

Spectral Data and Grotrian Diagrams for Highly Ionized Copper, Cu X-Cu XXIX

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Spectral Data and Grotrian Diagrams for Highly Ionized Copper, Cu x–Cu xxix

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Wavelengths, energy levels, level classifications, intensities, and transition probabilities for the copper spectra Cu x to Cu xxix are compiled. The data are critically evaluated and the best results, in the authors' judgment, are quoted. A short review of the work on each stage of ionization is included. Grotrian diagrams are also presented to provide graphical overviews. The literature has been surveyed to March 1990.

Key words: compilation; copper; ions; spectra; wavelengths.

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1. Introduction

We have undertaken to publish a series of compilations of spectra of highly ionized atoms of particular interest to the fusion energy community. These selected elements occur as impurities in wall materials of fusion machines or are internally injected into the hot plasmas for diagnostics. Much new work on these spectra has appeared in recent years. We have critically compiled these data into single publications for each element; each publication includes wavelengths, classifications, intensities, Grotrian diagrams, and a short review of the literature, for each ion of the element. Those already published include Ti, Fe, Ni, and Mo.¹⁻⁴ The present compilation contains data for Cu x to Cu xxix. It is closely correlated with a companion work by Sugar and Musgrove (1990)⁵, which is a critical compilation of all the known energy levels of copper in all stages of ionization. The level values quoted here are taken from that compilation. This series is complimentary to the energy level compilations by the National Institute of Standards and Technology (U.S.A.). The elements Ti, Fe, and Ni are included in a monograph containing energy levels of the iron-period elements by Sugar and Corliss (1985)⁶ and Mo energy levels by Sugar and Musgrove (1988)⁷.

All the relevant papers on copper published through March 1989 were collected and surveyed, and the best measurements, in our judgement, were included in the tables. We were aided by the following comprehensive compilations: Kelly (1987)⁸ for wavelength data, Kaufman and Sugar (1986)⁹ for forbidden lines arising within ground configurations of the type ns^2np^k ($n = 2$ and 3, $k = 1$ to 5), and a review article by Fawcett (1984)¹⁰. In addition we consulted the *Bibliographies on Atomic Energy Levels and Spectra*¹¹⁻¹⁵ and a bibliographic database containing references collected since the last published bibliography maintained by the Atomic Energy Levels Data Center located at N.I.S.T.

In the following section we give brief comments on each ion, including comments on the accuracy of the wavelength data. The values for the energy levels have been taken from the original article or recalculated from the most reliable wavelength data. For the He- and H-sequences, only theoretical results are given since they are considered to be more accurate than the experimental values.

We give wavelengths in air above 2000 Å and in vacuum below 2000 Å. For conversion of ionization energies from cm^{-1} to eV, we use the conversion factor 8065.5410(24) cm^{-1}/eV given by Cohen and Taylor (1987)¹⁶.

1.1. References for Introduction

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2. Brief Comments on Each Copper Ion

Cu x (Ca sequence)

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 {}^3F_2$

Classification of emission lines from the $3p^6 3d^2 - 3p^5 3d^3$ transition array in the range of 132–155 Å was made by Fawcett *et al.* (1980)²⁷. They used vacuum spark observations and obtained a wavelength uncertainty of ± 0.007 Å.

Alexander *et al.* (1966)⁵ identified the $3p^6 3d^2 - 3p^6 3d4f$ transitions in the wavelength range of 86.1–88.0 Å using vacuum spark observations. They identified the transitions, ${}^1D_2 - {}^1D_2$, 1F_3 and ${}^3F - {}^3P$, 3G . Tabulated wavelengths are from improved measurements by Even-Zohar and Fraenkel (1968)²⁵, who classified 5 new lines due to the ${}^3P - {}^3D$, ${}^1D_2 - {}^3D_3$ and ${}^3F_4 - {}^3F_3$ transitions. Their wavelength uncertainty is ± 0.005 Å.

Cu xi (K sequence)

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d {}^2D_{3/2}$

The transition arrays, $3p^6 3d {}^2D - 3p^5 3d^2 {}^2P$, 2D , 2F in the range of 134.9–150.4 Å were first identified and measured by Goldsmith and Fraenkel (1970)³⁴ with an

uncertainty of $\pm 0.005 \text{ \AA}$ in a vacuum spark. Ramonas and Ryabtsev (1980)⁵⁹ remeasured the spectrum in a wider range with a wavelength uncertainty of $\pm 0.003 \text{ \AA}$ using low-inductance vacuum sparks. They classified 16 lines in the range of $108 - 185 \text{ \AA}$, and improved and extended the earlier analysis. From observations with a laser-produced plasma, Kaufman *et al.* (1989)⁴⁵ remeasured seven lines in the range of $134.9 - 149.5 \text{ \AA}$ with an uncertainty of $\pm 0.005 \text{ \AA}$, in agreement with those of Ref. 59. The wavelengths are adopted from Ref. 59. The line at 147.742 \AA is classified as the $3p^63d^2D_{5/2} - 3p^5(^2P^o)3d^2(^3F) ^2F_{7/2}$ transition in Ref. 59, but in Ref. 45 it is given as $3p^63d^2D_{5/2} - 3p^5(^2P^o)3d^2(^1G) ^2F_{7/2}$. We have adopted the designations of Ref. 59.

The $3p^63d^2D - 3p^64f^2F^o$ doublet was first identified by Alexander *et al.* (1965)⁴ in a vacuum spark. Even-Zohar and Fraenkel (1968)²⁵ extended the identifications to include $3p^63d^2D - 3p^6nf^2F^o$ ($n = 4$ to 6) at 78 \AA , 63 \AA , and 57 \AA . These wavelengths have an uncertainty of $\pm 0.01 \text{ \AA}$.

Hoory *et al.* (1970)³⁸ observed 15 lines in the range $72.3 - 76.3 \text{ \AA}$ with a vacuum spark and identified them as transitions from the $3p^53d4s^2P^o$, 2^4D^o , and 2^4F^o levels to the ground $3p^63d^2D$ levels. The uncertainty of the wavelengths is $\pm 0.005 \text{ \AA}$.

Cu xii (Ar sequence)

Ground state: $1s^22s^22p^63s^23p^6\ ^1S_0$

Sugar *et al.* (1987)⁶⁵ gave the spin-forbidden $3p^6\ ^1S - 3p^53d^2D^o$ transition as $174.739 \pm 0.005 \text{ \AA}$ and the allowed transition $3p^6\ ^1S_0 - 3p^53d\ ^1P^o$ at $139.175 \pm 0.005 \text{ \AA}$. The earlier measurements of the resonance transition were made by Even-Zohar and Fraenkel (1968)²⁵ and Goldsmith and Fraenkel (1970)³⁴ from vacuum spark observations. Even-Zohar and Fraenkel also identified the $3p^6\ ^1S_0 - 3p^54s$ ($^3/2, ^1/2$) $_1$, ($^1/2, ^1/2$) $_1$, and $3p^54d$ ($^3/2, ^1/2$) $_1$, ($^1/2, ^3/2$) $_1$ transitions in the range of $55 - 69 \text{ \AA}$. The uncertainty of the wavelengths is $\pm 0.01 \text{ \AA}$.

Swartz *et al.* (1976)⁷² identified 13 lines as the $3p^53d - 3p^54f$ transitions in the range of $70 - 81 \text{ \AA}$ with a high-voltage vacuum spark.

Cu xiii (Cl sequence)

Ground state: $1s^22s^22p^63s^23p^5\ ^2P_{3/2}$

The magnetic-dipole transition within the ground configuration, $3s^23p^5\ ^2P_{3/2} - 2P_{1/2}$ at $3500.4 \pm 0.3 \text{ \AA}$ (in air), was identified by Hinnov *et al.* (1982)³⁶ and Denne *et al.* (1983)¹⁷ with tokamak plasmas.

Goldsmith and Fraenkel (1970)³⁴ first identified the $3p^5\ ^2P^o - 3p^4(^3P)3d^2D$ multiplet and the $3p^5\ ^2P_{3/2} - 3p^4(^3P)3d\ ^2P_{3/2}$ transition in the range of

$138 - 145 \text{ \AA}$ with a three-electrode vacuum spark. New measurements of the $3p^5 - 3p^43d$ transitions in the range of $138 - 151 \text{ \AA}$ were provided by Kaufman *et al.* (1989)⁴⁶ in a laser-produced plasma. The uncertainty of the wavelengths is $\pm 0.005 \text{ \AA}$. The authors have communicated to us that the line at 148.318 \AA should be removed in Ref. 46.

Fawcett and Hayes (1975)²⁶ observed two lines due to the transitions $3s^23p^4(^3P)3d\ ^2D_{9/2} - 3s^23p^4(^3P)4f\ ^4G_{11/2}$ at $66.18 \pm 0.05 \text{ \AA}$ and $(^3P)4D_{7/2} - (^3P)4F_{9/2}$ at $65.24 \pm 0.05 \text{ \AA}$ in a laser-produced plasma.

Cu xiv (S sequence)

Ground state: $1s^22s^22p^63s^23p^4\ ^3P_2$

The magnetic-dipole line $3s^23p^4\ ^3P_2 - 3P_1$ at $4183.4 \pm 0.3 \text{ \AA}$ (in air) was identified by Denne *et al.* (1983)¹⁷, and the intercombination $^3P_1 - ^1S_0$ transition at $1190.4 \pm 0.5 \text{ \AA}$ was assigned by Roberts *et al.* (1987)⁶². Both were observed in tokamak discharges.

Fawcett and Hayes (1975)²⁶ first identified the $3s^23p^4\ ^3P_2 - 3s^23p^3(^4S^o)3d\ ^3D_3$ transition at $148.30 \pm 0.03 \text{ \AA}$ in a laser-produced plasma. Recently, Sugar and Kaufman (1986)⁶³ reported measurements of the $3s^23p^4 - 3s^23p^5$ transitions in the range of $250 - 302 \text{ \AA}$ and the $3s^23p^4 - 3s^23p^33d$ transitions in the range of $140 - 189 \text{ \AA}$. From an isoelectronic study of this sequence Kaufman *et al.* (1990)^{46a} revised some of the classifications and gave improved wavelengths with an uncertainty of $\pm 0.007 \text{ \AA}$.

Fawcett and Hayes (1975)²⁶ also identified the transitions $3s^23p^33d\ ^3G_5 - 3s^23p^34f\ ^3H_6$ at $61.70 \pm 0.05 \text{ \AA}$ and $^5D_4 - ^5F_5$ at $61.08 \pm 0.05 \text{ \AA}$.

Cu xv (P sequence)

Ground state: $1s^22s^22p^63s^23p^3\ ^4S_{3/2}^o$

Denne *et al.* (1983)¹⁷ and Denne *et al.* (1984)¹⁸ identified the two magnetic-dipole transitions $3s^23p^3\ ^4S_{3/2}^o - 2D_{3/2}$ and $^4S_{3/2}^o - 2P_{3/2}^o$ in tokamak discharges. Their wavelengths of $2085.3 \pm 0.2 \text{ \AA}$ (in air) and $944.6 \pm 0.2 \text{ \AA}$ are from the latter article.

The first measurement of the $3p^3 - 3p^23d$ transitions was reported by Fawcett and Hayes (1975)²⁶, who identified the $^4S_{3/2}^o - (^3P) ^4P_{5/2}$ and $^2D_{5/2} - (^3P) ^2F_{7/2}$ lines at $161.34 \pm 0.03 \text{ \AA}$ and $154.67 \pm 0.03 \text{ \AA}$. New measurements and classifications by Sugar and Kaufman (1986)⁶³ included seven lines in the range of $154.7 - 172.8 \text{ \AA}$. Wavelengths were measured in a laser-produced plasma with an uncertainty of $\pm 0.01 \text{ \AA}$. All the wavelengths tabulated have been reduced by 0.02 \AA , as suggested by them (1987)⁶⁶. Hutton *et al.* (1987)⁴¹ reported observations in a beam-foil spectrum of the $3s^23p^3 - 3s^23p^4$, $3s^23p^23d$ lines in the range of $154 - 297 \text{ \AA}$. We use their classifications

and the more accurate measurements by Sugar *et al.* (1990)⁶⁸, except for the lines at 157.9 Å and 155.1 Å. It should be noted that the classifications of the lines at 172.821 Å, 169.923 Å and 158.944 Å in Ref. 63 have been revised.

The transitions $3s^23p^23d\ ^2G_{9/2}-3s^23p^24f\ ^2H_{11/2}$ at 57.52 ± 0.01 Å and $4F_{9/2}-4G_{11/2}$ at 57.44 ± 0.01 Å were observed by Fawcett and Hayes (1975)²⁶ in a laser-produced plasma.

Cu xvi (Si sequence)

Ground state: $1s^22s^22p^63s^23p^2\ ^3P_0$

The magnetic-dipole transitions within the ground configuration $3s^23p^2\ ^3P_0-3P_1$ at 5375.8 ± 0.3 Å (in air), $3P_2-1D_2$ at 2539.7 ± 0.3 Å (in air), and $3P_1-1S_0$ at 952.8 ± 0.3 Å were observed by Denne *et al.* (1983)¹⁷ and the $3P_1-1D_2$ at 1871.3 ± 0.2 Å by Roberts *et al.* (1987)⁶² in tokamak discharges. Datla *et al.* (1989)¹⁶ assigned a new wavelength of 2544.7 Å (in air) for the $3P_2-1D_2$ line.

Fawcett and Hayes (1975)²⁶ identified only the $3s^23p^2\ ^3P_2-3s^23p^23d\ ^3D_3$ transition at 168.80 ± 0.03 Å with a laser-produced plasma. Sugar and Kaufman (1986)⁶³ provided the identification for 10 lines of the $3s^23p^2-3s^23p^3$ array and for 11 lines of $3s^23p^2-3s^23p^23d$ in the ranges of 195–298 Å and 164–185 Å, respectively. Sugar *et al.* (1990)⁷⁰ have revised the analysis in a study of this isoelectronic sequence. Wavelengths are given with an uncertainty of ± 0.005 Å in a laser-produced plasma. In a series of beam-foil measurements by Träbert (1986)⁷³, Träbert *et al.* (1987)⁷⁴, and Träbert *et al.* (1988)⁷⁵, the $3s^23p^2\ ^3P_{2,1}-3s^23p^3\ ^5S_2$ intercombination transitions were observed at 410.46 ± 0.4 Å and 387.56 ± 0.4 Å. The latter line is blended.

Observations in the range of 44–56 Å were performed by Khan (1978)⁴⁷ in a laser-produced plasma and by Kastner *et al.* (1978)⁴⁴ in a vacuum spark. The $3s^23p^23d-3s^23p^24f$ and $3s^23p^2-3s^23p^24d$ lines were classified in both references with wavelength differences of about 0.2 Å. For these transitions, wavelengths are taken from Ref. 44. In addition, we have tabulated the wavelengths of the $3s^23p^2-3s^23p^24s$ transitions from Ref. 47 and the $3s^23p^3-3s^23p^24f$ transitions tentatively identified in Ref. 44. It should be noted, however, that the wavelengths of 52.85 Å and 52.18 Å for the $3s^23p^2\ ^3P_{2,1}-3s^23p^24s\ ^3P_2$ transitions in Ref. 47 lead to an incorrect 3P ground term splitting.

Cu xvii (Al sequence)

Ground state: $1s^22s^22p^63s^23p^2\ ^2P_{1/2}$

Hinnov *et al.* (1982)³⁶ and Denne *et al.* (1983)¹⁷ observed the $3s^23p^2\ ^2P_{1/2}-2P_{3/2}$ magnetic-dipole transition in

tokamak plasmas. The wavelength value of 3007.6 ± 0.2 Å (in air) is from Ref. 17.

Träbert *et al.* (1987)⁷⁴ and Träbert *et al.* (1988)⁷⁵ identified the $3s^23p^2\ ^2P^o-3s^23p^2\ ^4P$ intercombination transitions with five lines in the range of 342–411 Å in a beam-foil spectrum. Wavelengths are taken from the latter article. The line at 387.0 ± 0.5 Å is blended.

Fawcett and Hayes (1975)²⁶ classified three lines at 218.76 Å, 183.47 Å, and 174.12 Å observed in a laser-produced plasma as the $3s^23p^2\ ^2P_{3/2}-3s^23p^2\ ^2P_{3/2}$ and $3s^23p^2-3s^23d$ ($2P_{3/2}-2D_{5/2}$, $2P_{1/2}-2D_{3/2}$) transitions. An extended analysis of the $3s^23p^2-3s^23p^2$, $3s^23p^2-3p^3$, and $3s^23p^2-3s^23d$ transitions was carried out by Sugar and Kaufman (1986)⁶³ with a laser-produced plasma and subsequently by Buchet-Poulizac and Buchet (1988)¹⁵ in a beam-foil source. Sugar *et al.* (1988)⁶⁷ reobserved these transitions of Cu^{16+} to Mo^{29+} in a tokamak discharge and made revisions and additions to the previous work. We adopted their wavelengths smoothed with respect to multiconfiguration Dirac-Fock calculations along isoelectronic sequences. The wavelength of $3s^23p^2\ ^4P_{1/2}-3p^3\ ^4S_{3/2}$ transition was given as 223.170 ± 0.01 Å in Ref. 67 and as 223.181 ± 0.01 Å by Litzén and Redfors (1988)⁵⁴. Buchet-Poulizac and Buchet identified the $3s^23p^2-3s^23p^23d$ transitions with five lines in the range of 176–201 Å. Their wavelengths have an uncertainty of ± 0.05 Å except the blended lines at 188.19 ± 0.2 Å and 180.70 ± 0.2 Å.

Khan (1978)⁴⁷ observed 11 lines in the wavelength range of 42–53 Å with a laser-produced plasma, and classified the $3s^23d-3s^24f$, $3s^23p^2-3s^23p^24s$, $3s^23p^23d-3s^23p^24f$, $3s^23p^2-3s^24s$, $3s^24d$ transitions. The wavelength uncertainties are ± 0.02 Å.

Cu xviii (Mg sequence)

Ground state: $1s^22s^22p^63s^2\ ^1S_0$

The magnetic-dipole transition $3s^23p^2\ ^3P_1-3P_2$ at 3941.6 ± 0.3 Å (in air) was observed in a tokamak plasma by Denne *et al.* (1983)¹⁷.

The singlet and triplet transitions $3s^23p^2-3s^23d$ in addition to the $3s^2\ ^1S_0-3s^23p^2\ ^1P_1$ resonance transition were classified by Fawcett and Hayes (1975)²⁶. Finkenthal *et al.* (1982)³³ identified the $3s^2\ ^1S_0-3s^23p^2\ ^3P_1$ intercombination transition with a line at 345.6 ± 0.5 Å in a tokamak discharge. Sugar and Kaufman (1986)⁶³ classified a large number of lines due to the arrays, $3s^23p^2-3p^3$, $3s^2-3s^23p$, and $3s^23p-3s^23d$, in the range of 185–270 Å. In a subsequent paper of Sugar and Kaufman (1986)⁶⁴ the arrays $3p^2-3p^23d$ and $3s^23d-3s^23d$ were added. Sugar and Kaufman (1987)⁶⁶ made some additions and revisions and suggested that the wavelengths given in Refs. 63 and 64 should be reduced by 0.02 Å. In this compilation, we give their results summarized in a paper by Sugar *et al.* (1989)⁶⁹ on the Mg I isoelectronic sequence. The uncertainty of the wavelengths is ± 0.005 Å.

Additional identifications were made by Litzén and Redfors (1987)⁵³, from which five new lines, including the spin-forbidden lines: $3s\ 3p\ ^1P_1 - 3p^2\ ^3P_2$ at 346.44 Å, $3s\ 3p\ ^3P_2 - 3p^2\ ^1D_2$ at 274.01 Å, and $3p^2\ ^1D_2 - 3p\ 3d\ ^3F_2$ at 228.16 Å, are taken. These wavelengths have an uncertainty of ± 0.02 Å. In an analysis of a beam-foil spectrum by Buchet-Poulizac and Buchet (1988)¹⁵, $n=3-3$ lines were reported, including two new lines at 272.30 ± 0.2 Å and 198.56 ± 0.05 Å corresponding to the $3s\ 3d\ ^3D_2 - 3p\ 3d\ ^3D_2$ and $3s\ 3p\ ^3P_2 - 3s\ 3d\ ^3D_1$ transitions, respectively. The latter one is 0.1 Å longer than the wavelength recalculated from the level values. Redfors (1988)⁶¹ identified 2 lines of the array $3p\ 3d - 3d^2$ at 219.410 and 240.028 Å. These observations were extended to seven lines by Sugar *et al.* (1989)⁶⁹.

Feldman *et al.* (1971)³² measured wavelengths in the range of 30–50 Å and identified the arrays $3s^2 - 3s\ 4p$, $3s\ 3p - 3s\ 4s$, $3s\ 3p - 3s\ n d$ ($n = 4, 5$), and $3s\ 3d - 3s\ n f$ ($n = 4, 5$). The measurement was performed in a low-inductance vacuum spark and the wavelengths have an uncertainty of ± 0.01 Å. The identifications were extended by Kastner *et al.* (1978)⁴⁴ to include the $3p\ 3d - 3p\ 4f$ transitions in the range of 48.8–51.5 Å with a similar light source. It should be noted that the $3p\ 3d\ ^3F_3 - 3p\ 4f\ ^3F_4$ line at 48.783 Å has been omitted because it is inconsistent with the 3F_4 level obtained from the line at 50.067 Å. In addition, the line at 50.306 Å given as questionable by Kastner *et al.* has been excluded. The wavelength of 49.885 Å for the $^3F_2 - ^3G_3$ transition identified as a blended line is apparently a misprint and should be 48.885 Å. Khan (1978)⁴⁷ proposed four new classifications of these arrays, but they do not fit with the level scheme of Kastner *et al.*

Swartz *et al.* (1971)⁷¹ identified the $2p^6\ 3s^2\ ^1S_0 - 2p^5\ 3s^2\ 3d\ ^1P_1$ inner-shell transition at 11.774 Å. The observation was made with a low-inductance vacuum spark with an uncertainty of ± 0.01 Å.

Cu xix (Na sequence)

Ground state: $1s^2\ 2s^2\ 2p^6\ ^1S_0$

The $n=3-3$ transitions were first observed by Feldman *et al.* (1971)³² in a low-inductance vacuum spark. They classified the $3s\ ^2S_{1/2} - 3p\ ^2P_{3/2}$ resonance transition at 273.34 Å and the $3p\ ^2P^o - 3d\ ^2D$ transition array in the range of 207–224 Å. Improved and extended measurements were made by Kononov *et al.* (1979)⁵¹ and Sugar and Kaufman (1986)⁶³ with laser-produced plasmas. From an isoelectronic comparison of the measured wavelengths of the $3s - 3p$ and the $3d - 4f$ doublets with Dirac-Fock calculations, Reader *et al.* (1987)⁶⁰ derived least squares adjusted wavelength values for these transitions with an uncertainty of ± 0.007 Å, which are adopted in the present compilation.

Jupén *et al.* (1988)⁴³ ascribed the line at 210.70 ± 0.05 Å measured by Buchet-Poulizac and

Buchet (1988)¹⁵ in a beam-foil spectrum to the core-excited $2p^5\ 3s\ 3p\ ^4D_{7/2} - 2p^5\ 3s\ 3d\ ^4F_{9/2}$ transition.

Kononov *et al.* (1977)⁵⁰ identified the $4f\ ^2F^o - 5g\ ^2G$ doublet at 111 Å and Kononov *et al.* (1979)⁵¹ reported the $4d\ ^2D - 5f\ ^2F^o$ doublet and the $4p\ ^2P_{3/2} - 5d\ ^2D_{5/2}$ and $4s\ ^2S_{1/2} - 5p\ ^2P_{3/2}$ transitions in the range of 85–103 Å with an uncertainty of ± 0.005 Å. The $4f\ ^2F^o - 5g\ ^2G$ and $4d\ ^2D - 5f\ ^2F^o$ doublets were remeasured by Sugar and Kaufman (1986)⁶³ in a laser-produced plasma with an uncertainty of ± 0.01 Å. We give the wavelengths of Kononov *et al.*

Feldman *et al.* also reported measurements for the $3s - np$ ($n = 4-6$), $3p - 4s$, nd ($n = 4-8$), $3d - nf$ ($n = 5-8$) transitions in the range of 22–46 Å. Their wavelengths were measured in a low-inductance vacuum spark with an uncertainty of ± 0.01 Å. Fawcett and Hayes (1975)²⁶ and Khan (1978)⁴⁷ identified the $3d\ ^2D - 4p\ ^2P^o$ doublet at ~ 53 Å. Improved remeasurements of the wavelengths were reported by Kononov *et al.* (1979)⁵¹ for 21 lines due to the $3s - 4p$, $5p$, $3p - 4s$, nd ($n = 4-6$), $3d - 4p$, and $3d - nf$ ($n = 4-7$) transitions. These results are adopted except for the blended doublet $3d\ ^2D - 7f\ ^2F^o$ at 26.44 Å. For $3s - 6p$, $3p - 7d$, $8d$, and $3d - 7f$, $8f$ the wavelengths in Ref. 32 are taken. The identification of the $3d\ ^2D - 8f\ ^2F^o$ doublet at 25.175 Å and 25.142 Å in Ref. 32 is tentative.

Feldman and Cohen (1967)³¹ identified the resonance line $2p^6\ 3s\ ^2S_{1/2} - 2p^5\ 3s^2\ ^2P_{3/2}$ at 13.11 ± 0.01 Å using a low-inductance vacuum spark.

Cu xx (Ne sequence)

Ground state: $1s^2\ 2s^2\ 2p^6\ ^1S_0$

Twelve lines of the $2s^2\ 2p^5\ 3s - 2s^2\ 2p^5\ 3p$ array in the range of 163–341 Å and 12 lines of the $2s^2\ 2p^5\ 3p - 2s^2\ 2p^5\ 3d$ array in the range of 212–272 Å were provided by Buchet *et al.* (1987)¹⁴ in a beam-foil study. The uncertainty of the wavelengths is ± 0.05 Å. For the weak line at 163.6 Å it is ± 0.1 Å.

Feldman *et al.* (1967)²⁹ classified seven resonance transitions from the $2s^2\ 2p^5\ 3s$, $2s^2\ 2p^5\ 3d$, and $2s\ 2p^6\ 3p$ $J=1$ levels to the ground $2s^2\ 2p^6\ ^1S_0$ level in the range of 10.6–12.8 Å using a low-inductance vacuum spark. Further classifications were given by Feldman and Cohen (1967)³⁰ for the $2p^6 - 2p^5\ 4d$ transitions and by Swartz *et al.* (1971)⁷¹ for the $2p^6 - 2p^5\ 4s$, $2p^5\ 5d$ and $2p^5\ 6d$ transitions. Boiko *et al.* (1978)⁸ measured these transitions again in their extensive investigation. We give the wavelengths for these transitions from the comprehensive observations of Gordon *et al.* (1980)³⁵ with a laser-produced plasma, including three new lines: $2s^2\ 2p^6\ ^1S_0 - 2s^2\ 2p^5\ 4d\ (^3/2, ^1/2)$ at 9.274 Å, $2s^2\ 2p^6\ ^1S_0 - 2s\ 2p^6\ 4p\ (^1/2, ^3/2)$ at 8.400 Å, and $2s^2\ 2p^6\ ^1S_0 - 2s\ 2p^6\ 4p\ (^1/2, ^3/2)$ at 8.385 Å. The uncertainty of the wavelengths is ± 0.005 Å. The $2s^2\ 2p^6 - 2s\ 2p^6\ 4p$ transitions are also identified by Hutcheon *et al.* (1980)³⁹.

