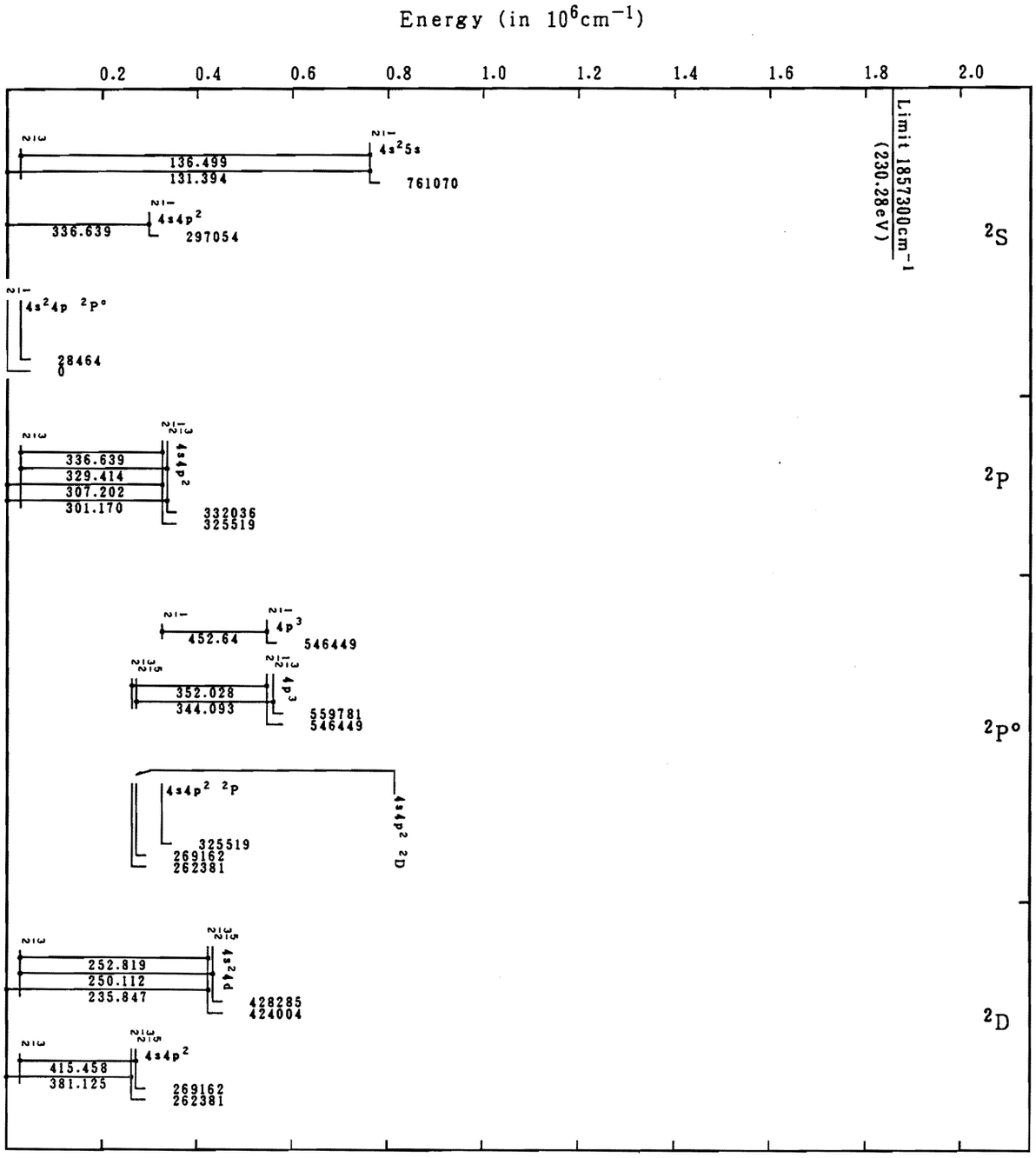
Mo XI(Ge−Sequence)



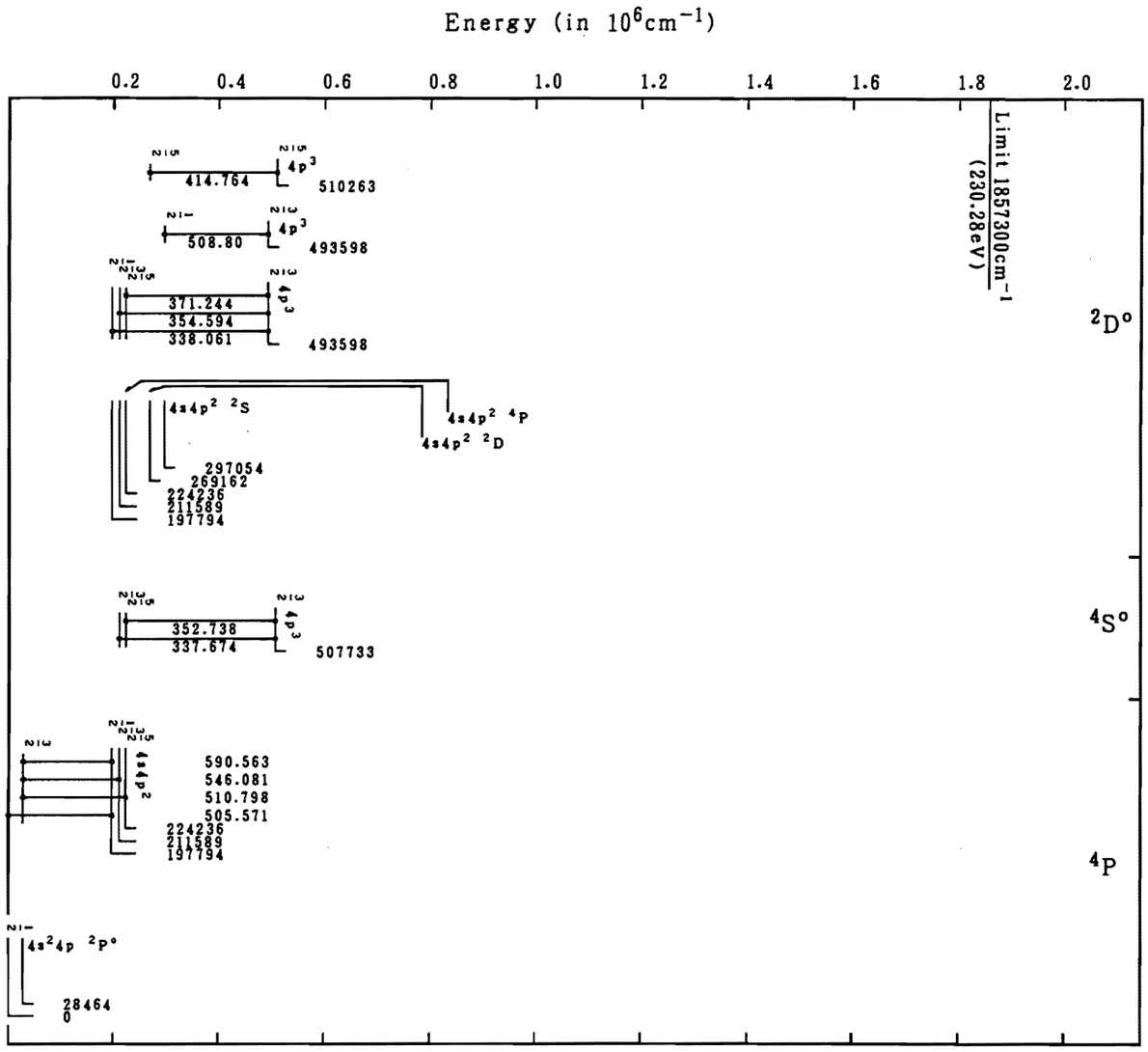
Mo XI(Ge–Sequence)



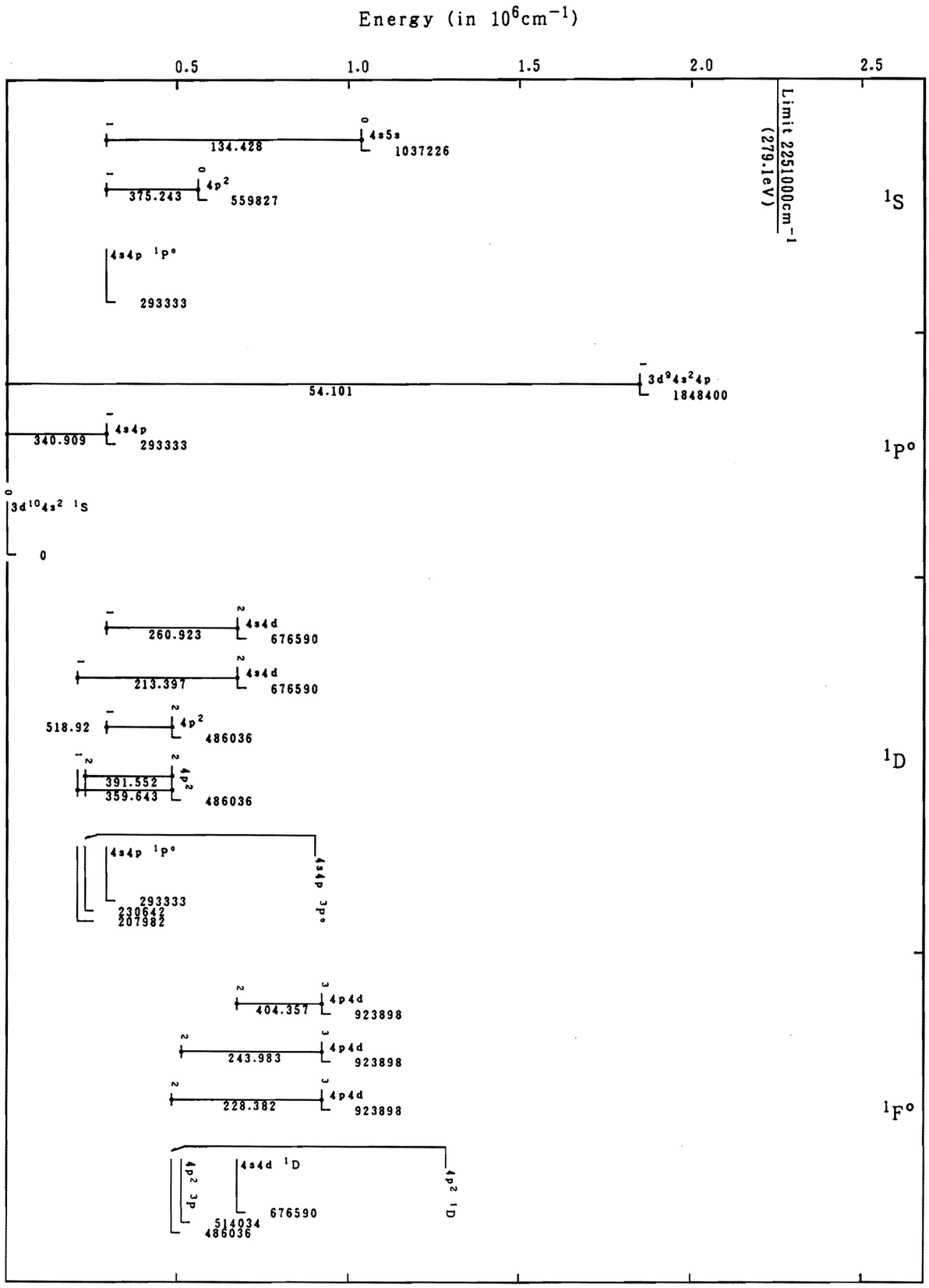
Mo XI(Ge–Sequence)



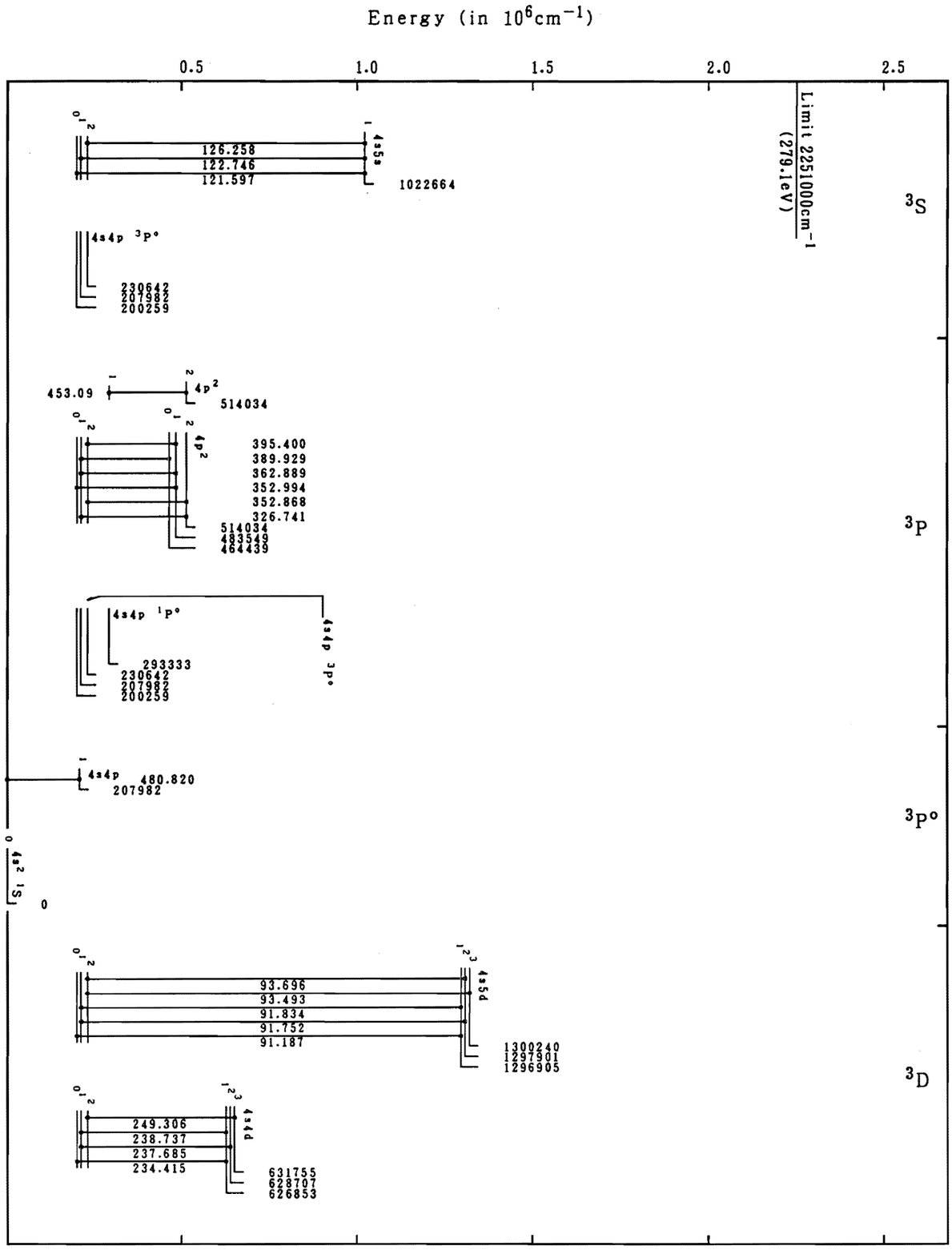
Mo XII(Ga−Sequence)



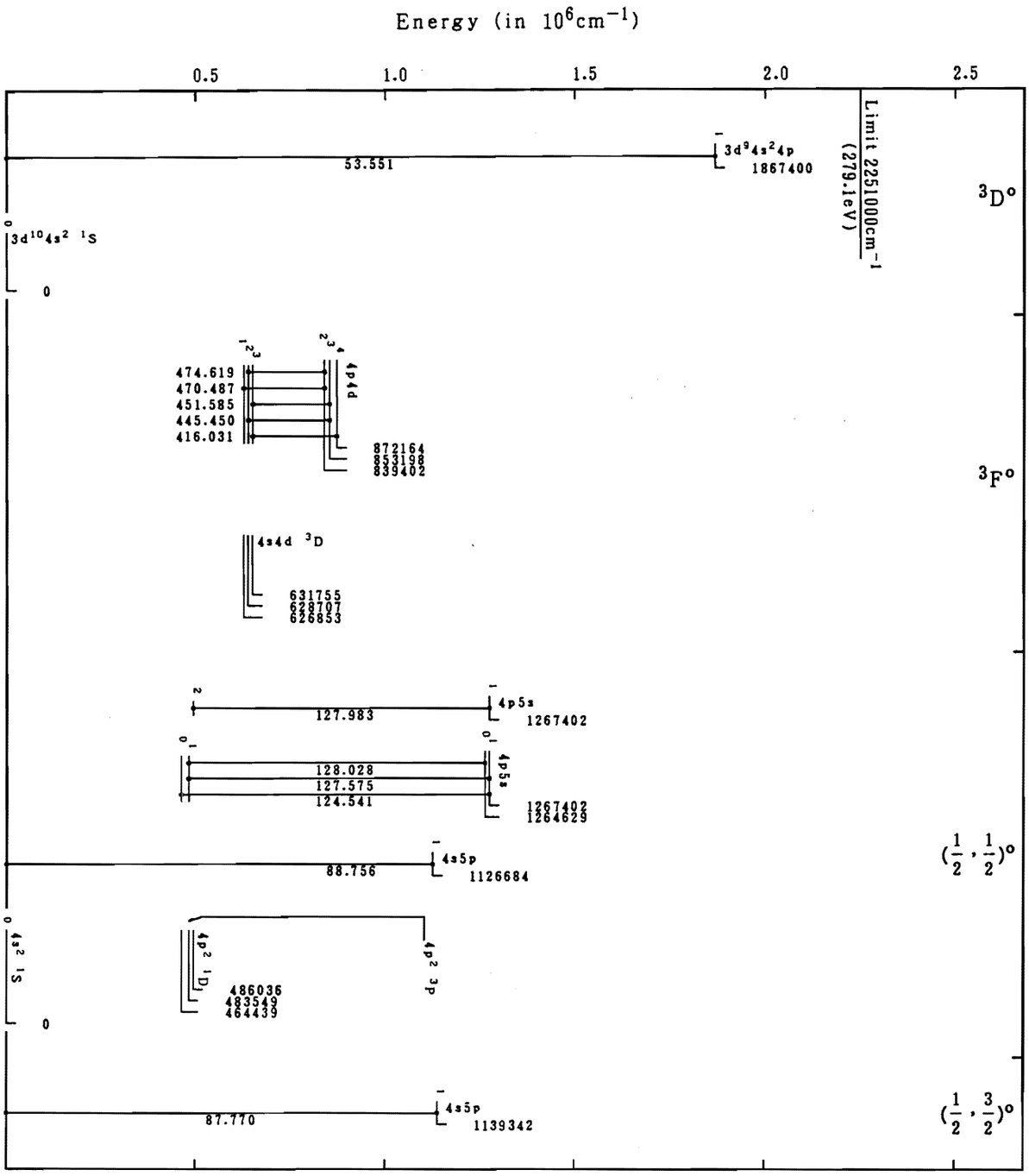
Mo XII(Ga−Sequence)



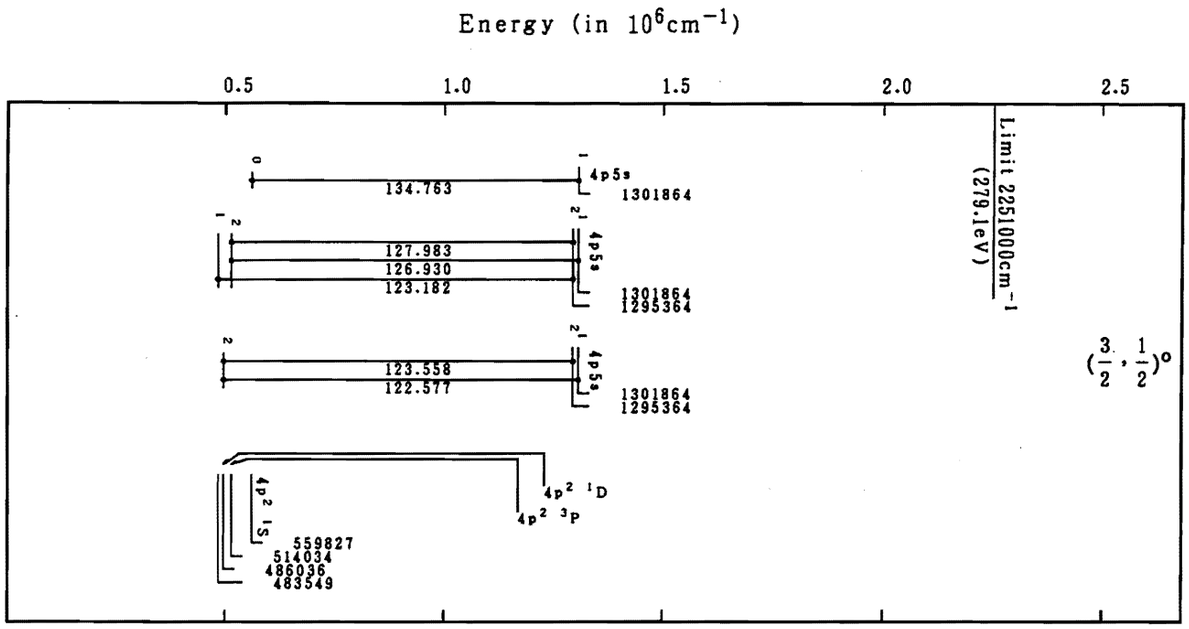
Mo XIII(Zn−Sequence)



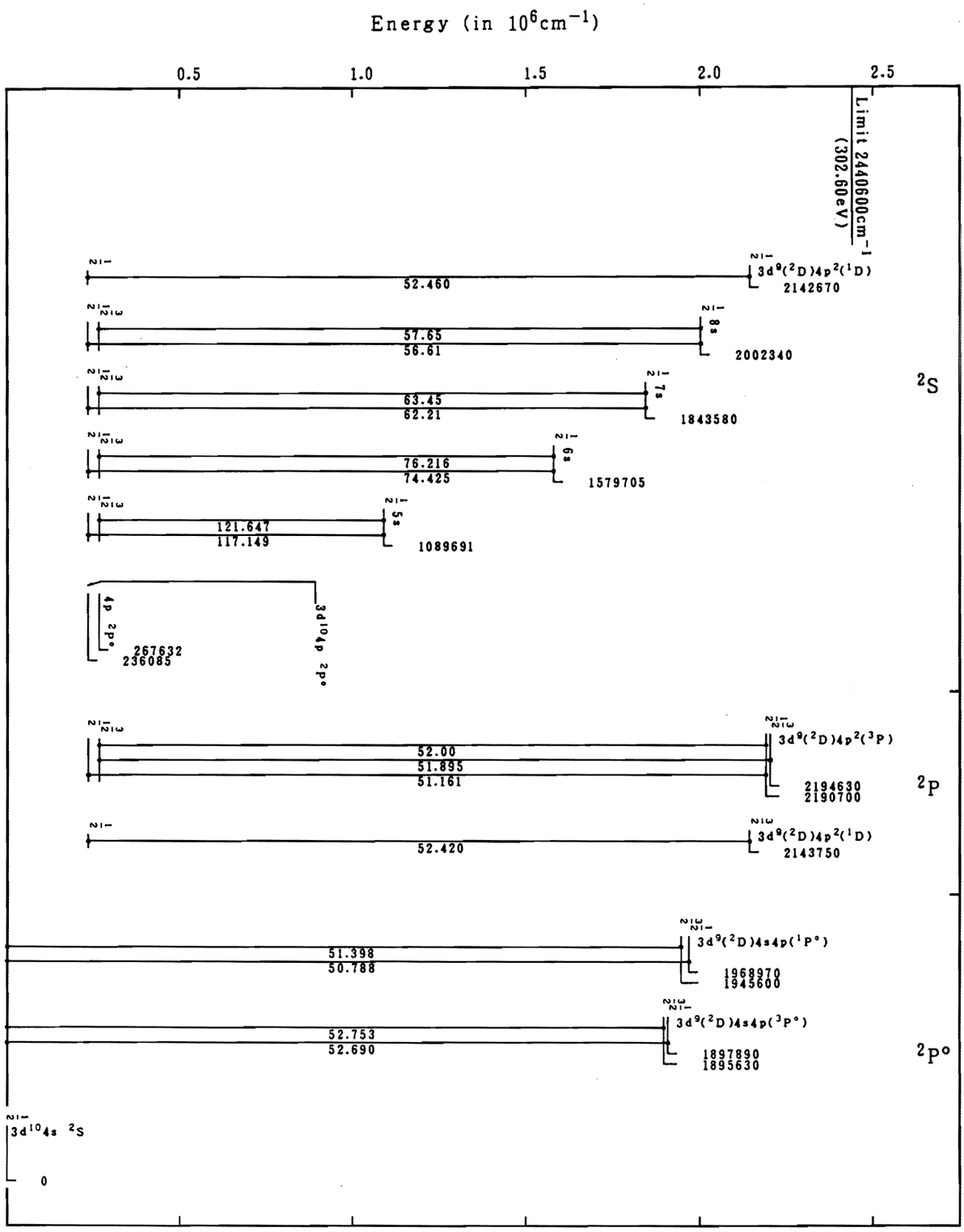
Mo XIII(Zn–Sequence)



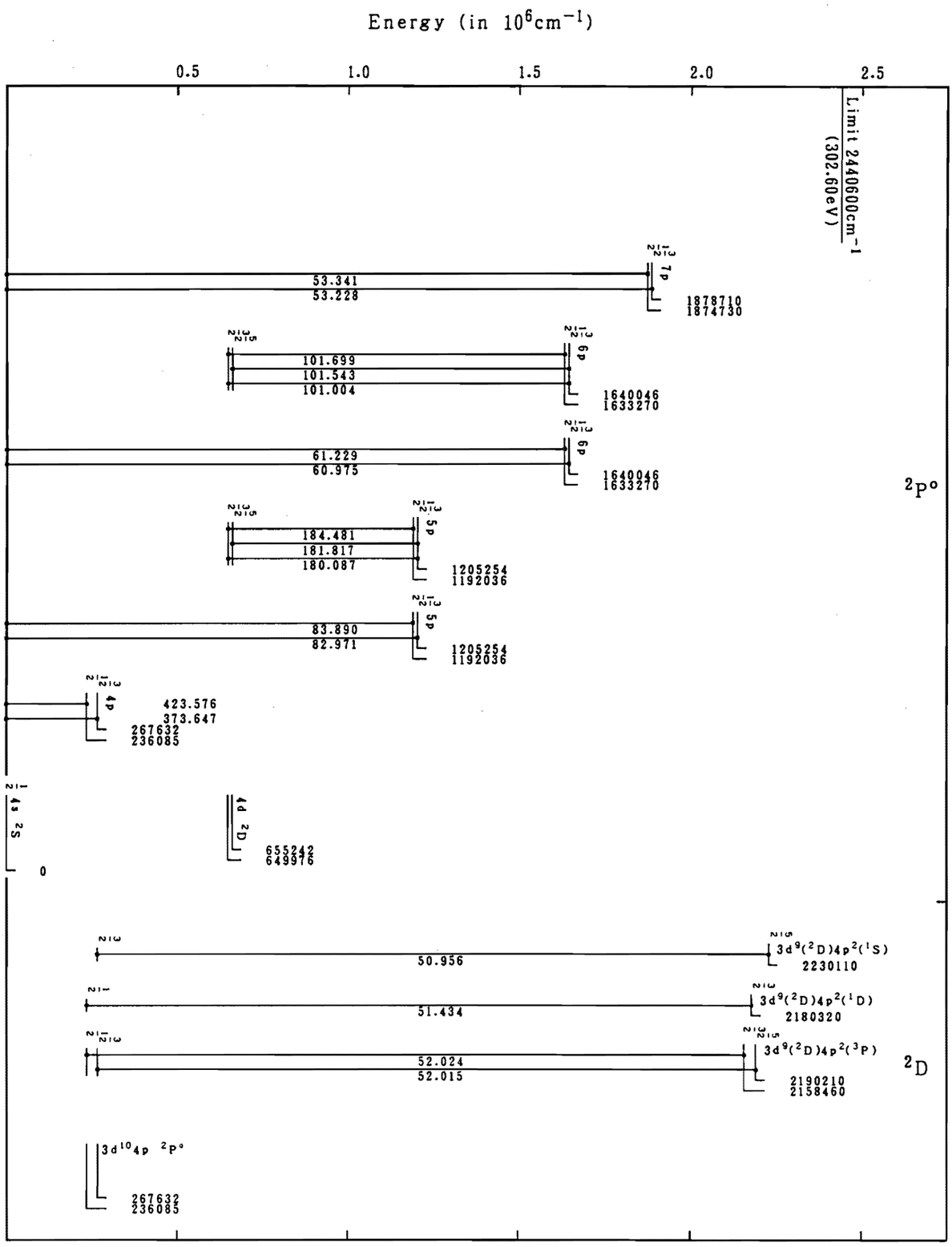
Mo XIII(Zn−Sequence)



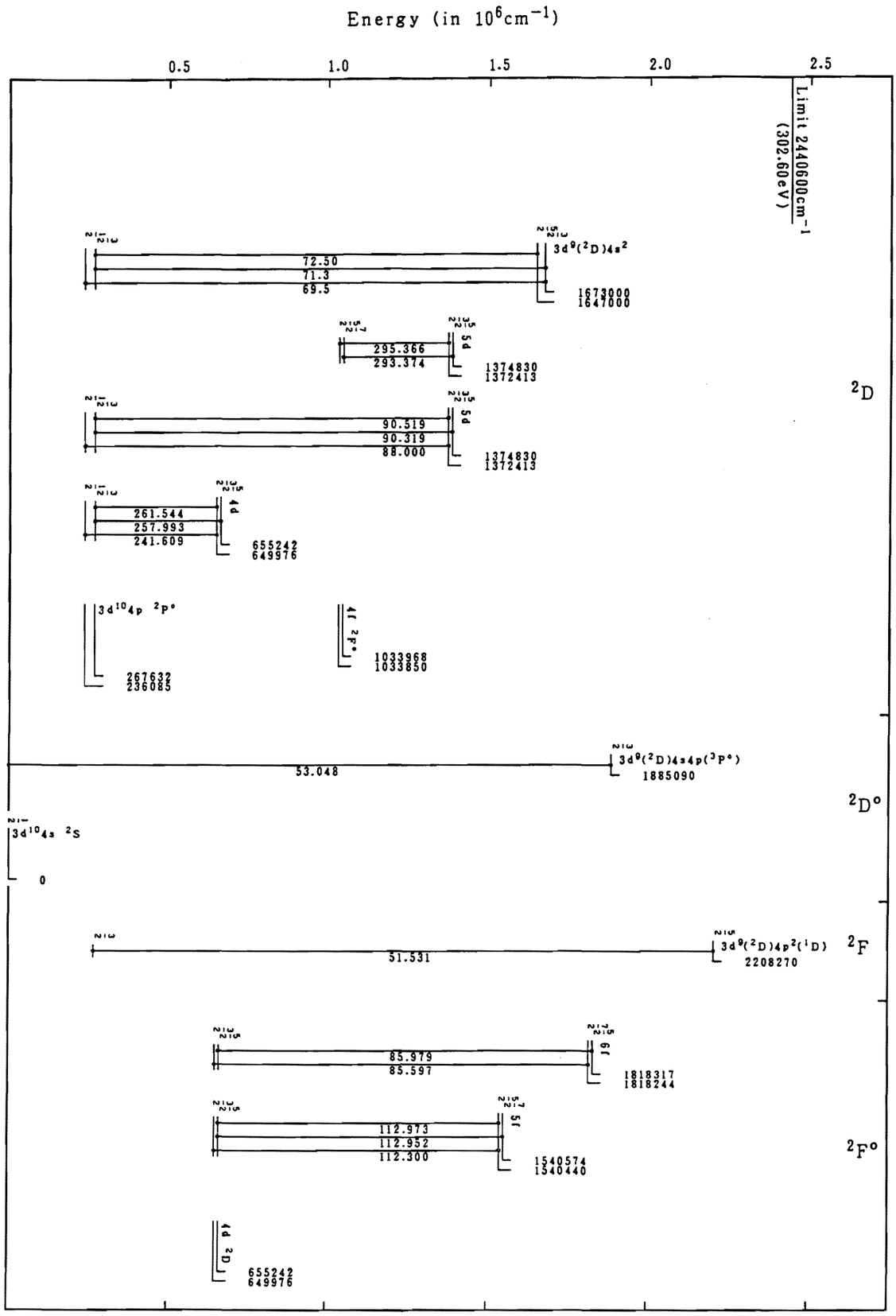
Mo XIII(Zn−Sequence)



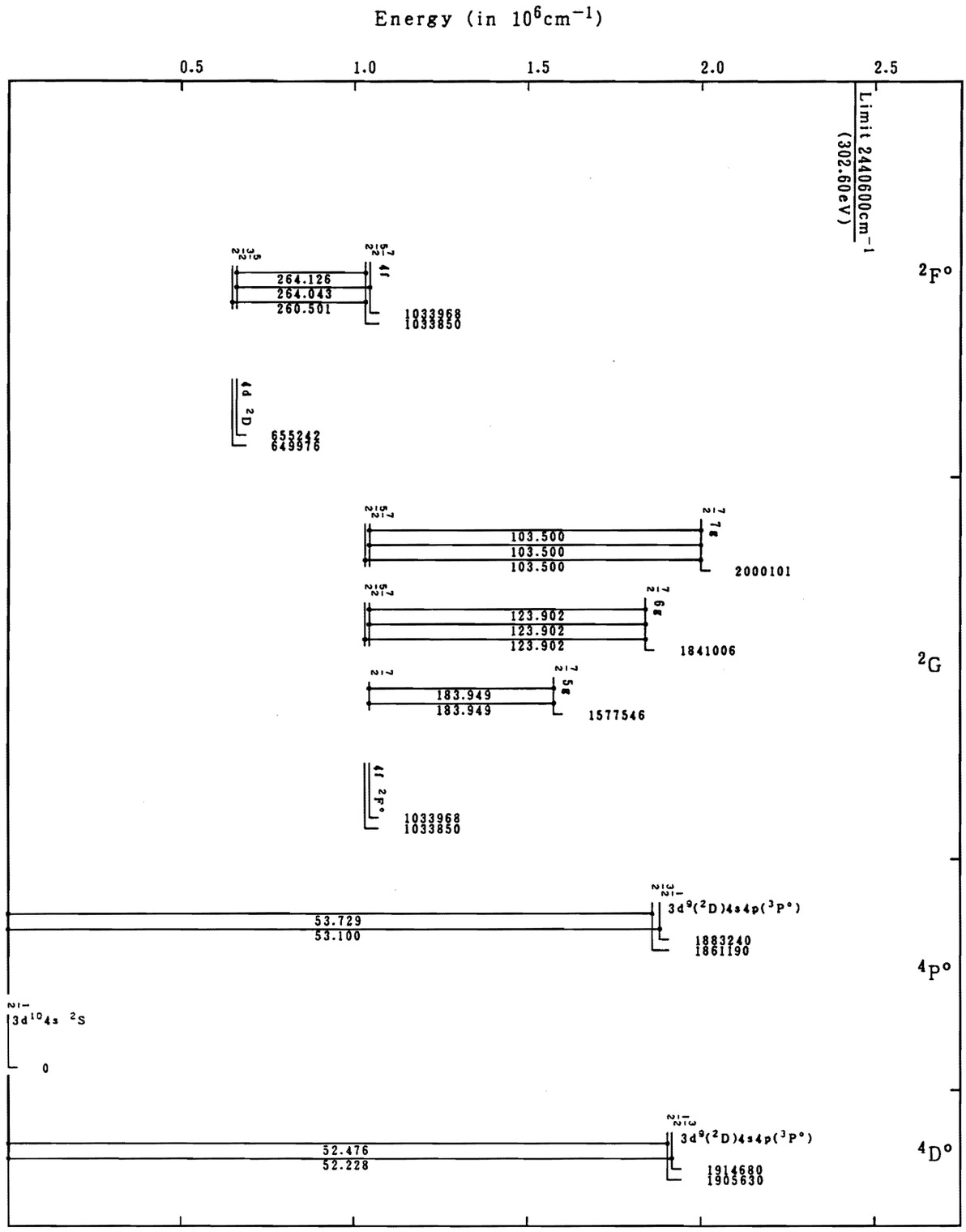
Mo XIV(Cu–Sequence)



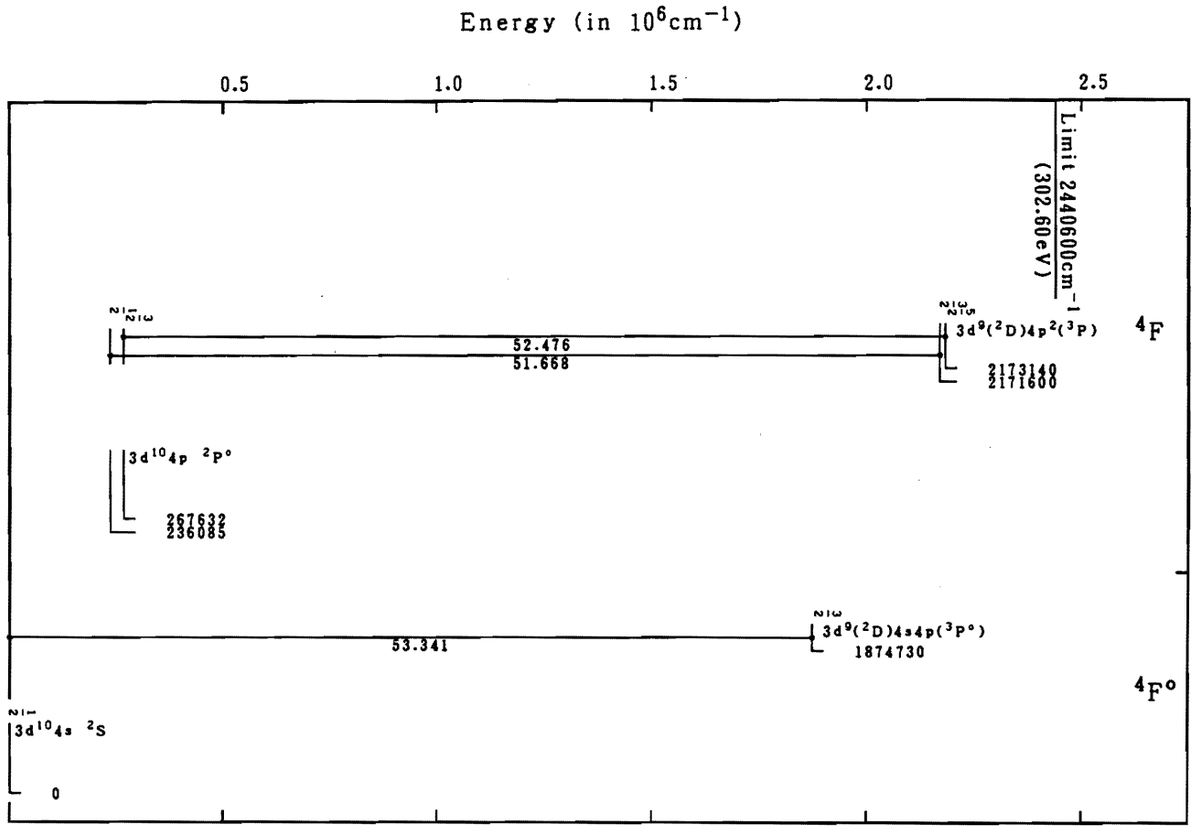
Mo XIV(Cu−Sequence)



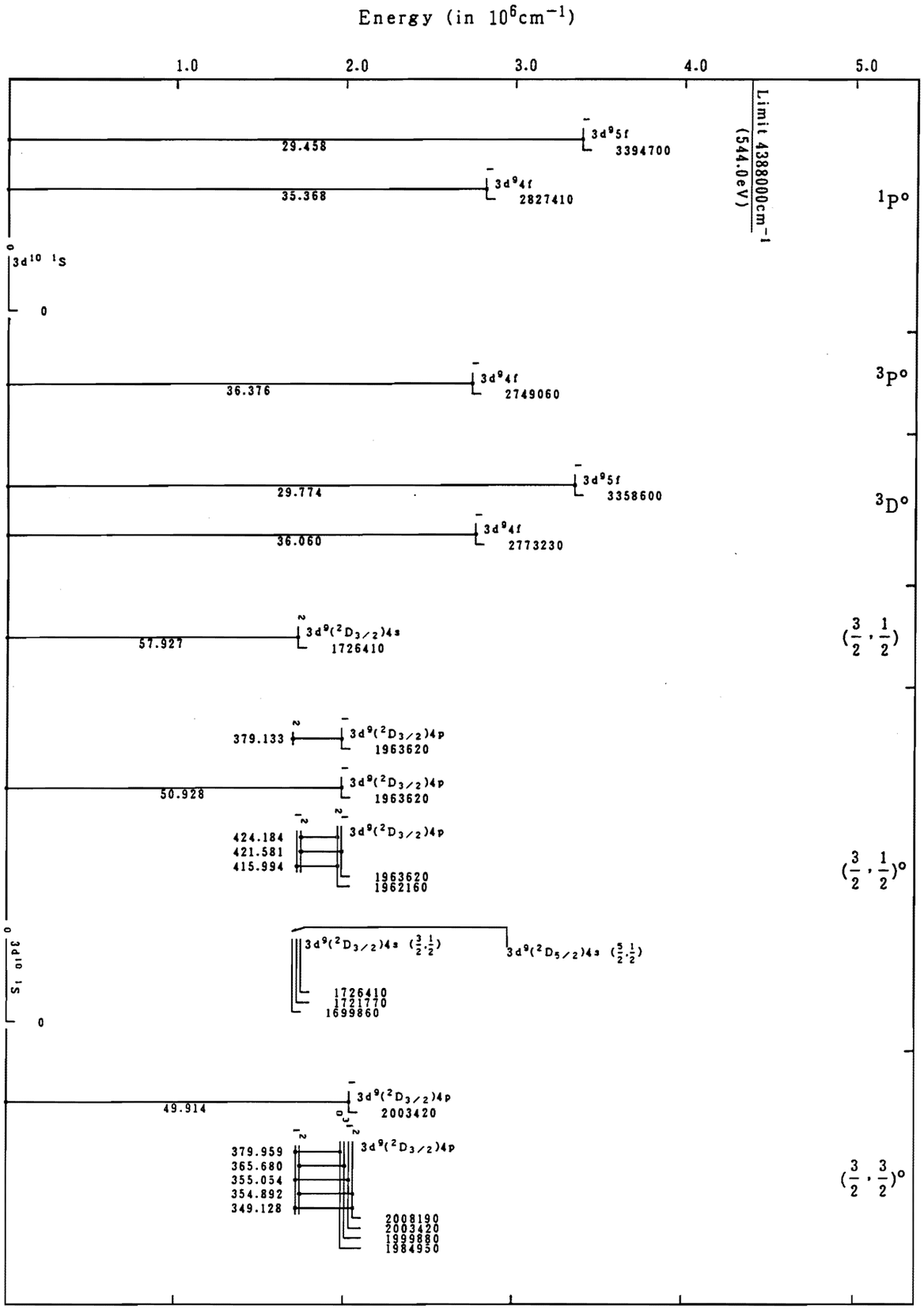
Mo XIV(Cu−Sequence)



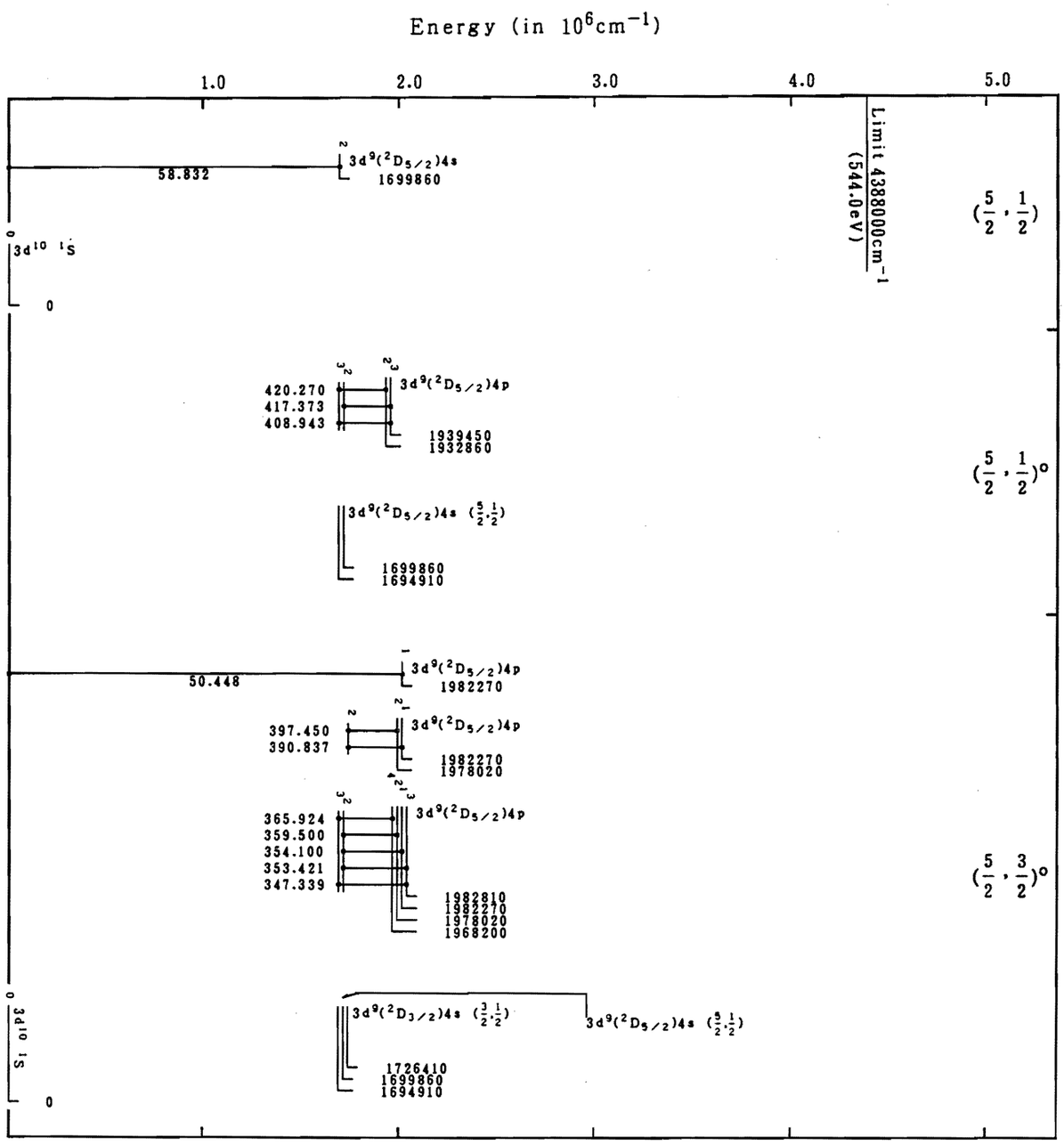
Mo XIV(Cu–Sequence)



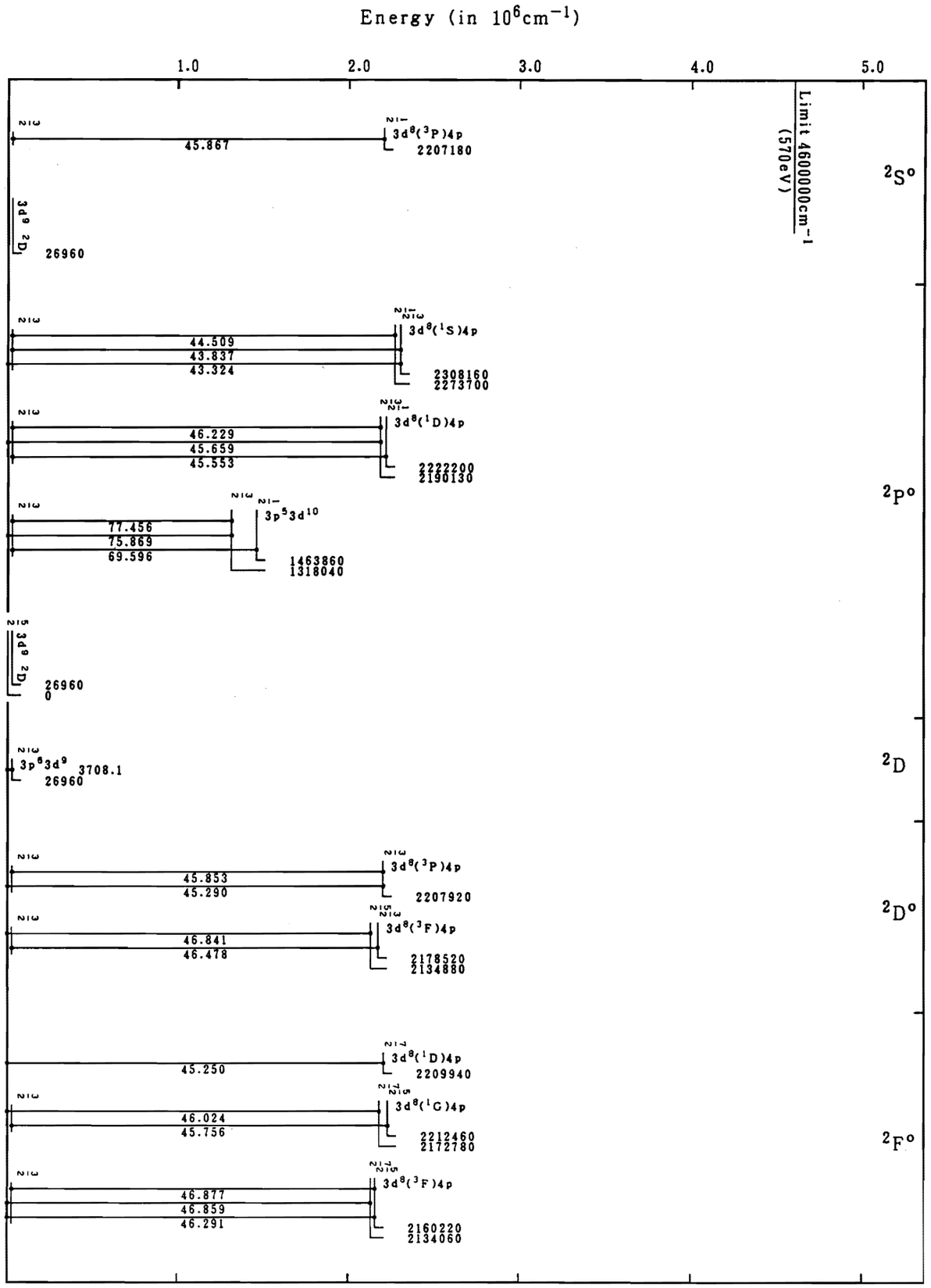
Mo XIV(Cu−Sequence)



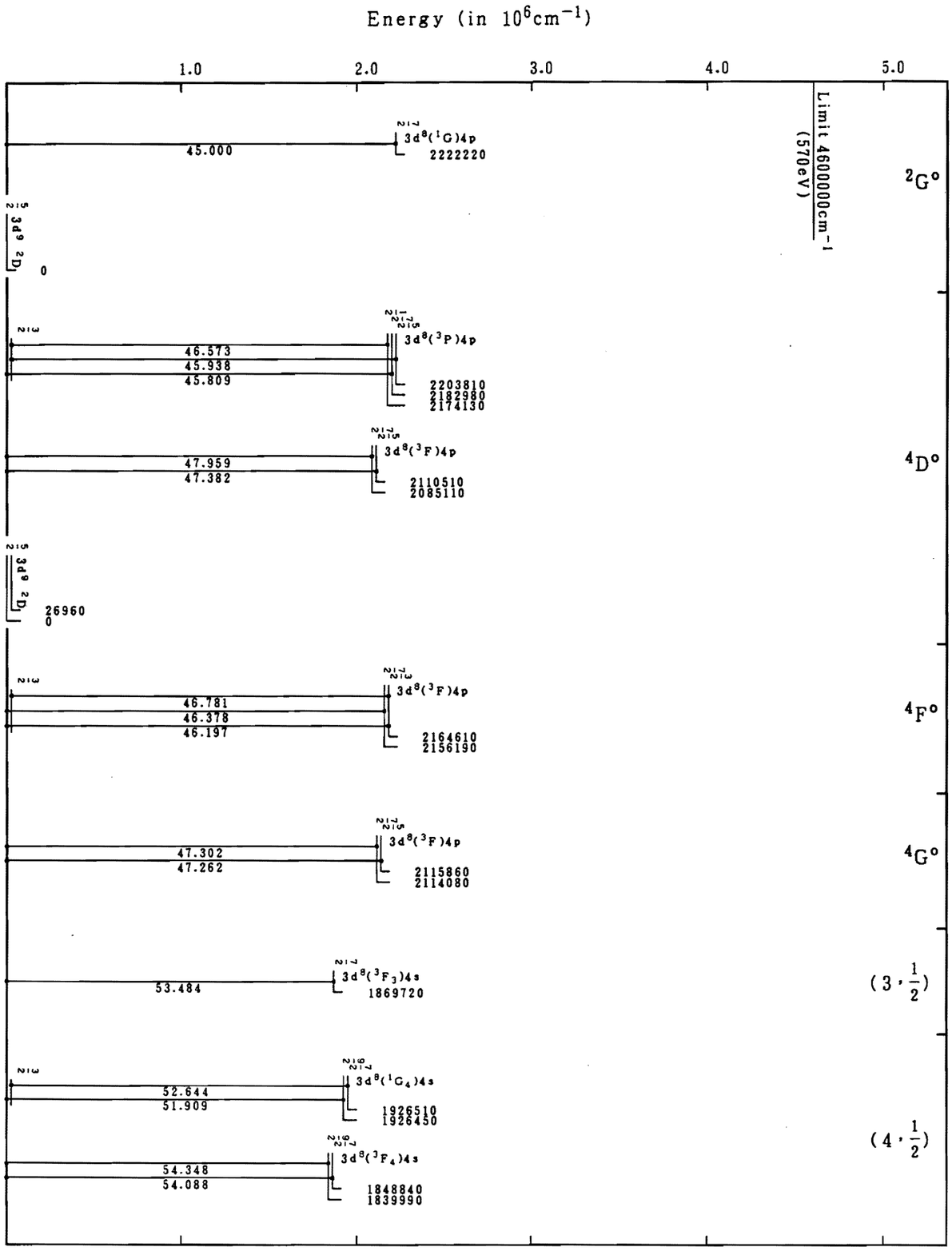
Mo XV(Ni−Sequence)