Cu xxI (F sequence)

Ground state: $1s^2 2s^2 2p^5 \ ^2P_{3/2}^o$

The magnetic-dipole transition within the ground $2s^2 2p^5$ configuration, $^2P_{3/2}^o - ^2P_{1/2}^o$ at $592.3 \pm 0.3 \text{ \AA}$, was observed in a tokamak discharge by Hinnov *et al.* (1982)³⁶.

Buchet-Poulizac and Buchet (1988)¹⁵ identified eight lines of the $2s^2 2p^4 3s - 2s^2 2p^4 3p$ array in the range of $279 - 346 \text{ \AA}$ and seven lines of the $2s^2 2p^4 3p - 2s^2 2p^4 3d$ array in the range of $245 - 264 \text{ \AA}$ in a beam-foil spectrum. The uncertainty of the wavelengths is $\pm 0.05 \text{ \AA}$ except for blended lines at 279.40 \AA and 257.50 \AA , for which it is $\pm 0.2 \text{ \AA}$.

Kononov *et al.* (1977)⁵⁰ first identified the $2s^2 2p^5 \ ^2P^o - 2s^2 2p^6 \ ^2S$ transitions at $90.353 \pm 0.01 \text{ \AA}$ and $78.388 \pm 0.01 \text{ \AA}$ in a laser-produced plasma. These lines were remeasured in laser-produced plasmas by Behring *et al.* (1985)⁶ and Sugar and Kaufman (1986)⁶³ with uncertainties of $\pm 0.02 \text{ \AA}$ and $\pm 0.01 \text{ \AA}$, respectively. Tabulated wavelengths are taken from Ref. 63. The values have been reduced by 0.02 \AA , as suggested by Sugar and Kaufman (1987)⁶⁶.

The $2p^5 - 2p^4 3s$ and $2p^4 3d$ transition arrays in the ranges of $11.7 - 12.2 \text{ \AA}$ and $10.8 - 11.4 \text{ \AA}$ were identified by Boiko *et al.* (1978)⁹, (1979)¹¹, and Boiko *et al.* (1979)¹⁰, and remeasured by Hutcheon *et al.* (1980)³⁹ and Gordon *et al.* (1980)³⁵ in laser-produced plasmas. Wavelengths adopted in this compilation are mainly from Ref. 35. Ref. 39 includes additional classifications for two lines at 12.029 \AA and 11.352 \AA . Wavelengths in Refs. 35 and 39 have uncertainties of $\pm 0.005 \text{ \AA}$ and $\pm 0.002 \text{ \AA}$, respectively.

Gordon *et al.* (1980)³⁵ also identified the $2s^2 2p^5 - 2s^2 2p^5 3p$ transitions in the range of $9.9 - 10.4 \text{ \AA}$.

The $2p^5 - 2p^4 4s$ and $2p^4 4d$ lines were observed by Gordon *et al.* (1980)³⁵ and Hutcheon *et al.* (1980)⁴⁰ in the ranges of $8.6 - 9 \text{ \AA}$ and $8.5 - 8.8 \text{ \AA}$. They are mostly blends and their classifications are given with question marks.

Cu xxII (O sequence)

Ground state: $1s^2 2s^2 2p^4 \ ^3P_2$

Two magnetic-dipole transitions within the ground $2s^2 2p^4$ configuration, $^3P_2 - ^3P_1$ at $657.7 \pm 0.3 \text{ \AA}$ and $^3P_2 - ^1D_2$ at $420.0 \pm 0.3 \text{ \AA}$, were observed by Hinnov *et al.* (1982)³⁶ in a tokamak discharge.

The $2s^2 2p^4 - 2s^2 2p^5$ transitions were identified and measured by Kononov *et al.* (1977)⁵⁰ and Behring *et al.* (1985)⁶, and the $2s^2 2p^5 \ ^1P_1 - 2p^6 \ ^1S_0$ by Peregudov *et al.* (1978)⁵⁸. These transitions were remeasured by Ekberg *et al.* (1987)²³ in a laser-produced plasma. They identified two intercombination transitions: $2s^2 2p^4 \ ^1D_2 - 2s^2 2p^5 \ ^3P_2$ at $114.974 \pm 0.015 \text{ \AA}$ and $2s^2 2p^5 \ ^3P_1 - 2p^6 \ ^1S_0$ at $74.383 \pm 0.015 \text{ \AA}$, in addition to the earlier identifications. For the $2s^2 2p^4 \ ^3P_2 - 2s^2 2p^5 \ ^1P_1$ intercombination

transition the wavelength of $65.43 \pm 0.01 \text{ \AA}$ is adopted from Kononov *et al.*, because it gives an consistent value of the 1P_1 with the lines at 93.302 \AA and 77.512 \AA .

The $2p^4 - 2p^3 3s$, $2p^3 3d$ and $2p^3 4d$ transitions were classified by Gordon *et al.* (1980)³⁵ in the ranges of $11 - 12 \text{ \AA}$, $10.3 - 10.6 \text{ \AA}$, and $8.0 - 8.4 \text{ \AA}$. The uncertainty of the wavelengths is $\pm 0.005 \text{ \AA}$. Many of the lines are multiply classified. Three lines at 11.573 \AA , 10.611 \AA , and 8.125 \AA have been omitted because they lead to an incorrect splitting between the ground term 3P levels. The levels derived from these data are given with question marks.

Cu xxIII (N sequence)

Ground state: $1s^2 2s^2 2p^3 \ ^4S_{3/2}^o$

Hinnov *et al.* (1982)³⁶ observed two magnetic-dipole transitions between the ground $2s^2 2p^3$ levels, $^4S_{3/2}^o - ^2D_{3/2}^o$ at $585.0 \pm 0.3 \text{ \AA}$ and $^4S_{3/2}^o - ^2D_{5/2}^o$ at $434.8 \pm 0.3 \text{ \AA}$, in a tokamak plasma.

The $2s^2 2p^3 - 2s^2 2p^4$ transitions were identified by Kononov *et al.* (1977)⁵⁰ and also by Behring *et al.* (1985)⁶ with laser-produced plasmas. For the $2s^2 2p^4 - 2p^5$ transitions, only the $^2D_{5/2}^o - ^2P_{3/2}^o$ at 96.762 \AA was reported in Ref. 6. With a more complete laser excitation Ekberg *et al.* (1987)²³ identified two lines at 80.057 \AA and 70.073 \AA as the $2s^2 2p^3 \ ^4S_{3/2}^o - 2s^2 2p^4 \ ^2D_{3/2}, ^2S_{1/2}$ spin-forbidden transitions in addition to 12 lines of the $2s^2 2p^3 - 2s^2 2p^4$ array and four lines of the $2s^2 2p^4 - 2p^5$ array. The wavelengths adopted from Ref. 23 have an uncertainty of $\pm 0.015 \text{ \AA}$.

Cu xxIV (C sequence)

Ground state: $1s^2 2s^2 2p^2 \ ^3P_0$

Hinnov *et al.* (1982)³⁶ identified the magnetic-dipole transitions between the ground $2s^2 2p^2$ levels, $^3P_1 - ^3P_2$ at 1776.0 \AA , $^3P_0 - ^3P_1$ at 756.9 \AA , and $^3P_2 - ^1D_2$ at 540.0 \AA and 414.1 \AA , in a tokamak plasma. The wavelengths have an uncertainty of $\pm 0.3 \text{ \AA}$.

Ekberg *et al.* (1987)²³ reported lines of the $2s^2 2p^2 - 2s^2 2p^3$ and $2s^2 2p^3 - 2p^4$ arrays, including the $2s^2 2p^2 \ ^3P_2 - 2s^2 2p^3 \ ^1D_2^o$ spin-forbidden transition at 82.195 \AA . The uncertainty of the wavelengths is $\pm 0.015 \text{ \AA}$.

Cu xxV (B sequence)

Ground state: $1s^2 2s^2 2p \ ^2P_{1/2}^o$

The magnetic-dipole transition $2s^2 2p \ ^2P_{1/2}^o - ^3P_{3/2}^o$ at $522.8 \pm 0.3 \text{ \AA}$ was observed in a tokamak plasma by Hinnov *et al.* (1982)³⁶.

Ekberg *et al.* (1987)²³ identified the $2s^2p^2\ ^4P - 2p^3\ ^4S^\circ$ array at 117.507 Å, 107.659 Å, and 97.272 Å in a laser-produced plasma. The wavelength uncertainty is ± 0.015 Å. We use the estimated value for the $2p^3\ ^4S^\circ$ level given by Edlén (1983)²² and denote the error by “+X”.

Cu xxvi (Be sequence)

Ground state: $1s^22s^2\ ^1S_0$

In a tokamak plasma, Hinnov *et al.* (1982)³⁶ identified the $2s2p\ ^3P_1 - ^3P_2$ magnetic-dipole transition at 648.0 ± 0.3 Å and also two lines at 227.8 ± 0.3 Å and 111.2 ± 0.3 Å as transitions from the $2s2p\ ^3P_0$ levels to the ground level, respectively. The more accurate wavelengths of 227.808 ± 0.010 Å and 111.186 ± 0.010 Å measured by Hinnov and reported by Denne *et al.* (1989) are adopted here.

New identifications in a beam-foil spectrum were made by Buchet *et al.* (1985)¹³ of the $2s2p - 2p^2$ transitions in the range of 113–173 Å, including the spin-forbidden transition $^3P_2 - ^1D_2$ at 113.14 ± 0.10 Å.

Brown *et al.* (1987)¹² classified the $2p3d - 2p4f$ and $2s3d - 2s4f$ transitions at about 27 Å, in addition to the $n=2-3$ transitions in the range of 8.5–9.8 Å, which were previously observed by Boiko *et al.* (1977)⁷ and Boiko *et al.* (1978)⁸. The wavelengths are taken from Ref. 12, except for 9.520 Å and 9.233 Å from Ref. 7. The uncertainty of the wavelengths is ± 0.010 Å for lines longer than 12 Å and ± 0.005 Å for shorter wavelengths. Many of the lines have multiple classifications.

Cu xxvii (Li sequence)

Ground state: $1s^22s\ ^2S_{1/2}$

Two resonance transitions $1s^22s\ ^2S_{1/2} - 1s^22p\ ^2P_{1/2,3/2}$ at 224.8 ± 0.3 Å and 153.6 ± 0.3 Å were observed in a tokamak plasma by Hinnov *et al.* (1982)³⁶. More accurate wavelengths were obtained by Knize *et al.* (1987)⁴⁸ with a similar source. They were then reobserved by Hinnov *et al.* [1989].⁷⁹ We give their wavelength values.

Brown *et al.* (1987)¹² using a laser-produced plasma classified the $3d\ ^2D_{5/2} - 4p\ ^2P_{3/2}$, $3d\ ^2D - 4f\ ^2F^\circ$, $3p\ ^2P^\circ - 4d\ ^2D$, and $3s\ ^2S_{1/2} - 4p\ ^2P_{3/2}$ transitions in the wavelength range of 24.2–25.9 Å with an uncertainty of ± 0.010 Å and the $2p\ ^2P^\circ - 3s\ ^2S$, $2p\ ^2P^\circ - 3d\ ^2D$, and $2s\ ^2S - 3p\ ^2P^\circ$ arrays in the range of 8.4–9.0 Å with an uncertainty of ± 0.005 Å.

Aglitskii and Panin (1985)¹ identified the inner-shell transitions $1s^22p\ ^2P_{3/2} - 1s2pnp\ ^2D_{5/2}$ ($n=3,4$) at 1.272 ± 0.002 Å and 1.213 ± 0.002 Å in a low-inductance vacuum spark.

Cu xxviii (He sequence)

Ground state: $1s^2\ ^1S_0$

Calculated energy levels of the configurations $1s2s$ and $1s2p$ and the ionization energy have been taken from Drake (1988)¹⁹. Level values for $n=3$ are from Drake's (1985)²⁰ privately circulated calculation. They have been reduced by 43 cm^{-1} as in Ref. 5 of the Introduction. For the levels with $n=4-5$, calculations of Vainshtein and Safronova (1985)⁷⁷ have been tabulated after adjusting them by about 1600 cm^{-1} to the ground state binding energy obtained by Drake. Wavelengths are calculated from the energy levels by the Ritz combination principle.

The $1s^2\ ^1S_0 - 1s2p\ ^1P_1$ resonance line was observed at 1.47758 ± 0.00007 Å by Aglitsky *et al.* (1988)³. The earlier measurements are less accurate. The $1s^2\ ^1S_0 - 1snp\ ^3P_1$ ($n=3$ to 5) transitions were reported by Aglitskii and Panin (1985)¹, but the singlets and triplets were not resolved. Turechek and Kunze (1975)⁷⁶ identified the forbidden transitions $1s^2\ ^1S_0 - 1s2p\ ^3P_{2,1}$ at 1.4805 ± 0.001 Å and 1.4840 ± 0.0005 Å and also the transitions $1s2p\ ^1P_1 - 2p^2\ ^1S_0$, 1D_2 at 1.430 Å and 1.435 Å.

Cu xxix (H sequence)

Ground state: $1s\ ^2S_{1/2}$

We have tabulated the wavelengths calculated from the theoretical level energies by Johnson and Soff (1985)⁴² for the $n=2$ shell, which are in close agreement with those by Mohr (1983)⁵⁵. All levels with $n=3-5$ are available from the work of Erickson (1977)²⁴. For the ns and np ($n=3-5$) levels, Erickson's values for the binding energies were subtracted from the ground state binding energy given by Johnson and Soff to obtain the predicted wavelengths.

3. Explanation of Tables of Spectroscopic Data

Cu x, Cu xxix, etc.

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

H sequence, C sequence, etc.

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

IP			Int	Approximate intensity of a spectral line, generally visually estimated from the blackness (or density) of the line on photographic plates.
$\lambda(\text{\AA})$	Principal ionization energy of the tabulated ions in cm^{-1} (eV).		f	
	Wavelength of listed spectral lines in Angstrom units (10^{-8} cm).			This column indicates magnetic dipole transitions denoted by M1.
C,T	Superscripts to the right of a wavelength value have the following meanings:	A		
	^c wavelength calculated from energy level data using the Ritz combination principle.		A	Radiative transition probability in s^{-1} . The notation $4.19 + 2$ denotes 4.19×10^2 .
	^t wavelength classification is tentative.	Acc		Accuracy estimate for the transition probability as follows: A 3%, B 10%, C 25%, D 50%, E > 50%.
Classification	Standard spectroscopic designation for lower (first) and upper levels generating the spectral lines; electronic configurations followed by the term in LS -, jj - or jl -coupling notation. The "o" on the term indicates odd parity. A term enclosed in parentheses refers to an intermediate state. Where only the total angular momentum J is given in successive listings, the preceding configuration and term labels apply.		References	Reference sources for the data. The numbers are keyed to the bibliographic listing following the tables. When several references are listed, they are distinguished by superscripts on the numbers as follows:
Energy Levels	Level values (in cm^{-1}) for lower (first) and upper (second) level of the transition. A symbol ? after the level value indicates level was derived from a tentatively classified line.			<ul style="list-style-type: none"> ◦ reference from which the adopted wavelength value is taken Δ reference from which the estimated intensity is taken. * reference containing the adopted oscillator strength and/or transition probability

4. Spectroscopic Data for Cu x-Cu xxix

Cu x (Ca sequence)		Ionization Energy = 1871000 cm^{-1} (232 eV)				
$\lambda(\text{\AA})$	Classification	Energy Levels (cm^{-1})		Int.	References	
154.591	$3p^6 3d^2 \ ^3F_2$	$3p^5(^2P^o) 3d^3(^2H) \ ^3G_3$	0	646870	4	27
154.363	3	4	2486	650310	3	27
153.767	4	5	5487	655820	6	27
153.711	$3p^6 3d^2 \ ^1G_4$	$3p^5(^2P^o) 3d^3(^2G) \ ^1H_5$		4	27	
140.071	$3p^6 3d^2 \ ^3F_2$	$3p^5(^2P^o) 3d^3(^4F) \ ^3F_2$	0	713920	7	27
139.868	3	3	2486	717450	6	27
139.771	4	4	5487	720940	7	27
137.036	$3p^6 3d^2 \ ^1G_4$	$3p^5(^2P^o) 3d^3(^2H) \ ^1G_4$		6	27	
133.034	$3p^6 3d^2 \ ^3F_4$	$3p^5(^2P^o) 3d^3(^4F) \ ^3D_3$	5487	757170	7	27
132.478	3	2	2486	757390	5	27
132.240	2	1	0	756200	3	27
88.032	$3p^6 3d^2 \ ^3P_2$	$3p^6 3d^4f \ ^3D_3$	30600+X	1166550+X	12	25
88.020	1	2			6	25
87.983	0	1			4	25
87.932	$3p^6 3d^2 \ ^1D_2$	$3p^6 3d^4f \ ^1D_2$	23900+X	1161140+X	10	5,25*
87.703	$3p^6 3d^2 \ ^1D_2$	$3p^6 3d^4f \ ^1F_3$	23900+X	1164110	10	5,25*

SPECTRAL DATA AND GROTRIAN DIAGRAMS FOR HIGHLY IONIZED COPPER

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Cu x (Ca sequence) Ionization Energy = 1871000 cm⁻¹ (232 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References		
87.516	$3p^6 3d^2$	1D_2	$3p^6 3d 4f$	3D_3	23900 + X	1166550 + X	5	25
87.135	$3p^6 3d^2$	3F_4	$3p^6 3d 4f$	3F_3	5487	1153140	0	25
87.018		4		4	5487	1154670	9	5,25°
86.964		3		2	2486	1152390	0	5,25°
86.907		3		3	2486	1153140	9	5,25°
86.792		3		4	2486	1154670	1	5,25°
86.776		2		2	0	1152390	9	5,25°
86.720		2		3	0	1153140	1	5,25°
86.422	$3p^6 3d^2$	3F_4	$3p^6 3d 4f$	3G_4	5487	1162520	1	5,25°
86.336		4		5	5487	1163750	14	5,25°
86.204		3		4	2486	1162520	10	5,25°
86.160		2		3	0	1160630	10	5,25°

Cu xi (K sequence) Ionization Energy = 2140000 cm⁻¹ (265.3 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References		
184.320	$3p^6 3d$	$^2D_{5/2}$	$3p^5 (^2P^o) 3d^2 (^1G)$	$^2F_{7/2}$	4060	546595	40	59
180.001	$3p^6 3d$	$^2D_{5/2}$	$3p^5 (^2P^o) 3d^2 (^1D)$	$^2F_{7/2}$	4060	559612	100	59
171.875		3/2		5/2	0	581818	50	59
150.369	$3p^6 3d$	$^2D_{5/2}$	$3p^5 (^2P^o) 3d^2 (^3F)$	$^2F_{5/2}$	4060	669100	30	34,59°
149.455		3/2		5/2	0	669100	320	34,45,59°
147.742		5/2		7/2	4060	680940	350	34,45,59°
136.386	$3p^6 3d$	$^2D_{3/2}$	$3p^5 (^2P^o) 3d^2 (^3P)$	$^2P_{1/2}^o$	0	733240	250	34,45,59°
136.034		5/2		3/2	4060	739200	350	34,45,59°
135.286		3/2		3/2	0	739200	100	34,45,59°
135.734	$3p^6 3d$	$^2D_{5/2}$	$3p^5 (^2P^o) 3d^2 (^3F)$	$^2D_{5/2}^o$	4060	740770	500	34,45,59°
135.655		5/2		3/2	4060	741240	90	34,59°
134.989		3/2		5/2	0	740770	120	34,59°
134.914		3/2		3/2	0	741240	400	34,45,59°
108.878	$3p^6 3d$	$^2D_{3/2}$	$3p^6 4p$	$^2P_{1/2}^o$	0	918459	70	59
108.479		5/2		3/2	4060	925897	100	59
108.002		3/2		3/2	0	925897	5	59
78.786	$3p^6 3d$	$^2D_{5/2}$	$3p^6 4f$	$^2F_{7/2}$	4060	1273300	13	4,25°
78.542		3/2		5/2	0	1273200	12	4,25°
76.256	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d (^3P^o) 4s$	$^2P_{3/2}^o$	4060	1315420	2	38
76.022		3/2		3/2	0	1315420	0	38
75.866	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d (^3F^o) 4s$	$^4F_{7/2}$	4060	1322170	1	38
75.472		3/2		5/2	0	1324990	1	38
75.325	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d (^3F^o) 4s$	$^2F_{7/2}$	4060	1331640	5	38
74.856		5/2		5/2	4060	1339930	0	38
74.633		3/2		5/2	0	1339930	4	38
73.982	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d (^3D^o) 4s$	$^4D_{7/2}^o$	4060	1355740	1	38
73.735		5/2		5/2	4060	1360260	2	38
73.516		3/2		5/2	0	1360260	0	38
72.956	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d (^1F^o) 4s$	$^2F_{7/2}$	4060	1374750	2	38

Cu xi (K sequence) Ionization Energy = 2140000 cm⁻¹ (265.3 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References		
72.792	$3p^6 3d$	$^2D_{5/2}$	$3p^5 3d(^3D^o) 4s$	$^2D_{3/2}^o$	4060	1377810	2	38
72.580		$^5/2$		$^5/2$	4060	1381830	4	38
72.580		$^3/2$		$^3/2$	0	1377810	4	38
72.369		$^3/2$		$^5/2$	0	1381830	1	38
63.192	$3p^6 3d$	$^2D_{5/2}$	$3p^6 5f$	$^2F_{7/2}^o$	4060	1586400	4	25
63.038		$^3/2$		$^5/2$	0	1586300	4	25
57.047	$3p^6 3d$	$^2D_{5/2}$	$3p^6 6f$	$^2F_{7/2}^o$	4060	1757000	0	25
56.915		$^3/2$		$^5/2$	0	1757000	0	25

Cu xii (Ar sequence) Ionization Energy = 2975000 cm⁻¹ (368.8 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References		
174.739	$3p^6$	1S_0	$3p^5 3d$	$^3D_1^o$	0	572282	5	65
139.175	$3p^6$	1S_0	$3p^5 3d$	$^1P_1^o$	0	718520	300	25,34,65°
80.666	$3p^5 3d$	$^1P_1^o$	$3p^5 (^2P_{1/2}) 4f$	$^{1/2} [{}^5/2]_2$	718520	1958200?	2	72
73.734	$3p^5 3d$	$^1F_3^o$	$3p^5 (^2P_{3/2}) 4f$	$^{3/2} [{}^7/2]_4$			3	72
72.821	$3p^5 3d$	$^3D_3^o$	$3p^5 (^2P_{3/2}) 4f$	$^{3/2} [{}^7/2]_4$			7	72
72.572	$3p^5 3d$	$^1F_3^o$	$3p^5 (^2P_{1/2}) 4f$	$^{1/2} [{}^7/2]_4$			10	72
72.373	$3p^5 3d$	$^3D_2^o$	$3p^5 (^2P_{1/2}) 4f$	$^{1/2} [{}^7/2]_3$			6	72
71.948	$3p^5 3d$	$^1D_2^o$	$3p^5 (^2P_{1/2}) 4f$	$^{1/2} [{}^5/2]_3$			6	72
71.700	$3p^5 3d$	$^3F_2^o$	$3p^5 (^2P_{3/2}) 4f$	$^{3/2} [{}^7/2]_3$			4	72
71.609	$3p^6 3d$	$^3F_3^o$	$3p^6 (^2P_{3/2}) 4f$	$^{3/2} [{}^9/2]_4$			7	72
71.530		4		5			8	72
71.033	$3p^5 3d$	$^3P_2^o$	$3p^5 (^2P_{3/2}) 4f$	$^{3/2} [{}^3/2]_2$			4	72
70.656		1		1			5	72
70.551		1		2			6	72
70.804	$3p^5 3d$	$^3P_2^o$	$3p^5 (^2P_{3/2}) 4f$	$^{3/2} [{}^5/2]_3$			4	72
69.128	$3p^6$	1S_0	$3p^5 4s$	$({}^3/2, {}^1/2)_1^o$	0	1446600	3	25
67.882	$3p^6$	1S_0	$3p^5 4s$	$({}^1/2, {}^1/2)_1^o$	0	1473100	3	25
56.333	$3p^6$	1S_0	$3p^5 4d$	$({}^3/2, {}^5/2)_1^o$	0	1775200	0	25
55.466	$3p^6$	1S_0	$3p^5 4d$	$({}^1/2, {}^3/2)_1^o$	0	1802900	0	25

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 Cu XIII (Cl sequence) Ionization Energy = 3234000 cm⁻¹ (401 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References		
3500.4	$3s^2 3p^5$	$^2P_{3/2}$	$3s^2 3p^5$	$^2P_{1/2}^o$	0	28560		M1	4.19+2	C	17°,36,78*
150.638	$3s^2 3p^5$	$^2P_{3/2}$	$3s^2 3p^4$	$(^1D) 3d$	$^2S_{1/2}$	0	663840	10			46
144.720	$3s^2 3p^5$	$^2P_{3/2}$	$3s^2 3p^4$	$(^3P) 3d$	$^2P_{3/2}$	0	690990	20			34,46°
143.756	$3s^2 3p^5$	$^2P_{1/2}$	$3s^2 3p^4$	$(^3P) 3d$	$^2D_{3/2}$	28560	724240	200bl			34,46°
142.963					$^5/2$	0	699480	200			34,46°
138.065					$^3/2$	0	724240	20			34,46°
66.18	$3s^2 3p^4$	$(^3P) 3d$	$^4F_{9/2}$	$3s^2 3p^4$	$(^3P) 4f$	$^4G_{11/2}^o$					26
65.24	$3s^2 3p^4$	$(^3P) 3d$	$^4D_{7/2}$	$3s^2 3p^4$	$(^3P) 4f$	$^4F_{9/2}$					26