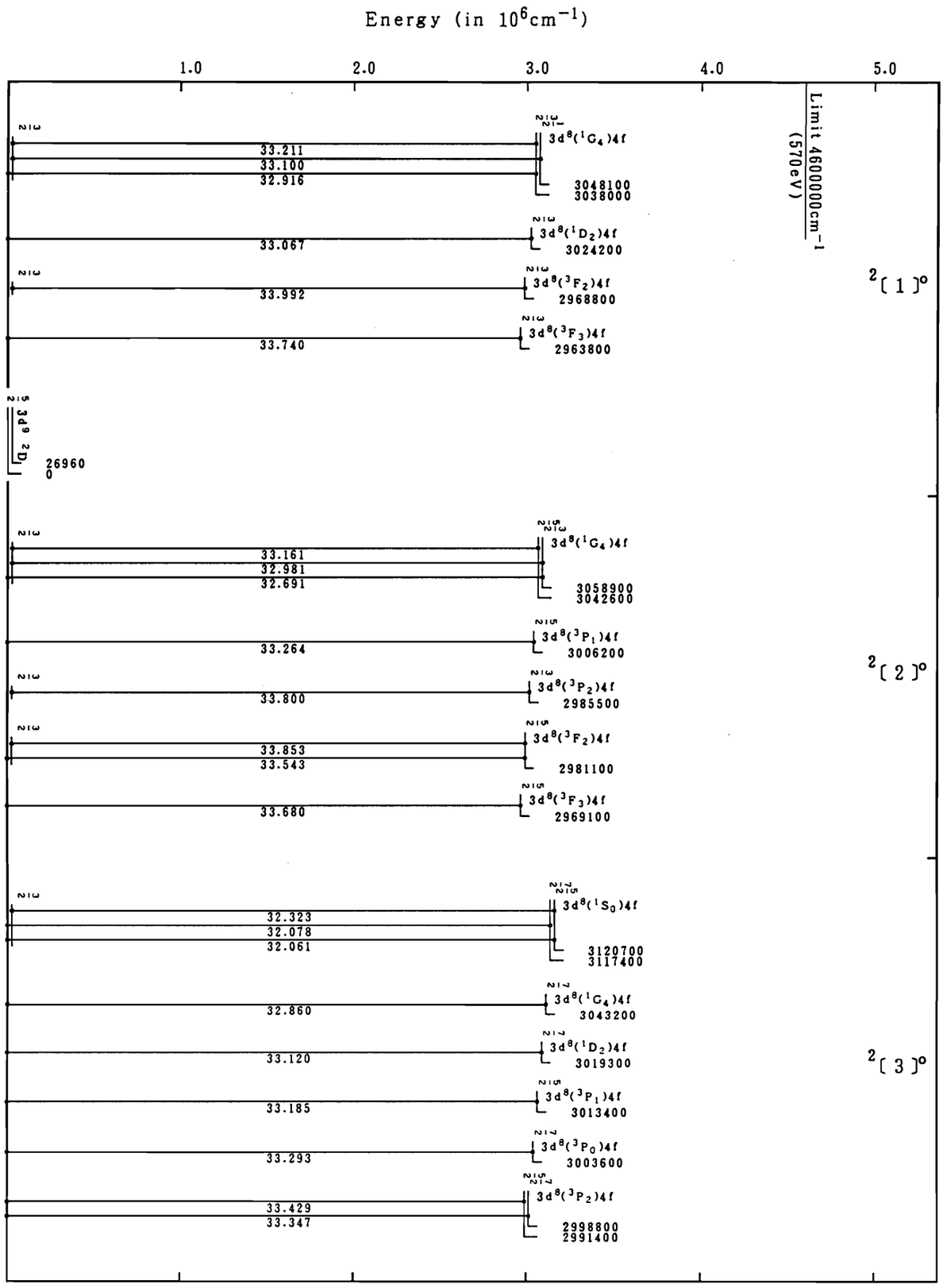
Mo XV(Ni–Sequence)



Mo XVI(Co−Sequence)



Mo XVI(Co−Sequence)



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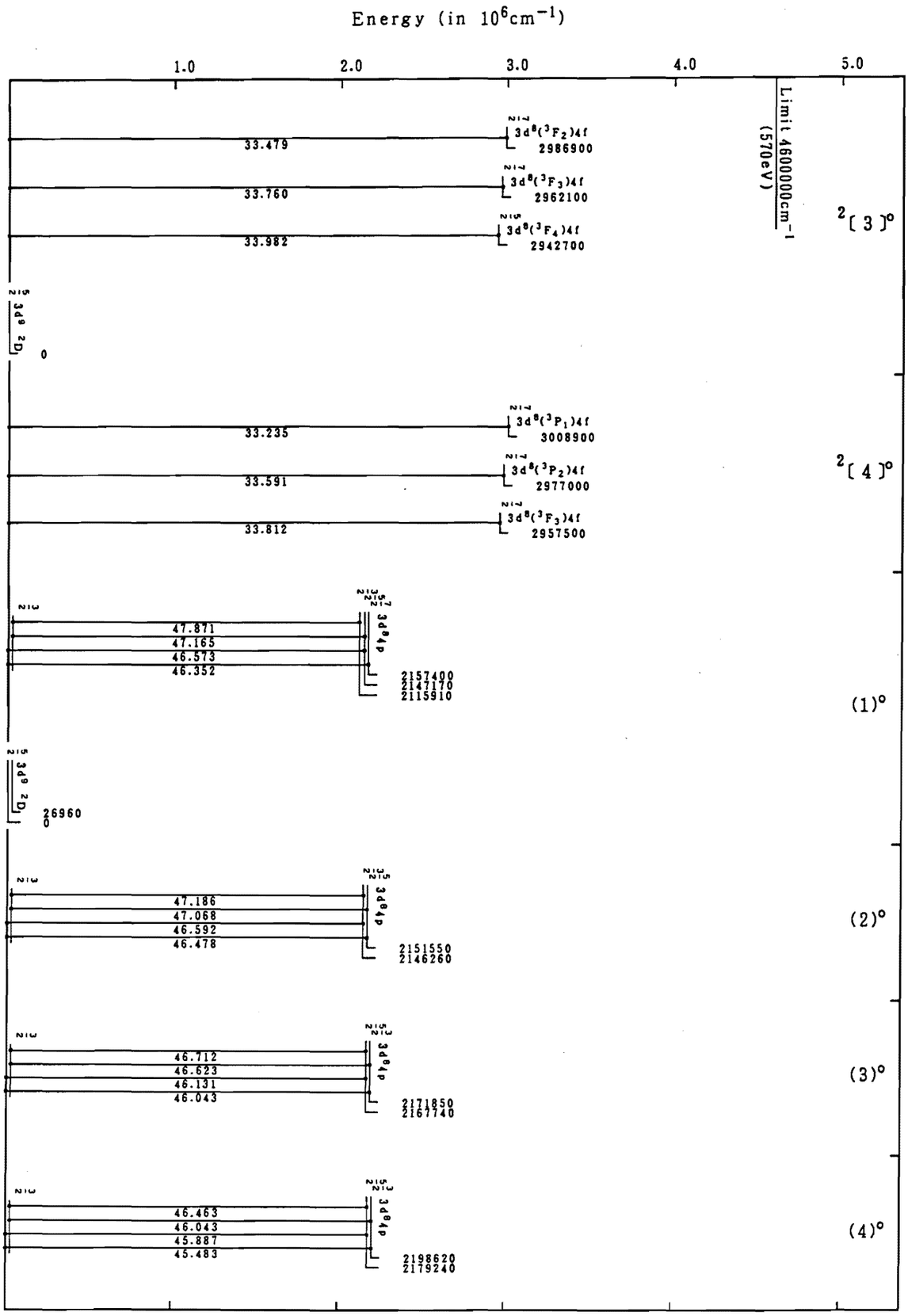

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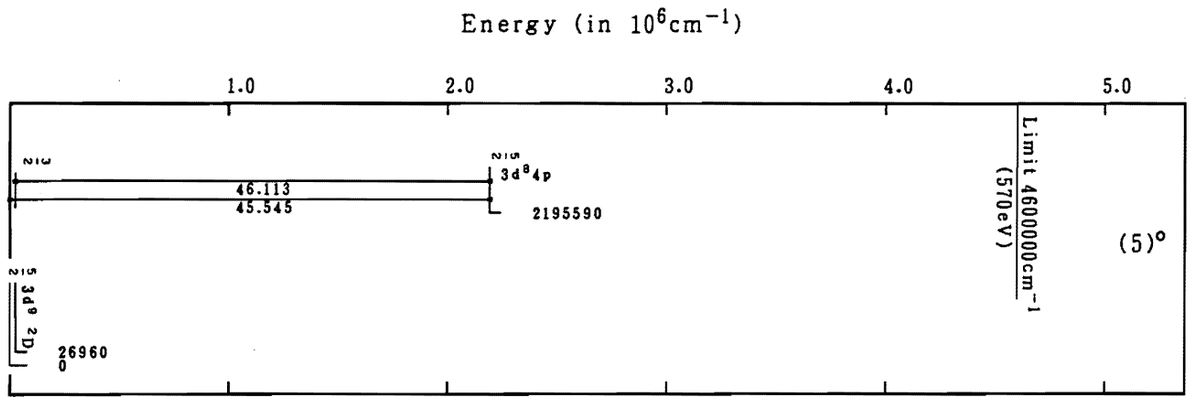
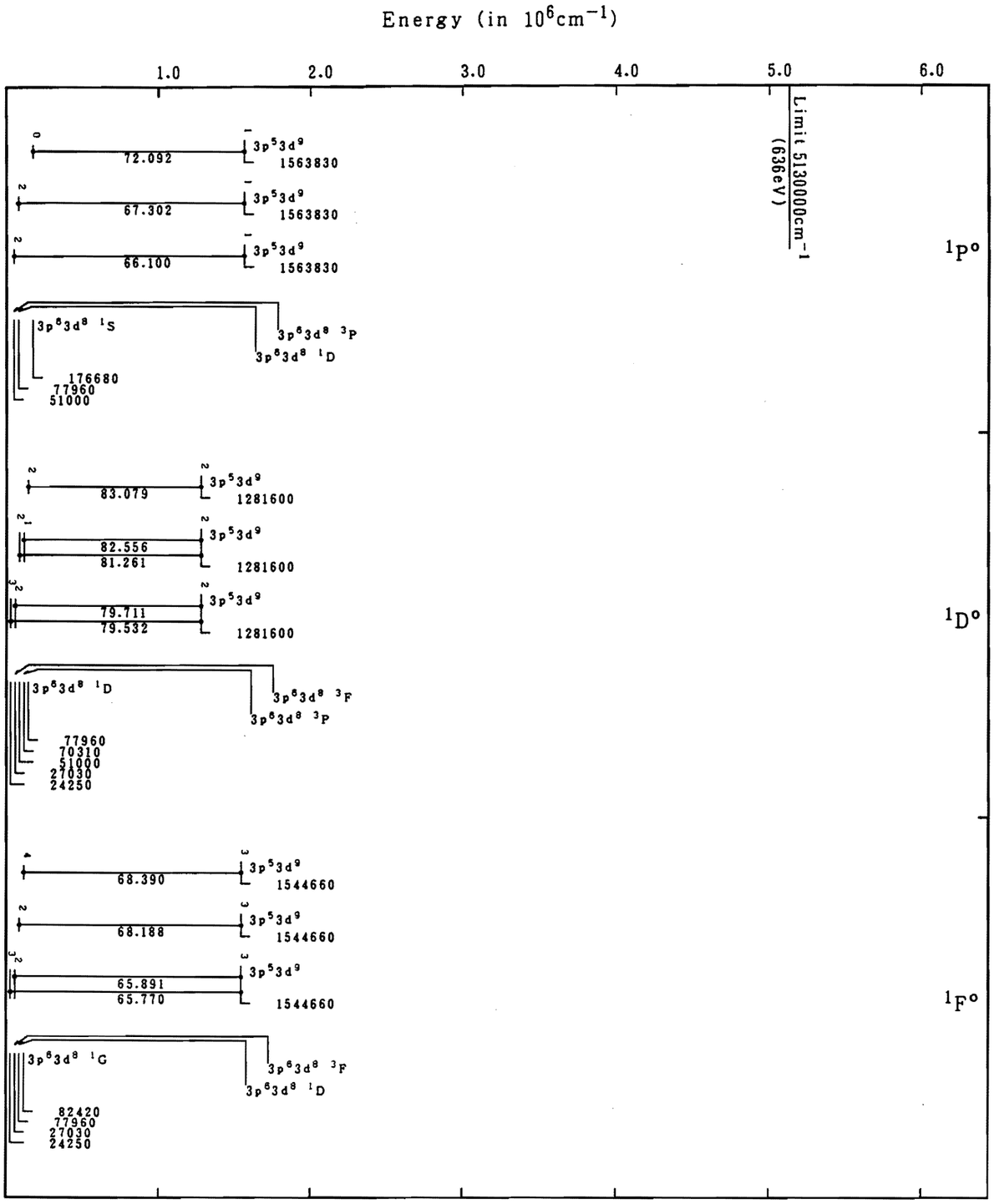
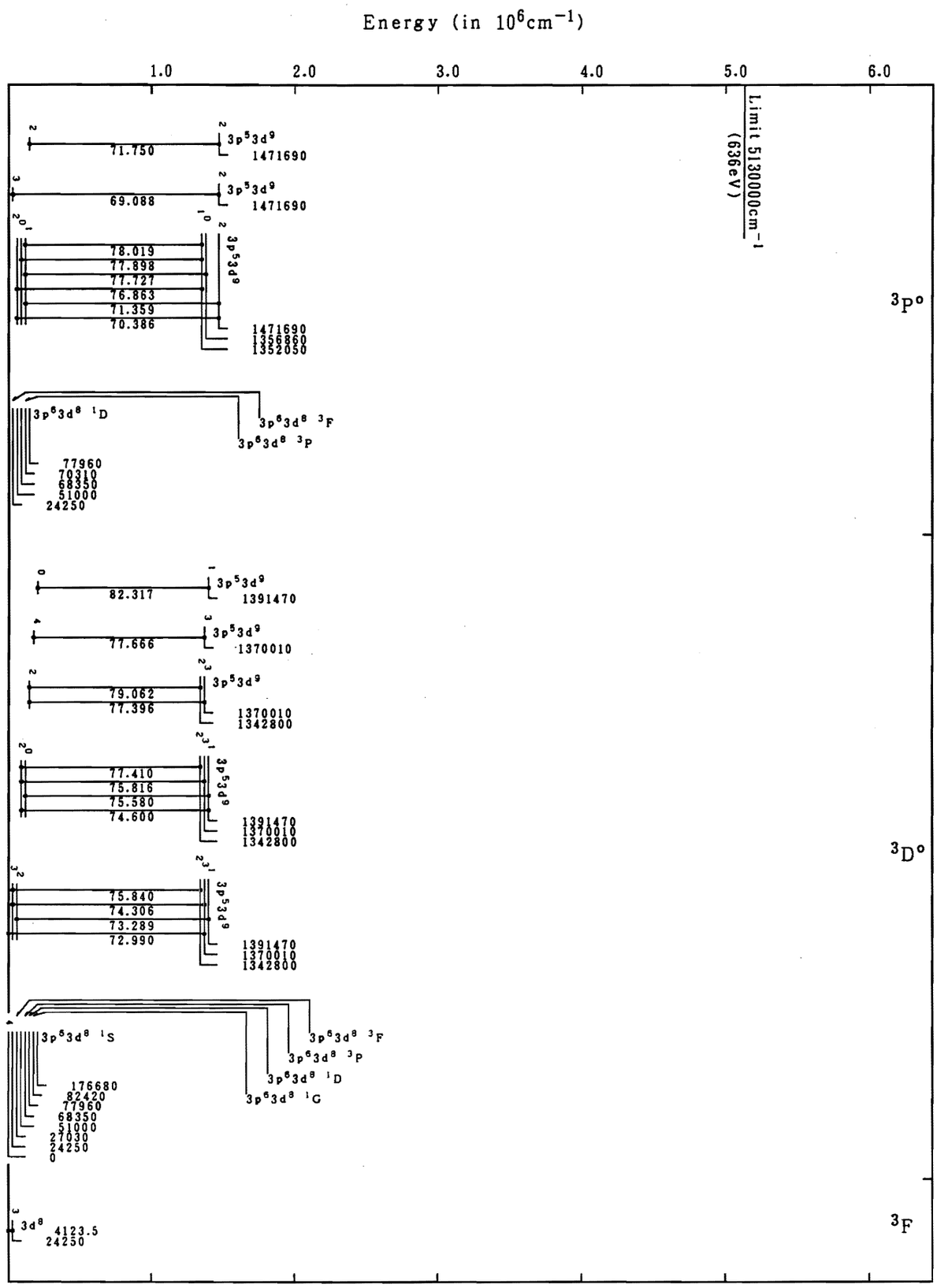


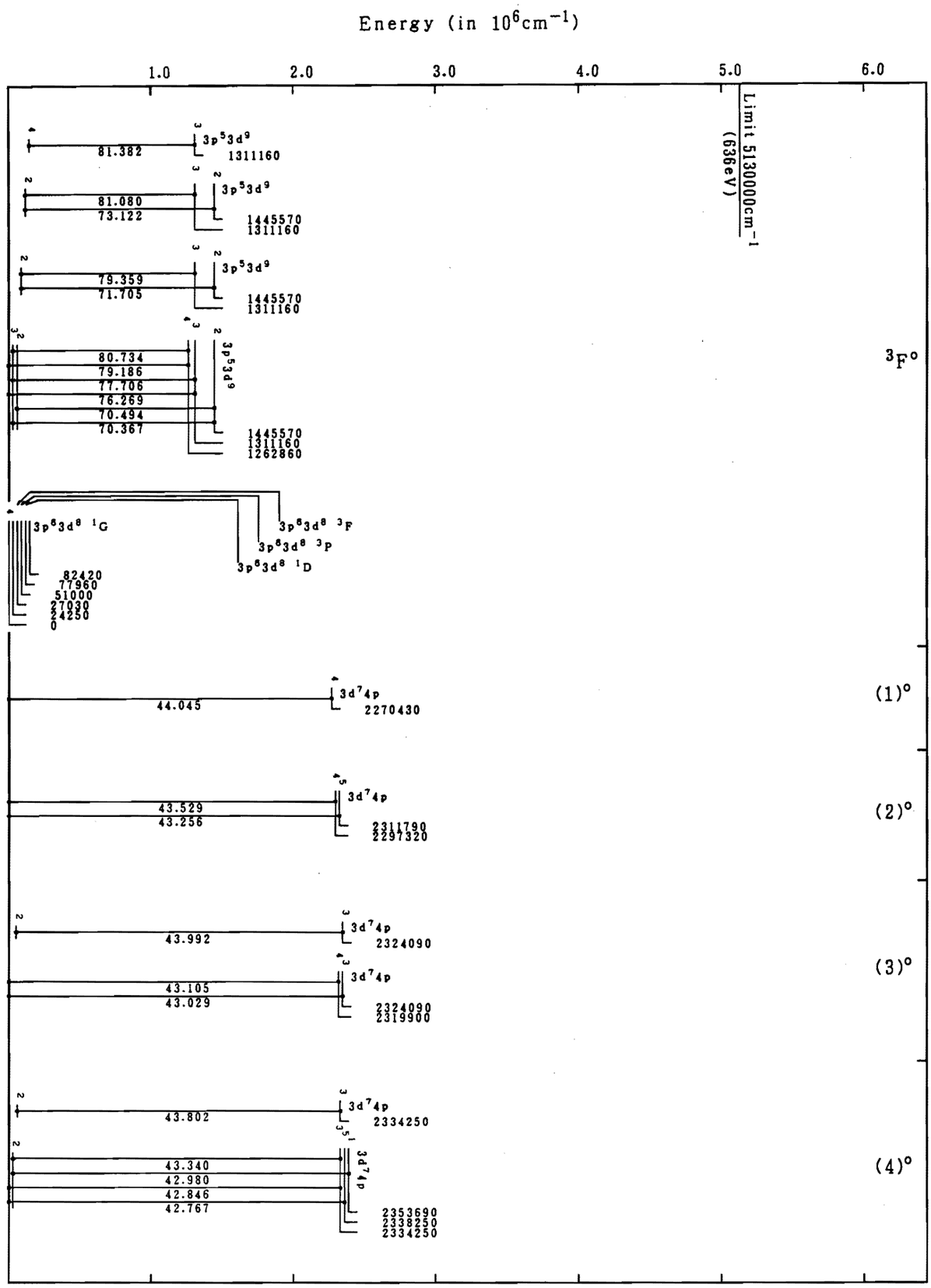
Mo XVI(Co−Sequence)



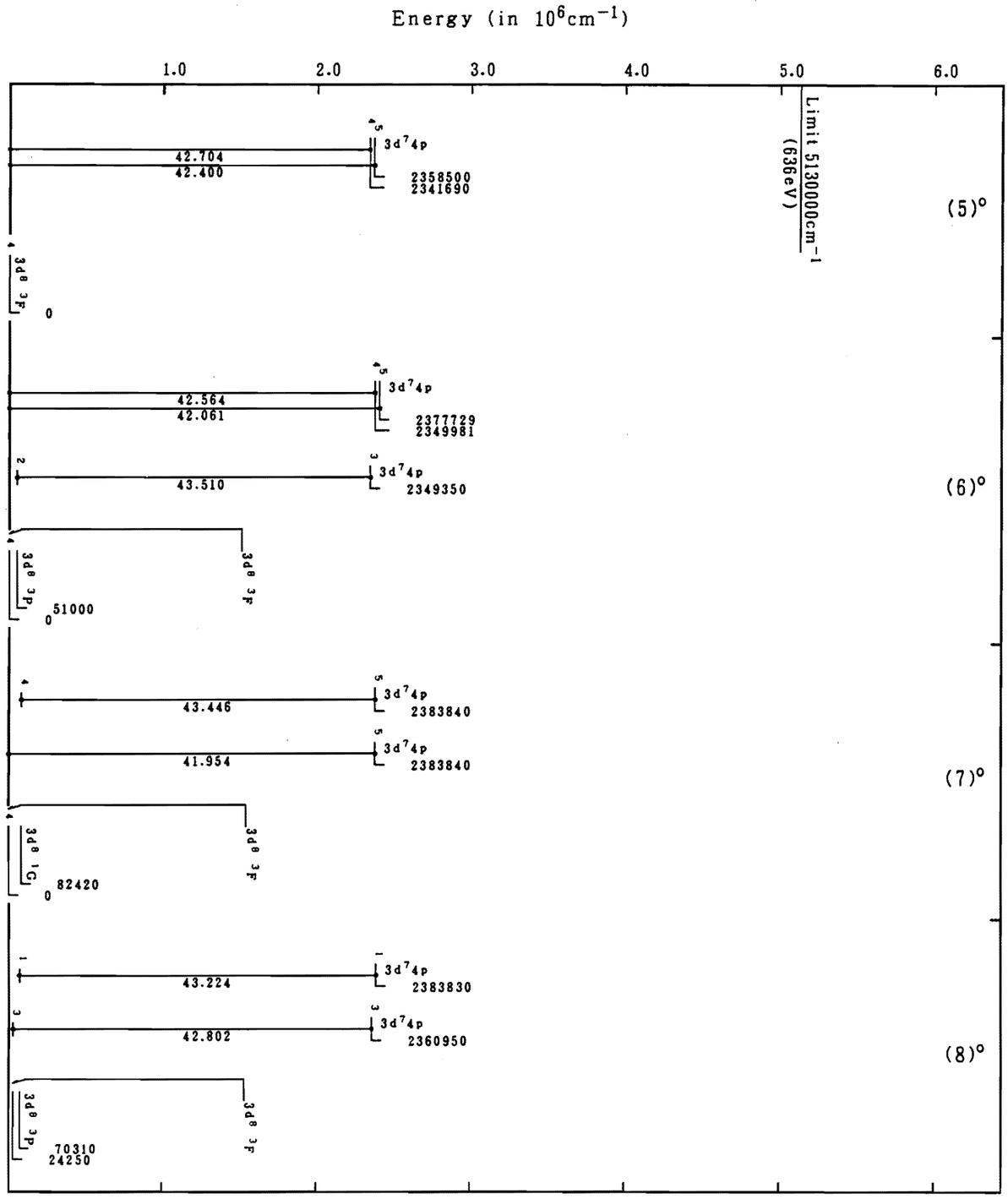
Mo XVII(Fe−Sequence)



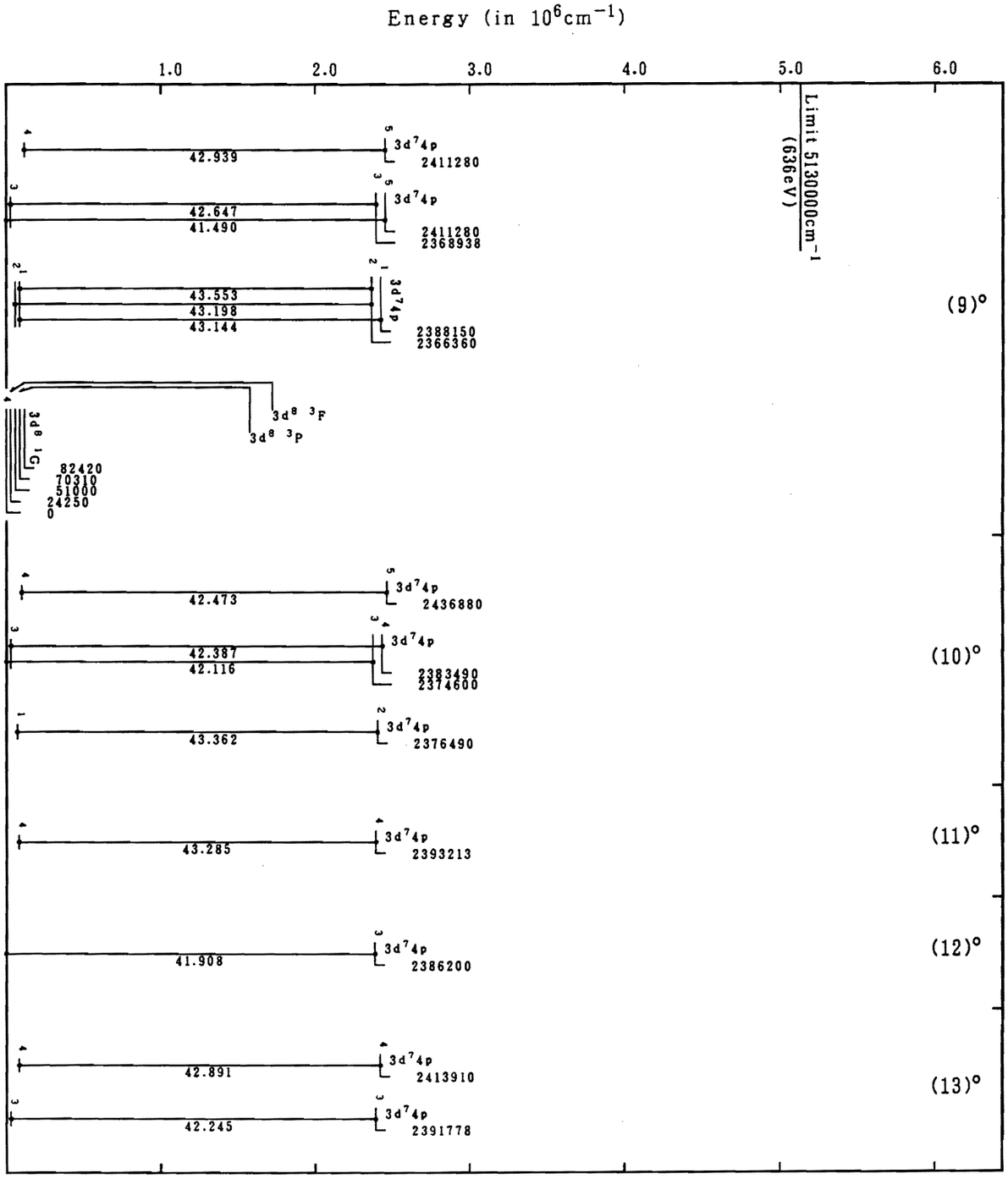
Mo XVII(Fe−Sequence)



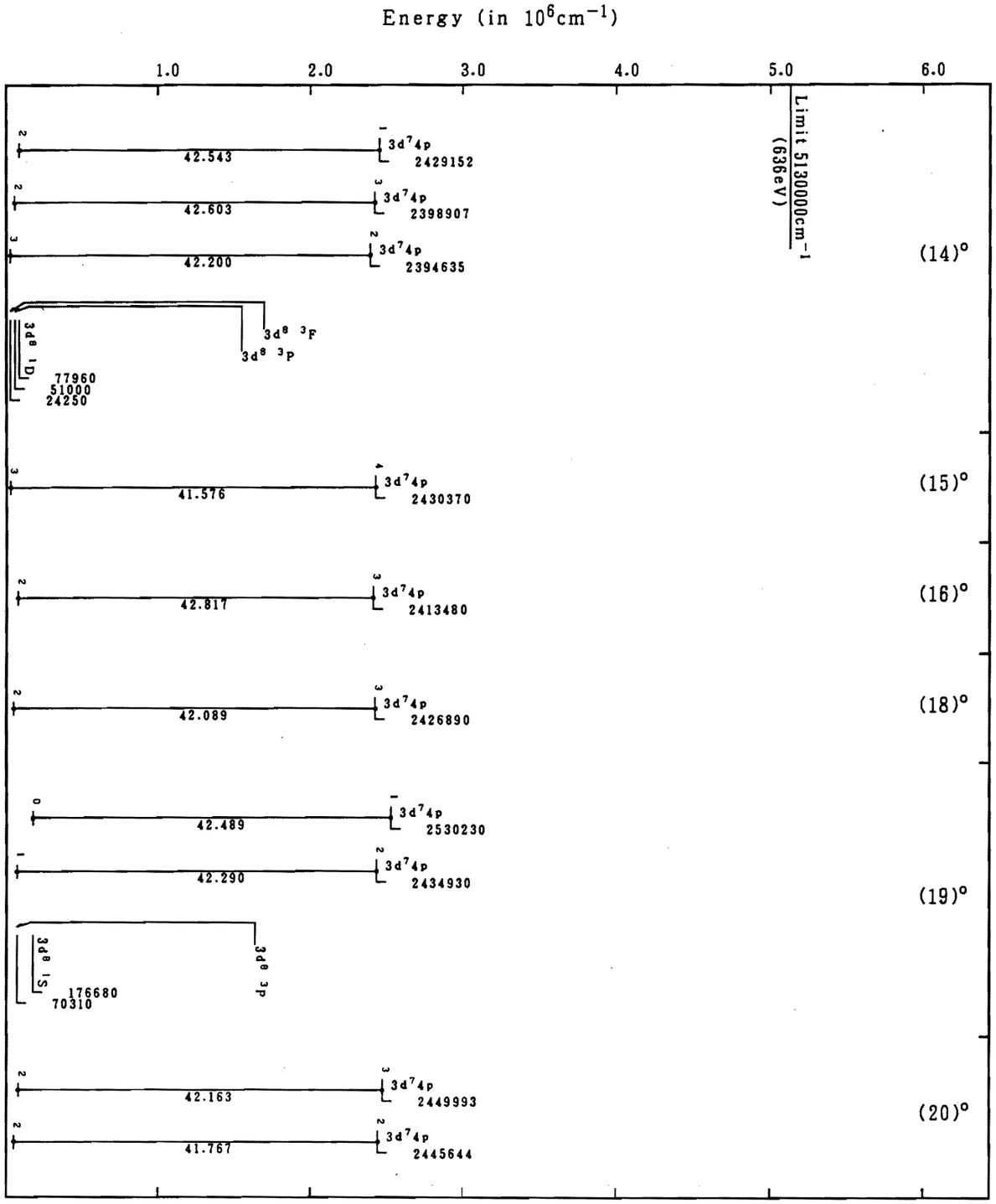
Mo XVII(Fe–Sequence)



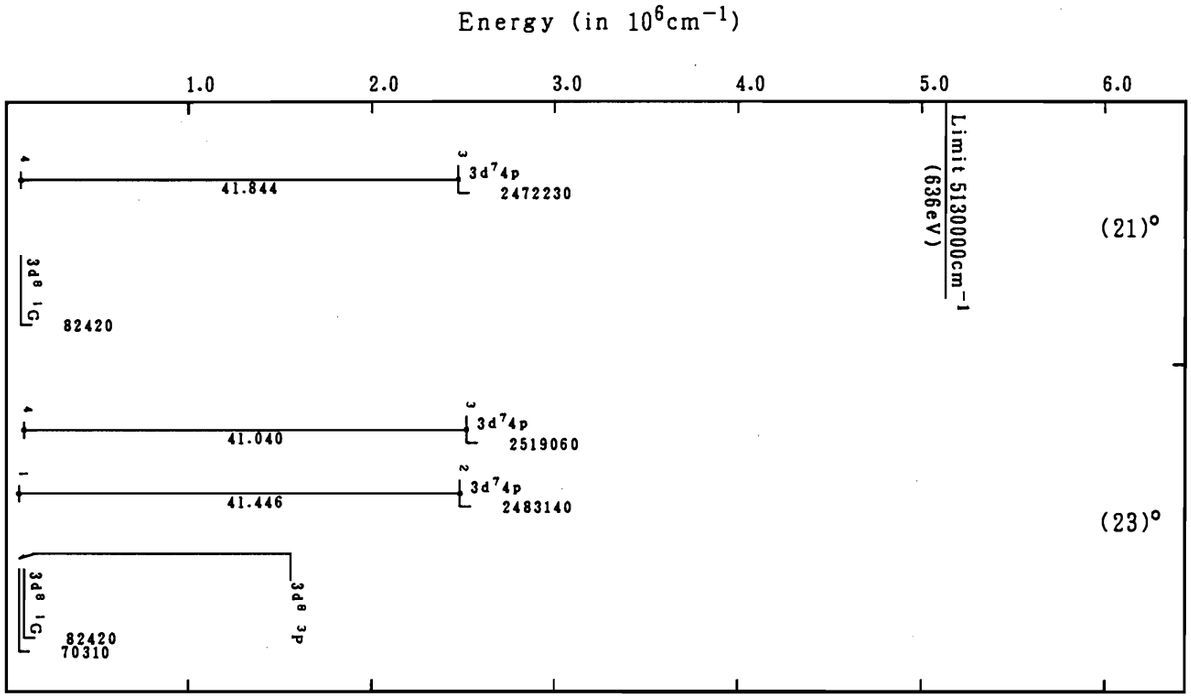
Mo XVII(Fe−Sequence)



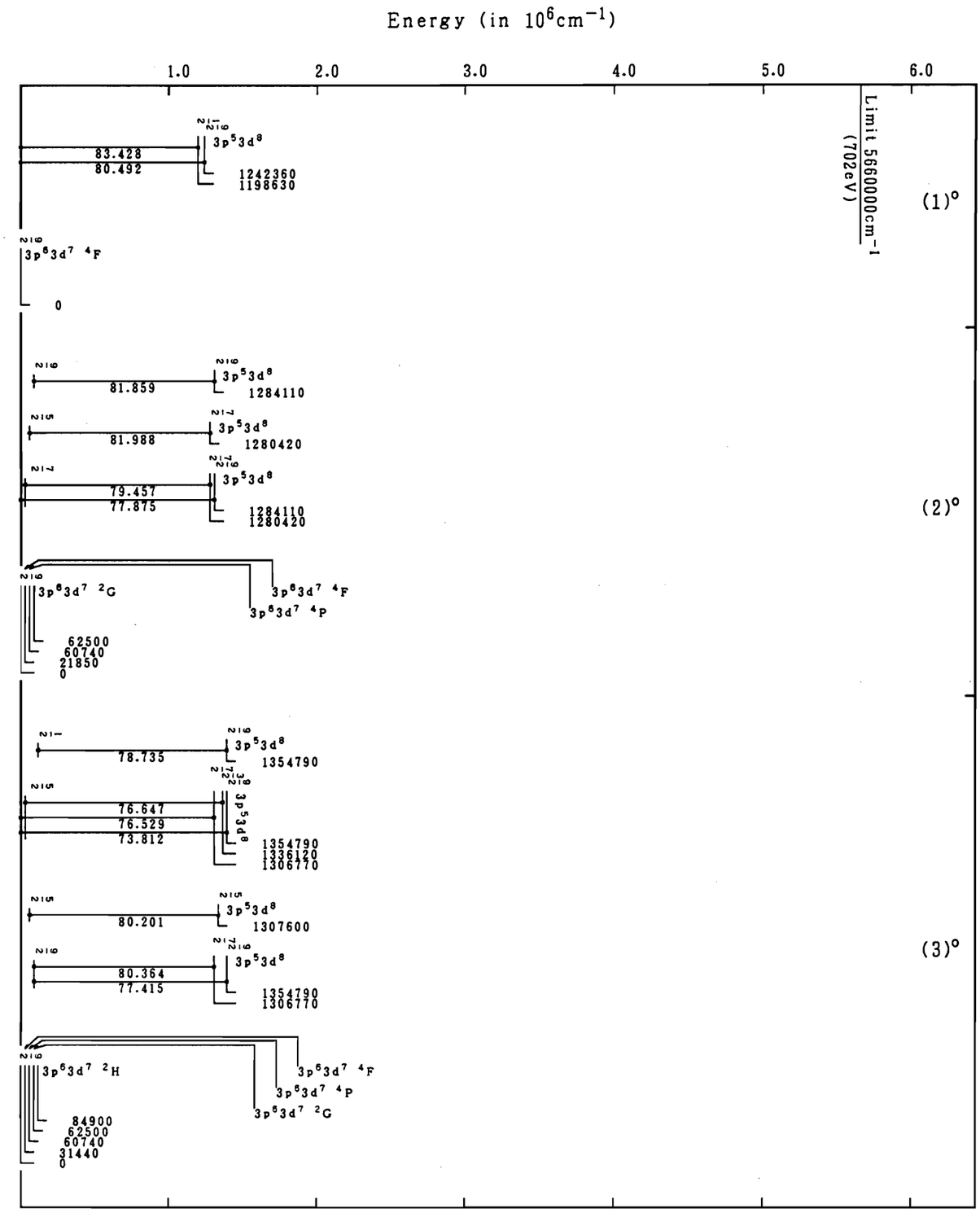
Mo XVII(Fe−Sequence)



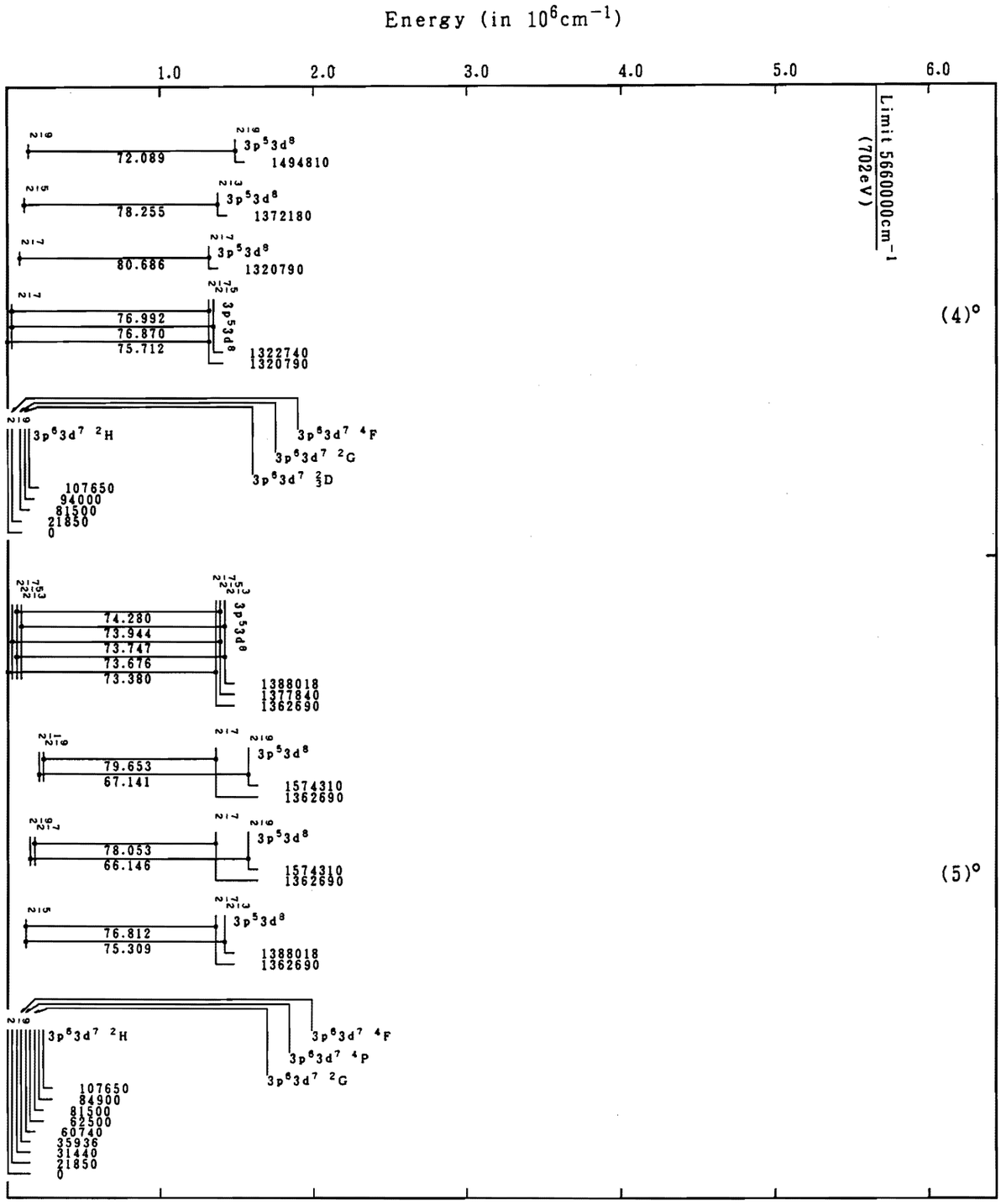
Mo XVII(Fe−Sequence)



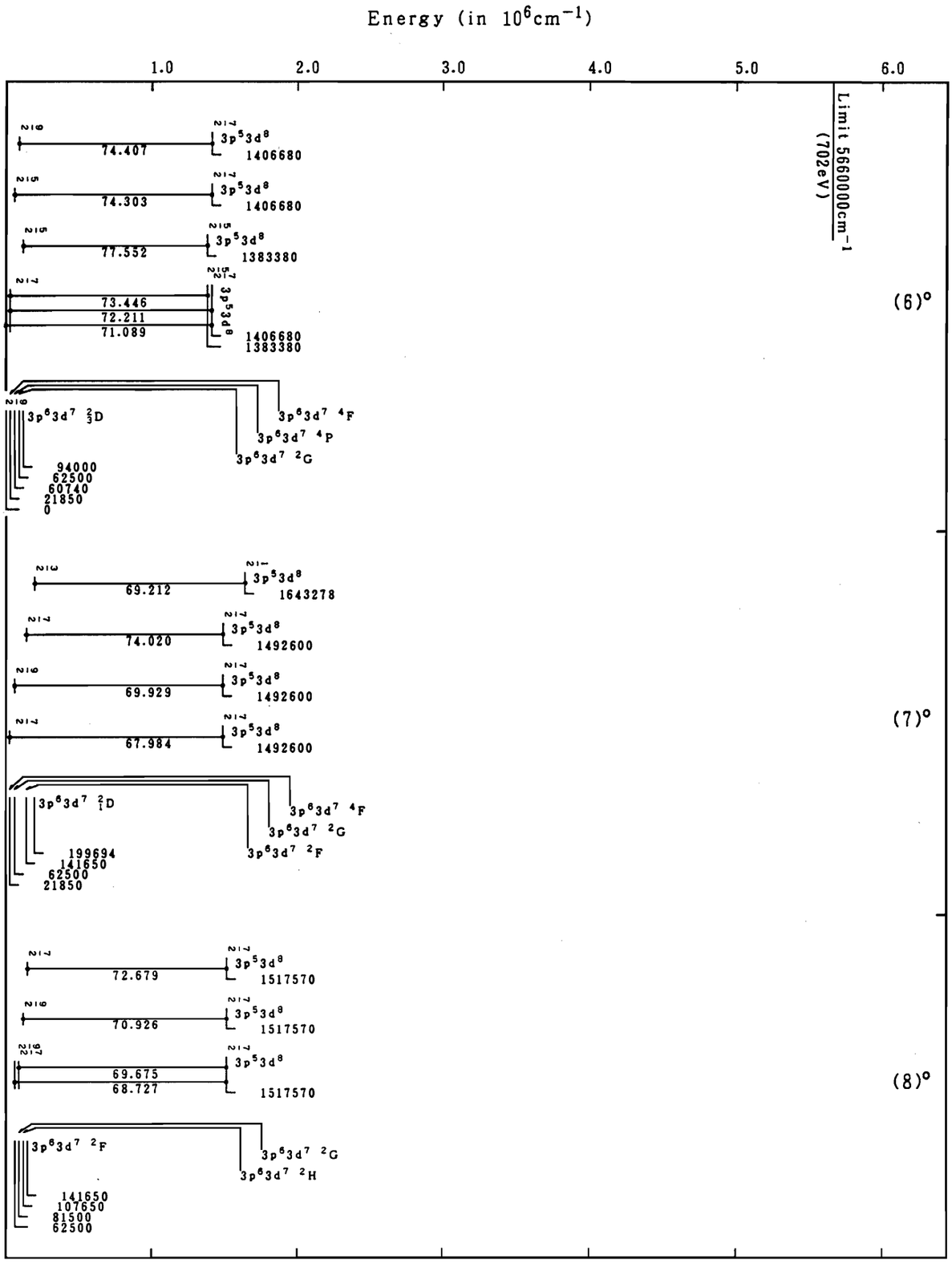
Mo XVII(Fe−Sequence)



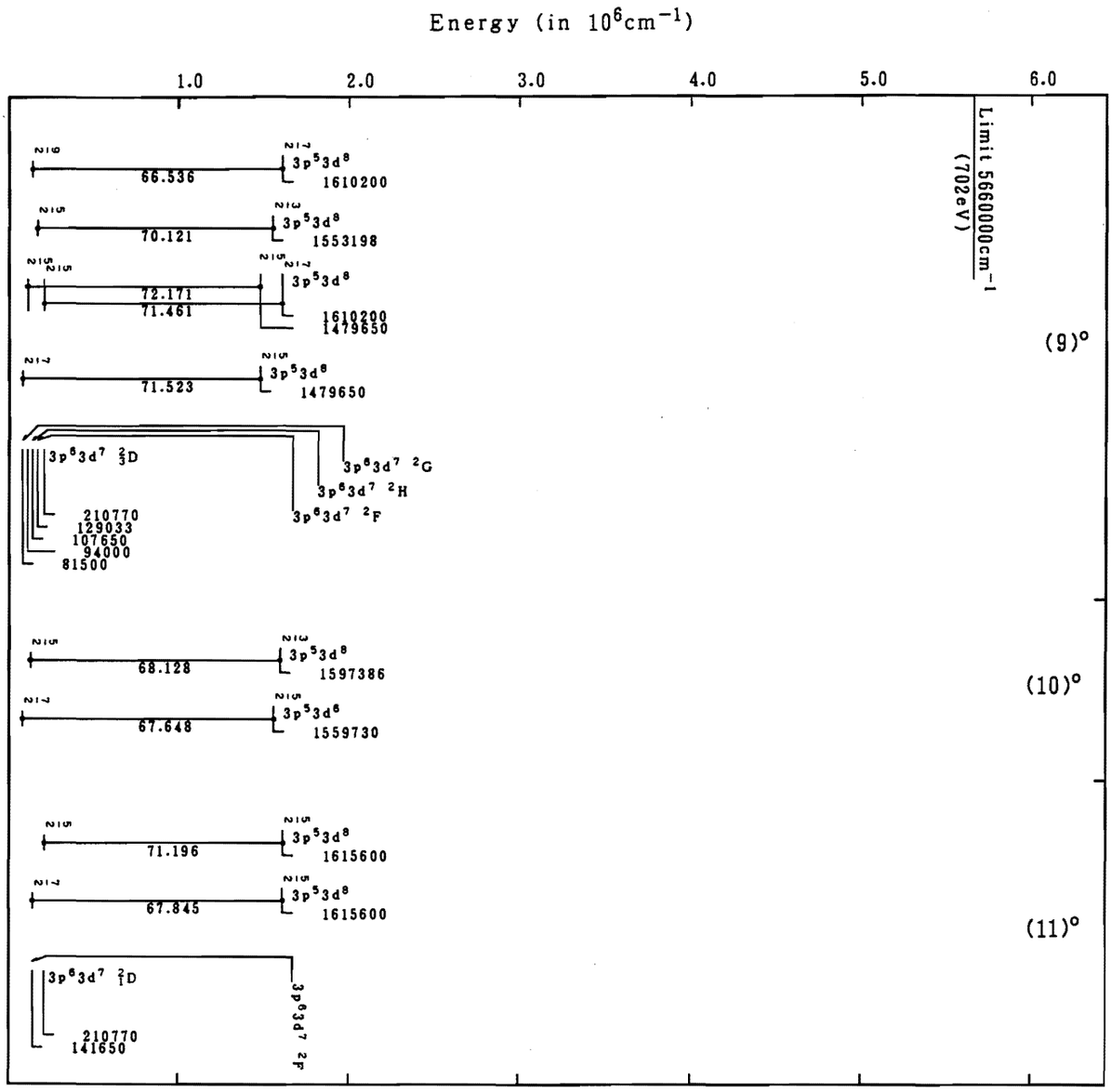
Mo XVIII(Mn−Sequence)



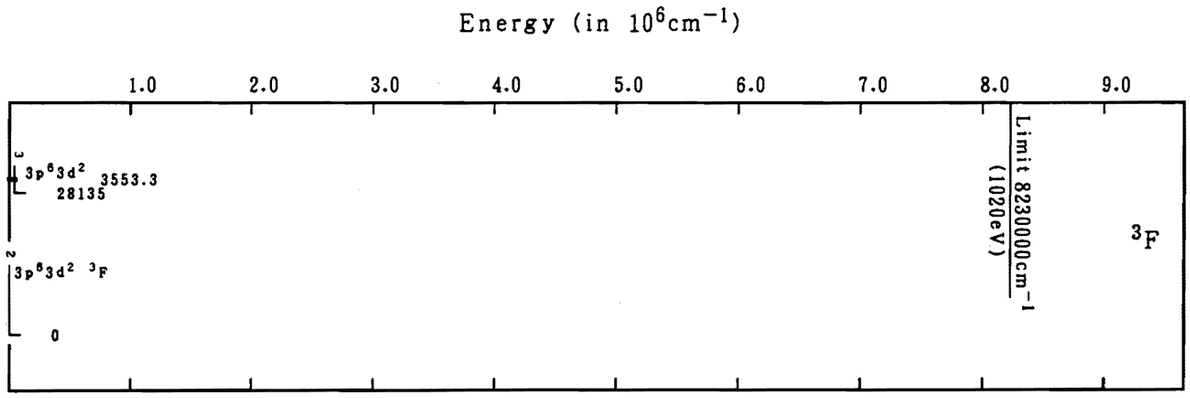
Mo XVIII(Mn−Sequence)



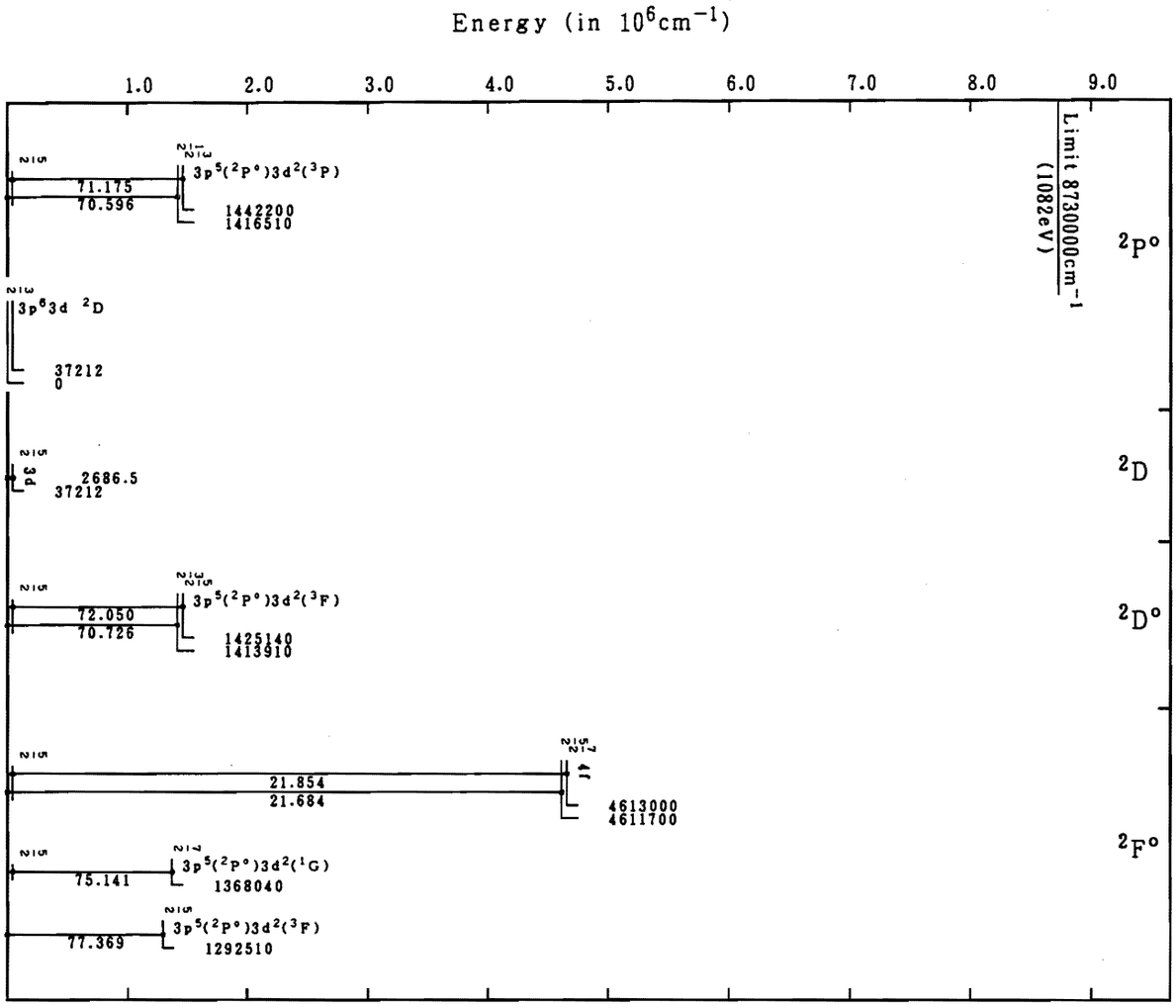
Mo XVIII(Mn−Sequence)