 Cu XIV (S sequence) Ionization Energy = 3508000 cm⁻¹ (435 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References		
4183.4	$3s^2 3p^4$	3P_2	$3s^2 3p^4$	3P_1	0	23897		M1	2.83+2	C	17,62°,78*
1190.4	$3s^2 3p^4$	3P_1	$3s^2 3p^4$	1S_0	23897	107902		M1	4.01+3	C	46a,62,78*
302.406	$3s^2 3p^4$	3P_1	$3s^2 3p^5$	3P_2	23897	354570	1				46a°,63
282.038				2	0	354570	1				46a°,63
250.429	$3s^2 3p^4$	1D_2	$3s^2 3p^5$	$^1P_1^o$	52540	451850	1				46a°,63
159.997	$3s^2 3p^4$	3P_1	$3s^2 3p^3$	$(^2D) 3d$	$^3P_2^o$	23897	648960	10			46a°
154.080				2	0	648960	50				46a°,63
152.466	$3s^2 3p^4$	1S_0	$3s^2 3p^3$	$(^2P^o) 3d$	$^1P_1^o$	107902	763830	20			46a°,63
151.938	$3s^2 3p^4$	1D_2	$3s^2 3p^3$	$(^2D^o) 3d$	$^1D_2^o$	52540	710700	5			46a°,63
150.836	$3s^2 3p^4$	3P_1	$3s^2 3p^3$	$(^4S) 3d$	$^3D_2^o$	23897	686870	20			46a°,63
148.318				2	0	674230	200bl				26,46a°,63
148.309	$3s^2 3p^4$	1D_2	$3s^2 3p^3$	$(^2D^o) 3d$	$^1F_3^o$	52540	726770	200bl			46a°
140.580	$3s^2 3p^4$	1D_2	$3s^2 3p^3$	$(^2P^o) 3d$	$^1P_1^o$	52540	763830	10			46a°,63
61.70	$3s^2 3p^3$	$(^2D^o) 3d$	$^3G_5^o$	$3s^2 3p^3$	$(^2D^o) 4f$	3H_6					26
61.08	$3s^2 3p^3$	$3d$	$^5D_4^o$	$3s^2 3p^3$	$4f$	5F_5		1			26

Cu xv (P sequence) Ionization Energy = 3903000 cm⁻¹ (484 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References		
2085.3	$3s^2 3p^3$	$^4S_{3/2}$	$3s^2 3p^3$	$^2D_{3/2}$	0	47940		M1	2.81+2	C	17,18°,78*
944.6	$3s^2 3p^3$	$^4S_{3/2}$	$3s^2 3p^3$	$^2P_{3/2}$	0	105865		M1	1.03+3	C	17,18°,78*
296.6	$3s^2 3p^3$	$^4S_{3/2}$	$3s 3p^4$	$^4P_{5/2}$	0	337100				41	
238.1	$3s^2 3p^3$	$^2D_{5/2}$	$3s 3p^4$	$^2P_{3/2}$	57803	477800				41	
163.274	$3s^2 3p^3$	$^2P_{1/2}$	$3s^2 3p^2$	(1D) $3d$	$^2P_{3/2}$	91106	703573	2		41,68°	
161.852	$3s^2 3p^3$	$^2D_{5/2}$	$3s^2 3p^2$	(1D) $3d$	$^2D_{5/2}$	57803	675651	5		41,68°	
160.143					$^3D_{3/2}$	47940	672380	10		41,68°	
161.381	$3s^2 3p^3$	$^4S_{3/2}$	$3s^2 3p^2$	(3P) $3d$	$^4P_{5/2}$	0	619652	40		26,41,68°	
159.677					$^3P_{3/2}$	0	626264	1		41,68°	
157.9					$^3P_{1/2}$	0	638300			41,68°	
158.944	$3s^2 3p^3$	$^2P_{3/2}$	$3s^2 3p^2$	(3P) $3d$	$^2D_{5/2}$	105962	735114	10		41,68°	
155.1					$^3D_{3/2}$	90950	735039			41	
154.713	$3s^2 3p^3$	$^2D_{5/2}$	$3s^2 3p^2$	(3P) $3d$	$^2F_{7/2}$	57803	704207	200		26,41,68°	
57.52	$3s^2 3p^2$	(1D) $3d$	$^2G_{9/2}$	$3s^2 3p^2$	(1D) $4f$	$^2H_{11/2}$		1		26	
57.44	$3s^2 3p^2$	$3d$	$^4F_{9/2}$	$3s^2 3p^2 4f$	$^4G_{11/2}$			1		26	

Cu xvi (Si sequence) Ionization Energy = 4194000 cm⁻¹ (520 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References		
5375.8	$3s^2 3p^2$	3P_0	$3s^2 3p^2$	3P_1	0	18596.7		M1	1.07+2	C	17,78*
2544.7	$3s^2 3p^2$	3P_2	$3s^2 3p^2$	1D_2	32747	72035		M1	3.28+2	C	16°,17,78*
1871.3				3P_1	18596.7	72035		M1	3.32+2	C	62,78*
952.8	$3s^2 3p^2$	3P_1	$3s^2 3p^2$	1S_0	18596.7	123550		M1	3.81+3	C	17,78*
410.46	$3s^2 3p^2$	3P_2	$3s 3p^3$	5S_2	32747	276430					73,74,75°
387.56				3P_1	18596.7	276430	bl				73,74,75°
298.162	$3s^2 3p^2$	3P_2	$3s 3p^3$	3D_0	32747	368118	1				63,70°
291.705				3P_1	18596.7	361409	2				63,70°
276.821				3P_0	0	361244	2				63,70°
261.247	$3s^2 3p^2$	3P_0	$3s 3p^3$	3P_1	32730	415501	1				63,70°
259.857				3P_2	32730	417557	3				63,70°
251.954				3P_1	18596.7	415501	1				63,70°
210.385	$3s^2 3p^2$	1D_2	$3s 3p^3$	1P_1	72016	547335	10				63,70°
209.160	$3s^2 3p^2$	3P_2	$3s 3p^3$	3S_1	32730	510826	10				63,70°
203.155				3P_1	18596.7	510826	10				63,70°
195.766				3P_0	0	510826	5				63,70°
192.461	$3s^2 3p^2$	1D_2	$3s^2 3p 3d$	3P_2	72016	591646	1				70
184.613	$3s^2 3p^2$	1D_2	$3s^2 3p 3d$	1D_2	72016	613690	20				63,70°

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Cu xvi (Si sequence) Ionization Energy = 4194000 cm⁻¹ (520 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References
178.959	$3s^2 3p^2$	3P_2	$3s^2 3p 3d$	$^3P_2^o$	32730	591646	5bl		63,70°
174.505		1		2	18596.7	591646	20		70
166.887		1		0	18596.7	617805	3		63,70°
165.504		1		1	18596.7	622812	2		63,70°
173.921	$3s^2 3p^2$	1S_0	$3s^2 3p 3d$	$^1P_1^o$	123550	698524	2		63,70°
168.879	$3s^2 3p^2$	3P_2	$3s^2 3p 3d$	$^3D_3^o$	32730	624870	20		26,63,70°
168.295		2		2	32730	626925	10		63,70°
166.025		0		1	0	602319	2		63,70°
168.019	$3s^2 3p^2$	3P_1	$3s^2 3p 3d$	$^1D_2^o$	18596.7	613690	1		63,70°
164.228	$3s^2 3p^2$	1D_2	$3s^2 3p 3d$	$^1F_3^o$	72016	680933	10		63,70°
154.271	$3s^2 3p^2$	3P_2	$3s^2 3p 3d$	$^1F_3^o$	32730	680933	5		70
56.06 ^T	$3s^2 3p 3d$	$^3D_3^o$	$3s^2 3p 4f$	3F_4	624870	2409000?			44
55.46 ^T	$3s^2 3p 3d$	$^3P_0^o$	$3s^2 3p 4f$	3D_1	617805	2421000?			44
54.48	$3s^2 3p 3d$	$^3F_3^o$	$3s^2 3p 4f$	3G_4	534500?	2370000	200		44°,47°
54.24		4		5	553300?	2397000	100		44°,47°
53.52	$3s^2 3p^2$	1D_2	$3s^2 3p 4s$	$^1P_1^o$	72016	1940000	300		47
52.85	$3s^2 3p^2$	3P_2	$3s^2 3p 4s$	$^3P_2^o$	32730	1930000	350		47
52.18		1		2	18596.7	1930000	350		47
52.41 ^T	$3s 3p^3$	$^1D_2^o$	$3s^2 3p 4f$	3G_3	464200?	2372000?			44
52.08 ^T	$3s 3p^3$	$^1D_2^o$	$3s^2 3p 4f$	1F_3	464200?	2384000?			44
45.90	$3s^2 3p^2$	1S_0	$3s^2 3p 4d$	$^1P_1^o$	123550	2302000			44
45.24	$3s^2 3p^2$	1D_2	$3s^2 3p 4d$	$^1F_3^o$	72016	2282000	300		44°,47°
45.21	$3s^2 3p^2$	3P_2	$3s^2 3p 4d$	$^3D_3^o$	32730	2244000	350		44°,47°
44.98		1		2	18596.7	2242000	350		44°,47°
44.63 ^T		0		1	0	2241000?			44
44.67	$3s^2 3p^2$	3P_2	$3s^2 3p 4d$	$^3F_3^o$	32730	2271000			44
44.47 ^T	$3s^2 3p^2$	3P_1	$3s^2 3p 4d$	$^3P_0^o$	18596.7	2267000?			44

Cu xvii (Al sequence) Ionization Energy = 4490000 cm⁻¹ (557 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References
3007.6	$3s^2 3p$	$^2P_{1/2}^o$	$3s^2 3p$	$^2P_{3/2}^o$	0	33239		M1	3.30+2 C 17°,36,78*
410.6	$3s^2 3p$	$^2P_{3/2}$	$3s 3p^2$	$^4P_{1/2}$	33239	277231			74,75°
387.0		3/2		3/2	33239	291810	bl		74,75°
364.45		3/2		5/2	33239	307708			74,75°
361.16		1/2		1/2	0	277113			74,75°
342.7		1/2		3/2	0	291692			74,75°
290.239	$3s^2 3p$	$^2P_{3/2}^o$	$3s 3p^2$	$^2D_{5/2}$	33239	377783	2		15,63,67°
268.647		1/2		3/2	0	372236	1		67

Cu xvii (Al sequence) Ionization Energy = 4490000 cm⁻¹ (557 eV) — Continued

λ (Å)	Classification	Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References
239.462	$3s3p^2$ $^4P_{5/2}$	$3p^3$ $^4S_{3/2}$	307708	725320	5			67
230.675		$3/2$	291810	725320	2			15,67°
223.170		$1/2$	277231	725320	1			54,63 ^a ,67°
224.841	$3s^23p$ $^2P_{1/2}$	$3s3p^2$ $^2S_{1/2}$	0	444759	10			15,63,67°
223.823	$3s^23p$ $^2P_{3/2}$	$3s3p^2$ $^2P_{1/2}$	33239	480016	10			15,63,67°
218.716		$3/2$	33239	490467	100			15,26,63, 67°
208.328		$1/2$	0	480016	3			67
203.881		$1/2$	0	490467	5			15,63,67°
200.40	$3s3p^2$ $^2D_{5/2}$	$3s3p3d$ $^2D_{5/2}$	377783	876785?				15
188.19	$3s3p^2$ $^2D_{5/2}$	$3s3p3d$ $^2F_{5/2}$	377783	909161?	bl			15
180.70		$5/2$	377783	931186?	bl			15
184.855	$3s^23p$ $^2P_{3/2}$	$3s^23d$ $^2D_{3/2}$	33239	574180	5			63,67°
183.485		$3/2$	33239	578243	100			15,26,63, 67°
174.168		$1/2$	0	574180	50			15,26,63, 67°
180.70	$3s3p^2$ $^4P_{5/2}$	$3s3p3d$ $^4D_{5/2}$	307708	861003?	bl			15
176.98		$3/2$	291810	856728?				15
52.76	$3s^23d$ $^2D_{5/2}$	$3s^24f$ $^2F_{7/2}$	578243	2474000	350			47
52.59		$3/2$	574180	2476000	450			47
51.16	$3s3p^2$ $^2D_{5/2}$	$3s3p4s$ $^2P_{3/2}$	377783	2332000	600			47
51.16	$3s3p3d$ $^4F_{7/2}$	$3s3p4f$ $^4G_{9/2}$			600			47
50.98		$5/2$			550			47
50.81		$9/2$			450			47
50.17	$3s^23p$ $^2P_{3/2}$	$3s^24s$ $^2S_{1/2}$	33239	2026000	450			47
49.90	$3s3p^2$ $^4P_{5/2}$	$3s3p4s$ $^4P_{3/2}$	307600	2312000	350			47
48.89		$3/2$	291692	2337000	350			47
43.31	$3s^23p$ $^2P_{3/2}$	$3s^24d$ $^2D_{5/2}$	33239	2342000	500			47
42.81		$1/2$	0	2336000	400			47

Cu xviii (Mg sequence) Ionization Energy = 5105000 cm⁻¹ (633 eV)

λ (Å)	Classification	Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References
3941.6	$3s3p$ 3P_1	$3s3p$ 3P_2	289401	314753	M1	2.16+2	C	17,78*
430.44	$3s3d$ 1D_2	$3p3d$ 1D_2	917020	1149319	2			53
395.67	$3s3p$ 1P_1	$3p^2$ 1D_2	426987	679710	4			53
346.44	$3s3p$ 1P_1	$3p^2$ 3P_2	426987	715608	2			53
345.542	$3s^2$ 1S_0	$3s3p$ 3P_1	0	289401				15,33,69°
334.002	$3s3d$ 3D_1	$3p3d$ 3F_2	818630	1118029	1			15,69°
317.563		2	820704	1135602	5			15,69°
300.417		3	823970	1156841	10			15,69°

Cu xviii (Mg sequence) Ionization Energy = 5105000 cm⁻¹ (633 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)	Int.	f	A (s ⁻¹)	Acc.	References
302.406	3s3d ³ D ₁	3p3d ¹ D ₂	818630 1149319	1			69	
275.813	3s3d ³ D ₂	3p3d ³ D ₁	820704 1183252	3			69	
274.779	3	2	823970 1187907	1			69	
272.30	2	2	820704 1187907	bl			15	
262.087	3	3	823970 1205542	5			15,69°	
259.857	2	3	820704 1205542	2			15,69°	
274.01	3s3p ³ P ₂	3p ² ¹ D ₂	314753 679710	5			53	
256.202	1	2	289401 679710	3			69	
272.120	3s3d ¹ D ₂	3p3d ¹ F ₃	917020 1284495	30			15,53,64,69°	
270.316	3s3p ³ P ₂	3p ² ³ P ₁	314753 684689	10			15,69°	
266.258	1	0	289401 664977	20			15,69°	
252.981	1	1	289401 684689	10			15,69°	
249.467	2	2	314753 715608	100			15,69°	
246.991	0	1	279816 684689	10			15,69°	
234.610	1	2	289401 715608	10			69	
265.145	3s3p ¹ P ₁	3p ² ¹ S ₀	426987 804139	10			53,69°	
261.820	3s3d ¹ D ₂	3p3d ¹ P ₁	917020 1298970	3			53,69°	
257.464	3s3d ³ D ₂	3p3d ³ P ₂	820704 1209104	2			69	
256.612	1	1	818630 1208326	2			69	
240.028	3p3d ¹ F ₃	3d ² ¹ G ₄	1284495 1701113	10			61,69°	
234.199	3s ² ¹ S ₀	3s3p ¹ P ₁	0 426987	500			15,26,69°	
228.16	3p ² ¹ D ₂	3p3d ³ F ₂	679710 1118029	2			53	
223.170	3p3d ³ P ₂	3d ² ³ F ₃	1209104 1657191	20			69	
219.410	3p3d ³ D ₃	3d ² ³ F ₄	1205542 1661315	10			61,69°	
213.087	2	3	1187907 1657191	5			69	
212.551	1	2	1183252 1653727	2			69	
212.939	3p ² ¹ D ₂	3p3d ¹ D ₂	679710 1149319	10			15,69°	
204.110	3p ² ³ P ₂	3p3d ³ D ₃	715608 1205542	200bl			69	
198.718	1	2	684689 1187907	100			69	
192.954	0	1	664977 1183252	50			15,69°	
204.072	3s3p ¹ P ₁	3s3d ¹ D ₂	426987 917020	30			15,26,69°	
202.962	3p ² ³ P ₂	3p3d ³ P ₁	715608 1208326	5			69	
202.635	2	2	715608 1209104	50			69	
191.083	1	0	684689 1208022	3			69°	
190.965	1	1	684689 1208326	10			15,69°	
190.689	1	2	684689 1209104	2			15,69°	
202.086	3p ² ¹ S ₀	3p3d ¹ P ₁	804139 1298970	30			53,69°	
198.56	3s3p ³ P ₂	3s3d ³ D ₁	314753 818630				15	
197.647	2	2	314753 820704	10			15,63 ^a ,69°	
196.379	2	3	314753 823970	200			15,26,69°	
188.953	1	1	289401 818630	20			69	
188.215	1	2	289401 820704	200			15,26,69°	
185.594	0	1	279816 818630	50			15,26,69°	
198.224	3p3d ³ F ₄	3d ² ³ F ₄	1156841 1661315	10			69	
191.723	3	3	1135602 1657191	30			69	
190.174	3p ² ¹ D ₂	3p3d ³ D ₃	679710 1205542	20			69	

Cu xviii (Mg sequence) Ionization Energy = 5105000 cm⁻¹ (633 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)	Int.	f	A (s ⁻¹)	Acc.	References
175.785	$3p^2$ 3P_2	$3p3d$ 1F_3	715608	1284495	5		64,69°	
165.349	$3p^2$ 1D_2	$3p3d$ 1F_3	679710	1284495	10		15,64,69°	
51.496 ^T	$3p3d$ 1P_1	$3p4f$ 1D_2	1298970	3240900?			44	
51.287	$3p3d$ 1F_3	$3p4f$ 1G_4	1284495	3234300?			44	
50.118	$3p3d$ 3D_1	$3p4f$ 3F_2	1183252	3178500?			44	
50.067	$3p3d$ 3D_1	$3p4f$ 3F_2	1205542	3202900			44°,47	
49.862	$3p3d$ 3D_2	$3p4f$ 3D_3	1187907	3193400			44	
49.769	$3p3d$ 3P_1	$3p4f$ 3D_2	1208326	3217600			44	
49.639	1	1	1208326	3222900	bl		44	
49.639	0	1	1208022	3222900	bl		44°,47	
49.558	$3s3d$ 3D_3	$3s4f$ 3F_4	823970	2841800	4		32°,44	
49.490	2	3	820704	2841300	4		32°,44°	
49.452	1	2	818630	2840800	3		32°,44	
49.395	$3p3d$ 1D_2	$3p4f$ 1F_3	1149319	3173800			44	
49.010	$3p3d$ 3F_3	$3p4f$ 3G_4	1135602	3176000			44°,47	
48.885	2	3	1118029	3163600	bl		44	
48.885	4	5	1156841	3202500	bl		44°,47	
47.585	$3s3p$ 3P_2	$3s4s$ 3S_1	314753	2416400	3		32	
47.012	1	1	289401	2416400	2		32	
46.781	0	1	279816	2416400	1		32	
41.173	$3s3p$ 3P_2	$3s4d$ 3D_2	314753	2743500	3		32	
41.134	2	3	314753	2745800	6		32	
40.769	1	1	289401	2742100	3		32	
40.749	1	2	289401	2743500	5		32	
40.613	0	1	279816	2742100	2		32	
38.876	$3s^2$ 1S_0	$3s4p$ 1P_1	0	2572300	5		32	
35.294	$3s3d$ 3D_3	$3s5f$ 3F_4	823970	3657300	3		32	
35.256	2	3	820704	3657100	2		32	
35.238	1	2	818630	3656500	2		32	
30.325	$3s3p$ 3P_2	$3s5d$ 3D_3	314753	3612400	5		32	
30.104	1	2	289401	3611200	4		32	
30.019	0	1	279816	3611000	3		32	
11.774	$2p^63s^2$ 1S_0	$2p^63s^23d$ 1P_1	0	8493000	2		71	

Cu xix (Na sequence) Ionization Energy = 5408660 cm⁻¹ (670.588 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)	Int.	References	
303.549	$2p^63s$ ${}^2S_{1/2}$	$2p^63p$ ${}^2P_{1/2}$	0	329436	200	15,60°,63 ^A
273.354	$1/2$	$3/2$	0	365826	150	15,32,51 ^A ,60°,63
224.237	$2p^63p$ ${}^2P_{3/2}$	$2p^63d$ ${}^2D_{3/2}$	365826	811791	100	15,32,51 ^A ,60°,63
221.369	$3/2$	$5/2$	365826	817560	450	15,32,51 ^A ,60°,63
207.312	$1/2$	$3/2$	329436	811791	350	15,32,51 ^A ,60°,63

SPECTRAL DATA AND GROTRIAN DIAGRAMS FOR HIGHLY IONIZED COPPER

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Cu xix (Na sequence) Ionization Energy = 5408660 cm⁻¹ (670.588 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)			Int.	References
210.70	$2p^5 3s 3p$	${}^4D_{7/2}$	$2p^5 3s 3d$				15,43°
111.353	$2p^6 4f$	${}^2F_{7/2}$	$2p^6 5g$	${}^2G_{9/2}$	2925400	3823400	15,50,51°,63
111.274		${}^5/2$		${}^7/2$	2924400	3823100	50,51°,63
103.179	$2p^6 4d$	${}^2D_{5/2}$	$2p^6 5f$	${}^2F_{7/2}$	2849500	3818700	51°,63
102.960		${}^3/2$		${}^5/2$	2847000	3818100	51°,63
90.990	$2p^6 4p$	${}^2P_{3/2}^o$	$2p^6 5d$	${}^2D_{5/2}$	2681600	3780600	51
85.90	$2p^6 4s$	${}^2S_{1/2}$	$2p^6 5p$	${}^2P_{3/2}^o$	2535440	3699300	51
53.889	$2p^6 3d$	${}^2D_{3/2}$	$2p^6 4p$	${}^2P_{1/2}^o$	811791	2667490	26,47,51°
53.643		${}^5/2$		${}^3/2$	817560	2681600	26,47,51°
47.442	$2p^6 3d$	${}^2D_{5/2}$	$2p^6 4f$	${}^2F_{7/2}$	817560	2925400	21,51 ^A ,60°,63
47.335		${}^3/2$		${}^5/2$	811791	2924400	21,51 ^A ,60°,63
46.090	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 4s$	${}^2S_{1/2}$	365826	2535440	28,32,51°,63
45.332		${}^1/2$		${}^1/2$	329436	2535440	32,51°
40.298	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 4d$	${}^2D_{3/2}$	365826	2847000	32,51°
40.263		${}^3/2$		${}^5/2$	365826	2849500	28,32,51°
39.725		${}^1/2$		${}^3/2$	329436	2847000	28,32,51°
37.488	$2p^6 3s$	${}^2S_{1/2}$	$2p^6 4p$	${}^2P_{1/2}^o$	0	2667490	28,32,51°
37.293		${}^1/2$		${}^3/2$	0	2681600	28,32,51°
33.317	$2p^6 3d$	${}^2D_{5/2}$	$2p^6 5f$	${}^2F_{7/2}$	817560	3818700	28,32°
33.266		${}^3/2$		${}^5/2$	811791	3818100	28,32,51°
29.277	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 5d$	${}^2D_{5/2}$	365826	3780600	28,32°
28.987		${}^1/2$		${}^3/2$	329436	3779300	28,32,51°
28.674	$2p^6 3d$	${}^2D_{5/2}$	$2p^6 6f$	${}^2F_{7/2}$	817560	4305000	28,32,51°
28.631		${}^3/2$		${}^5/2$	811791	4304500	32,51°
27.075	$2p^6 3s$	${}^2S_{1/2}$	$2p^6 5p$	${}^2P_{1/2}^o$	0	3693400	32,51°
27.032		${}^1/2$		${}^3/2$	0	3699300	32,51°
26.452	$2p^6 3d$	${}^2D_{5/2}$	$2p^6 7f$	${}^2F_{7/2}$	817560	4598000	32°,51 ^A
26.416		${}^3/2$		${}^5/2$	811791	4597400	32°,51 ^A
25.526	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 6d$	${}^2D_{5/2}$	365826	4283400	32,51°
25.297		${}^1/2$		${}^3/2$	329436	4282500	32,51°
25.175 ^T	$2p^6 3d$	${}^2D_{5/2}$	$2p^6 8f$	${}^2F_{7/2}$	817560	4789800?	32
25.142 ^T		${}^3/2$		${}^5/2$	811791	4789200?	32
23.704	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 7d$	${}^2D_{5/2}$	365826	4584500	32
23.503		${}^1/2$		${}^3/2$	329436	4584200	32
23.621	$2p^6 3s$	${}^2S_{1/2}$	$2p^6 6p$	${}^2P_{1/2}^o$	0	4233500	32
23.599		${}^1/2$		${}^3/2$	0	4237500	32
22.661	$2p^6 3p$	${}^2P_{3/2}^o$	$2p^6 8d$	${}^2D_{5/2}$	365826	4778800	32
22.475		${}^1/2$		${}^3/2$	329436	4778800	32
13.11	$2p^6 3s$	${}^2S_{1/2}$	$2p^5 3s^2$	${}^2P_{3/2}^o$	0	7627800?	31