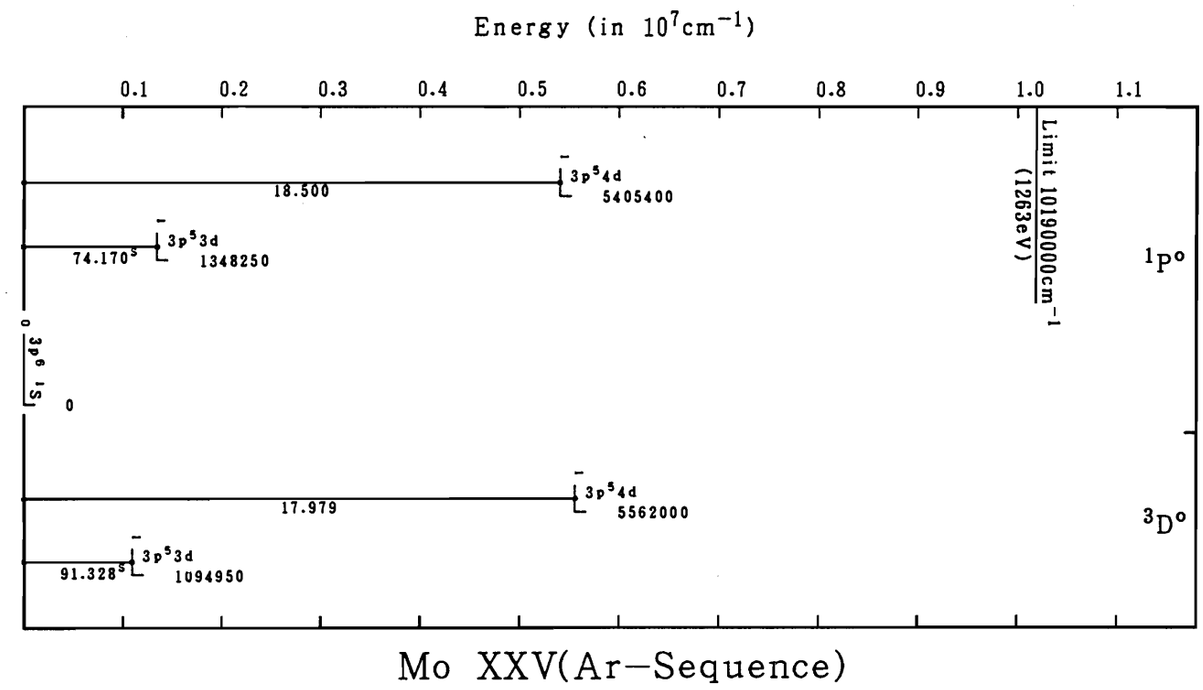
Mo XVIII(Mn−Sequence)



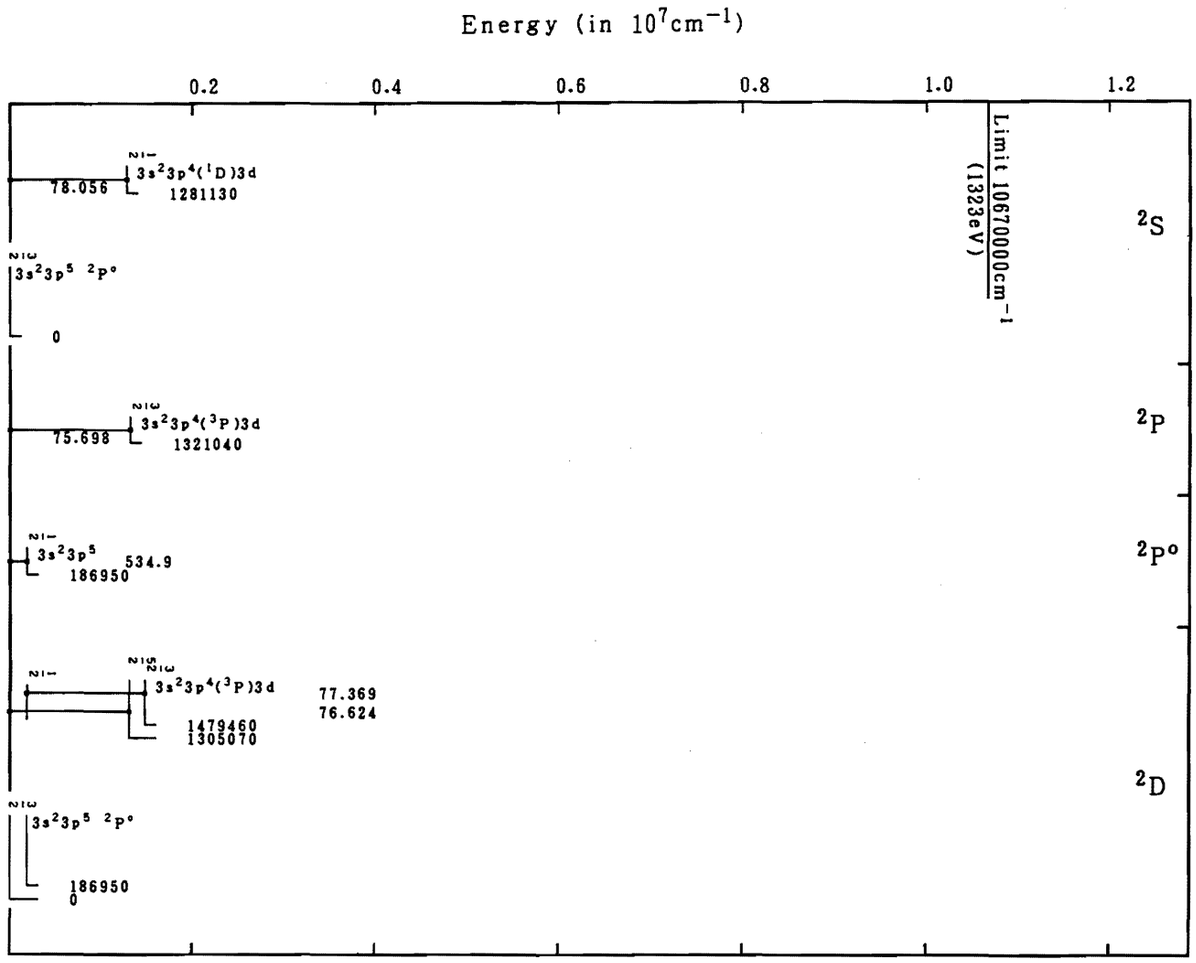
Mo XXIII(Ca−Sequence)



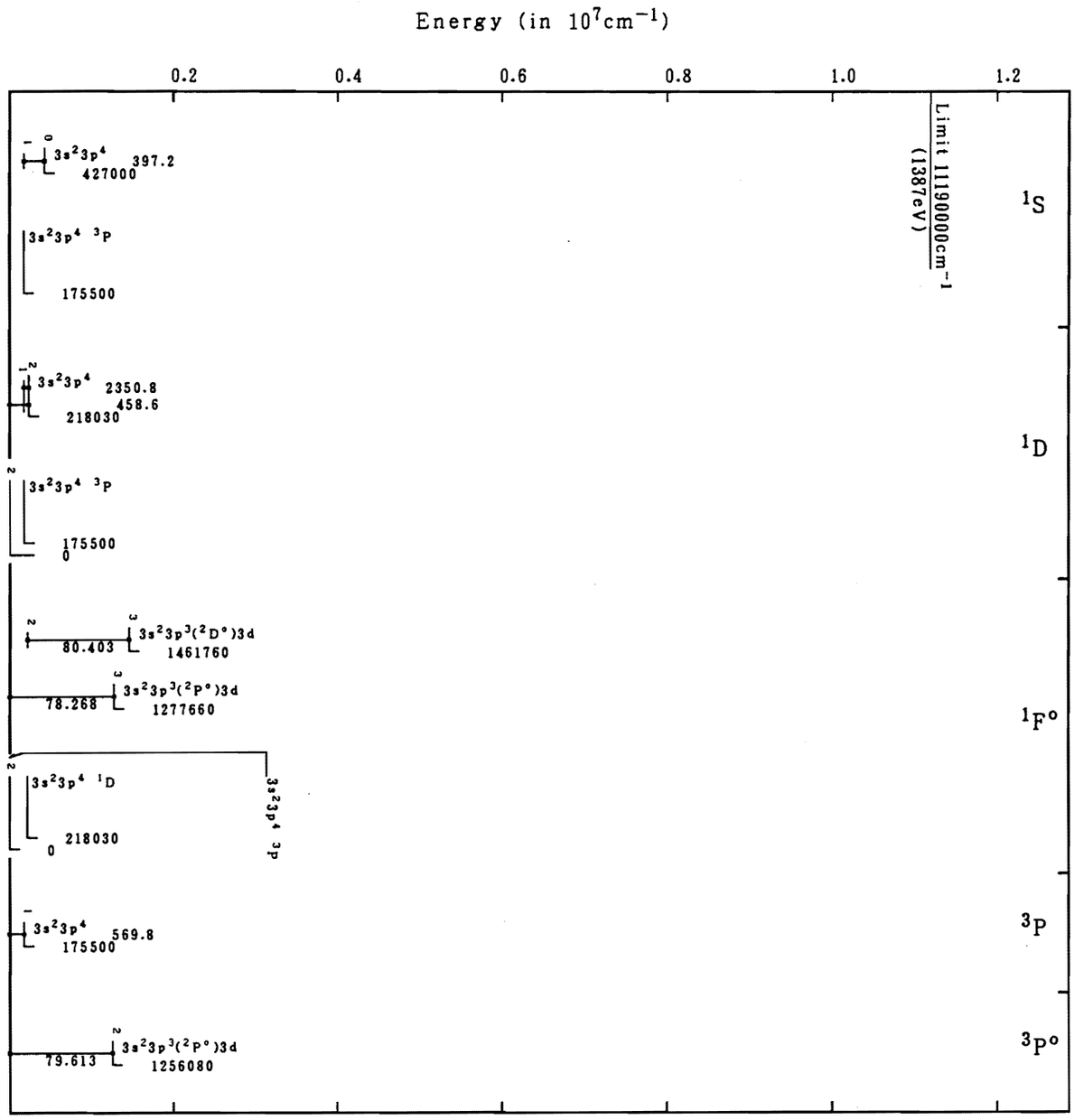
Mo XXIV(K−Sequence)



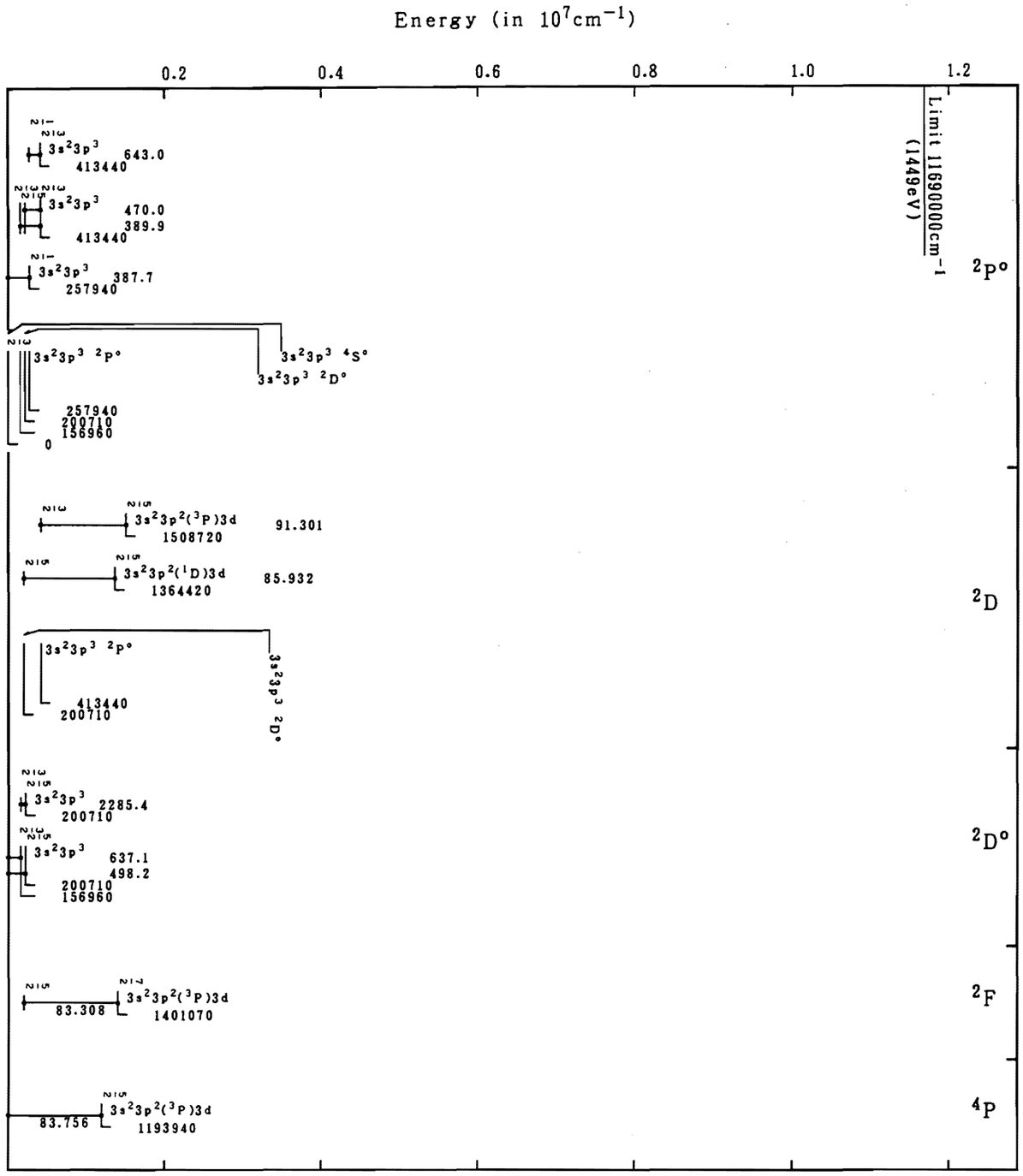
Mo XXV(Ar−Sequence)



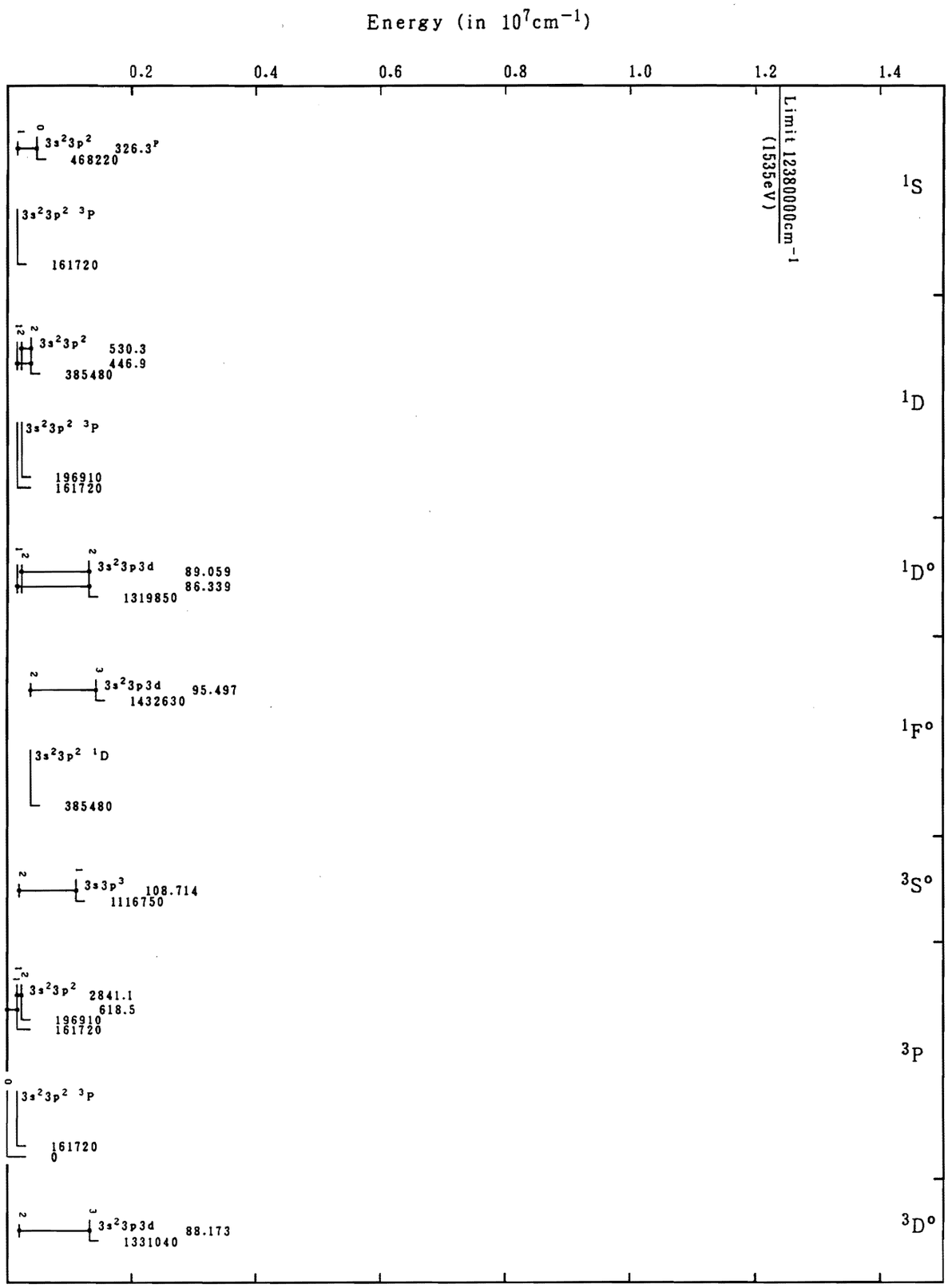
Mo XXVI(Cl−Sequence)



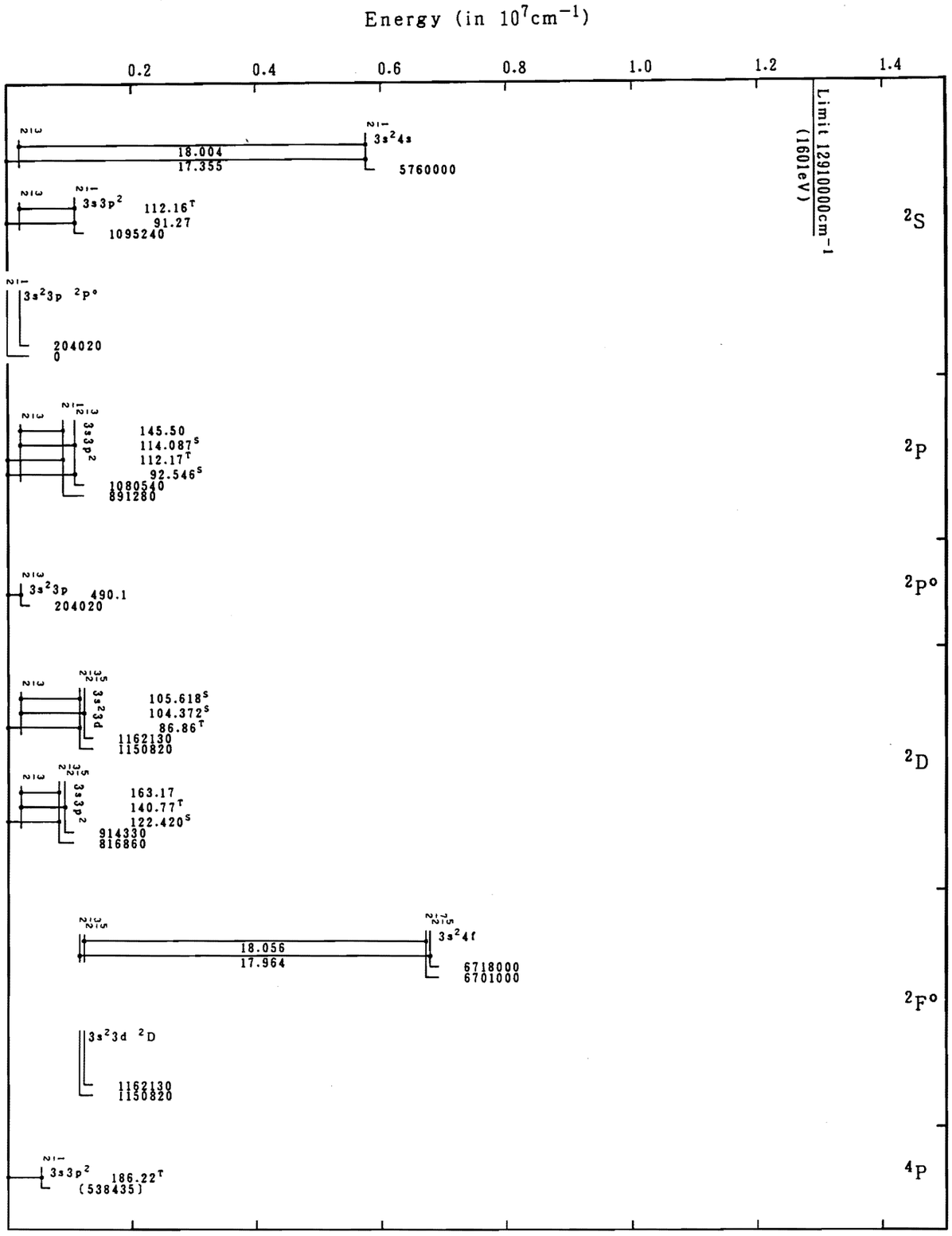
Mo XXVII(S−Sequence)



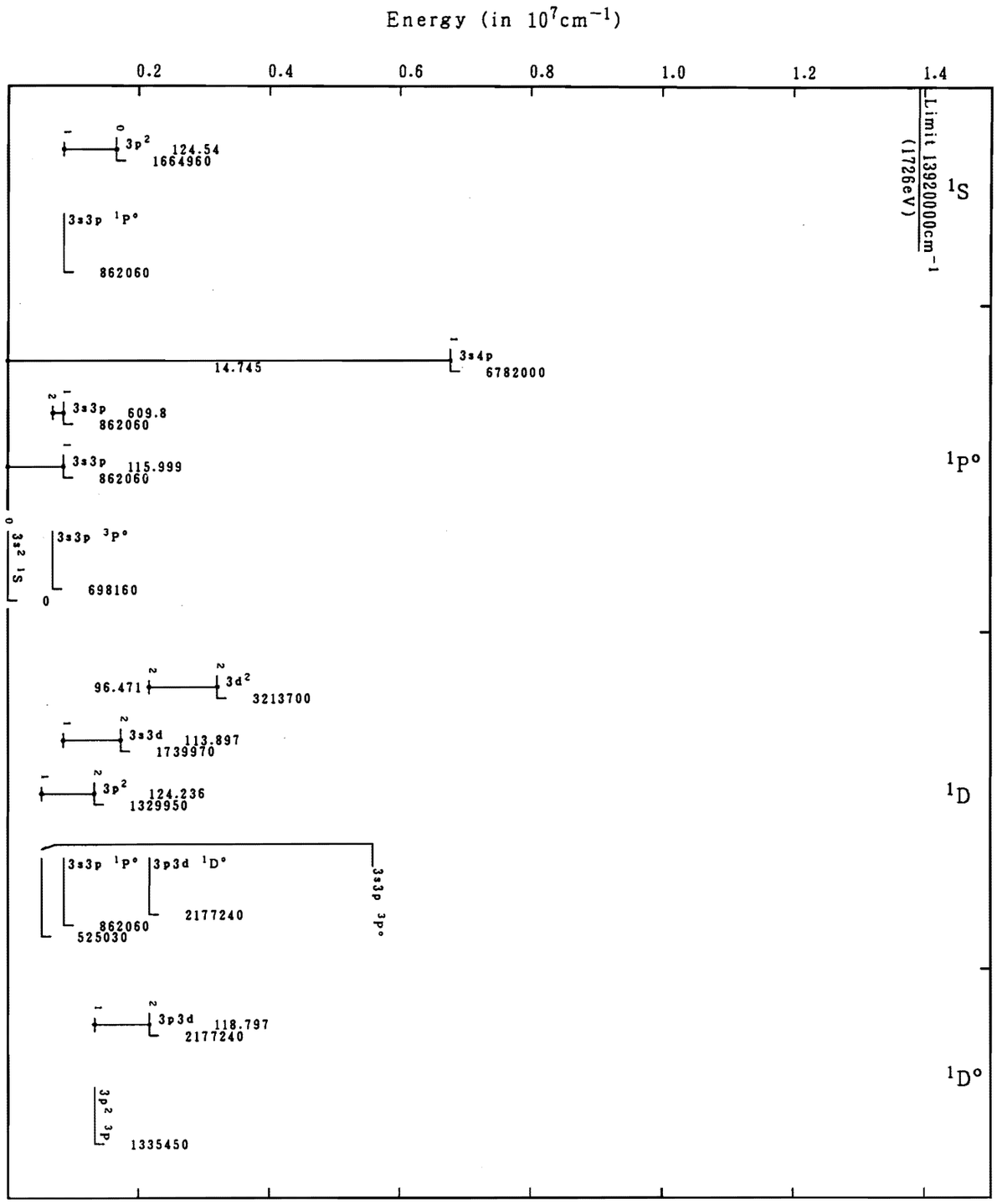
Mo XXVIII(P−Sequence)