Cu xx (Ne sequence) Ionization Energy = 13628000 cm⁻¹ (1689.6 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References		
340.77	$2s^2 2p^5 3s$	($^{3/2}, \frac{1}{2}$) ₀	$2s^2 2p^5 3p$	($^{3/2}, \frac{1}{2}$) ₁	7777270	8070680	14	
330.44		1		2	7795650	8098270	14	
311.53		2		2	7777270	8098270	14	
328.69	$2s^2 2p^5 3s$	($^{1/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3p$	($^{1/2}, \frac{1}{2}$) ₁	7955050	8259280	14	
317.63		0		1	7943950	8259280	14	
296.07	$2s^2 2p^5 3s$	($^{3/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3p$	($^{3/2}, \frac{3}{2}$) ₁	7795650	8133410	14	
287.09		2		3	7777270	8125590	14	
279.40		1		2	7795650	8153580	14	
265.72		2		2	7777270	8153580	14	
288.94	$2s^2 2p^5 3s$	($^{1/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3p$	($^{1/2}, \frac{3}{2}$) ₁	7955050	8301150	14	
284.70		1		2	7955050	8306290	14	
272.30	$2s^2 2p^5 3p$	($^{3/2}, \frac{3}{2}$) ₂	$2s^2 2p^5 3d$	($^{3/2}, \frac{3}{2}$) ₁	8153580	8520820	14	
232.84		1		2	8133410	8562820	14	
258.18	$2s^2 2p^5 3p$	($^{3/2}, \frac{3}{2}$) ₂	$2s^2 2p^5 3d$	($^{3/2}, \frac{5}{2}$) ₂	8153580	8540750	14	
241.25		3		4	8125590	8540100	14	
237.57		2		3	8153580	8574510	14	
247.00	$2s^2 2p^5 3p$	($^{1/2}, \frac{3}{2}$) ₂	$2s^2 2p^5 3d$	($^{1/2}, \frac{3}{2}$) ₂	8306290	8711110	14	
238.52	$2s^2 2p^5 3p$	($^{1/2}, \frac{3}{2}$) ₁	$2s^2 2p^5 3d$	($^{1/2}, \frac{5}{2}$) ₂	8301150	8720400	14	
237.57		2		3	8306290	8727220	14	
227.85	$2s^2 2p^5 3p$	($^{3/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3d$	($^{3/2}, \frac{3}{2}$) ₀	8070680	8509560	14	
223.83		2		3	8098270	8545040	14	
215.30		2		2	8098270	8562820	14	
212.75	$2s^2 2p^5 3p$	($^{3/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3d$	($^{3/2}, \frac{5}{2}$) ₂	8070680	8540750	14	
163.6	$2s^2 2p^5 3s$	($^{3/2}, \frac{1}{2}$) ₁	$2s^2 2p^5 3p$	($^{1/2}, \frac{1}{2}$) ₀	7795650	8406900	14	
12.827	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 3s$	($^{3/2}, \frac{1}{2}$) ₁	0	7795650	9	8,29,35°
12.570	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 3s$	($^{1/2}, \frac{1}{2}$) ₁	0	7955050	6	8,29,35°
11.736	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 3d$	($^{3/2}, \frac{3}{2}$) ₁	0	8520820	7	8,29,35°
11.594	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 3d$	($^{3/2}, \frac{5}{2}$) ₁	0	8626510	10	8,29,35°
11.383	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 3d$	($^{1/2}, \frac{3}{2}$) ₁	0	8787010	8	8,29,35°
10.653	$2s^2 2p^6$ 1S ₀		$2s^2 2p^6 3p$	($^{1/2}, \frac{1}{2}$) ₁	0	9387000	5	8,29,35°,71
10.597	$2s^2 2p^6$ 1S ₀		$2s^2 2p^6 3p$	($^{1/2}, \frac{3}{2}$) ₁	0	9436000	4	8,29,35°,71
9.521	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 4s$	($^{3/2}, \frac{1}{2}$) ₁	0	10504000	1	8,35°,39,71 ^A
9.375	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 4s$	($^{1/2}, \frac{1}{2}$) ₁	0	10667000	1	8,35°,39,71 ^A
9.274	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 4d$	($^{3/2}, \frac{3}{2}$) ₁	0	10783000		35
9.237	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 4d$	($^{3/2}, \frac{5}{2}$) ₁	0	10828000		8,30,35°
9.106	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 4d$	($^{1/2}, \frac{3}{2}$) ₁	0	10984000		8,30,35°
8.447	$2s^2 2p^6$ 1S ₀		$2s^2 2p^5 5d$	($^{3/2}, \frac{5}{2}$) ₁	0	11840000	1	8,35°,71 ^A
8.400	$2s^2 2p^6$ 1S ₀		$2s^2 2p^6 4p$	($^{1/2}, \frac{1}{2}$) ₁	0	11905000		35°,39
8.385	$2s^2 2p^6$ 1S ₀		$2s^2 2p^6 4p$	($^{1/2}, \frac{3}{2}$) ₁	0	11926000		35°,39

Cu xx (Ne sequence) Ionization Energy = 13628000 cm⁻¹ (1689.6 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References	
8.333	$2s^2 2p^6$ 1S_0		$2s^2 2p^5 5d$ (${}^{1/2}, {}^{3/2}$) ¹		0	12002000	
8.073	$2s^2 2p^6$ 1S_0		$2s^2 2p^5 6d$ (${}^{3/2}, {}^{5/2}$) ¹		0	12389000	
7.972	$2s^2 2p^6$ 1S_0		$2s^2 2p^5 6d$ (${}^{1/2}, {}^{3/2}$) ¹		0	12544000	

Cu xxi (F sequence) Ionization Energy = 14550000 cm⁻¹ (1804 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References
592.3	$2s^2 2p^5$ ${}^2P_{3/2}$		$2s^2 2p^5$ ${}^2P_{1/2}$	0	168830	M1	8.62+4	C	36,78*
346.25	$2s^2 2p^4$ (1D) $3s$ ${}^2D_{3/2}$		$2s^2 2p^4$ (1D) $3p$ ${}^2F_{5/2}$	8458000	8747000				15
305.44	$5/2$		$7/2$	8452000	8779000				15
932.02	$2s^2 2p^4$ (3P) $3s$ ${}^4F_{3/2}$		$2s^2 2p^4$ (3P) $3p$ ${}^4P_{1/2}$	8969000	8964000				15
325.97	$2s^2 2p^4$ (3P) $3s$ ${}^4P_{3/2}$		$2s^2 2p^4$ (3P) $3p$ ${}^4D_{5/2}$	8363000	8670000				15
293.58	$5/2$		$7/2$	8206000	8547000				15
242.30	$5/2$		$3/2$	8206000	8619000				15
302.56	$2s^2 2p^4$ (3P) $3s$ ${}^2P_{3/2}$		$2s^2 2p^4$ (3P) $3p$ ${}^2D_{5/2}$	8236000	8566000				15
279.40	$2s^2 2p^4$ (1D) $3s$ ${}^2D_{5/2}$		$2s^2 2p^4$ (1D) $3p$ ${}^2D_{5/2}$	8452000	8810000	bl			15
263.88	$2s^2 2p^4$ (3P) $3p$ ${}^2D_{5/2}$		$2s^2 2p^4$ (3P) $3d$ ${}^2F_{7/2}$	8566000	8945000				15
262.12	$2s^2 2p^4$ (3P) $3p$ ${}^4D_{7/2}$		$2s^2 2p^4$ (3P) $3d$ ${}^4F_{9/2}$	8547000	8928500?				15
257.50	$3/2$		$5/2$	8619000	9007000	bl			15
252.74	$5/2$		$7/2$	8670000	9066000				15
259.60	$2s^2 2p^4$ (1D) $3p$ ${}^2D_{5/2}$		$2s^2 2p^4$ (1D) $3d$ ${}^2F_{7/2}$	8810000	9195000				15
250.48	$2s^2 2p^4$ (3P) $3p$ ${}^4P_{5/2}$		$2s^2 2p^4$ (3P) $3d$ ${}^4D_{7/2}$						15
245.40	$2s^2 2p^4$ (1D) $3p$ ${}^2F_{5/2}$		$2s^2 2p^4$ (1D) $3d$ ${}^2G_{7/2}$	8747000	9154000				15
90.341	$2s^2 2p^5$ ${}^2P_{1/2}$		$2s^2 p^6$ ${}^2S_{1/2}$	168830	1275750	30			6,50,63°
78.384	$3/2$		$1/2$	0	1275750	100			6,50,63°
12.186	$2s^2 2p^5$ ${}^2P_{3/2}$		$2s^2 2p^4$ (3P) $3s$ ${}^4P_{5/2}$	0	8206000				35°,39
12.029	$3/2$		$1/2$	0	8313000				39
11.956	$3/2$		$3/2$	0	8363000	6			9,10 ^a ,11, 35°,39
12.165	$2s^2 2p^5$ ${}^2P_{1/2}$		$2s^2 2p^4$ (3P) $3s$ ${}^2P_{1/2}$	168830	8388000	5			9,10 ^a ,11, 35°,39
12.140	$3/2$		$3/2$	0	8236000	7			9,10 ^a ,11, 35°,39
11.920	$3/2$		$1/2$	0	8388000	4			9,10 ^a ,11, 35°,39
12.061	$2s^2 2p^5$ ${}^2P_{3/2}$		$2s^2 2p^4$ (1D) $3s$ ${}^2D_{3/2}$	168830	8458000	7			9,10 ^a ,11, 35°,39
11.830	$3/2$		$5/2$	0	8452000	8			9,10 ^a ,11, 35°,39
11.736	$2s^2 2p^5$ ${}^2P_{1/2}$		$2s^2 2p^4$ (1S) $3s$ ${}^2S_{1/2}$	168830	8690000				35
11.352	$2s^2 2p^5$ ${}^2P_{3/2}$		$2s^2 2p^4$ (3P) $3d$ ${}^4P_{3/2}$	168830	8979000				39
11.162	$3/2$		$1/2$	0	8959000	7			9,10 ^a ,11, 35°,39
11.136	$3/2$		$3/2$	0	8979000	10			9,10 ^a ,11, 35°,39

Cu xxI (F sequence) Ionization Energy = 14550000 cm⁻¹ (1804 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References
11.185	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^3P) 3d$	$^2P_{3/2}$	168830	9108000	6		9,10 ^a ,11, 35°,39
11.114	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^4(^3P) 3d$	$^2F_{5/2}$	0	8998000?			35°,39
11.097	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^1D) 3d$	$^2S_{1/2}$	168830	9180000	45		9,10 ^a ,11,35°
10.893		$_{3/2}$		$_{1/2}$	0	9180000	14		9,10 ^a ,11, 35°,39
11.065	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^1D) 3d$	$^2P_{3/2}$	168830	9206000	12		9,10 ^a ,11, 35°,39
11.002		$_{1/2}$		$_{1/2}$	168830	9258000	12		9,10 ^a ,11, 35°,39
10.863		$_{3/2}$		$_{3/2}$	0	9206000	28		9,10 ^a ,11, 35°,39
10.801		$_{3/2}$		$_{1/2}$	0	9258000	16		9,10 ^a ,11,39°
11.014	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^1D) 3d$	$^2D_{3/2}$	168830	9248000	14		9,10 ^a ,11, 35°,39
10.858		$_{3/2}$		$_{5/2}$	0	9209000	28		9,10 ^a ,11, 35°,39
10.813		$_{3/2}$		$_{3/2}$	0	9248000	16		9,10 ^a ,11, 35°,39
10.971	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^4(^3P) 3d$	$^2D_{5/2}$	0	9115000	14		9,10 ^a ,11, 35°,39
10.800	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^1S) 3d$	$^2D_{3/2}$	168830	9428000	5		9,10 ^a ,11, 35°,39
10.392	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^5(^3P^o) 3p$	$^4P_{3/2}$	168830	9792000			35
10.203		$_{3/2}$		$_{5/2}$	0	9801000?			35
10.354	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^5(^3P^o) 3p$	$^4D_{5/2}$	0	9658000			35
10.316		$_{3/2}$		$_{3/2}$	0	9694000			35
10.306	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^5(^3P^o) 3p$	$^2D_{3/2}$	168830	9872000			35
10.291		$_{3/2}$		$_{5/2}$	0	9717000			35
10.282	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^5(^3P^o) 3p$	$^2S_{1/2}$	168830	9894000?			35
10.260	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^5(^3P^o) 3p$	$^2P_{3/2}$	0	9747000			35
10.234		$_{3/2}$		$_{1/2}$	0	9771000			35
10.121	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^5(^1P^o) 3p$	$^2D_{3/2}$	168830	10049000			35
9.912		$_{3/2}$		$_{5/2}$	0	10089000			35
10.074	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^5(^1P^o) 3p$	$^2P_{1/2}$	168830	10095000			35
10.057		$_{1/2}$		$_{3/2}$	168830	10112000			35
8.984	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^4(^3P) 4s$	$^2P_{3/2}$	0	11131000?			35
8.873		$_{3/2}$		$_{1/2}$	0	11270000?			40
8.936	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^1D) 4s$	$^2D_{3/2}$	168830	11357000?			35°,40
8.811		$_{3/2}$		$_{5/2}$	0	11349000?			35°,40
8.808		$_{3/2}$		$_{3/2}$	0	11357000?			40
8.911	$2s^2 2p^5$	$^2P_{3/2}^o$	$2s^2 2p^4(^3P) 4s$	$^4P_{1/2}$	0	11222000?			40
8.870		$_{3/2}$		$_{3/2}$	0	11274000?			35
8.777	$2s^2 2p^5$	$^2P_{1/2}^o$	$2s^2 2p^4(^3P) 4d$	$^2P_{3/2}$	168830	11563000?			35°,40
8.648		$_{3/2}$		$_{3/2}$	0	11563000?			40

Cu xxI (F sequence) Ionization Energy = 14550000 cm⁻¹ (1804 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References
8.772	$2s^2 2p^5$	$^2P_{1/2}$	$2s^2 2p^4(^1S)4s$	$^2S_{1/2}$	168830		11566000?		40
8.648		$^3/2$		$^1/2$	0		11566000?		40
8.754	$2s^2 2p^5$	$^2P_{3/2}$	$2s^2 2p^4(^3P)4d$	$^2D_{5/2}$	0		11423000?		35
8.754		$^3/2$		$^3/2$	0		11423000?		35
8.714	$2s^2 2p^5$	$^2P_{1/2}$	$2s^2 2p^4(^1D)4d$	$^2S_{1/2}$	168830		11642000?		40
8.591		$^3/2$		$^1/2$	0		11642000?		35°,40
8.714	$2s^2 2p^5$	$^2P_{1/2}$	$2s^2 2p^4(^1D)4d$	$^2P_{3/2}$	168830		11642000?		40
8.707		$^1/2$		$^1/2$	168830		11658000?		35°,40
8.591		$^3/2$		$^3/2$	0		11642000?		35°,40
8.574		$^3/2$		$^1/2$	0		11658000?		40
8.707	$2s^2 2p^5$	$^2P_{1/2}$	$2s^2 2p^4(^1D)4d$	$^2D_{3/2}$	168830		11658000?		35°,40
8.591		$^3/2$		$^5/2$	0		11640000?		35
8.574		$^3/2$		$^3/2$	0		11658000?		40
8.601	$2s^2 2p^5$	$^2P_{3/2}$	$2s^2 2p^4(^3P)4d$	$^4F_{3/2}$	0		11506000?		35°,40
8.691		$^3/2$		$^5/2$	0		11506000?		35
8.652	$2s^2 2p^5$	$^2P_{3/2}$	$2s^2 2p^4(^3P)4d$	$^4P_{5/2}$	0		11558000?		35
8.591	$2s^2 2p^5$	$^2P_{3/2}$	$2s^2 2p^4(^1D)4d$	$^2F_{5/2}$	0		11640000?		35
8.554	$2s^2 2p^5$	$^2P_{1/2}$	$2s^2 2p^4(^1S)4d$	$^2D_{3/2}$	168830		11859000?		35°,40

Cu xxII (O sequence) Ionization Energy = 15450000 cm⁻¹ (1916 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References
657.7	$2s^2 2p^4$	3P_2	$2s^2 2p^4$	3P_1	0		151990	M1	6.78+4 C 36,78*
420.0	$2s^2 2p^4$	3P_2	$2s^2 2p^4$	1D_2	0		237950	M1	6.52+4 C 36,78*
114.974	$2s^2 2p^4$	1D_2	$2s^2 p^5$	3P_2	237950		1107710	3	23°
104.620	$2s^2 2p^4$	3P_1	$2s^2 p^5$	3P_2	151990		1107710	5	23°,50
95.222		1		1	151990		1202170	5	23°,50
90.864		0		1	101620		1202170	5	23°,50
90.276		2		2	0		1107710	25	6,23°,50
88.395		1		0	151990		1283280	5	23°,50
83.183		2		1	0		1202170	15	6,23°,50
98.180	$2s 2p^5$	1P_1	$2p^6$	1S_0	1528080		2546610	10	23°,58
93.302	$2s^2 2p^4$	1S_0	$2s 2p^5$	1P_1	456290		1528080	4	23°,50
77.512	$2s^2 2p^4$	1D_2	$2s 2p^5$	1P_1	237950		1528080	30	6,23°,50
74.383	$2s 2p^5$	3P_1	$2p^6$	1S_0	1202170		2546610	1	23
65.43	$2s^2 2p^4$	3P_2	$2s 2p^5$	1P_1	0		1528080	2	23°,49,50°
11.621	$2s^2 2p^4$	3P_1	$2s^2 2p^3(^4S^o)$	$3s$	3S_1	151990		8758000?	35
11.416		2		1	0		8758000?		35
11.573	$2s^2 2p^4$	1D_2	$2s^2 2p^3(^2D^o)$	$3s$	$^3D_2^o$	237950		8876000?	35
11.468	$2s^2 2p^4$	1D_2	$2s^2 2p^3(^2D^o)$	$3s$	$^1D_2^o$	237950		8958000?	35
11.468	$2s^2 2p^4$	1S_0	$2s^2 2p^3(^2P^o)$	$3s$	$^1P_1^o$	456290		9177000?	35

Cu xxII (O sequence)

Ionization Energy = 15450000 cm⁻¹ (1916 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	<i>f</i>	<i>A</i> (s ⁻¹)	Acc.	References
11.466	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2D^\circ) 3s$	${}^3D_2^\circ$	151990		8876000?		35
11.440		1		1	151990		8893000?		35
11.266		2		2	0		8876000?		35
11.198		2		3	0		8930000?		35
11.349	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3s$	${}^3P_1^\circ$	237950		9049000?		35
11.198		2		2	237950		9166000?		35
11.266	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2P^\circ) 3s$	${}^3P_0^\circ$	151990		9028000?		35
11.097		1		2	151990		9166000?		35
11.185	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3s$	${}^1P_1^\circ$	237950		9177000?		35
10.611	$2s^2 2p^4$	3P_2	$2s^2 2p^3({}^4S^\circ) 3d$	${}^3D_3^\circ$	0		9424000?		35
10.611	$2s^2 2p^4$	1S_0	$2s^2 2p^3({}^2P^\circ) 3d$	${}^1P_1^\circ$	456290		9880000?		35
10.611	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3d$	${}^3F_3^\circ$	237950		9666000?		35
10.597	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2D^\circ) 3d$	${}^1F_3^\circ$	237950		9675000?		35
10.560	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3d$	${}^3P_2^\circ$	237950		9708000?		35
10.406	$2s^2 2p^4$	3P_2	$2s^2 2p^3({}^2D^\circ) 3d$	${}^3D_3^\circ$	0		9610000?		35
10.406	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3d$	${}^1D_2^\circ$	237950		9848000?		35
10.406	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 3d$	${}^1F_3^\circ$	237950		9848000?		35
10.392	$2s^2 2p^4$	3P_2	$2s^2 2p^3({}^2D^\circ) 3d$	${}^3P_2^\circ$	0		9623000?		35
10.374	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2P^\circ) 3d$	${}^3P_1^\circ$	151990		9791000?		35
10.342	$2s^2 2p^4$	3P_2	$2s^2 2p^3({}^2P^\circ) 3d$	${}^3F_3^\circ$	0		9666000?		35
10.316	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2P^\circ) 3d$	${}^3D_2^\circ$	151990		9846000?		35
8.385	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^4S^\circ) 4d$	${}^3D_2^\circ$	151990		12077000?		35
8.333		0		1	101620		12102000?		35
8.281		2		2	0		12077000?		35
8.275		2		3	0		12085000?		35
8.281	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2D^\circ) 4d$	${}^1D_2^\circ$	237950		12314000?		35
8.281	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2D^\circ) 4d$	${}^1F_3^\circ$	237950		12314000?		35
8.275	$2s^2 2p^4$	1S_0	$2s^2 2p^3({}^2P^\circ) 4d$	${}^1P_1^\circ$	456290		12541000?		35
8.275	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2D^\circ) 4d$	${}^3D_2^\circ$	151990		12237000?		35
8.125		2		3	0		12308000?		35
8.222	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 4d$	${}^3F_3^\circ$	237950		12400000?		35
8.171	$2s^2 2p^4$	3P_2	$2s^2 2p^3({}^2D^\circ) 4d$	${}^3F_3^\circ$	0		12238000?		35
8.171	$2s^2 2p^4$	3P_1	$2s^2 2p^3({}^2P^\circ) 4d$	${}^3P_2^\circ$	151990		12390000?		35
8.086		1		1	151990		12519000?		35
8.125	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 4d$	${}^1F_3^\circ$	237950		12546000?		35
8.125	$2s^2 2p^4$	1D_2	$2s^2 2p^3({}^2P^\circ) 4d$	${}^3D_2^\circ$	237950		12532000?		35
8.125	$2s^2 2p^4$	3P_0	$2s^2 2p^3({}^2P^\circ) 4d$	${}^3D_1^\circ$	101620		12409000?		35
8.086		1		2	151990		12532000?		35

Cu xxiii (N sequence) Ionization Energy = 16620000 cm⁻¹ (2060 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References	
1691.0	$2s^2 2p^3$	$^2D_{5/2}$	$2s^2 2p^3$	$^2D_{5/2}$	170860	230070	M1	$1.49 + 3$	C	37,78*
585.0	$2s^2 2p^3$	$^4S_{3/2}$	$2s^2 2p^3$	$^2D_{5/2}$	0	170860	M1	$6.40 + 4$	C	36,78*
434.8				$5/2$	0	230070	M1	$7.98 + 3$	C	36,78*
111.071	$2s^2 2p^3$	$^4S_{3/2}$	$2s 2p^4$	$^4P_{5/2}$	0	900330	4bl			23°
98.848				$3/2$	0	1011650	4bl			6,23°
96.485				$1/2$	0	1036430	70			6,23°
108.519	$2s^2 2p^3$	$^2P_{1/2}$	$2s 2p^4$	$^2D_{3/2}$	327900	1249110	1			23°
99.243	$2s 2p^4$	$^2P_{3/2}$	$2p^5$	$^2P_{1/2}$	1485340	2492890	4bl			23
96.845	$2s 2p^4$	$^2D_{5/2}$	$2p^5$	$^2P_{3/2}$	1283940	2316720	5bl			6,23°
93.007				$3/2$	1249110	2316720	2			23
80.400				$1/2$	1249110	2492890	1			23
94.888	$2s^2 2p^3$	$^2D_{5/2}$	$2s 2p^4$	$^2D_{5/2}$	230070	1283940	10bl			6,23°, 50
92.728				$3/2$	170860	1249110	5			6,23°, 50
91.000	$2s^2 2p^3$	$^2P_{1/2}$	$2s 2p^4$	$^2S_{1/2}$	327900	1427080	5			6,23°
83.340	$2s^2 2p^3$	$^2P_{3/2}$	$2s 2p^4$	$^2P_{1/2}$	446780	1646680	15bl			6,23°, 50
80.057	$2s^2 2p^3$	$^4S_{3/2}$	$2s 2p^4$	$^2D_{3/2}$	0	1249110	1			23
79.664	$2s^2 2p^3$	$^2D_{5/2}$	$2s 2p^4$	$^2P_{3/2}$	230070	1485340	20			6,23°, 50
76.076				$3/2$	170860	1485340	1			23
67.759				$1/2$	170860	1646680	2			23
79.615	$2s^2 2p^3$	$^2D_{3/2}$	$2s 2p^4$	$^2S_{1/2}$	170860	1427080	5			6,23°
70.073	$2s^2 2p^3$	$^4S_{3/2}$	$2s 2p^4$	$^2S_{1/2}$	0	1427080	1			23

Cu xxiv (C sequence) Ionization Energy = 17600000 cm⁻¹ (2182 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	f	A (s ⁻¹)	Acc.	References	
1776.0	$2s^2 2p^2$	3P_1	$2s^2 2p^2$	3P_2	132120	188430	M1	$1.57 + 3$	C	36,78*
756.9		0		1	0	132120	M1	$3.55 + 4$	C	36,78*
540.0	$2s^2 2p^2$	3P_2	$2s^2 2p^2$	1D_2	188430	373620	M1	$5.78 + 4$	C	36,78*
414.1		1		2	132120	373620	M1	$6.53 + 4$	C	36,78*
120.442	$2s^2 2p^2$	3P_2	$2s 2p^3$	3D_3	188430	1018700	2			23
119.572		1		2	132120	968440	3			23
104.292		0		1	0	958850	3			23
105.859	$2s 2p^3$	1P_1	$2p^4$	1S_0	1573500	2518200	2			23
105.760	$2s 2p^3$	3P_2	$2p^4$	3P_1	1196100	2141600	4			23
100.637		0		1	1147900	2141600	3			23
103.702	$2s 2p^3$	3D_3	$2p^4$	3P_2	1018700	1983000	7			23
98.576		2		2	968440	1983000	1			23
97.639		1		2	958850	1983000	3			23
87.055		1		0	958850	2107500	2			23
85.226		2		1	968440	2141600	4			23
99.243	$2s^2 2p^2$	3P_2	$2s 2p^3$	3P_2	188430	1196100	4bl			6,23°
98.444		1		0	132120	1147900	1			23
96.845		1		1	132120	1164700	5bl			23

Cu xxiv (C sequence) Ionization Energy = 17600000 cm⁻¹ (2182 eV) — Continued

λ (Å)	Classification	Energy Levels (cm ⁻¹)			Int.	f	A (s ⁻¹)	Acc.	References
96.930	$2s^2 2p^2$ 1D_2	$2s 2p^3$ $^1D_2^o$	373620	1404900	8				23
94.888	$2s^2 2p^2$ 1S_0	$2s 2p^3$ $^1P_1^o$	519650	1573500	10bl				23
87.128	$2s^2 2p^2$ 3P_2	$2s 2p^3$ $^3S_1^o$	188430	1335700	7				6,23°
83.084			132120	1335700	1				6,23°
83.340	$2s^2 2p^2$ 1D_2	$2s 2p^3$ $^1P_1^o$	373620	1573500	15bl				23
82.195	$2s^2 2p^2$ 3P_2	$2s 2p^3$ $^1D_2^o$	188430	1404900	4				23

Cu xxv (B sequence) Ionization Energy = 18620000 cm⁻¹ (2308 eV)

λ (Å)	Classification	Energy Levels (cm ⁻¹)			Int.	f	A (s ⁻¹)	Acc.	References
522.8	$2s^2 2p$ $^2P_{1/2}^o$	$2s^2 2p$ $^2P_{3/2}^o$	0	191280		M1	6.26 + 4	C	36,78*
117.507	$2s^2 2p$ $^4P_{5/2}$	$2p^3$ $^4S_{5/2}^o$	662770 + X	1513780 + X	3				23
107.659	$3/2$	$3/2$	584920 + X	1513780 + X	3				23
97.272	$1/2$	$3/2$	485730 + X	1513780 + X	3				23

Cu xxvi (Be sequence) Ionization Energy = 19986000 cm⁻¹ (2478 eV)

λ (Å)	Classification	Energy Levels (cm ⁻¹)			Int.	f	A (s ⁻¹)	Acc.	References
648.0	$1s^2 2s 2p$ $^3P_1^o$	$1s^2 2s 2p$ $^3P_2^o$	438970	593290		M1	4.74 + 4	C	36,78*
227.808	$1s^2 2s^2$ 1S_0	$1s^2 2s 2p$ $^3P_1^o$	0	438970					17a°
173.34	$1s^2 2s 2p$ $^1P_1^o$	$1s^2 2p^2$ 1D_2	899390	1477200					13
158.70	$1s^2 2s 2p$ $^3P_2^o$	$1s^2 2p^2$ 3P_1	593290	1223400					13
152.29	1	0	438970	1095600					13
145.70	2	2	593290	1279600					13
127.48	1	1	438970	1223400					13
120.56	0	1	393900	1223400					13
119.00	1	2	438970	1279600					13
122.58	$1s^2 2s 2p$ $^1P_1^o$	$1s^2 2p^2$ 1S_0	899390	1716100					13
113.14	$1s^2 2s 2p$ $^3P_2^o$	$1s^2 2p^2$ 1D_2	593290	1477200					13
111.186	$1s^2 2s^2$ 1S_0	$1s^2 2s 2p$ $^1P_1^o$	0	899390					13,17a°,36
27.395	$1s^2 2p 3d$ 3F_3	$1s^2 2p 4f$ 3G_4	12156000	15806000	1				12
27.013	4	5			1				12
27.182	$1s^2 2s 3d$ 3D_3	$1s^2 2s 4f$ 3F_4	11672000?	15351000	1				12
9.746	$1s^2 2p^2$ 1S_0	$1s^2 2p 3s$ $^1P_1^o$	1716100	11977000	30				7,12°
9.520	$1s^2 2p^2$ 3P_1	$1s^2 2p 3s$ $^3P_0^o$	1223400	11728000					7
9.520	$1s^2 2p^2$ 1D_2	$1s^2 2p 3s$ $^1P_1^o$	1477200	11977000					7
9.489	$1s^2 2s 2p$ $^1P_1^o$	$1s^2 2s 3s$ 1S_0	899390	11439000	1				12

SPECTRAL DATA AND GROTRIAN DIAGRAMS FOR HIGHLY IONIZED COPPER

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Cu xxvi (Be sequence) Ionization Energy = 19986000 cm⁻¹ (2478 eV) — Continued

λ (Å)	Classification	Energy Levels (cm ⁻¹)			Int.	f	A (s ⁻¹)	Acc.	References
9.375	$1s^2 2p^2 \ ^1D_2$	$1s^2 2p 3d \ ^3P_2$	1477200	12144000	3			7,12°	
9.359	$1s^2 2s 2p \ ^3P_2$	$1s^2 2s 3s \ ^3S_1$	593290	11278000	15			7,12°	
9.324	$1s^2 2p^2 \ ^1S_0$	$1s^2 2p 3d \ ^1P_1$	1716100	12441000	6			7,12°	
9.233	$1s^2 2p^2 \ ^1D_2$	$1s^2 2p 3d \ ^1D_2$	1477200	12308000				7	
9.194	$1s^2 2p^2 \ ^3P_2$	$1s^2 2p 3d \ ^3F_3$	1279600	12156000	12			12	
9.194	$1s^2 2s 2p \ ^1P_1$	$1s^2 2s 3d \ ^1D_2$	899390	11777000	12			8,12°	
9.149	$1s^2 2p^2 \ ^3P_1$	$1s^2 2p 3d \ ^3D_2$	1223400	12154000	3			7,12°	
9.042	2	3	1279600	12339000	10bl			12	
9.026	0	1	1095600	12175000	20			12	
9.131	$1s^2 2p^2 \ ^1D_2$	$1s^2 2p 3d \ ^1F_3$	1477200	12428000	10			12	
9.026	$1s^2 2s 2p \ ^3P_2$	$1s^2 2s 3d \ ^3D_3$	593290	11672000	20			12	
9.026	2	2	593290	11669000	20			12	
8.908	1	1	438970	11663000	0			7,12°	
8.908	1	2	438970	11669000	5			8,12°	
8.876	0	1	393900	11663000	2bl			12	
8.970	$1s^2 2p^2 \ ^3P_2$	$1s^2 2p 3d \ ^1F_3$	1279600	12428000	8			7,12°	
8.970	$1s^2 2p^2 \ ^3P_1$	$1s^2 2p 3d \ ^3P_1$	1223400	12372000	8			12	
8.970	$1s^2 2s 2p \ ^1P_1$	$1s^2 2p 3p \ ^1P_1$	899390	12049000	8			7,12°	
8.773	$1s^2 2s 2p \ ^1P_1$	$1s^2 2p 3p \ ^1D_2$	899390	12293000	5			7,12°	
8.661	$1s^2 2s^2 \ ^1S_0$	$1s^2 2s 3p \ ^1P_1$	0	11546000	3			12	
8.691 ^a	$1s^2 2s^2 \ ^1S_0$	$1s^2 2s 3p \ ^3P_1$	0	11546000	3			12	
8.618	$1s^2 2s 2p \ ^3P_2$	$1s^2 2p 3p \ ^3P_2$	593330	12197000	12			7,12°	
8.551	$1s^2 2s 2p \ ^3P_2$	$1s^2 2p 3p \ ^1D_2$	593330	12293000	3			7,12°	

^aGiven in Ref. 12 as a Li-like line, which masks this weaker transition.Cu xxvii (Li sequence) Ionization Energy = 20870000 cm⁻¹ (2587.5 eV)

λ (Å)	Classification	Energy Levels (cm ⁻¹)			Int.	References	
224.795	$1s^2 2s \ ^2S_{1/2}$	$1s^2 2p \ ^2P_{1/2}$	0	444899		36,48°, 79°	
159.507	1/2	3/2	0	651432	4	12 ^a , 36, 48°, 79°	
25.893	$1s^2 3d \ ^2D_{5/2}$	$1s^2 4p \ ^2P_{3/2}$	11967000	15828000	1		12
25.646	$1s^2 3d \ ^2D_{5/2}$	$1s^2 4f \ ^2F_{7/2}$	11967000	15806000	7		12
25.543	3/2	5/2	11947000	15862000	6		12
25.291	$1s^2 3p \ ^2P_{3/2}$	$1s^2 4d \ ^2D_{5/2}$	11903000	15857000	3		12
24.943	1/2	3/2	11841000	15850000	1		12
24.291	$1s^2 3s \ ^2S_{1/2}$	$1s^2 4p \ ^2P_{3/2}$	11711000	15828000	1		12
9.042	$1s^2 2p \ ^2P_{3/2}$	$1s^2 3s \ ^2S_{1/2}$	651432	11711000	10bl		12
8.876	1/2	1/2	444899	11711000	2bl		12

Cu xxvii (Li sequence) Ionization Energy = 20870000 cm⁻¹ (2587.5 eV) — Continued

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References
8.856	$1s^2 2p$ $^2P_{3/2}$		$1s^2 3d$ $^2D_{3/2}$	651432	11947000	2
8.837		$^{3/2}$		651432	11967000	25
8.691		$^{1/2}$		444899	11947000	15
8.445	$1s^2 2s$ $^2S_{1/2}$		$1s^2 3p$ $^2P_{1/2}$	0	11841000	10
8.401		$^{1/2}$		0	11903000	20
1.272	$1s^2 2p$ $^2P_{3/2}^o$		$1s 2p 3p$ $^2D_{5/2}$	651432	79260000	1
1.213	$1s^2 2p$ $^2P_{3/2}^o$		$1s 2p 4p$ $^2D_{5/2}$	651432	83090000	1

Cu xxviii (He sequence) Ionization Energy = 89224060 cm⁻¹ (11062.378 eV)

λ (Å)	Classification		Energy Levels (cm ⁻¹)		Int.	References
373.246 ^c	$1s 2s$ 3S_1		$1s 2p$ $^3P_0^o$	67035105	67303025	20
347.767 ^c		1		67035105	67322654	20
206.756 ^c		1		67035105	67518768	20
283.237 ^c	$1s 2s$ 1S_0		$1s 2p$ $^1P_1^o$	67324766	67677827	20
155.588 ^c	$1s 2s$ 3S_1		$1s 2p$ $^1P_1^o$	67035105	67677827	20
52.0725 ^c	$1s 4p$ $^1P_1^o$		$1s 5s$ 1S_0	83830300	85750700	77
51.3769 ^c	$1s 4p$ $^3P_1^o$		$1s 5s$ 3S_1	83787900	85734300	77
50.3373 ^c	$1s 4s$ 1S_0		$1s 5p$ $^1P_1^o$	83786500	85773100	77
50.0726 ^c	$1s 4s$ 3S_1		$1s 5p$ $^3P_1^o$	83754400	85751500	77
24.0835 ^c	$1s 3p$ $^1P_1^o$		$1s 4s$ 1S_0	79634283	83786500	19,77
23.6863 ^c	$1s 3p$ $^3P_1^o$		$1s 4s$ 3S_1	79532544	83754400	19,77
23.2557 ^c	$1s 3s$ 1S_0		$1s 4p$ $^1P_1^o$	79530270	83830300	19,77
23.0695 ^c	$1s 3s$ 3S_1		$1s 4p$ $^3P_1^o$	79453169	83787900	19,77
16.3494 ^c	$1s 3p$ $^1P_1^o$		$1s 5s$ 1S_0	79634283	85750700	19,77
16.1245 ^c	$1s 3p$ $^3P_1^o$		$1s 5s$ 3S_1	79532544	85734300	19,77
16.0184 ^c	$1s 3s$ 1S_0		$1s 5p$ $^1P_1^o$	79530270	85773100	19,77
15.8772 ^c	$1s 3s$ 3S_1		$1s 5p$ $^3P_1^o$	79453169	85751500	19,77
8.43708 ^c	$1s 2p$ $^1P_1^o$		$1s 3s$ 1S_0	67677827	79530270	19,20
8.24367 ^c	$1s 2p$ $^3P_1^o$		$1s 3s$ 3S_1	67322654	79453169	19,20
8.12380 ^c	$1s 2s$ 1S_0		$1s 3p$ $^1P_1^o$	67324766	79634283	19,20
8.00164 ^c	$1s 2s$ 3S_1		$1s 3p$ $^3P_1^o$	67035105	79532544	19,20
6.20784 ^c	$1s 2p$ $^1P_1^o$		$1s 4s$ 1S_0	67677827	83786500	20,77
6.08578 ^c	$1s 2p$ $^3P_1^o$		$1s 4s$ 3S_1	67322654	83754400	20,77
6.05857 ^c	$1s 2s$ 1S_0		$1s 4p$ $^1P_1^o$	67324766	83830300	20,77

Cu xxviii (He sequence) Ionization Energy = 89224060 cm^{-1} (11062.378 eV) — Continued

$\lambda (\text{\AA})$	Classification	Energy Levels (cm^{-1})		Int.	References
5.96915 ^c	1s 2s ³ S ₁	1s 4p ³ P ₁ ^o	67035105	83787900	20,77
5.53315 ^c	1s 2p ¹ P ₁ ^o	1s 5s ¹ S ₀	67677827	85750700	20,77
5.43134 ^c	1s 2p ³ P ₁ ^o	1s 5s ³ S ₁	67322654	85734300	20,77
5.42054 ^c	1s 2s ¹ S ₀	1s 5p ¹ P ₁ ^o	67324766	85773100	20,77
5.34291 ^c	1s 2s ³ S ₁	1s 5p ³ P ₁ ^o	67035105	85751500	20,77
1.48588 ^c	1s ² ¹ S ₀	1s 2p ³ P ₁ ^o	0	67322654	1,20,76
1.48107 ^c	0	2	0	67518768	20,76
1.47759 ^c	1s ² ¹ S ₀	1s 2p ¹ P ₁ ^o	0	67677827	1,3,20,52,56, 57,76
1.4343	1s 2p ¹ P ₁ ^o	2p ² ¹ D ₂	67677827	137400000	76
1.4302	1s 2p ¹ P ₁ ^o	2p ² ¹ S ₀	67677827	137600000	76
1.25735 ^c	1s ² ¹ S ₀	1s 3p ³ P ₁ ^o	0	79532544	1,19
1.25574 ^c	1s ² ¹ S ₀	1s 3p ¹ P ₁ ^o	0	79634283	1,19
1.19349 ^c	1s ² ¹ S ₀	1s 4p ³ P ₁ ^o	0	83787900	1,77
1.19289 ^c	1s ² ¹ S ₀	1s 4p ¹ P ₁ ^o	0	83830300	1,77
1.16616 ^c	1s ² ¹ S ₀	1s 5p ³ P ₁ ^o	0	85751500	1,77
1.16587 ^c	1s ² ¹ S ₀	1s 5p ¹ P ₁ ^o	0	85773100	1,77

Cu xxix (H sequence) Ionization Energy = 93299090 cm^{-1} (11567.617 eV)

$\lambda (\text{\AA})$	Classification	Energy Levels (cm^{-1})		Int.	References
385.0671 ^c	2s ² S _{1/2}	2p ² P _{3/2} ^o	69902760	70162455	42
7.770236 ^c	2p ² P _{3/2}	3d ² D _{5/2}	70162455	83032077	24,42
7.631439 ^c	2s ² S _{1/2}	3p ² P _{3/2} ^o	69902760	83006449	24,42
5.760688 ^c	2p ² P _{3/2}	4d ² D _{5/2}	70162455	87521643	24,42
5.679217 ^c	2s ² S _{1/2}	4p ² P _{3/2} ^o	69902760	87510822	24,42
5.144289 ^c	2p ² P _{3/2}	5d ² D _{5/2}	70162455	89601488	24,42
5.077872 ^c	2s ² S _{1/2}	5p ² P _{3/2} ^o	69902760	89596047	24,42
1.430694 ^c	1s ² S _{1/2}	2p ² P _{1/2} ^o	0	69896140	2,42
1.425264 ^c	1/2	3/2	0	70162455	2,42
1.204726 ^c	1s ² S _{1/2}	3p ² P _{3/2} ^o	0	83006449	24
1.142716 ^c	1s ² S _{1/2}	4p ² P _{3/2} ^o	0	87510822	24
1.116121 ^c	1s ² S _{1/2}	5p ² P _{3/2} ^o	0	89596047	24

5. Explanation of Grotrian Diagrams

Notations on the Diagrams generally have the same meanings as for the Tables (see Explanation of Tables).

Abscissa

Energy of 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. 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.

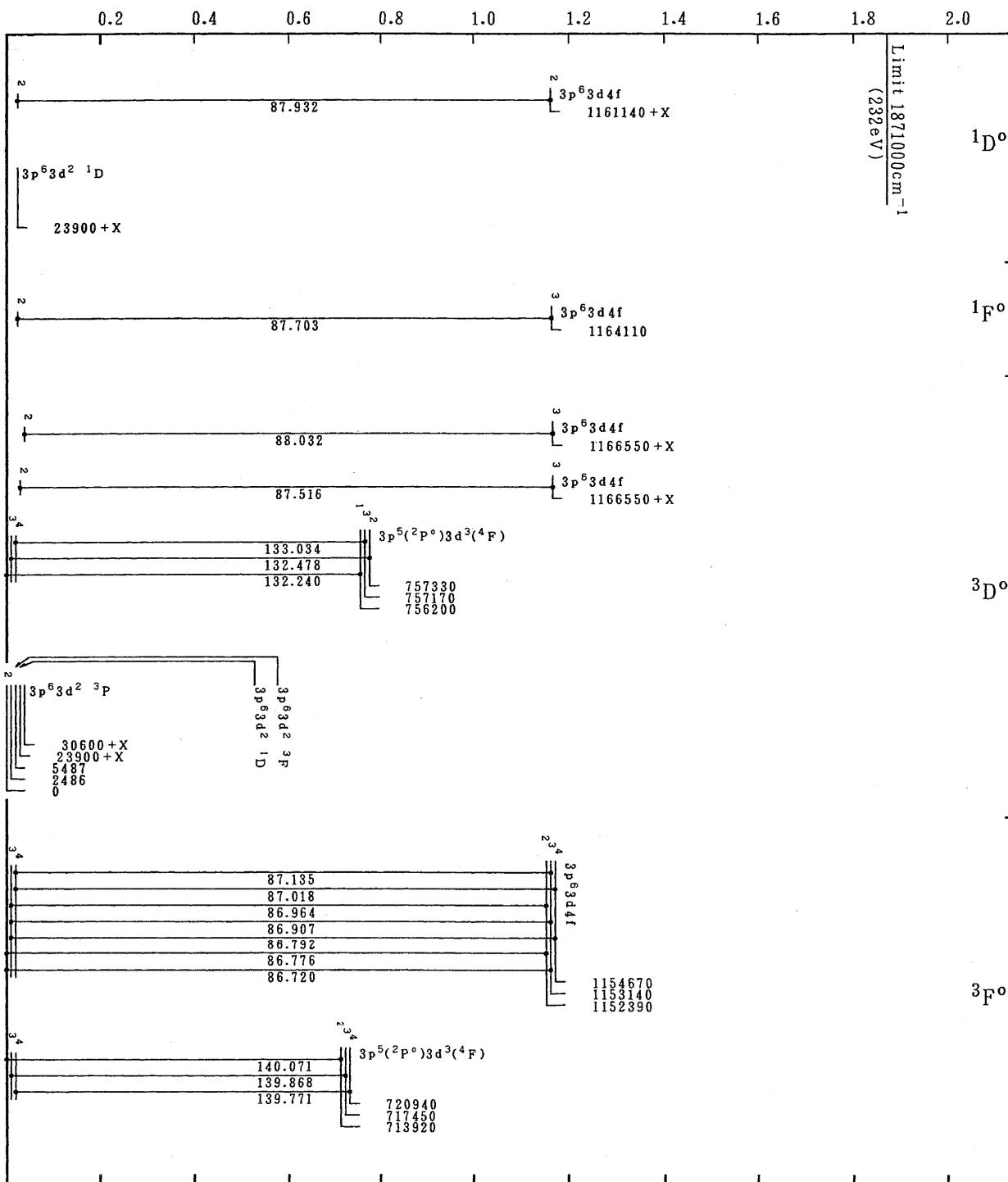
Horizontal lines

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

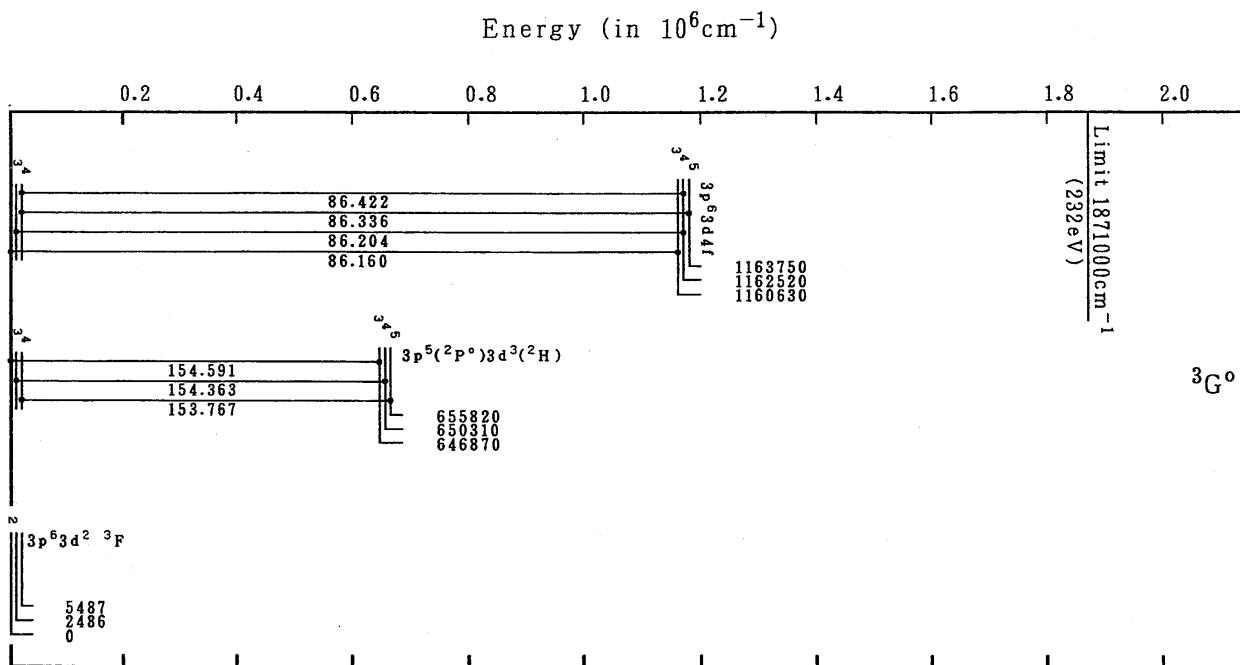
Limit

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

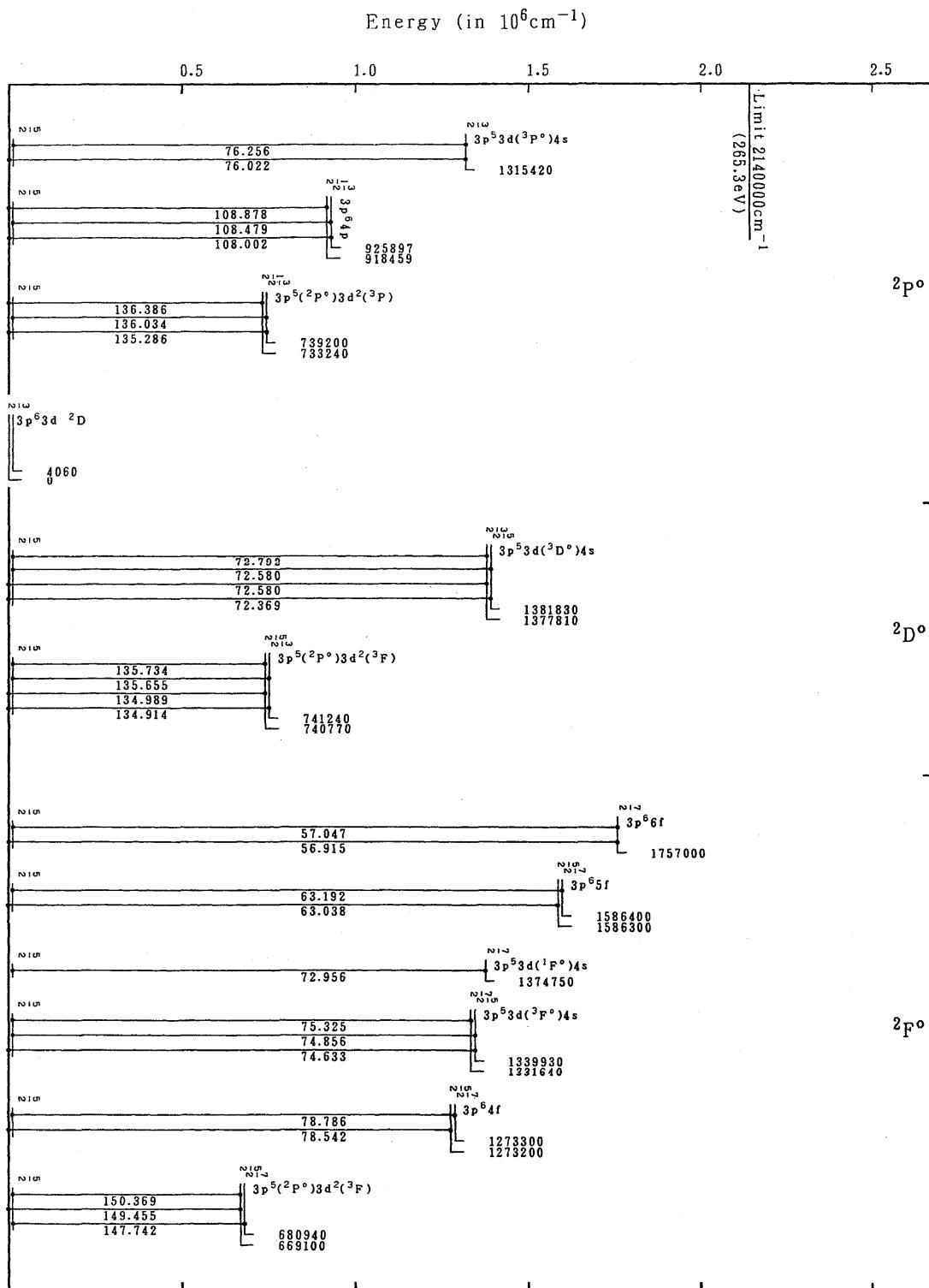
6. Grotrian Diagrams for Cu x-Cu xxix

Energy (in 10^6 cm^{-1})

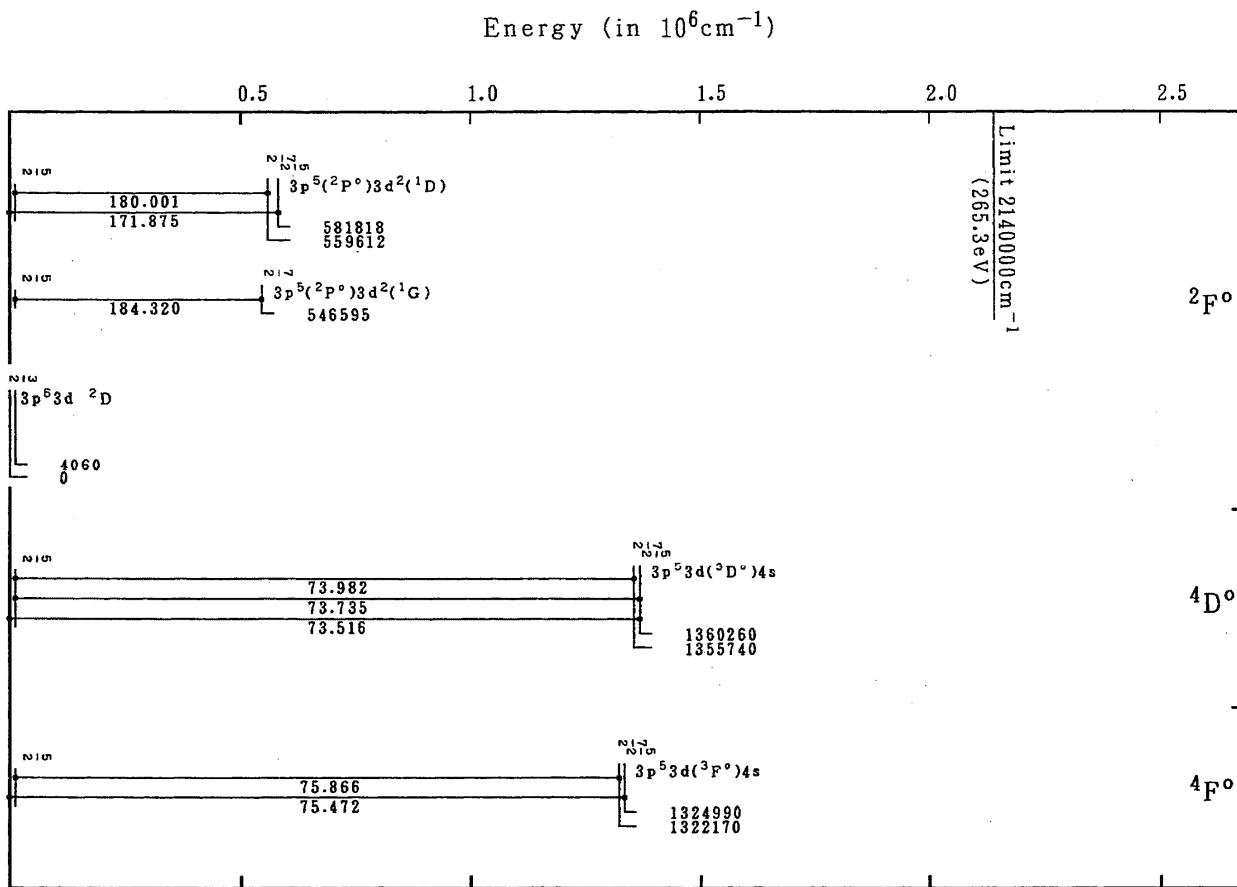
Grotrian diagrams for Cu x (Ca sequence)