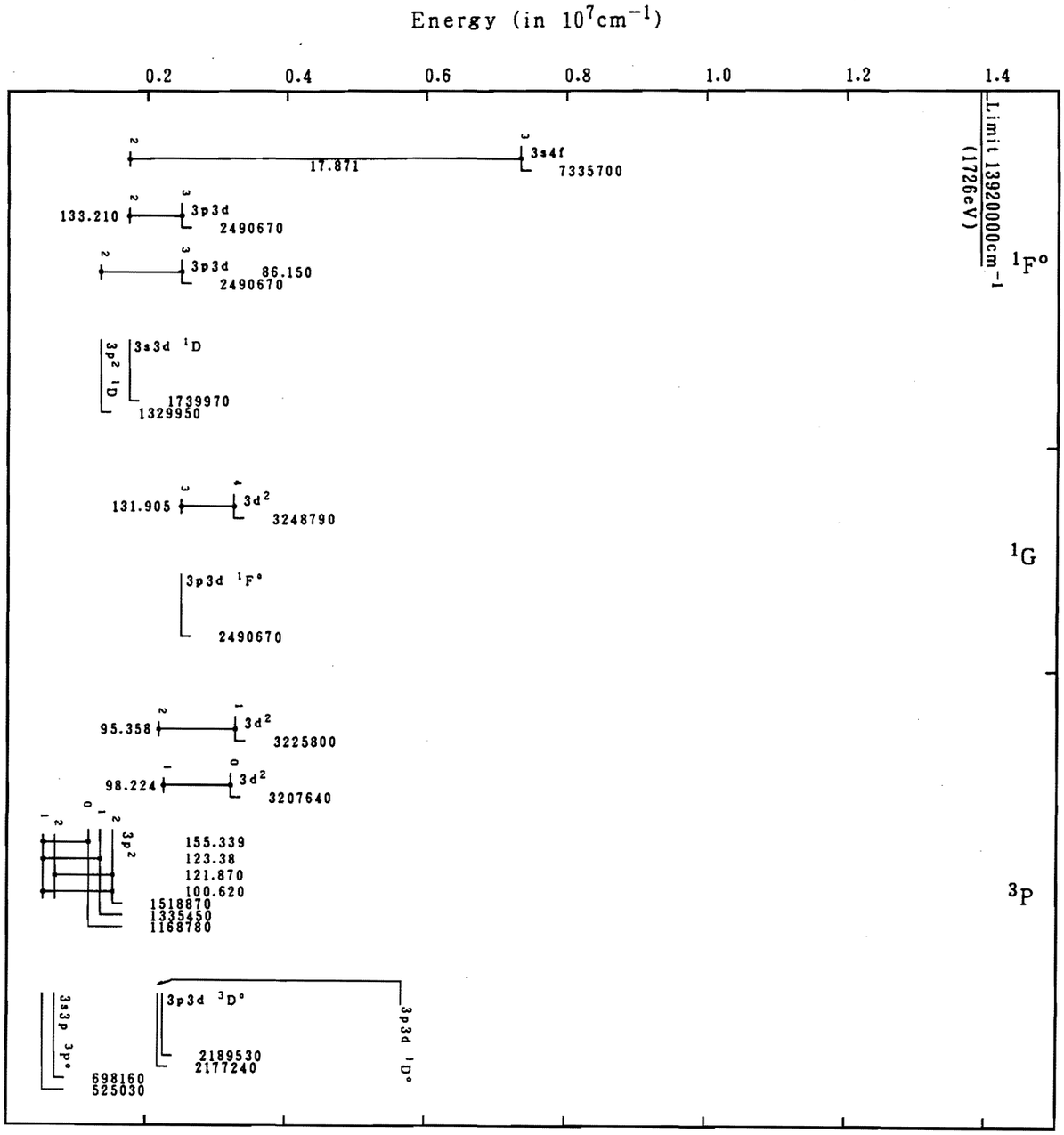
Mo XXIX(Si−Sequence)



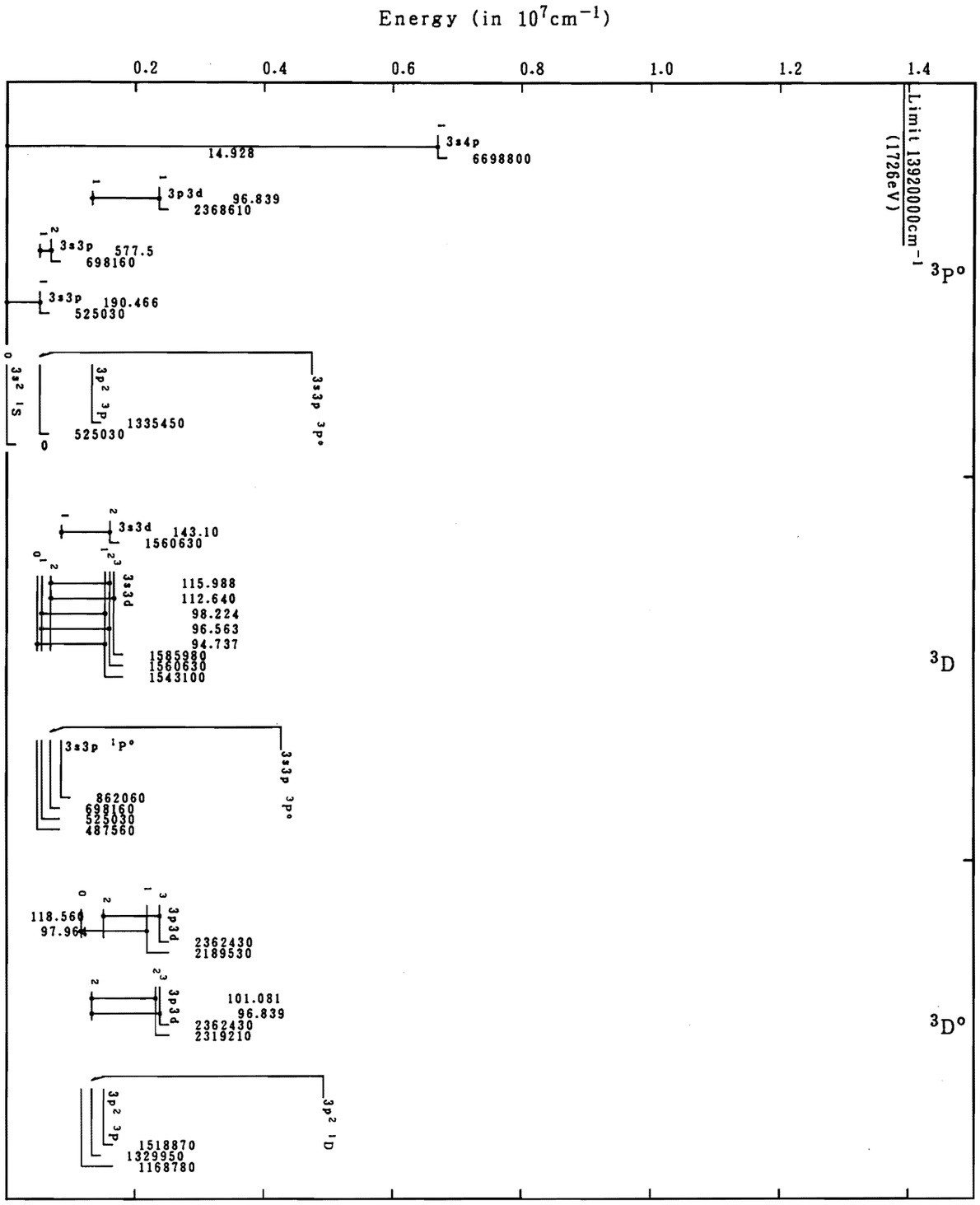
Mo XXX(Al–Sequence)



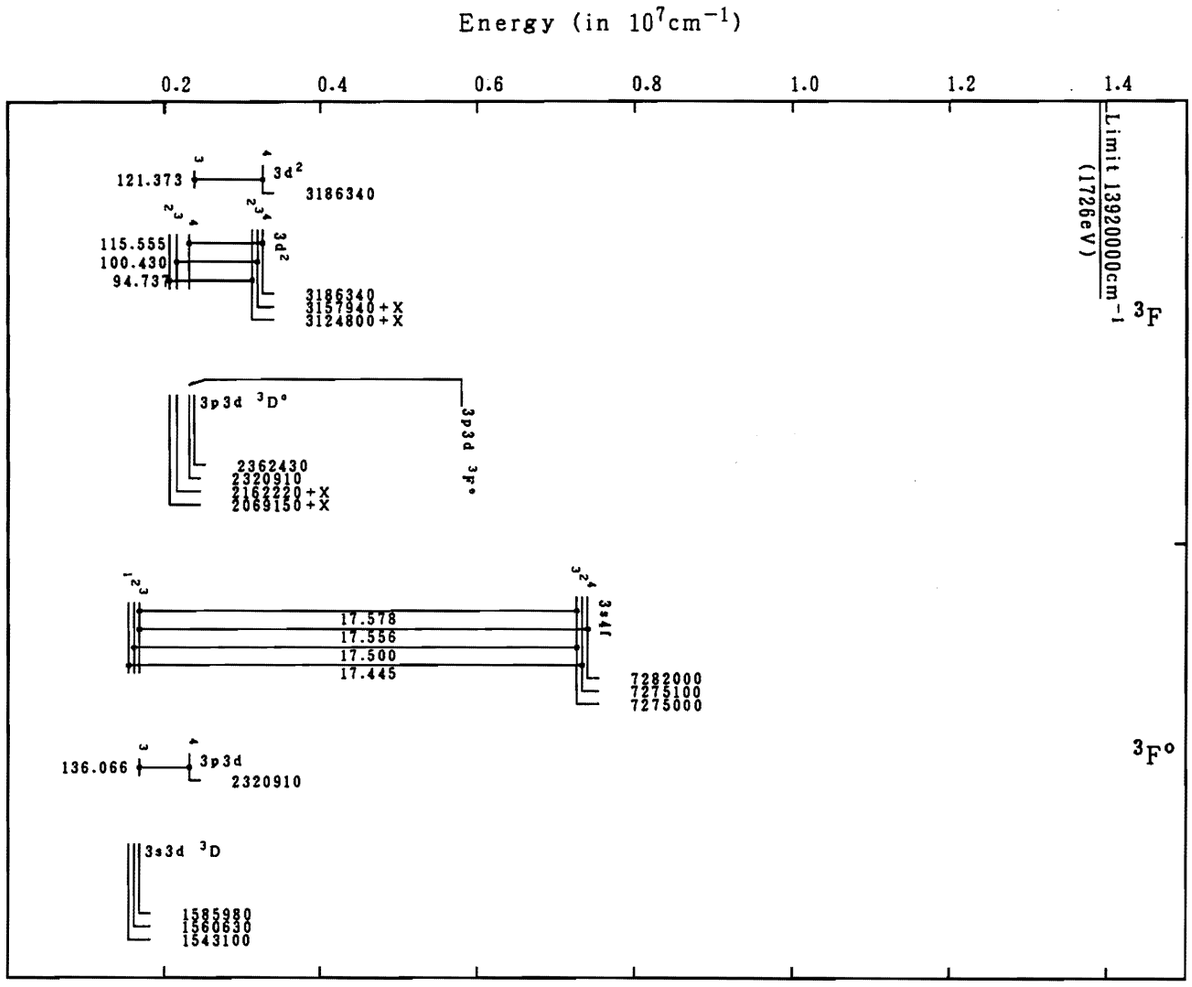
Mo XXXI(Mg−Sequence)



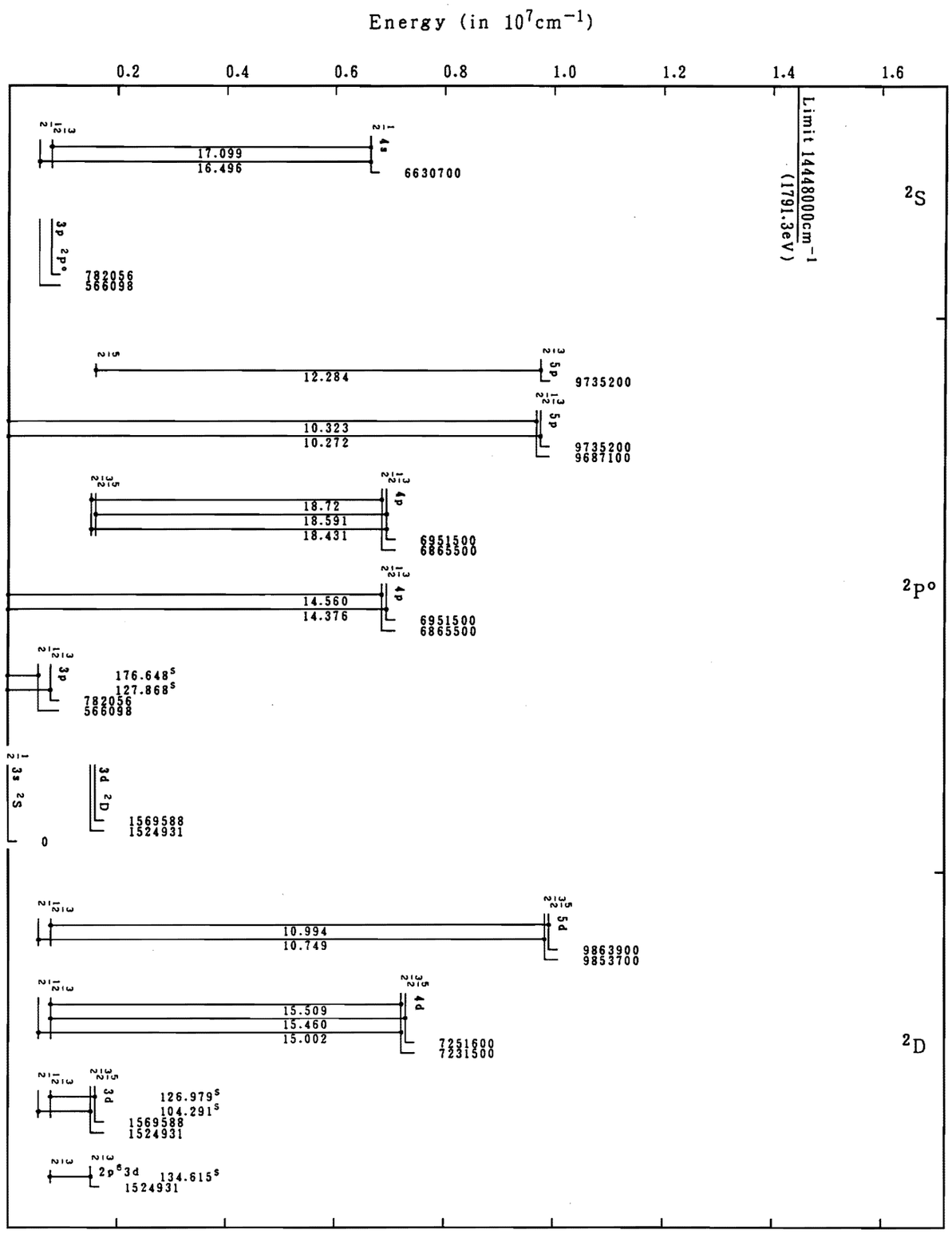
Mo XXXI(Mg−Sequence)



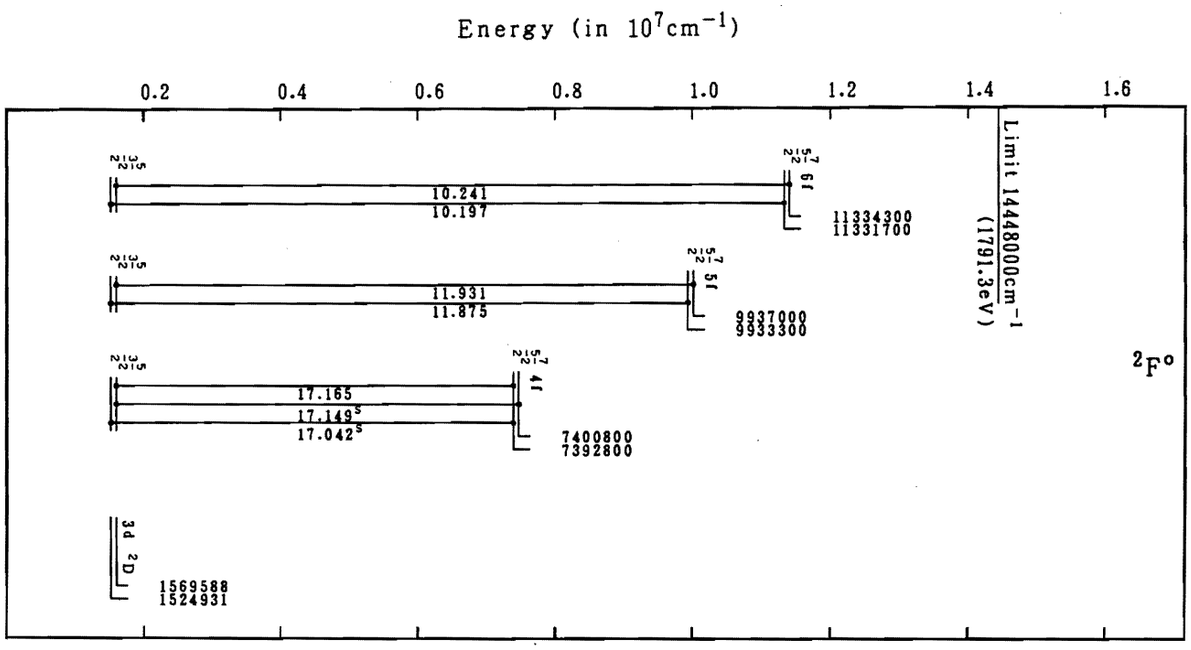
Mo XXXI(Mg−Sequence)



Mo XXXI(Mg−Sequence)



Mo XXXII(Na−Sequence)



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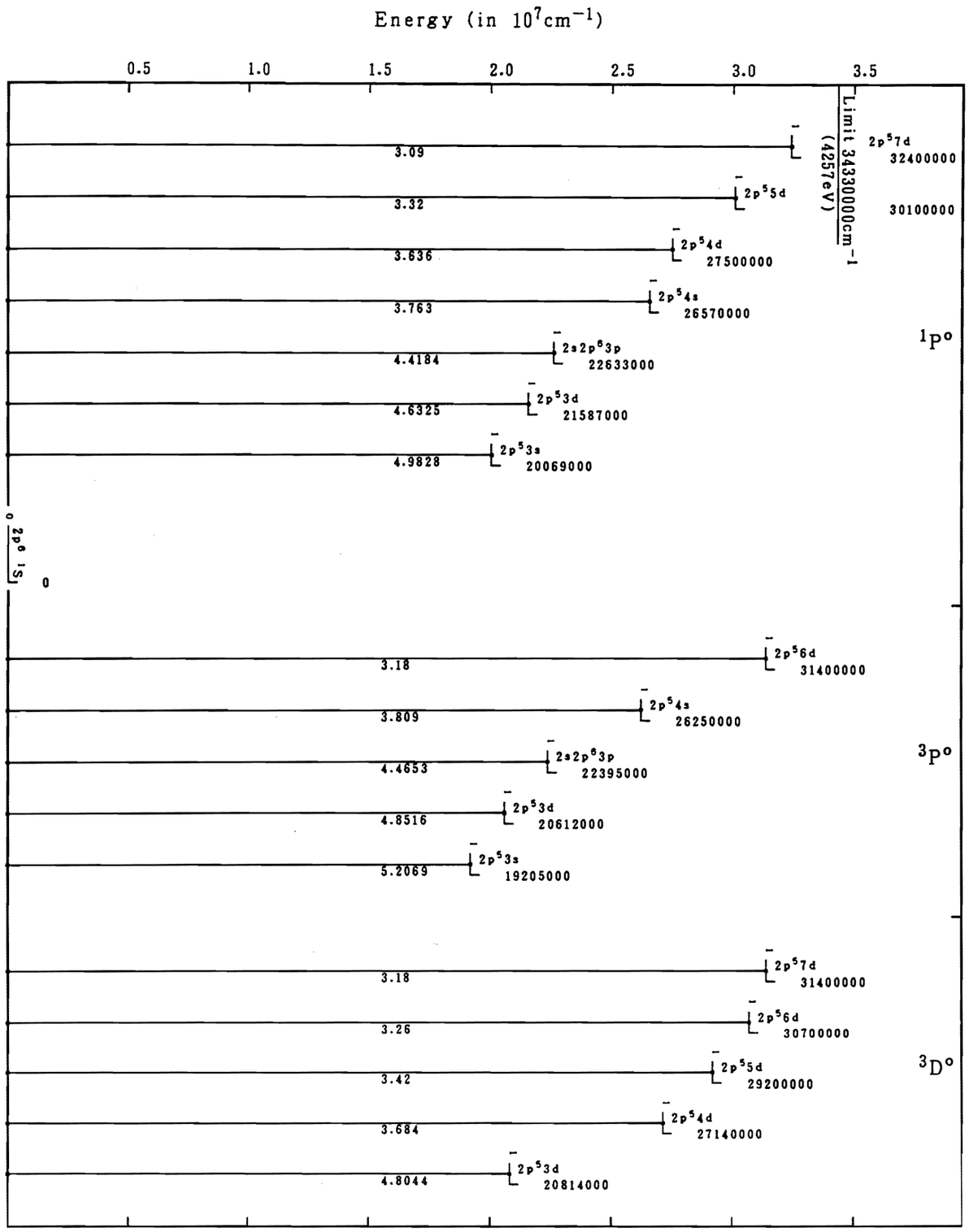
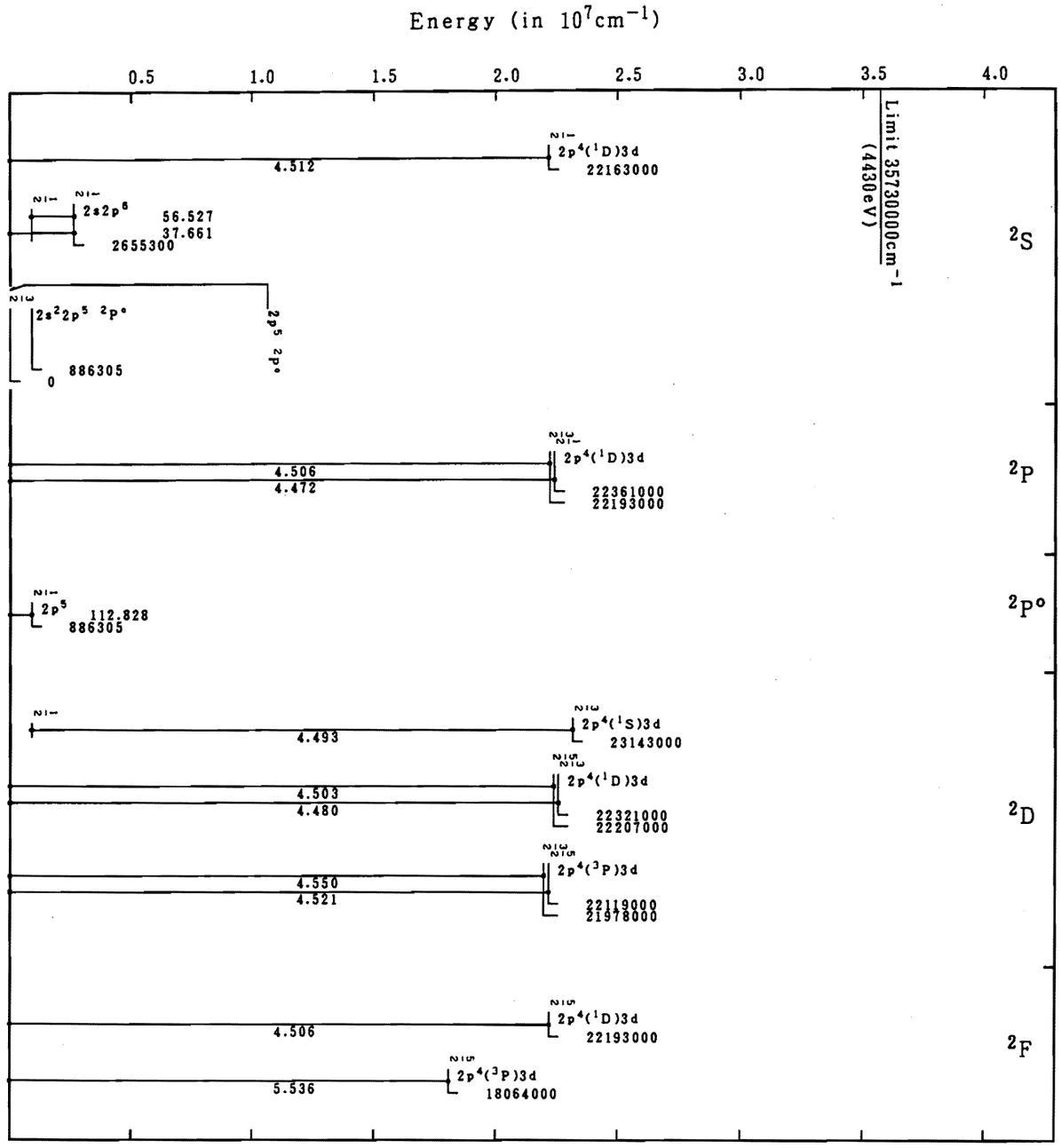
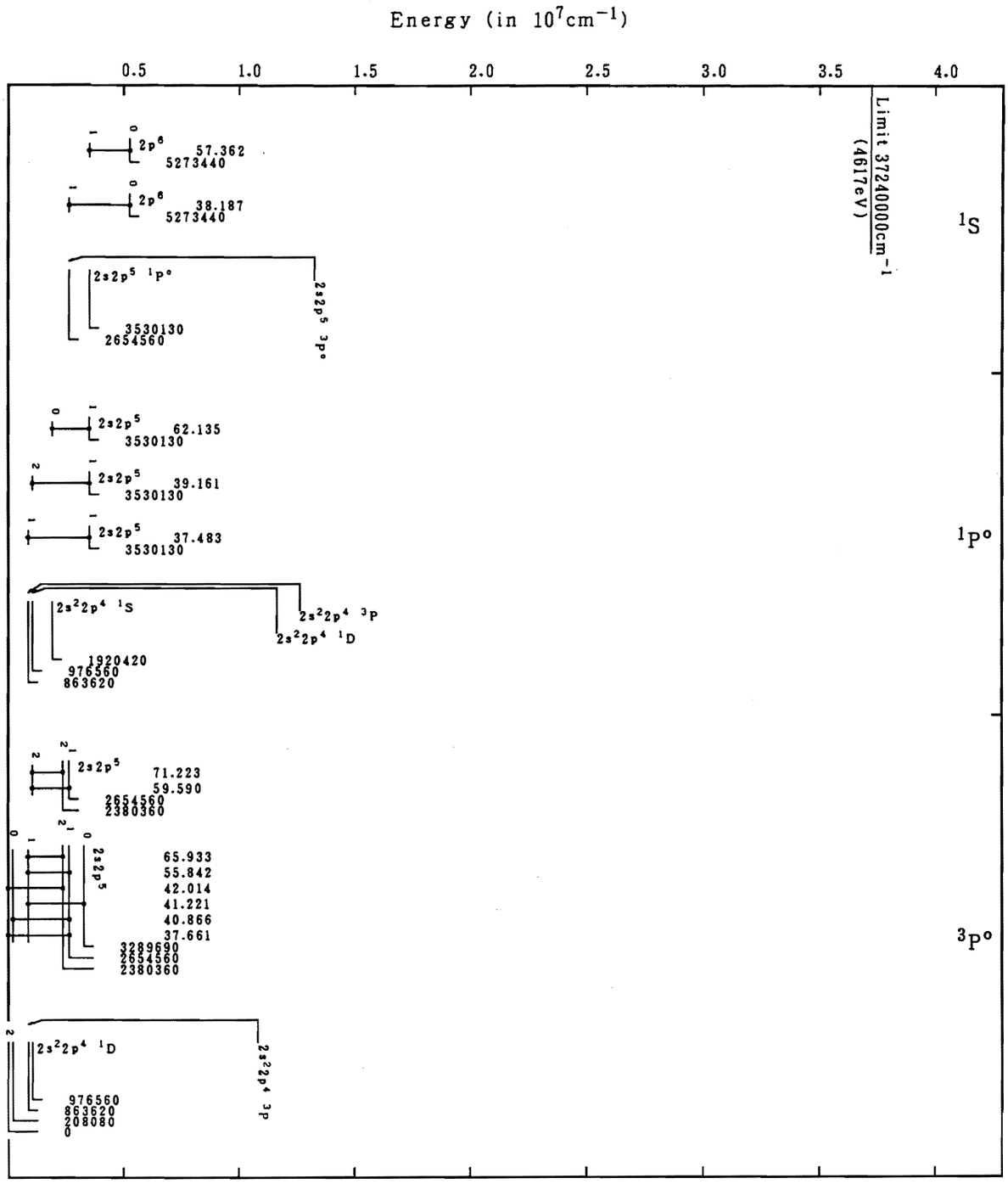