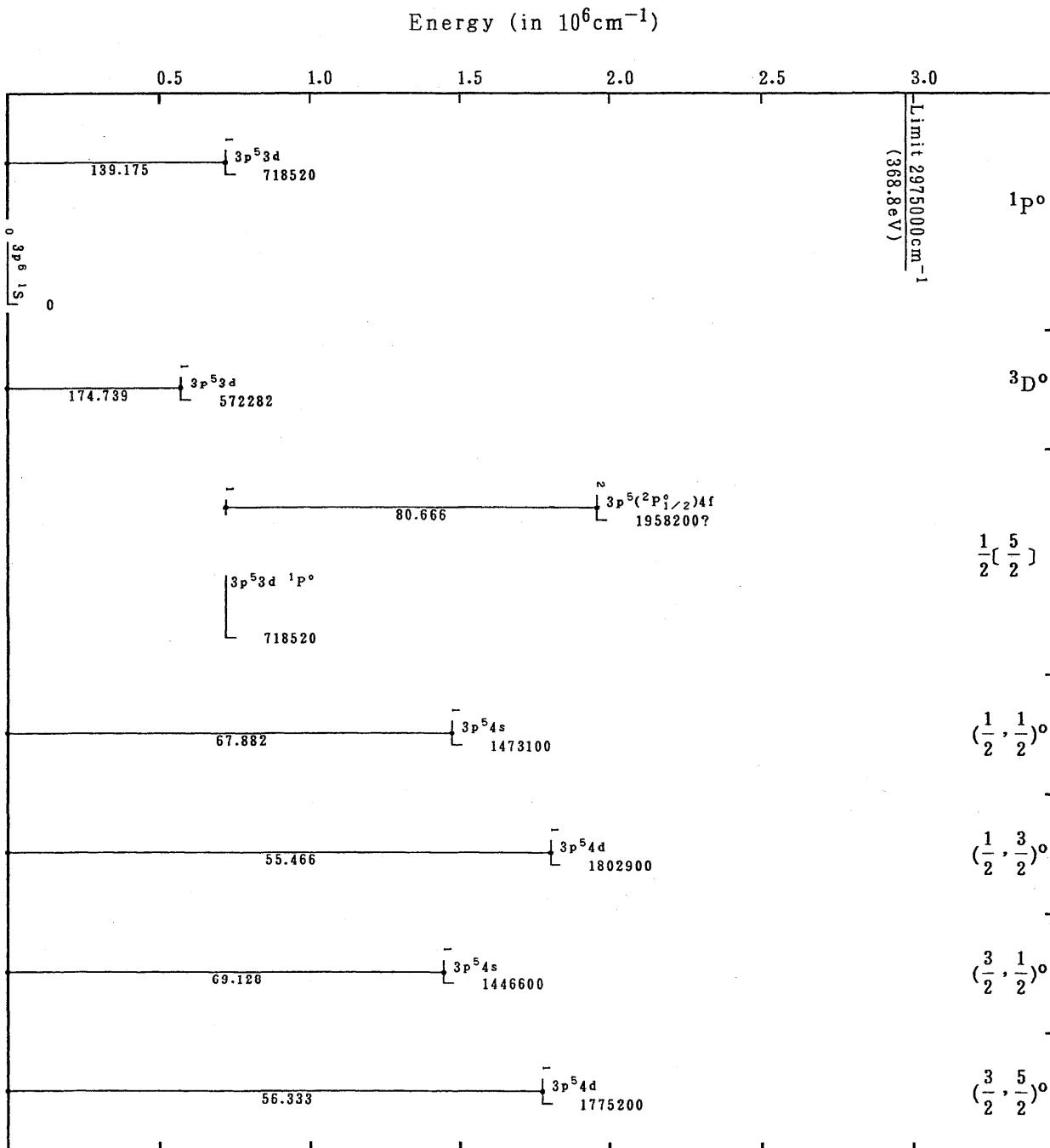
Grotrian diagrams for Cu x (Ca sequence) – Continued



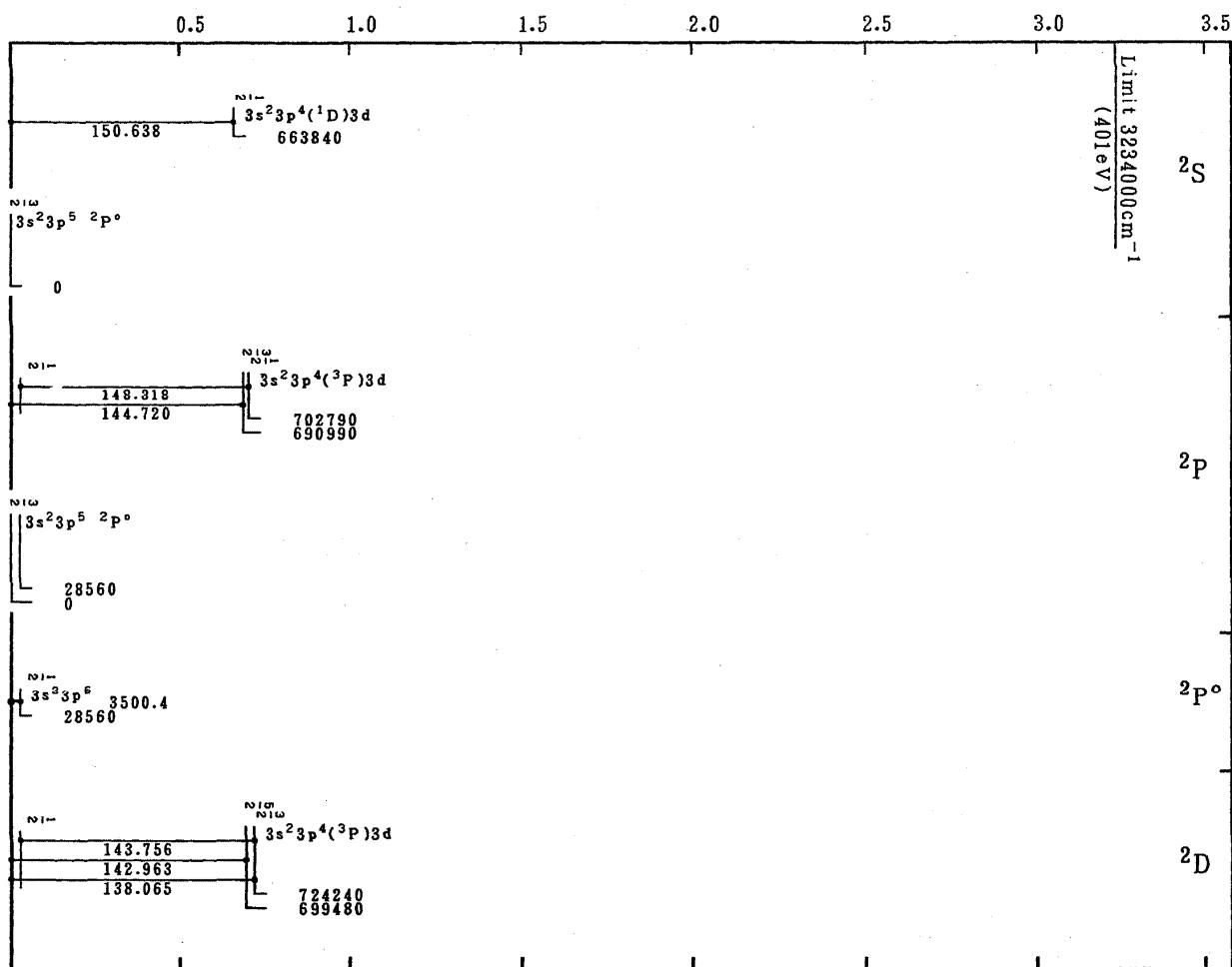
Grotian diagrams for Cu xi (K sequence)



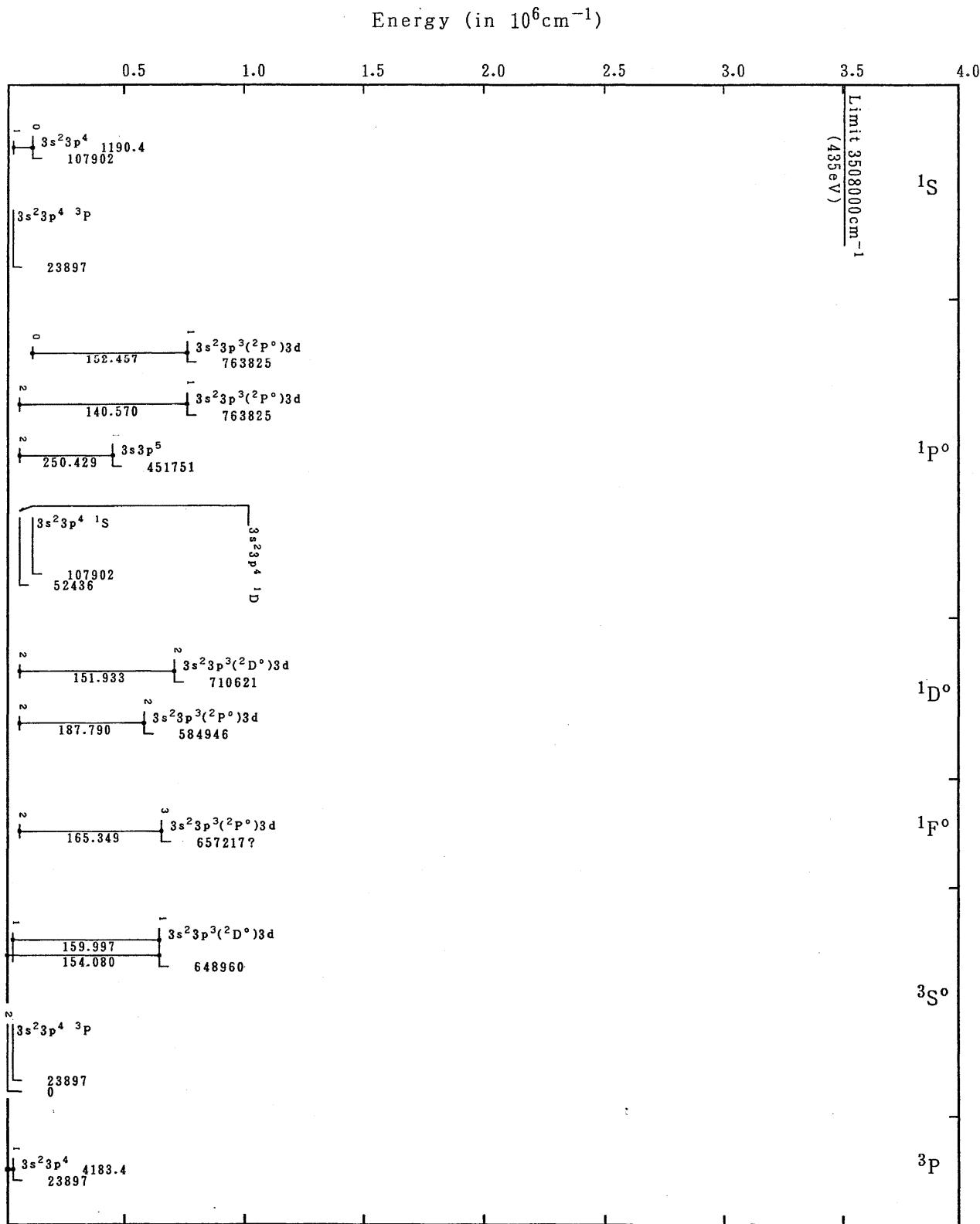
Grotrian diagrams for Cu xi (K sequence) — Continued



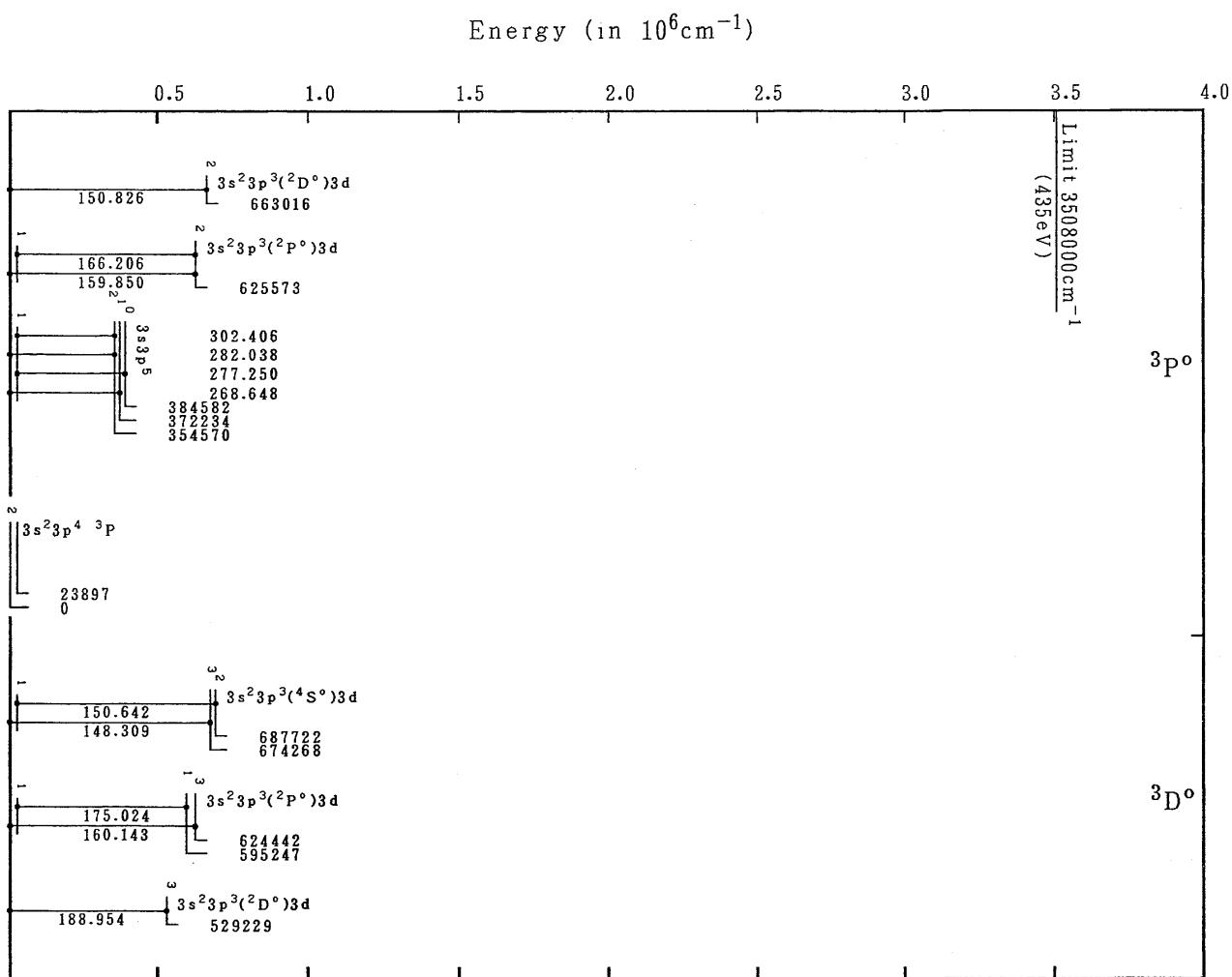
Grotrian diagrams for Cu XII (Ar sequence)

Energy (in 10^6 cm^{-1})

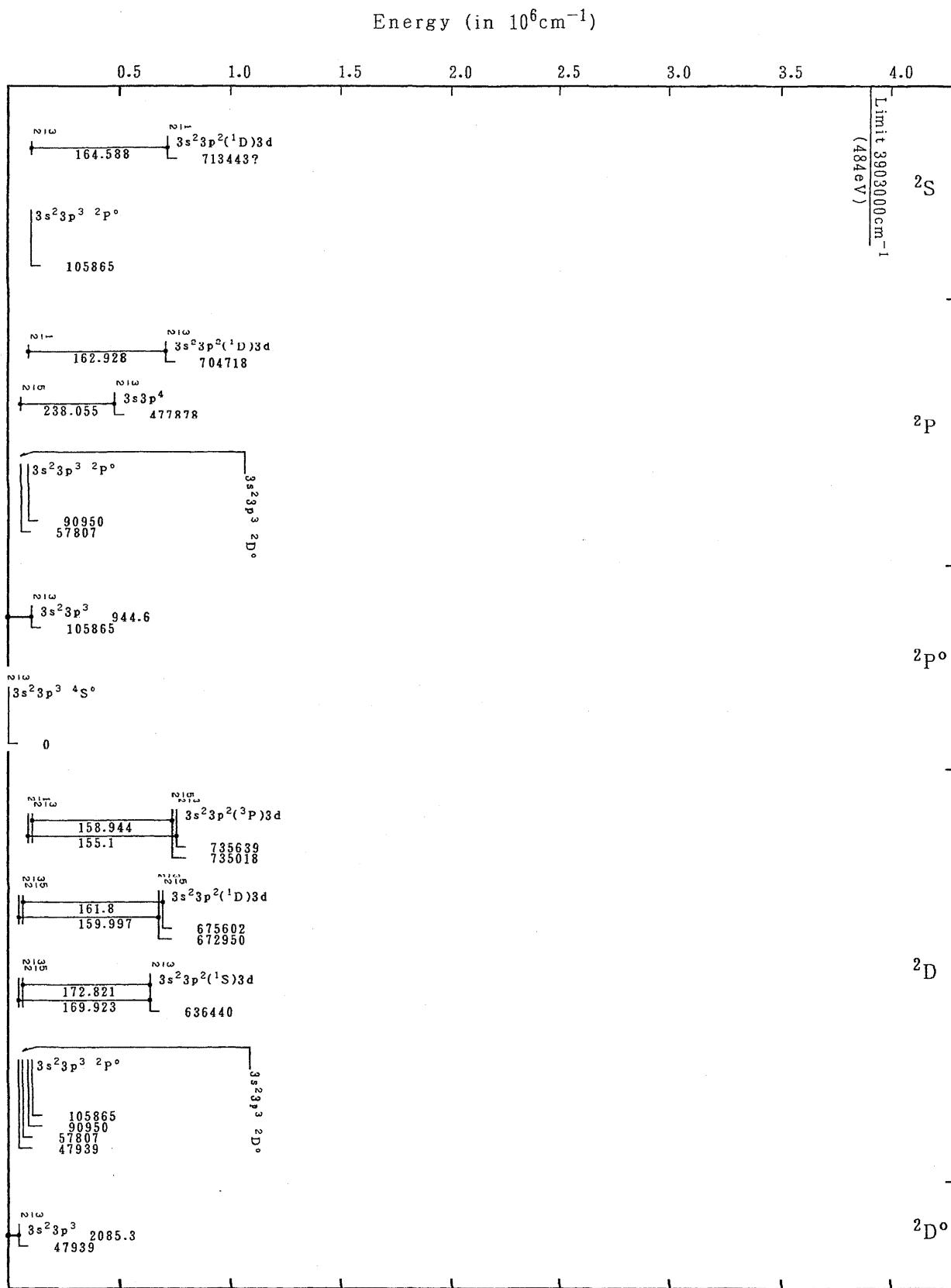
Grotrian diagrams for Cu XIII (Cl sequence)



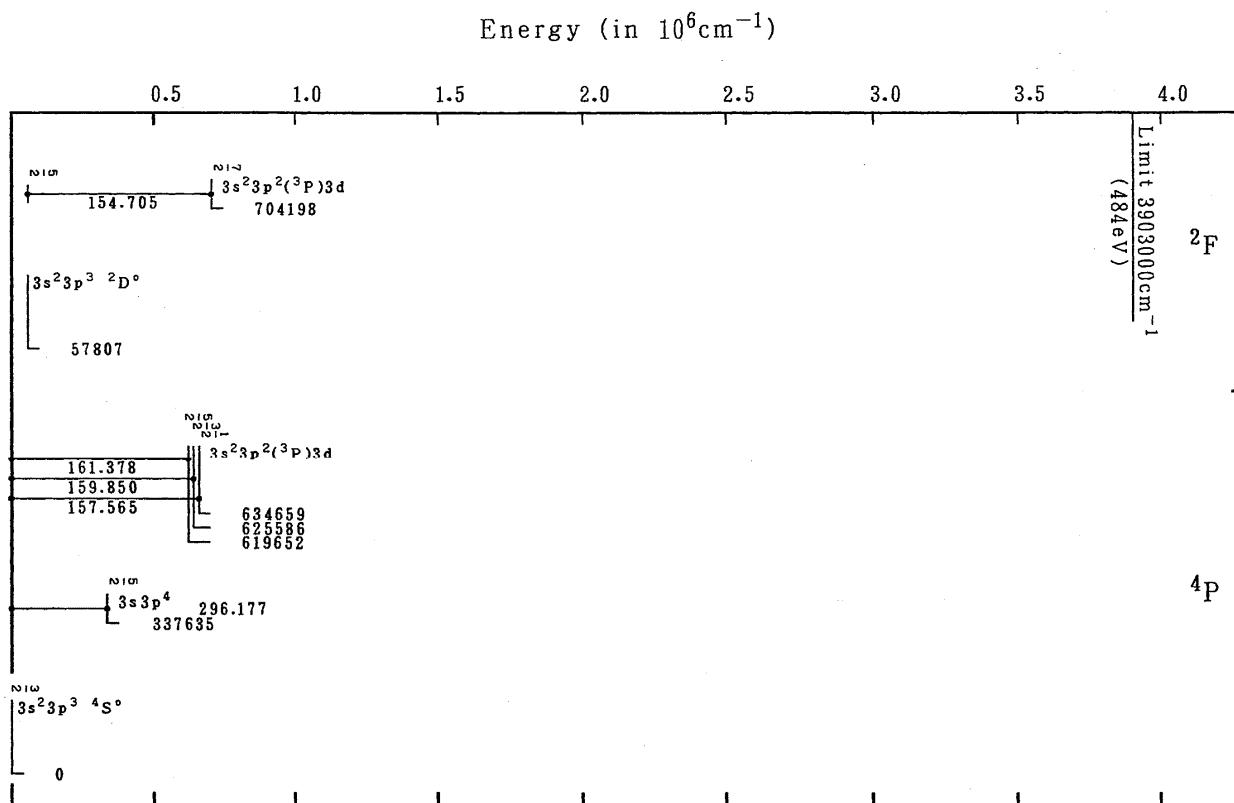
Grotrian diagrams for Cu XIV (S sequence)



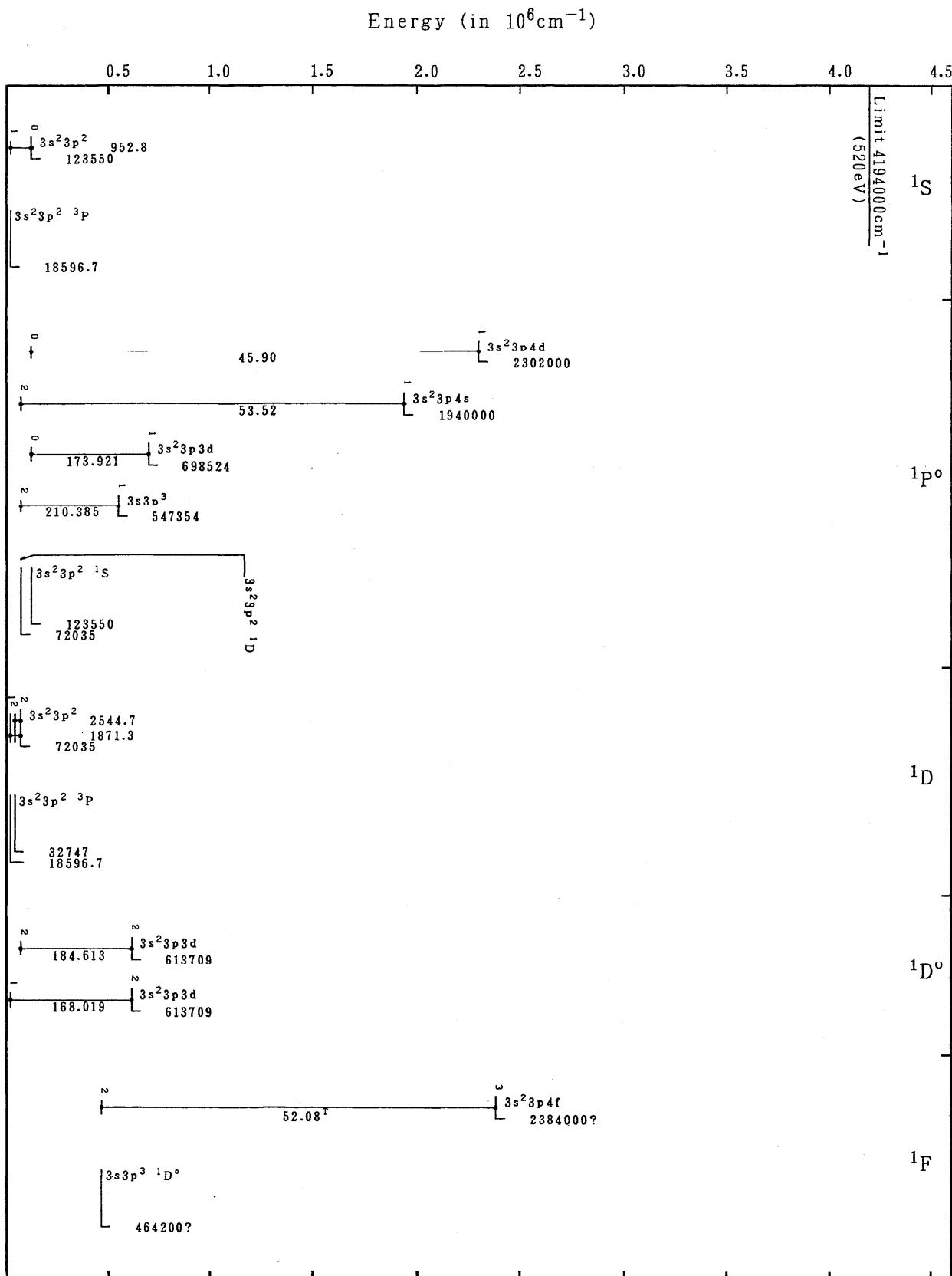
Grotrian diagrams for Cu XIV (S sequence) – Continued



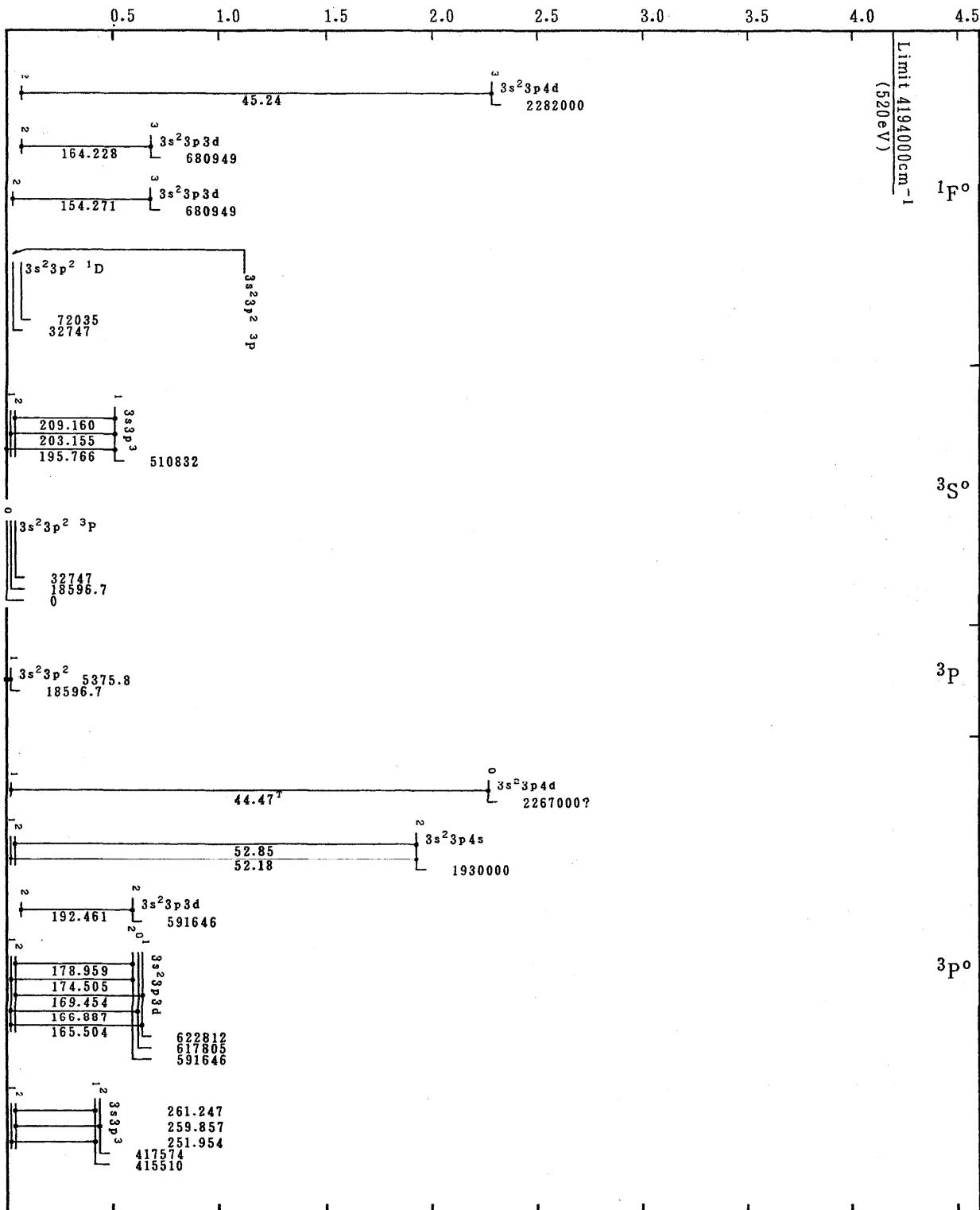
Grotrian diagrams for Cu XV (P sequence)



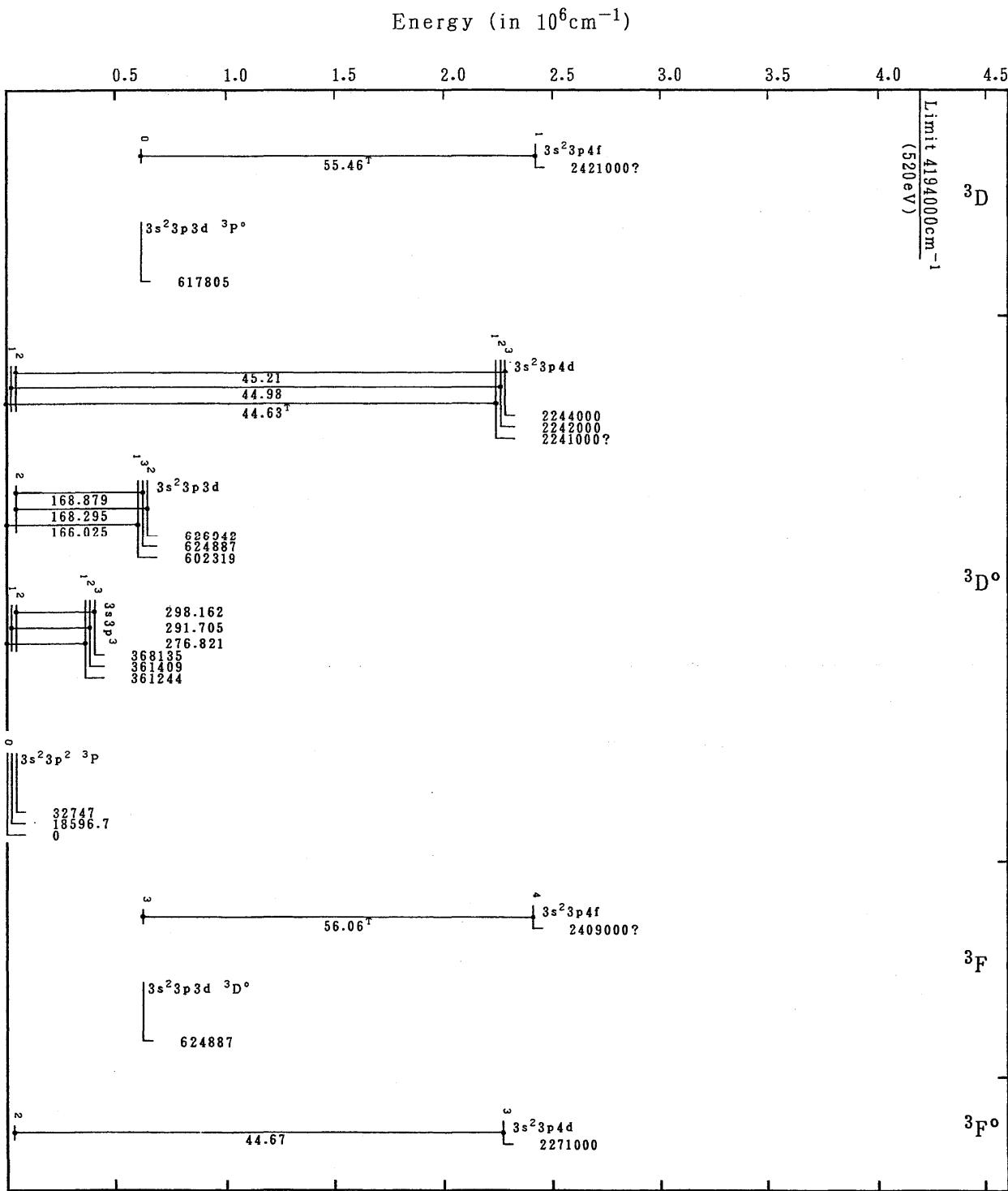
Grotrian diagrams for Cu xv (P sequence) — Continued



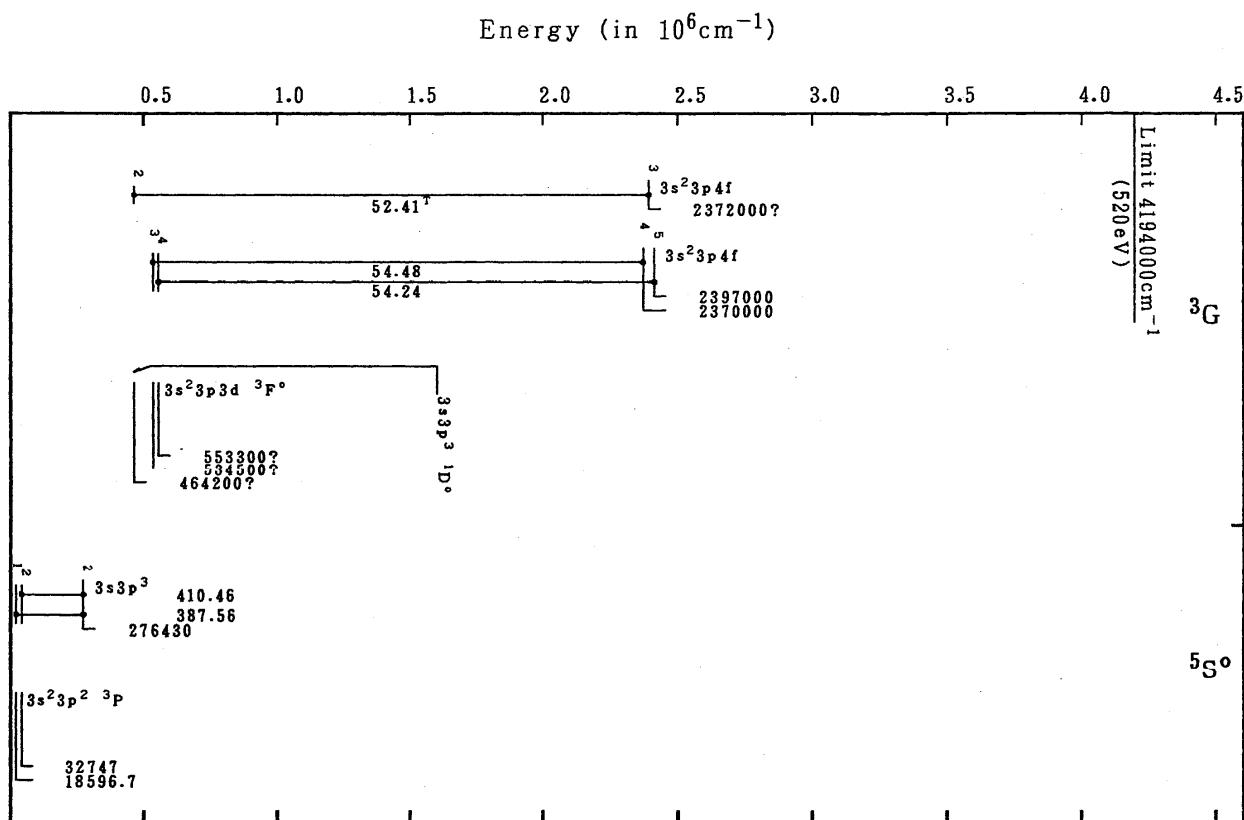
Grotrian diagrams for Cu XVI (Si sequence)

Energy (in 10^6 cm^{-1})

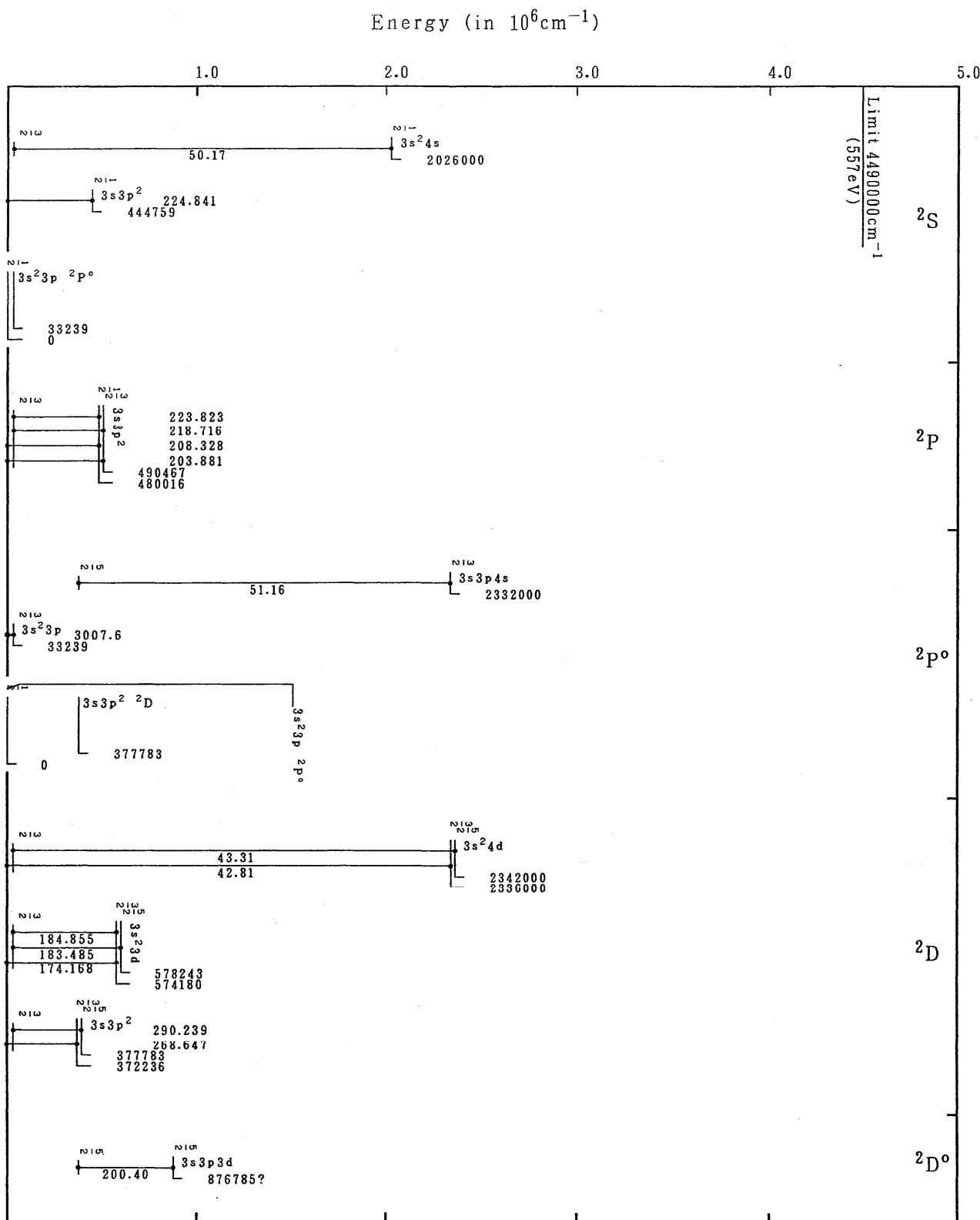
Grotrian diagrams for Cu XVI (Si sequence) -- Continued



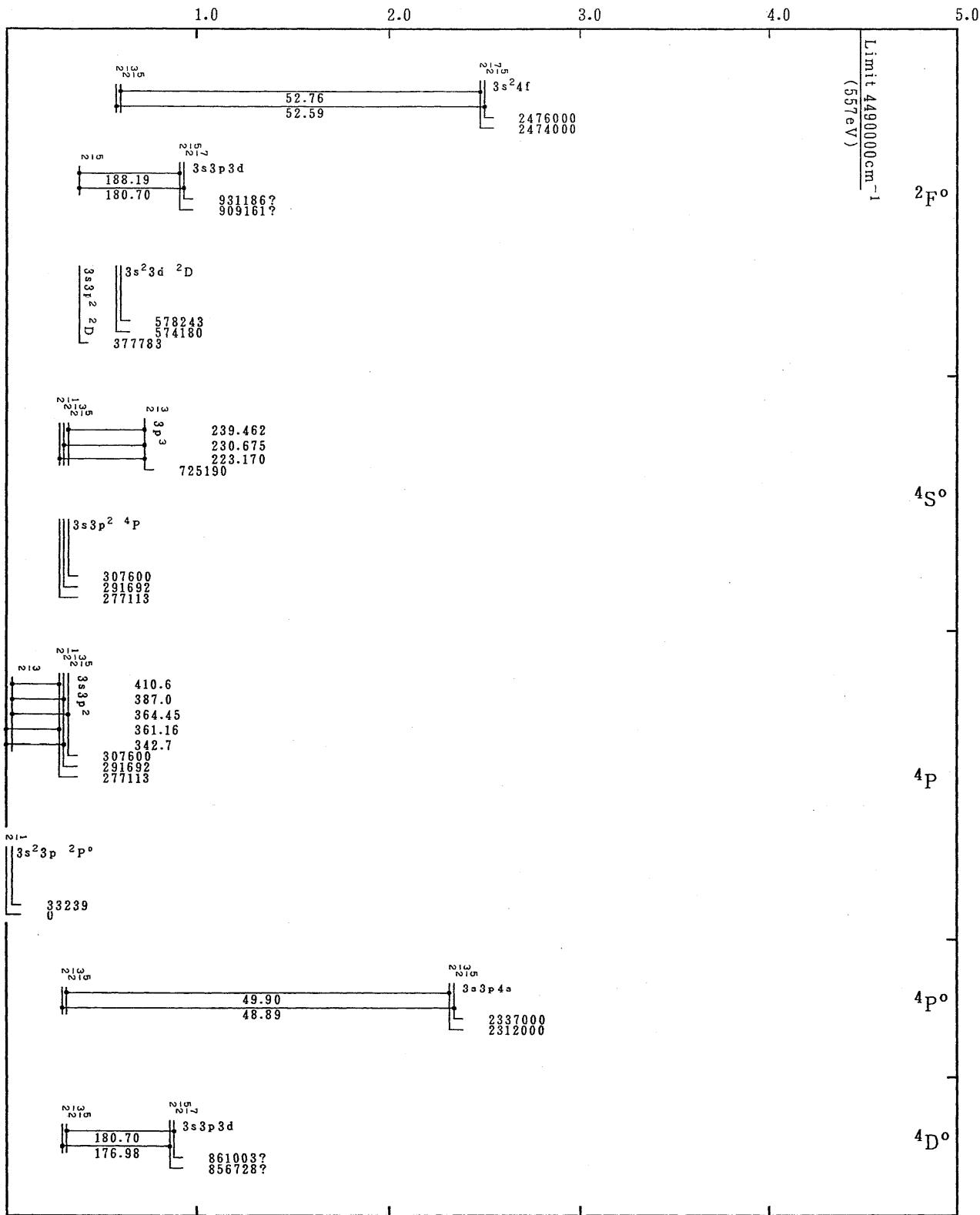
Grotrian diagrams for Cu xvi (Si sequence) — Continued



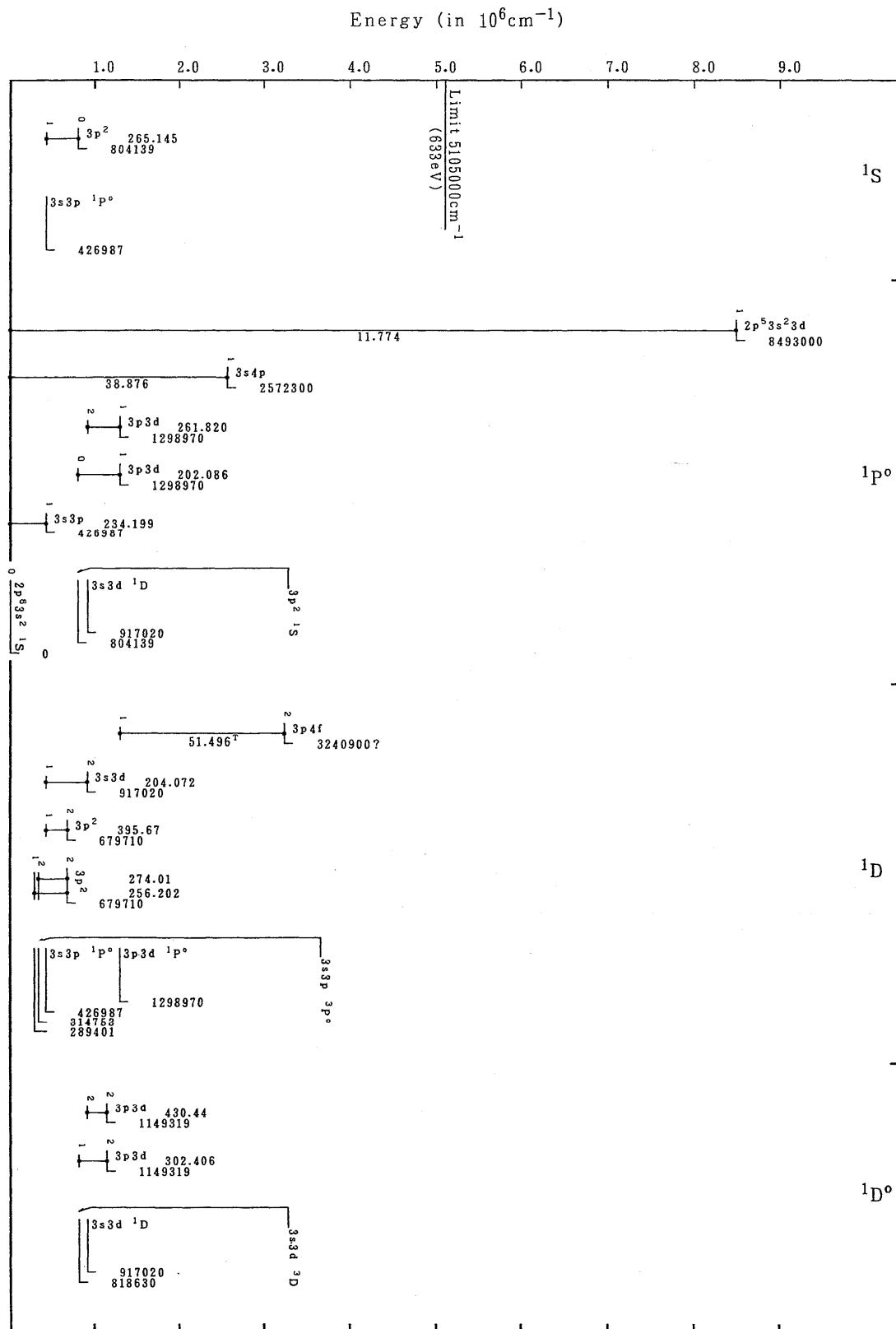
Grotrian diagrams for Cu xvi (Si sequence) – Continued



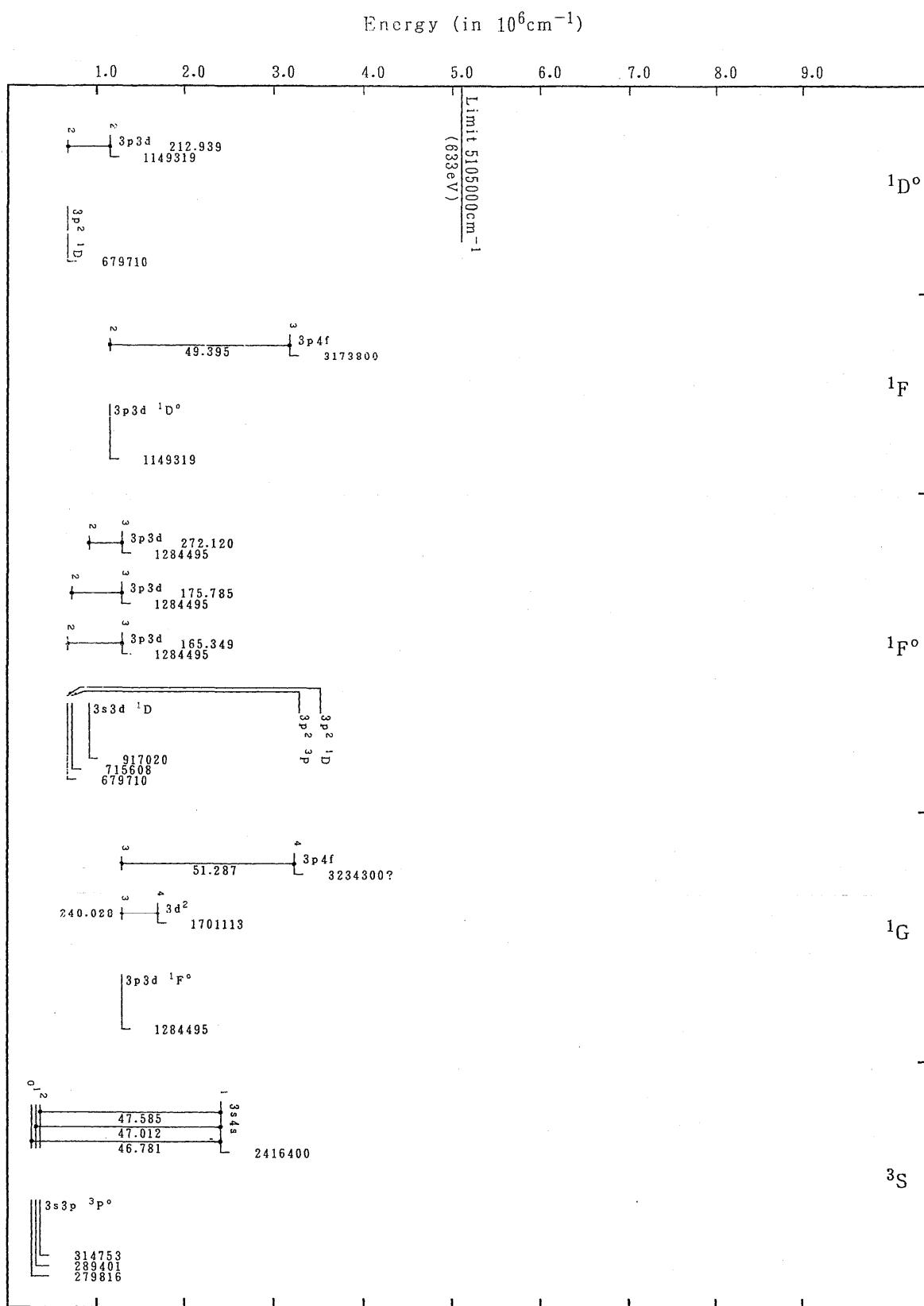
Grotrian diagrams for Cu XVII (Al sequence)

Energy (in 10^6 cm^{-1})