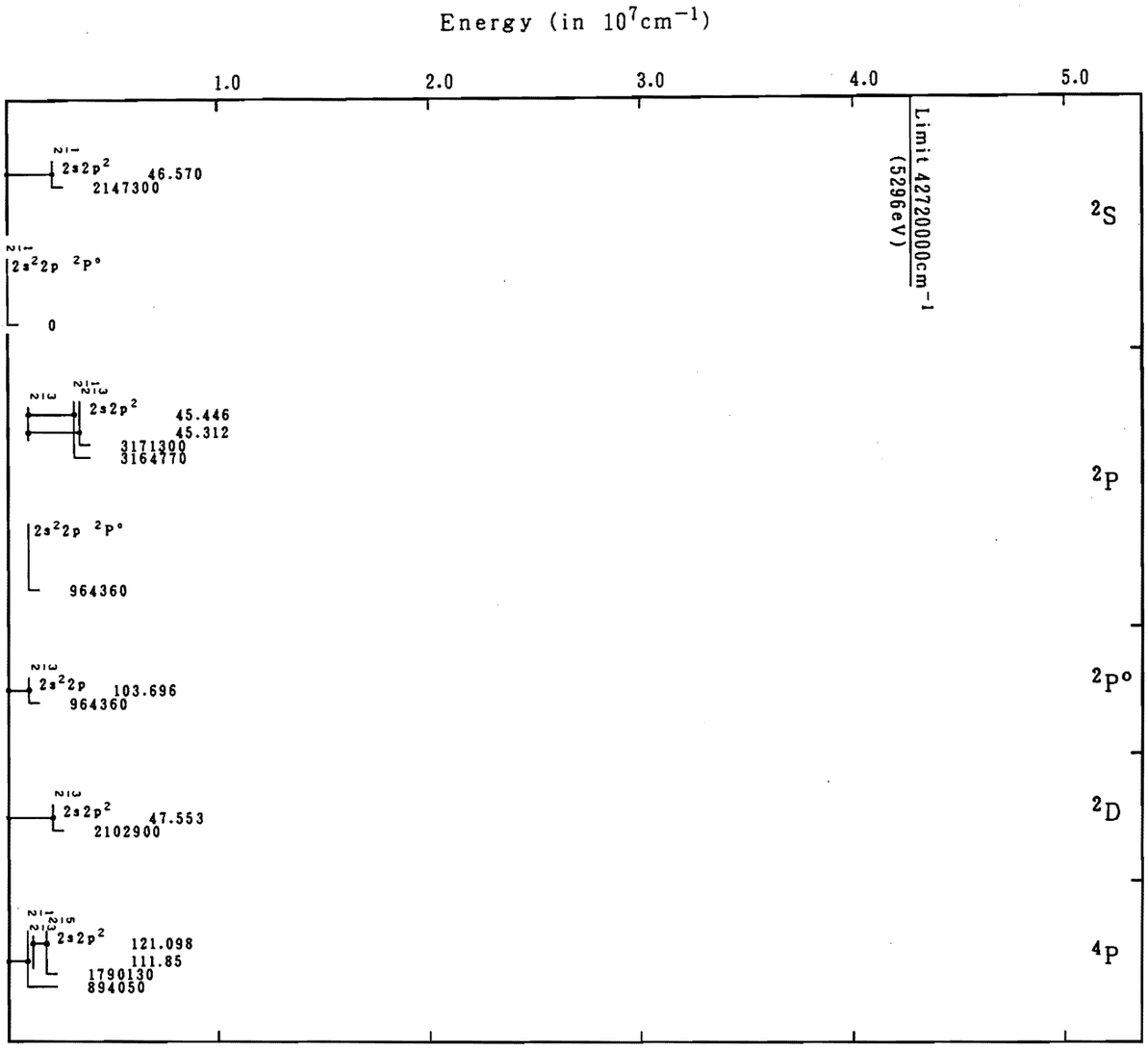
Mo XXXIII(Ne−Sequence)



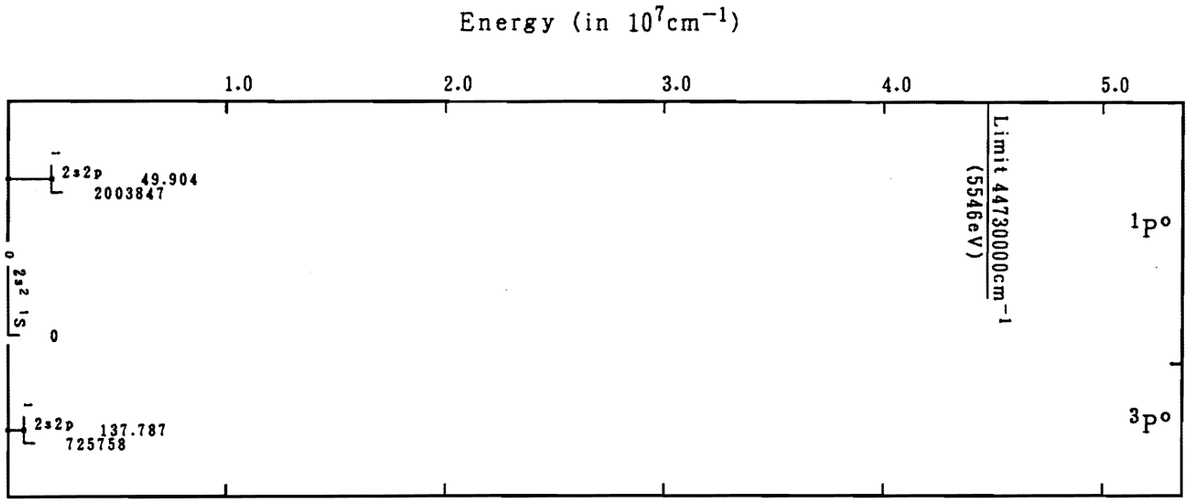
Mo XXXIV(F−Sequence)



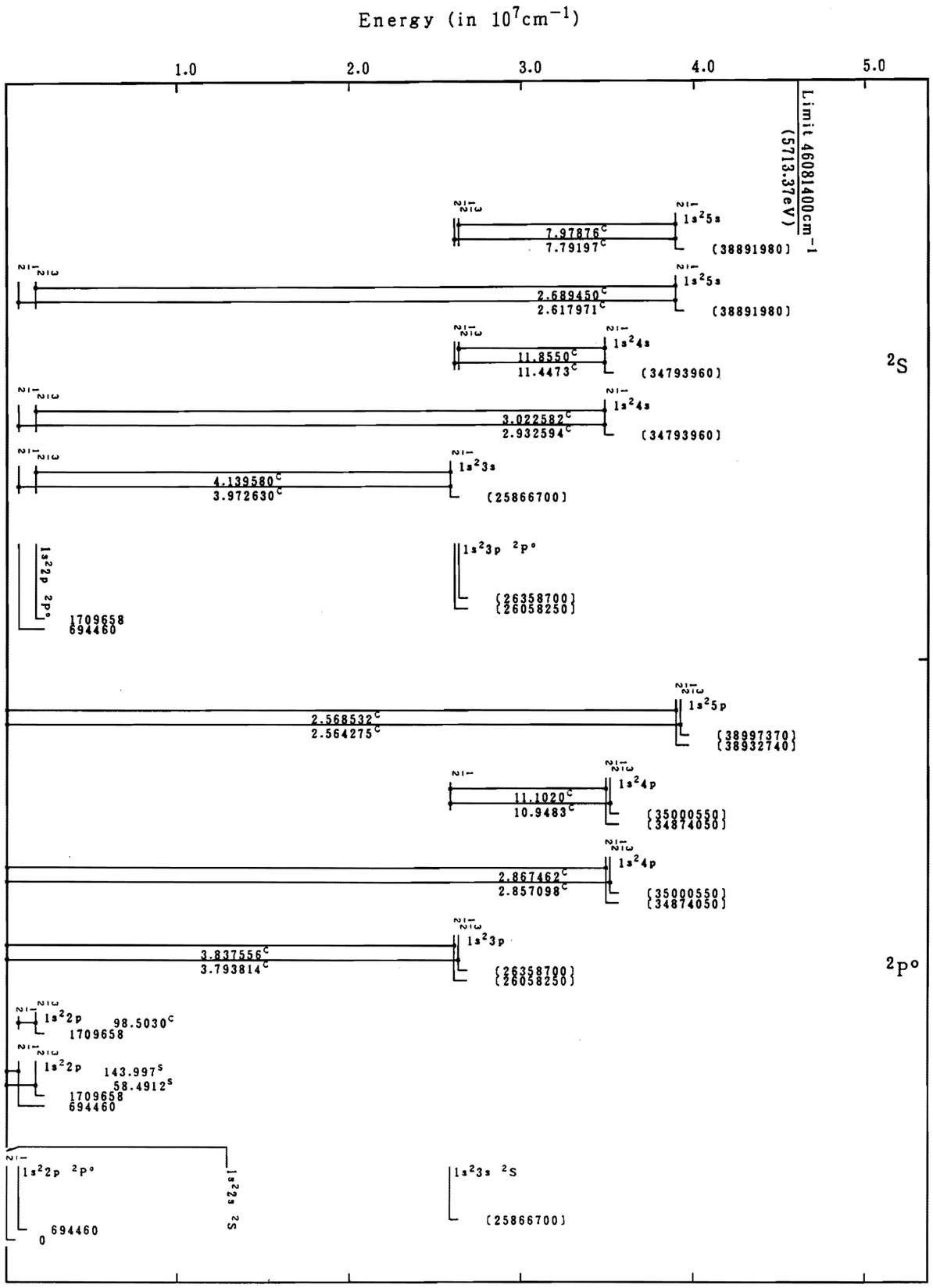
Mo XXXV(O−Sequence)



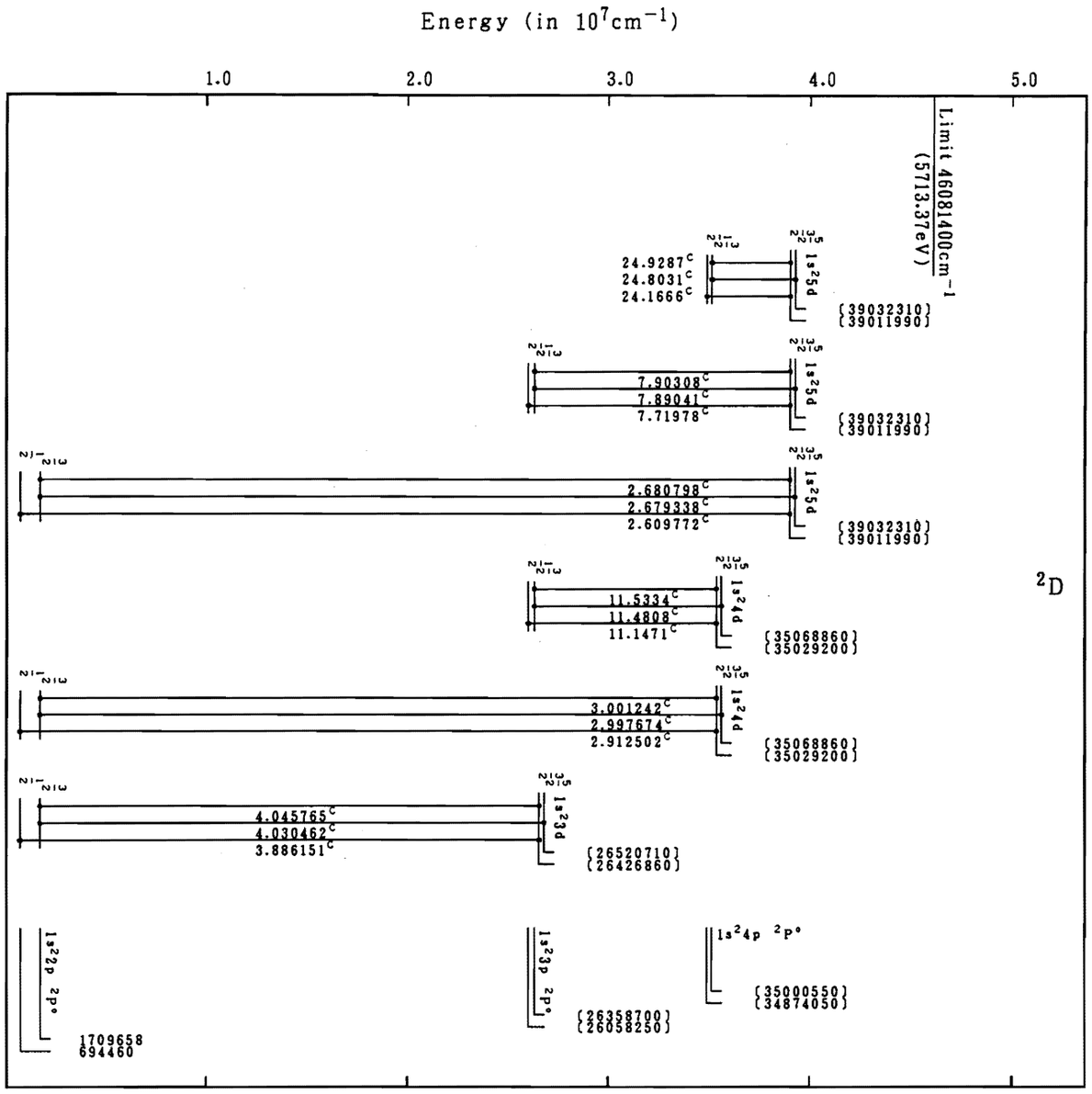
Mo XXXVIII(B−Sequence)



Mo XXXIX(Be−Sequence)



Mo XL(Li–Sequence)



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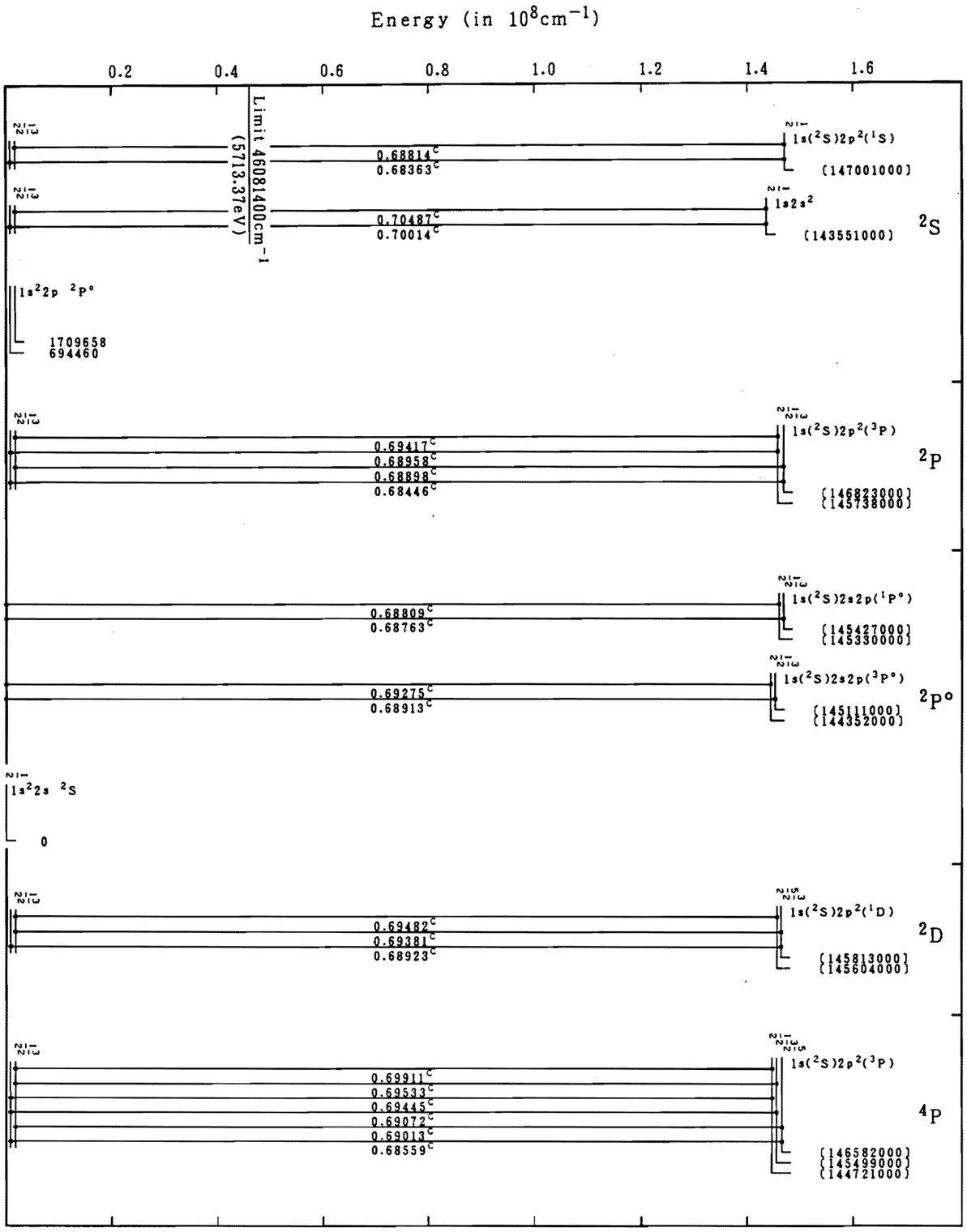

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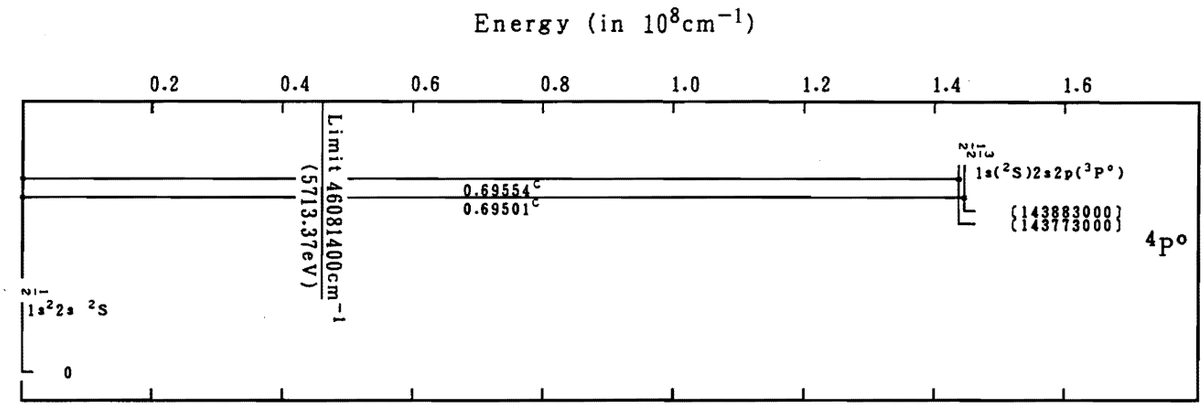
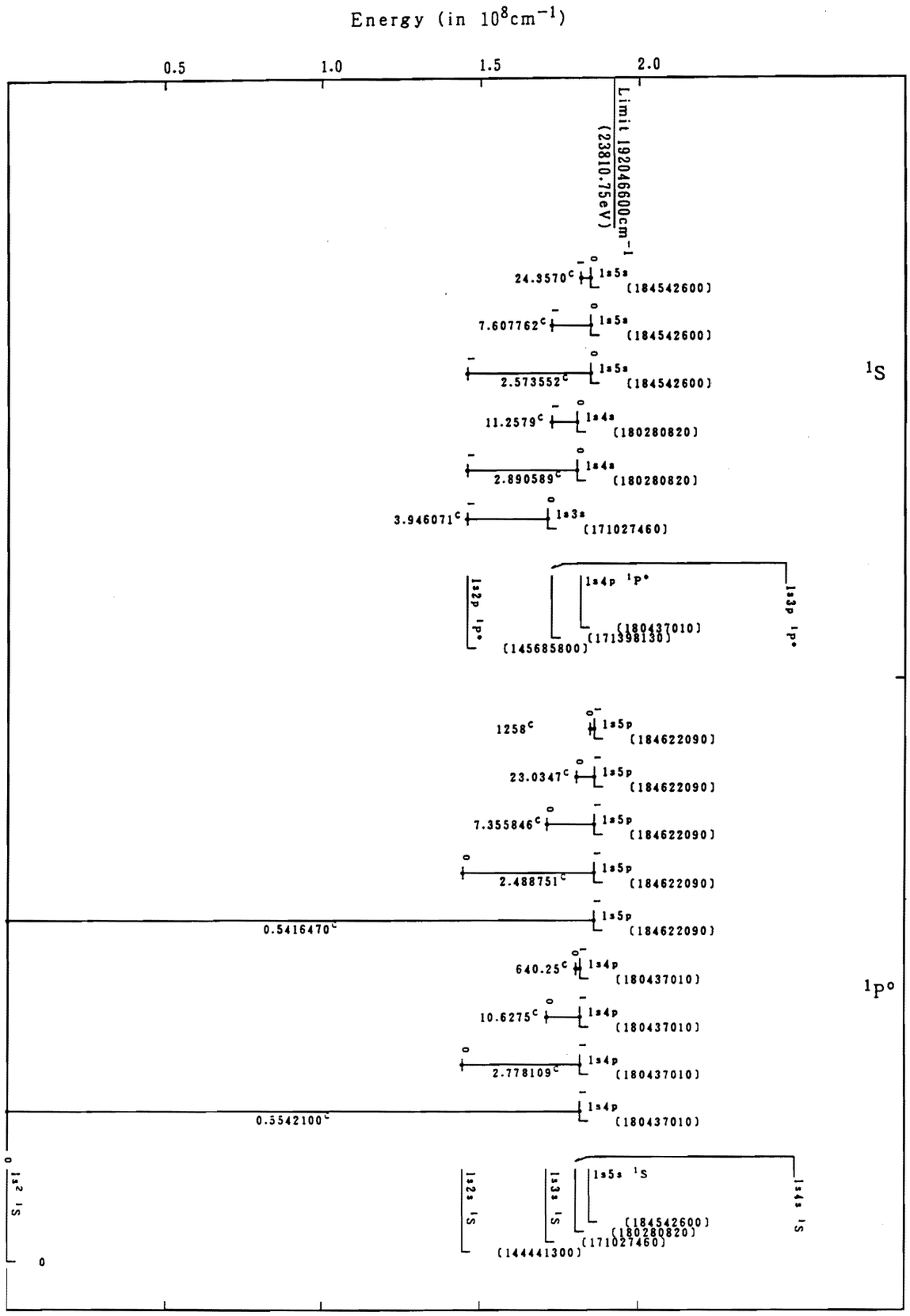
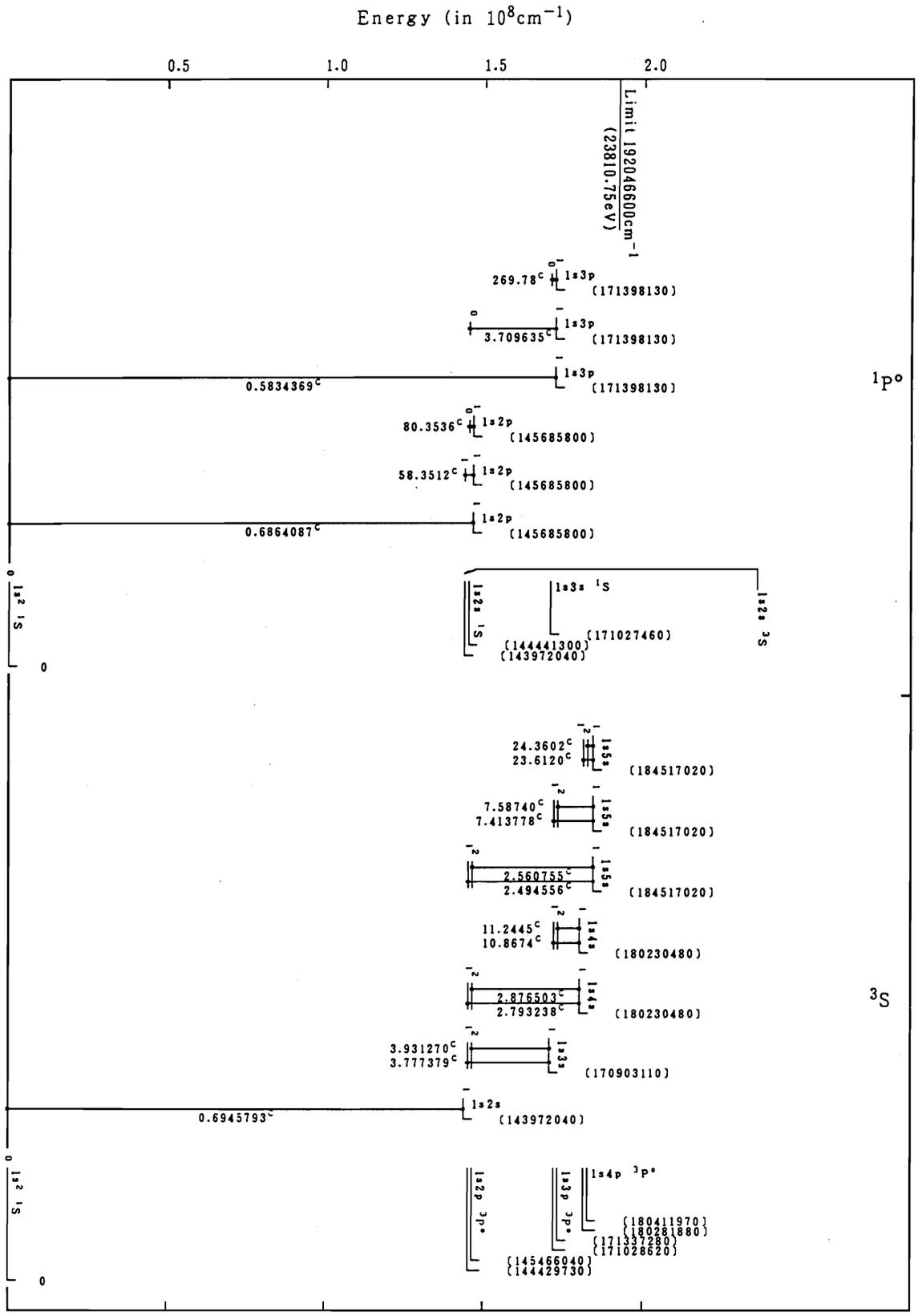


Mo XL(Li−Sequence)



Mo XLI(He–Sequence)



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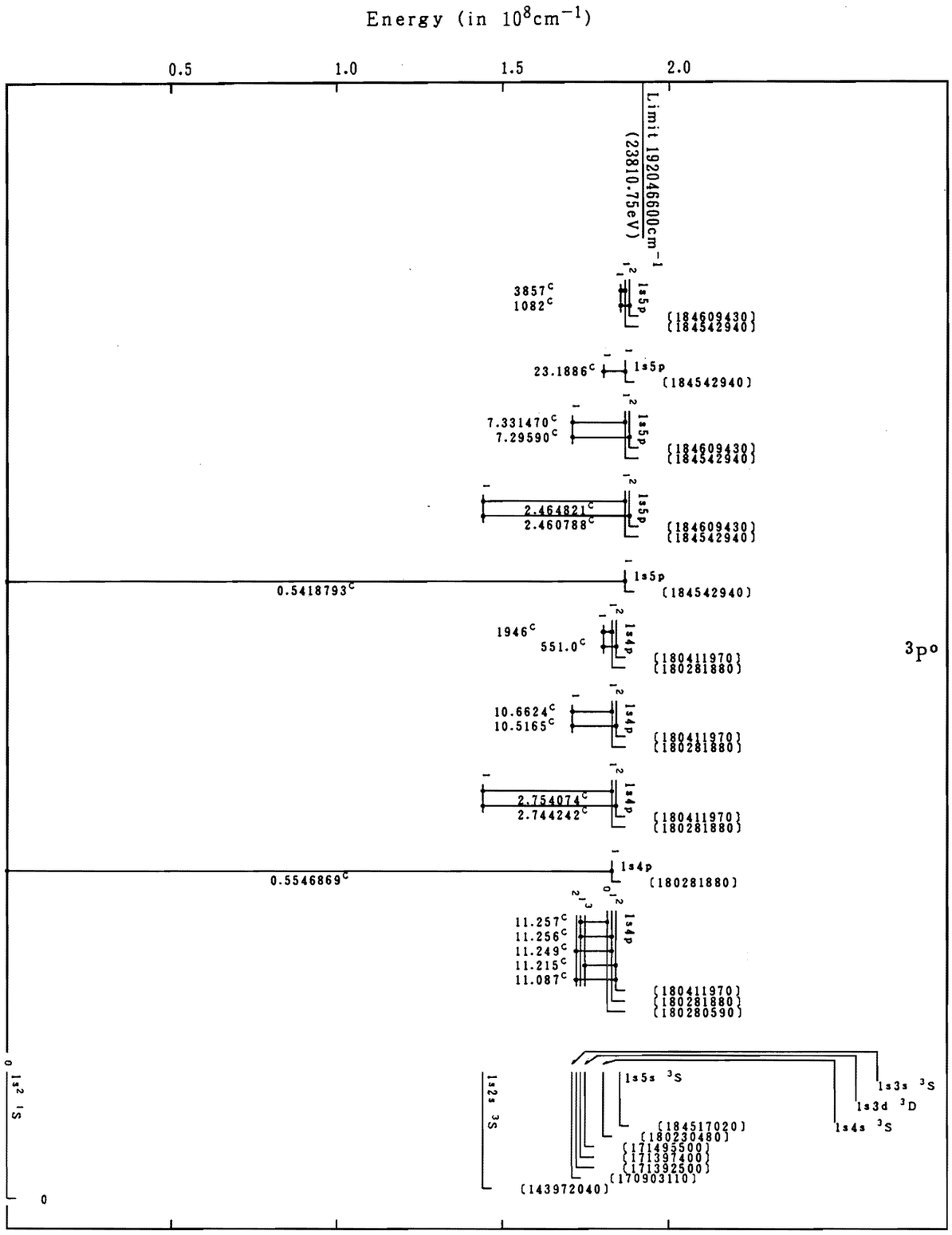

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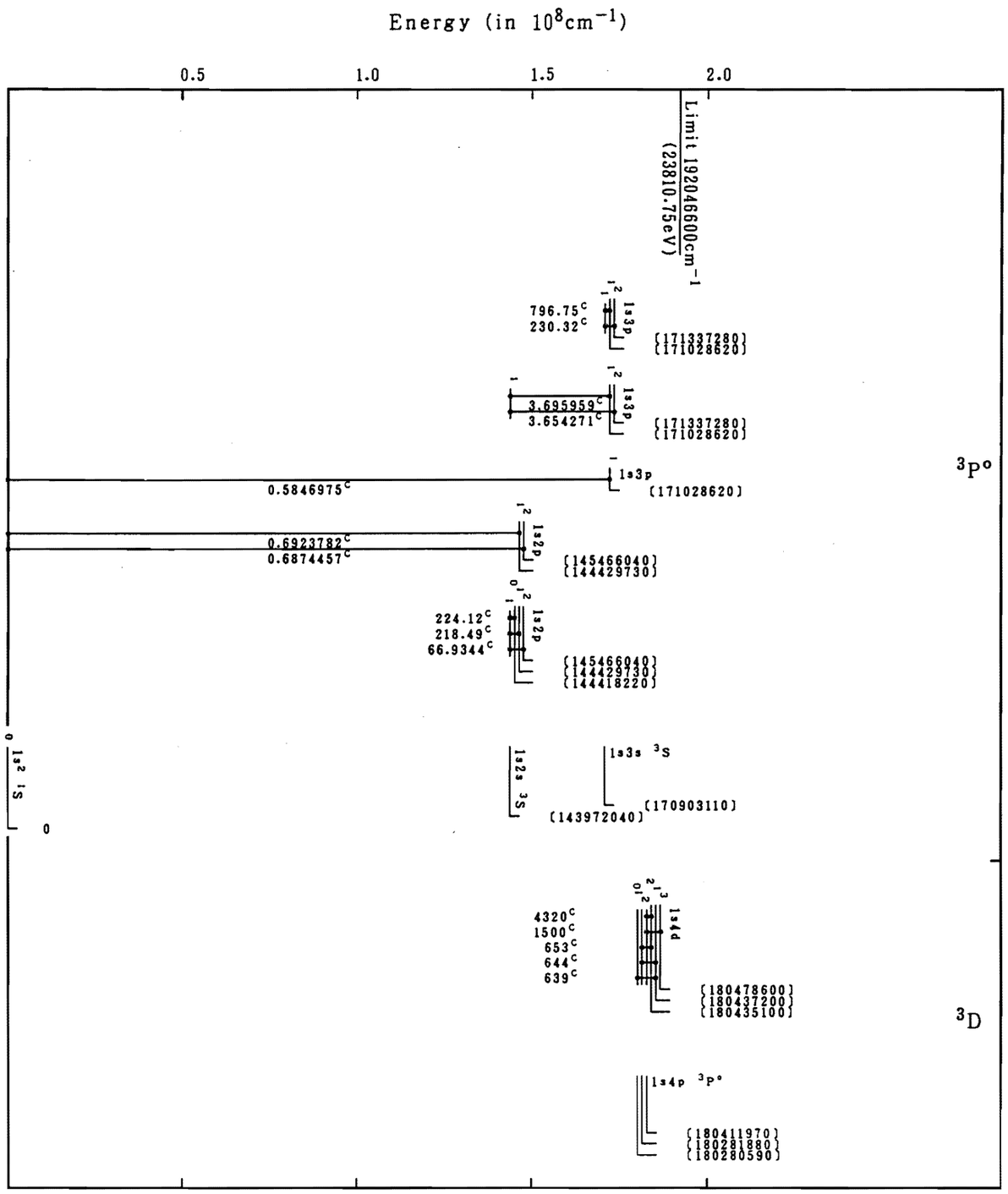

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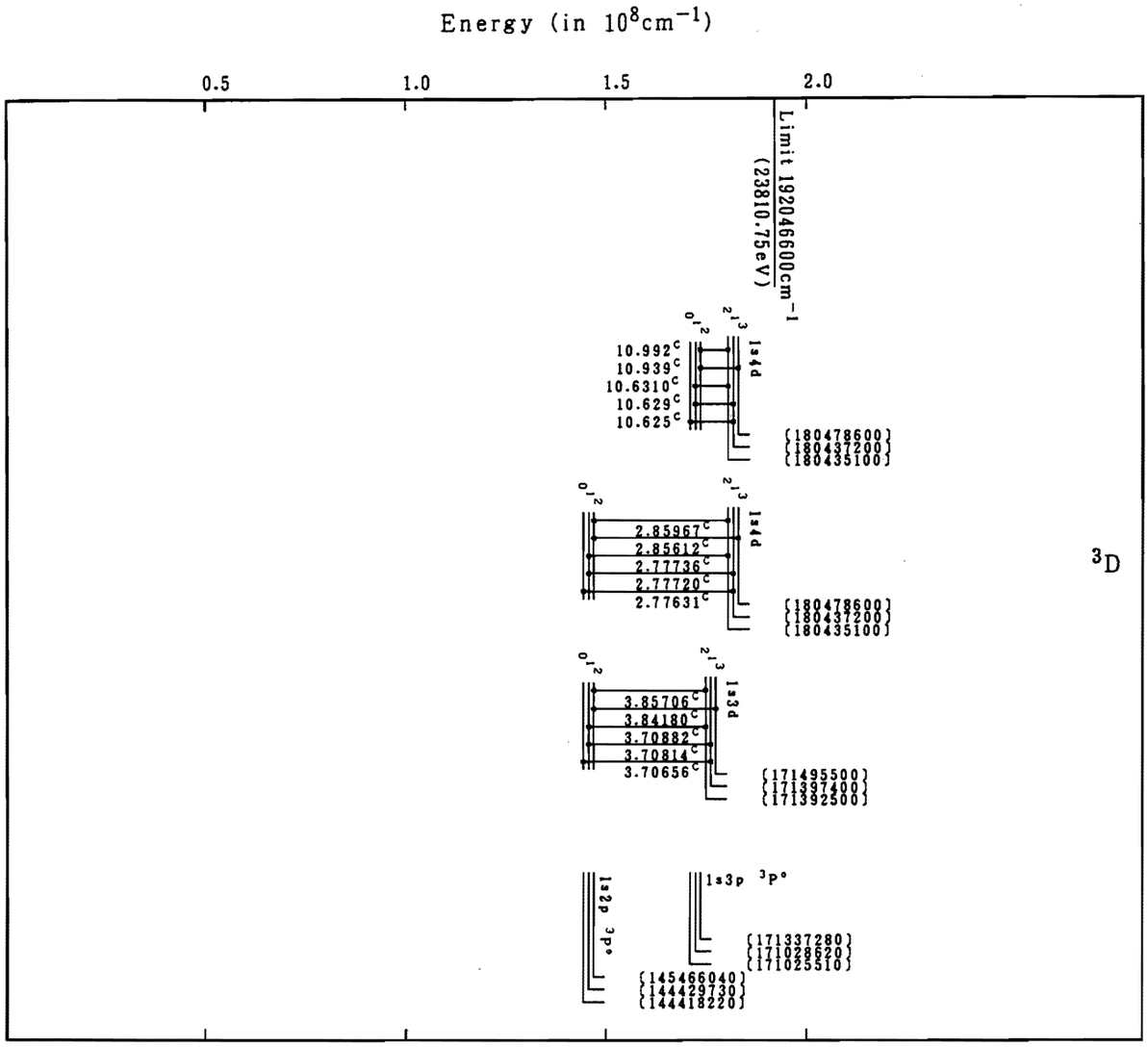

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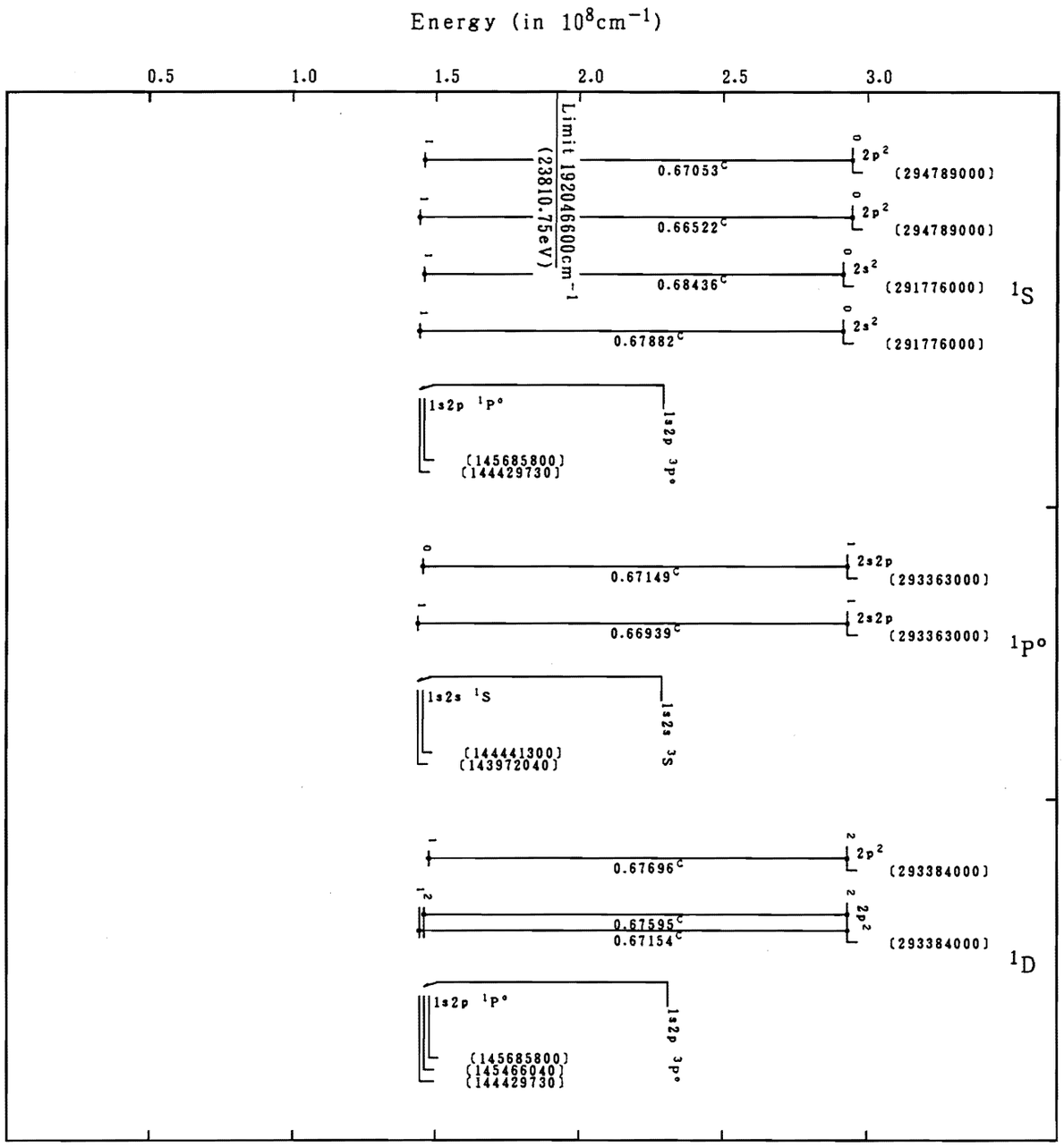

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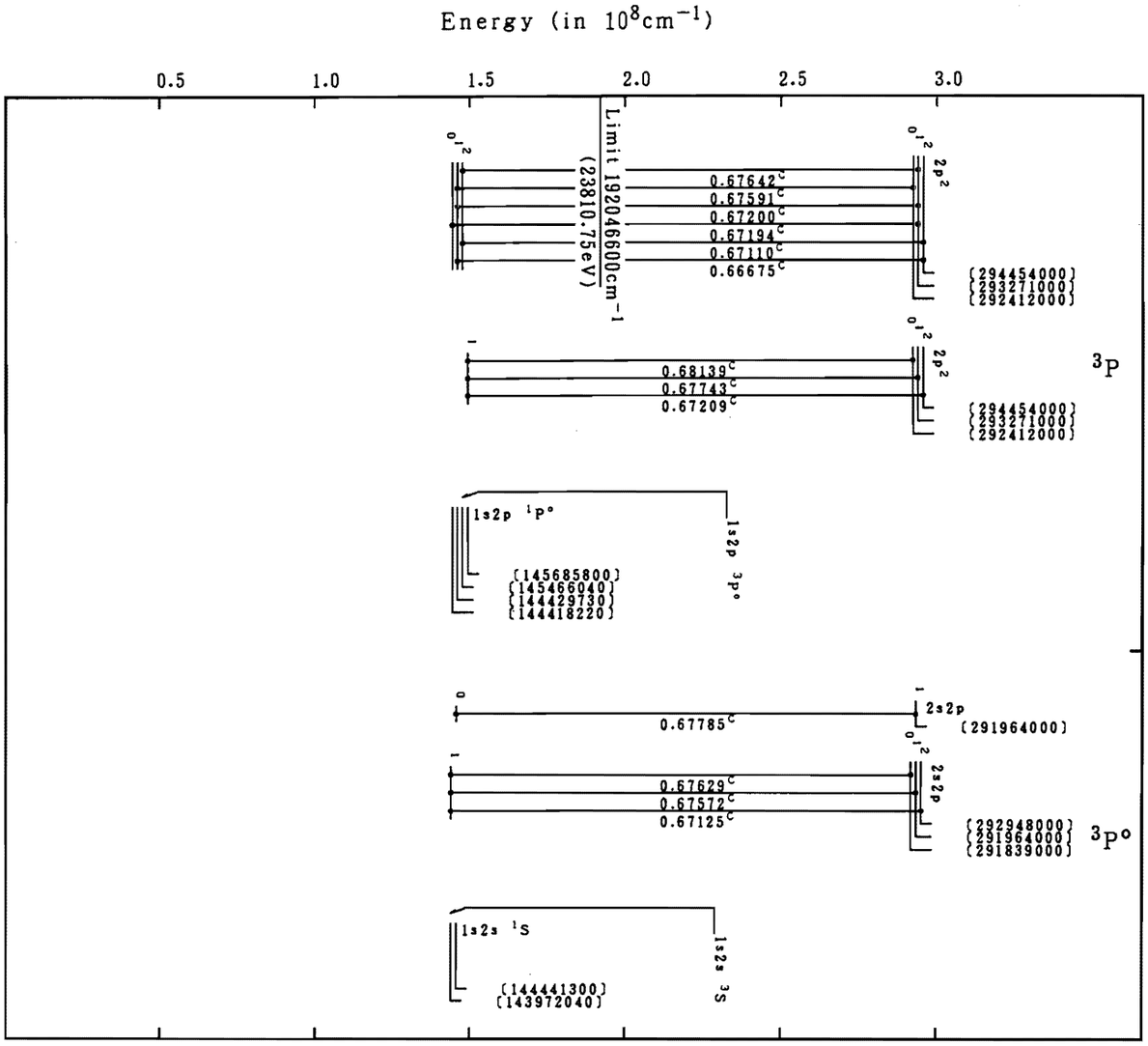

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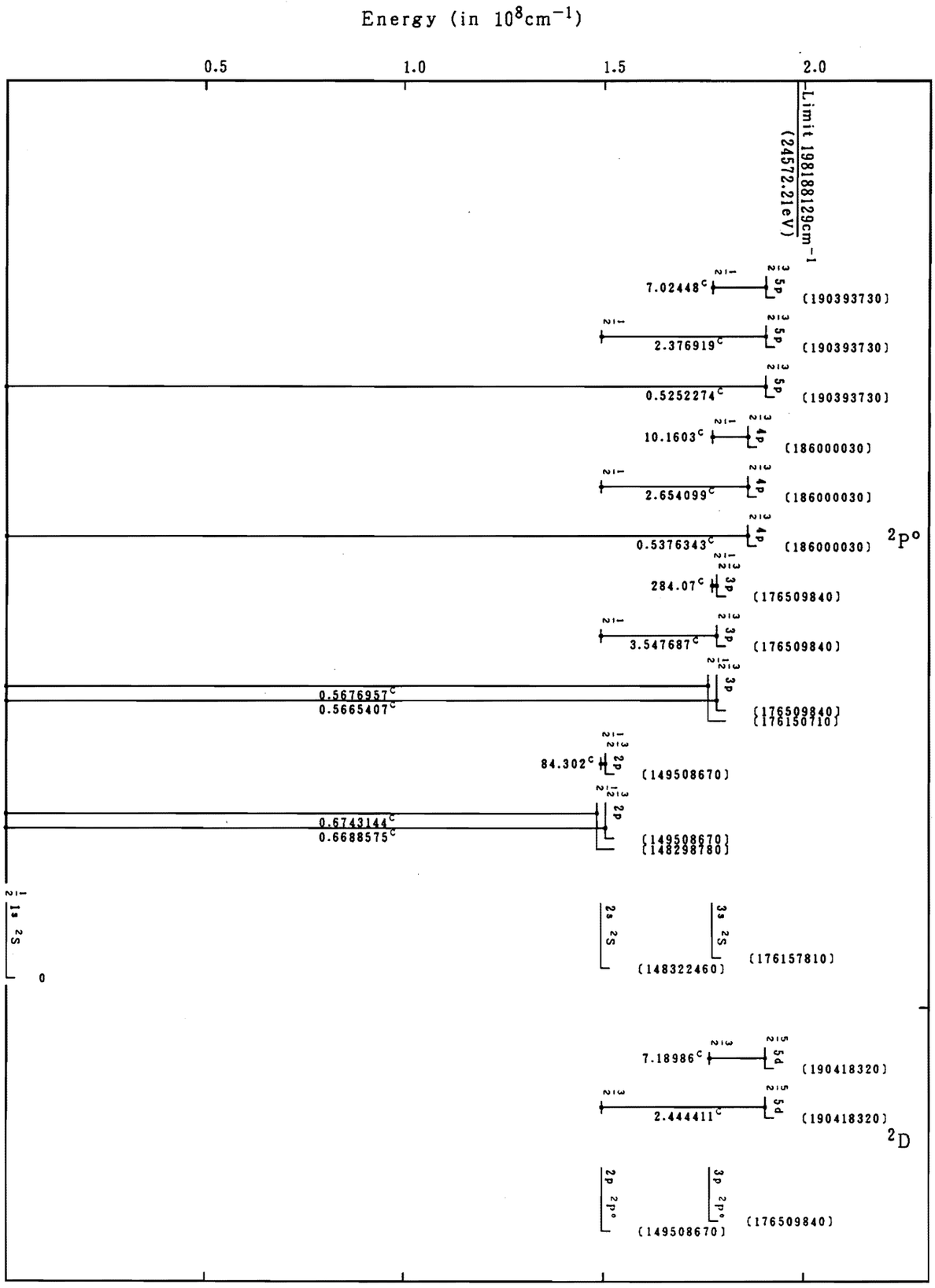
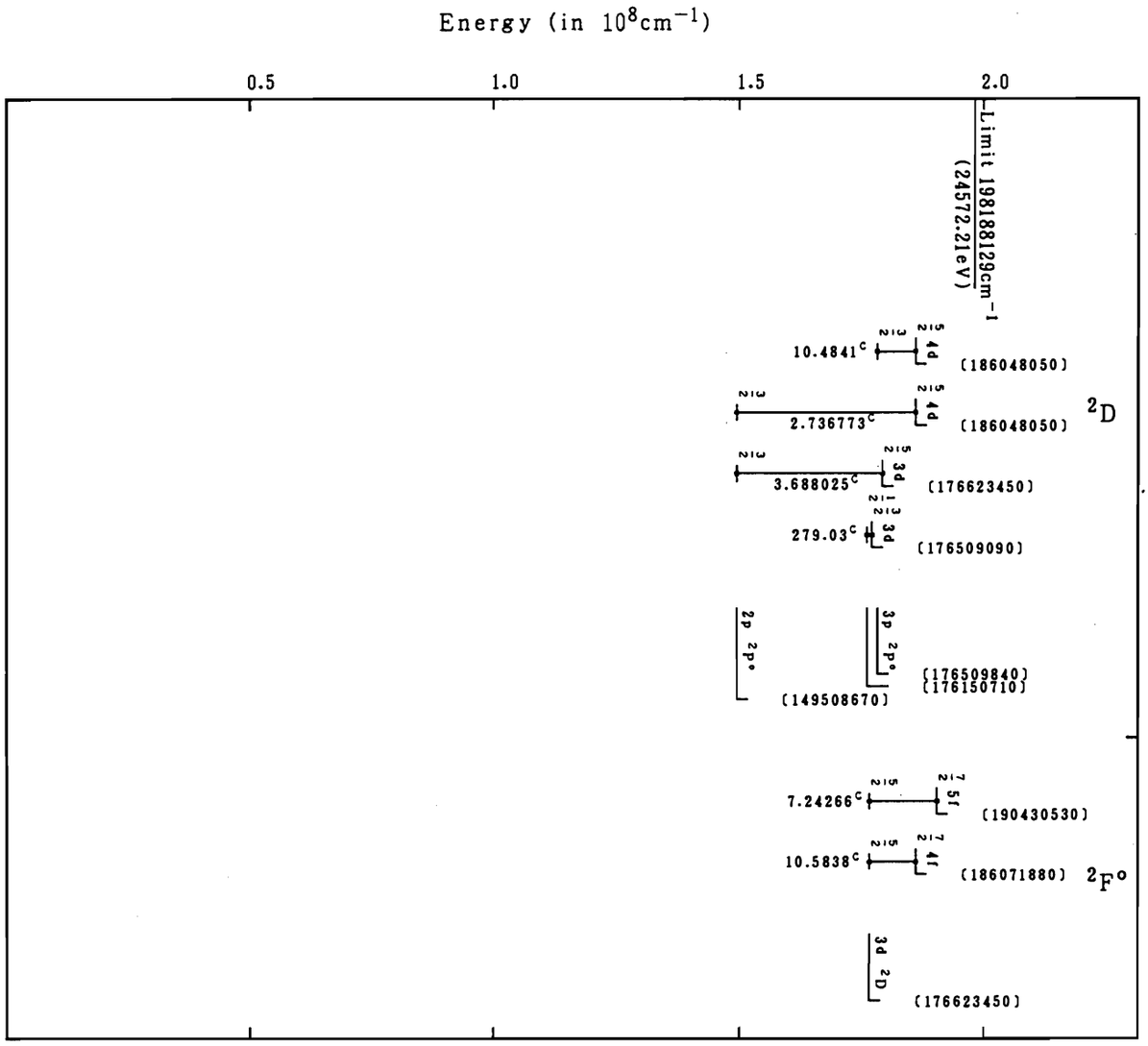


Mo XLII(H−Sequence)



Mo XLII(H−Sequence)