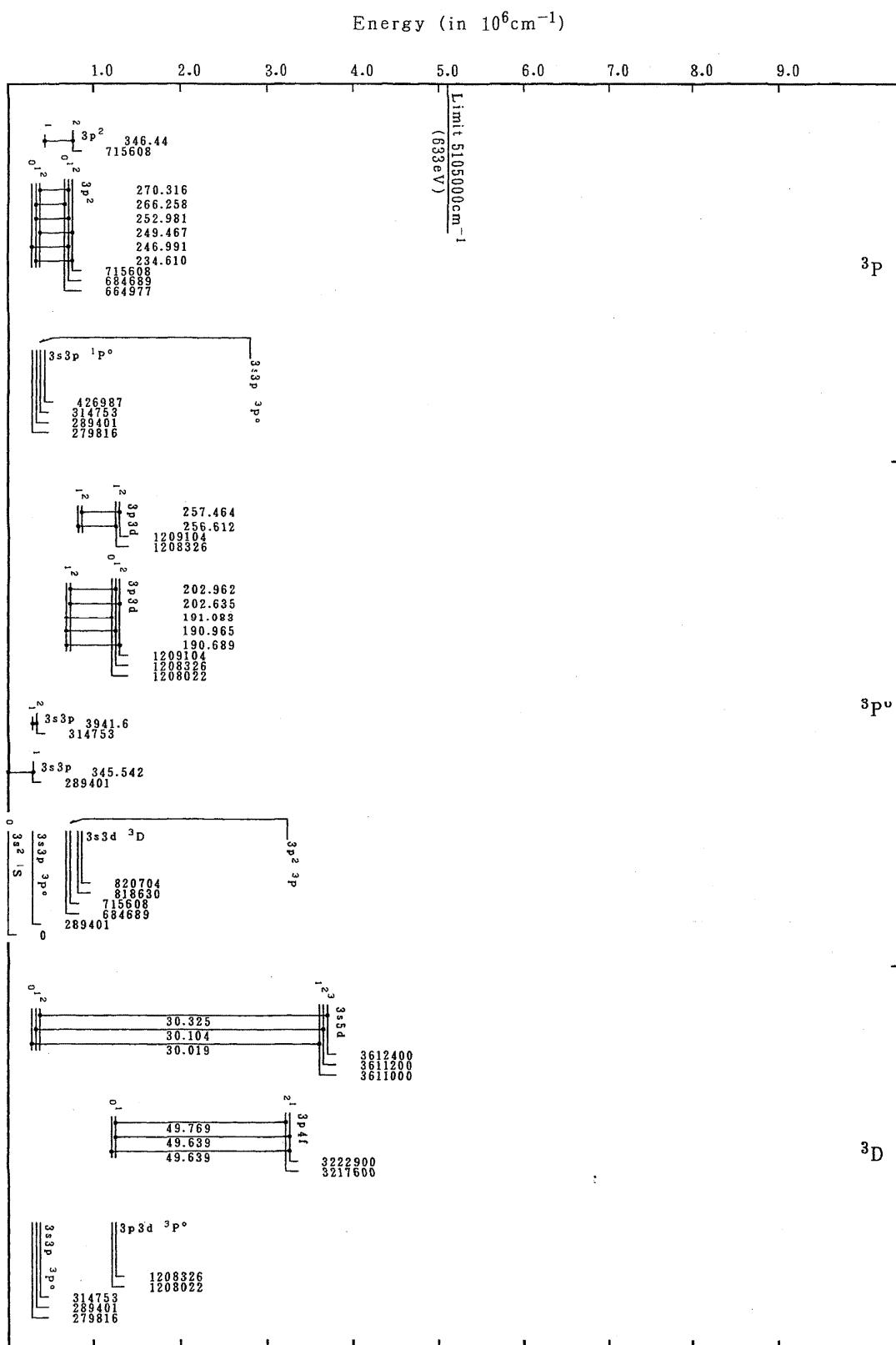
Grotrian diagrams for Cu XVII (Al sequence) — Continued



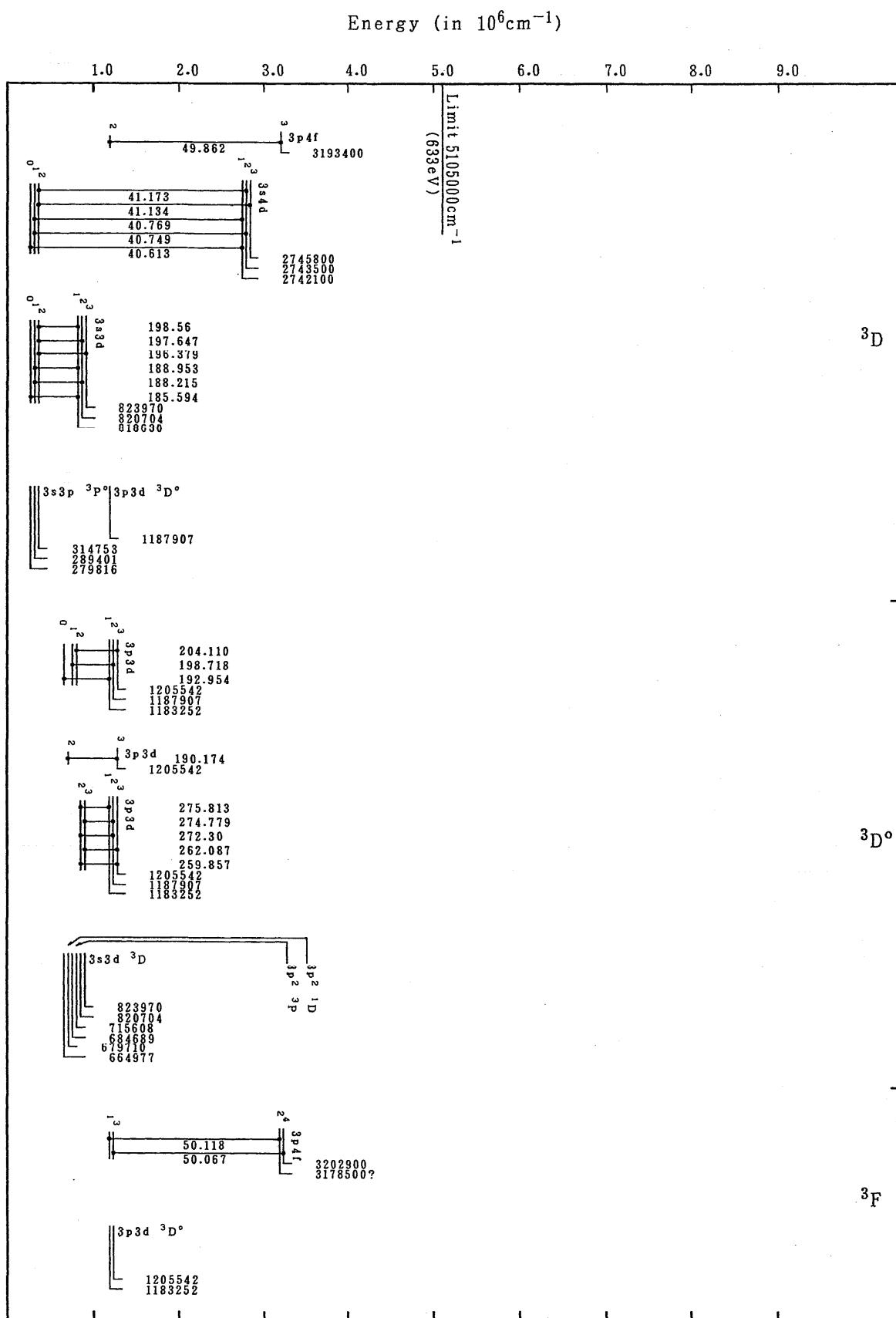
Grotrian diagrams for Cu XVIII (Mg sequence)



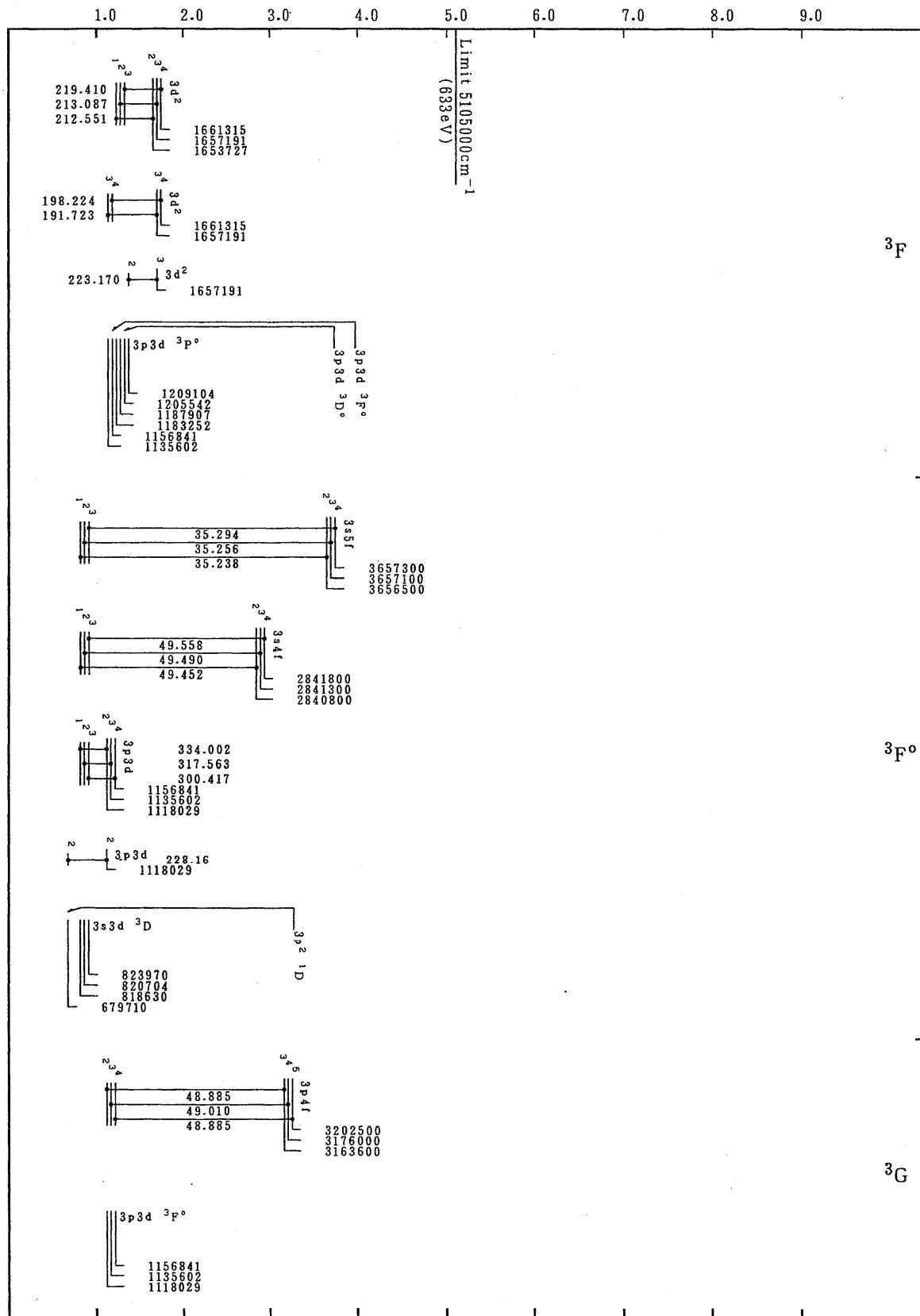
Grotrian diagrams for Cu XVIII (Mg sequence) -- Continued



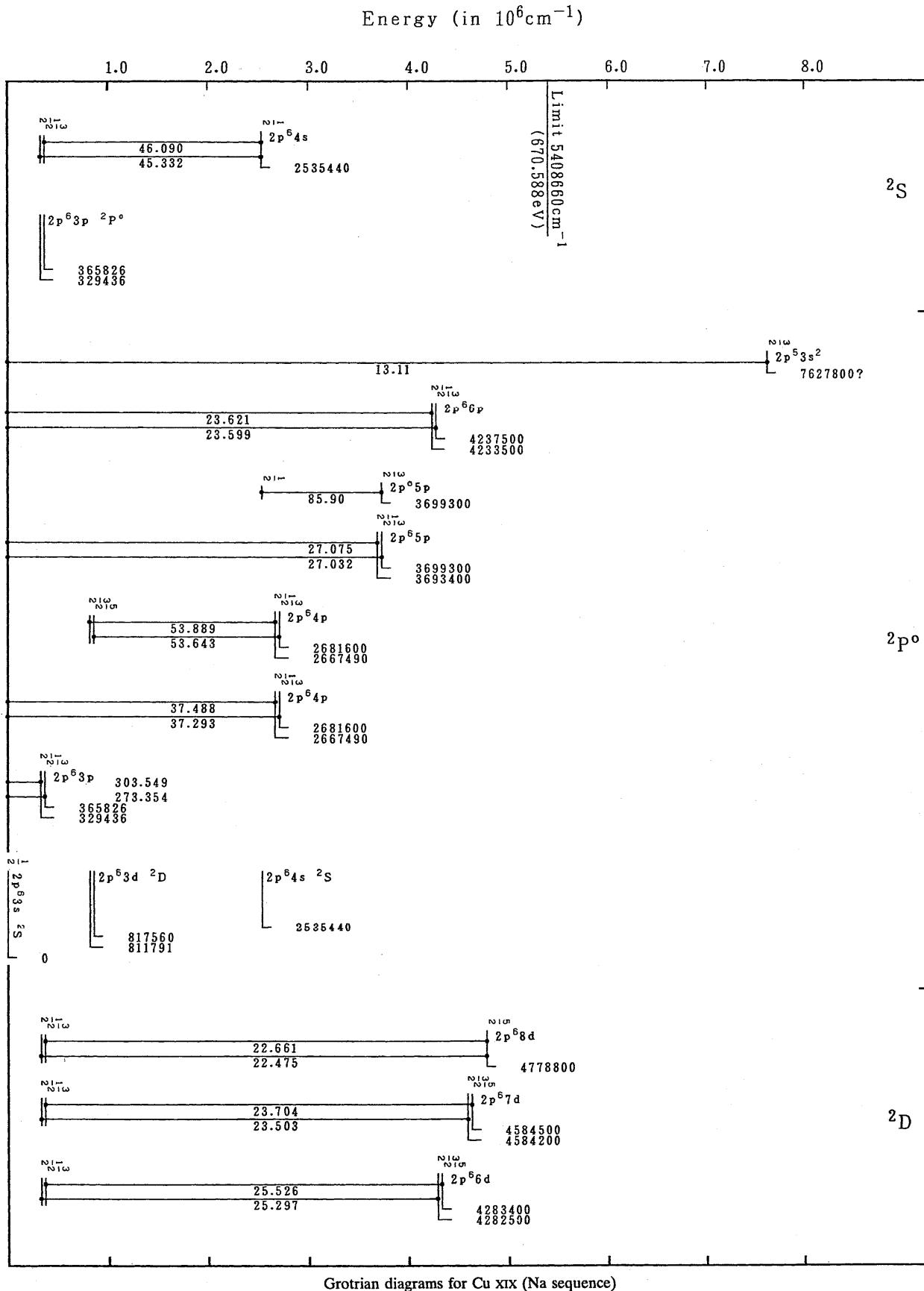
Grotrian diagrams for Cu XVIII (Mg sequence) — Continued



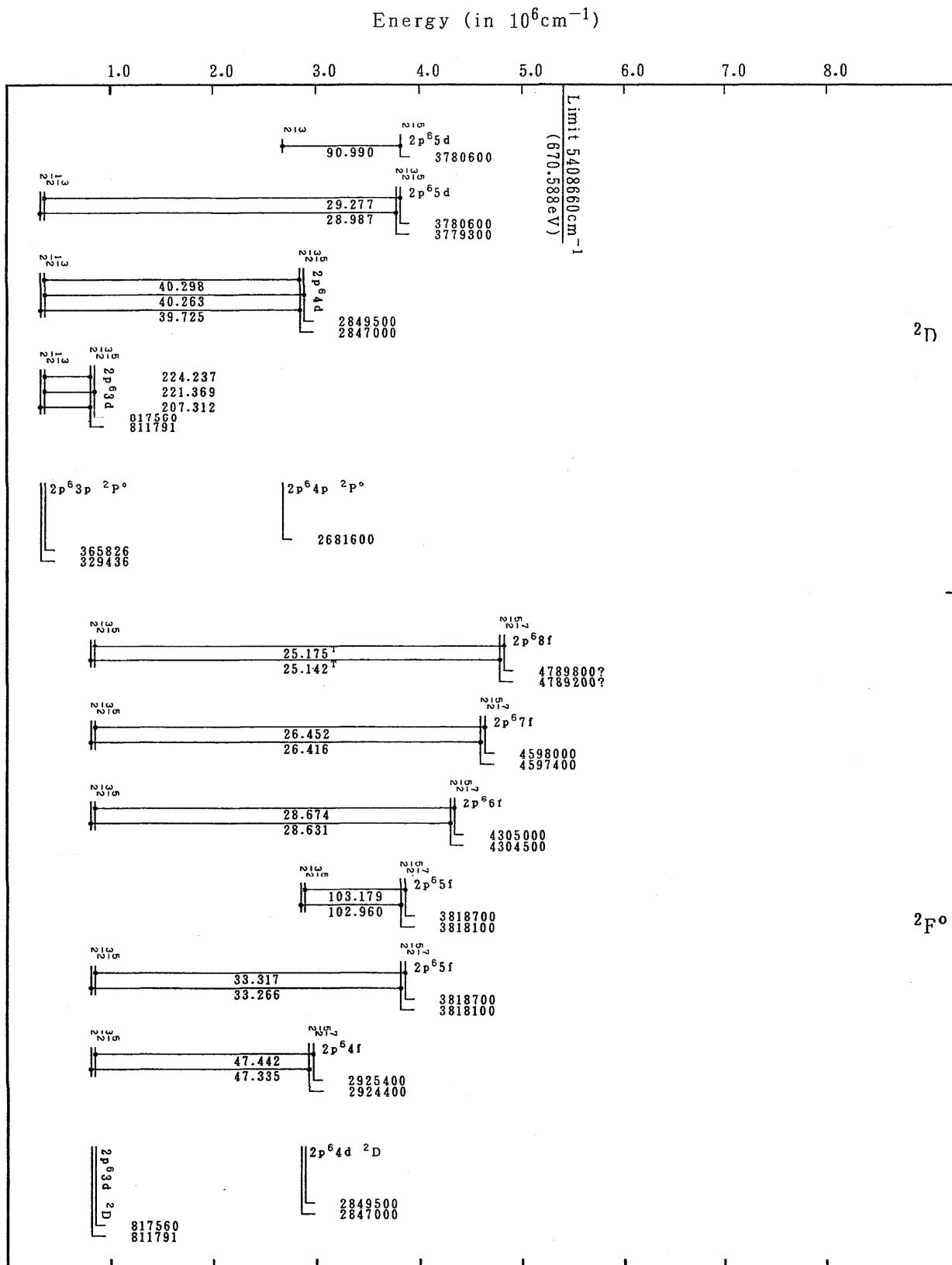
Grotrian diagrams for Cu XVIII (Mg sequence) — Continued

Energy (in 10^6 cm^{-1})

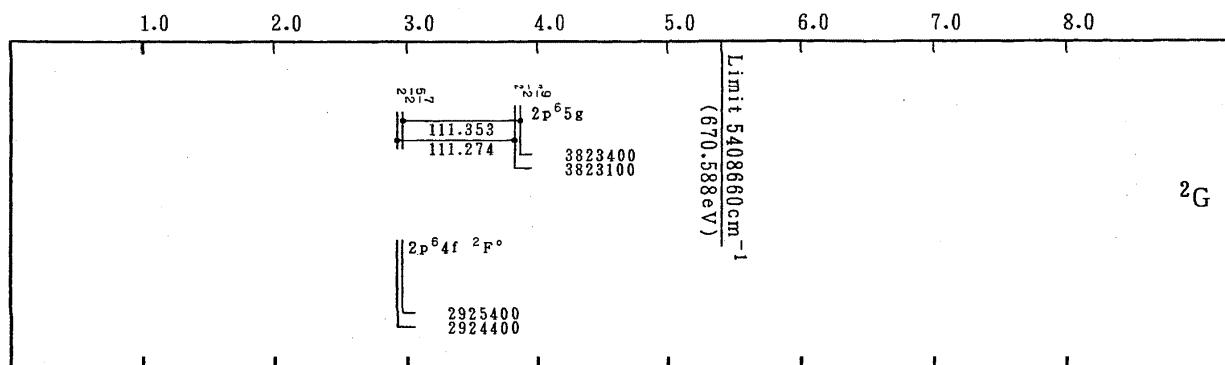
Grotrian diagrams for Cu XVIII (Mg sequence) — Continued



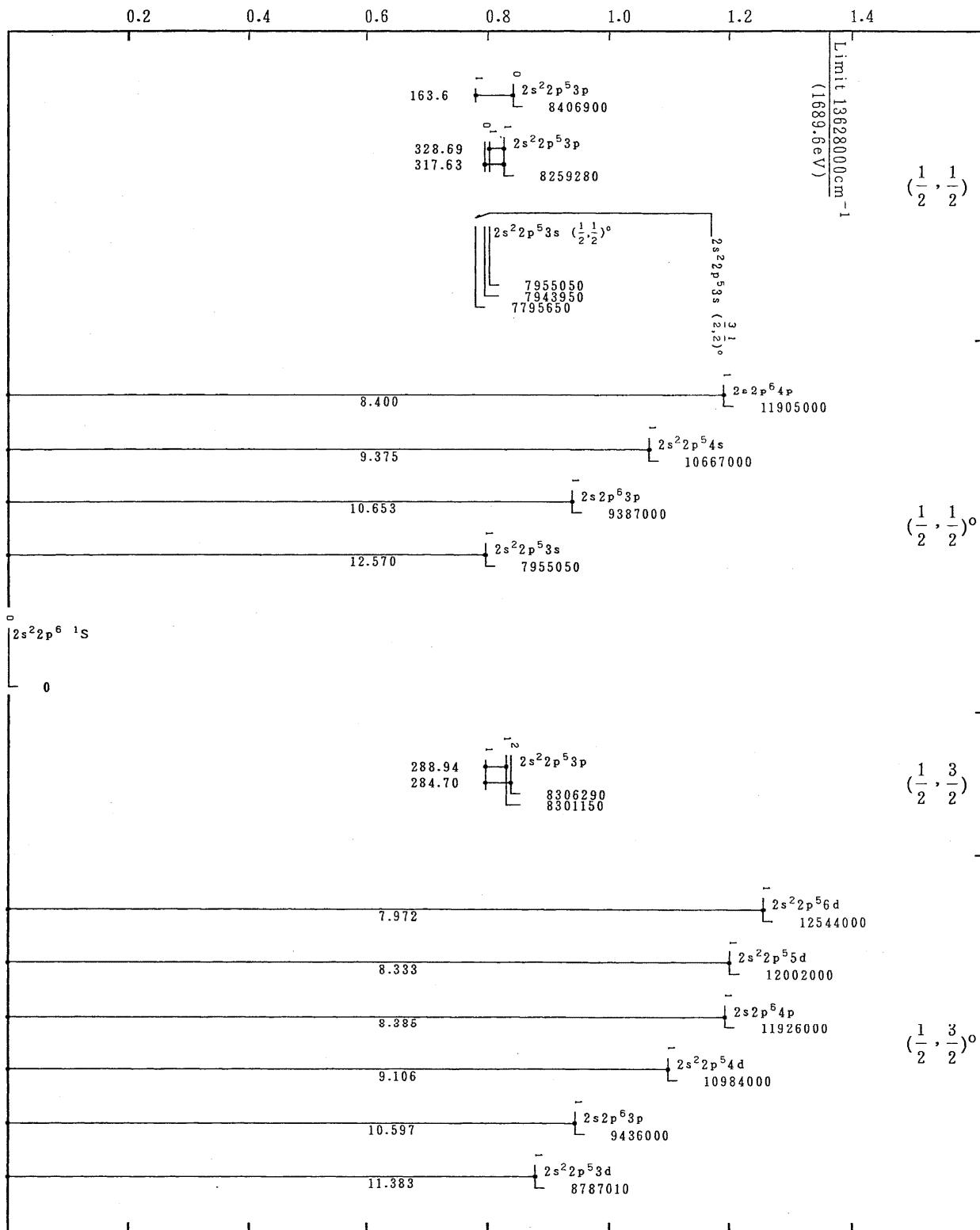
Grotrian diagrams for Cu xix (Na sequence)



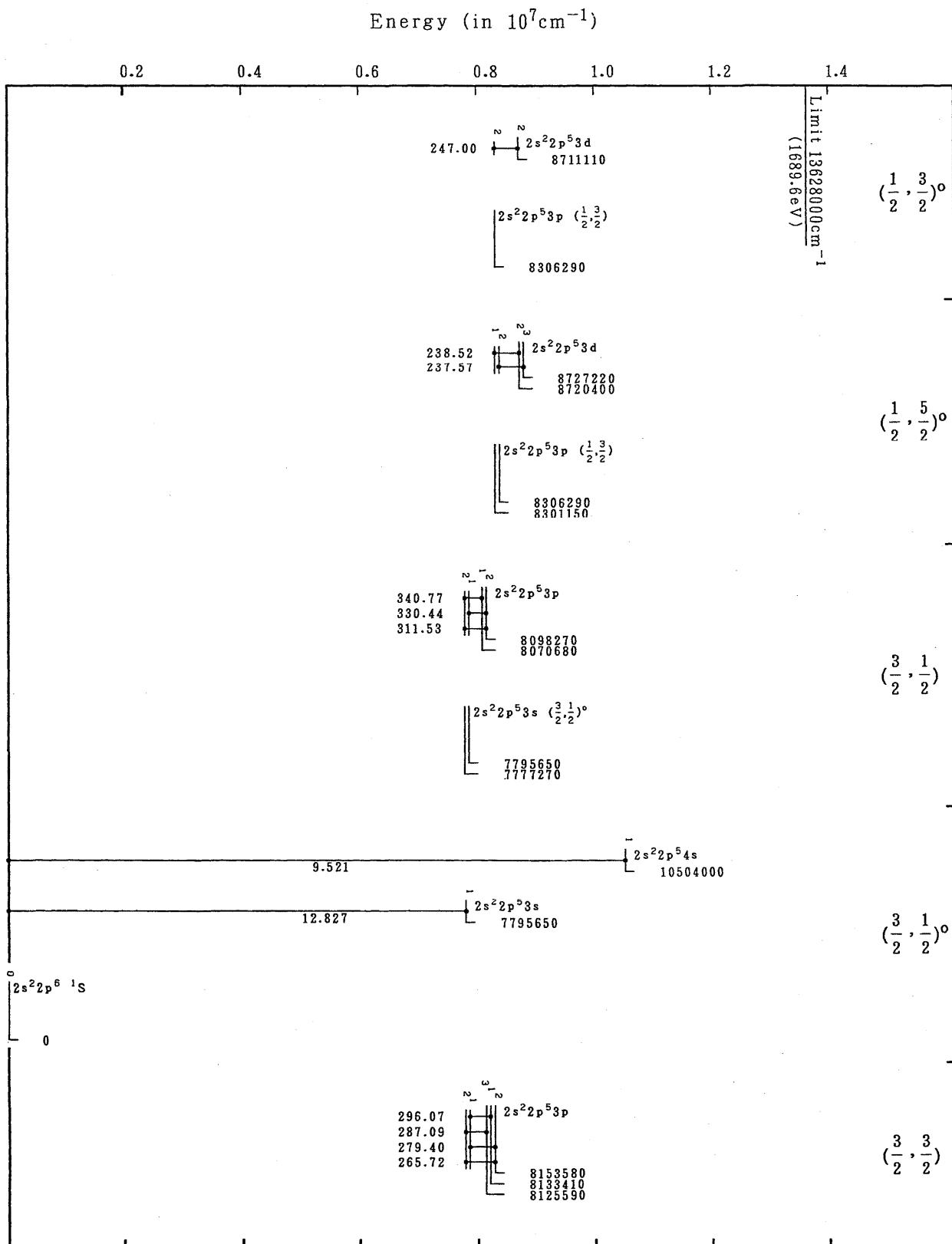
Grotrian diagrams for Cu xix (Na sequence) – Continued

Energy (in 10^6 cm^{-1})

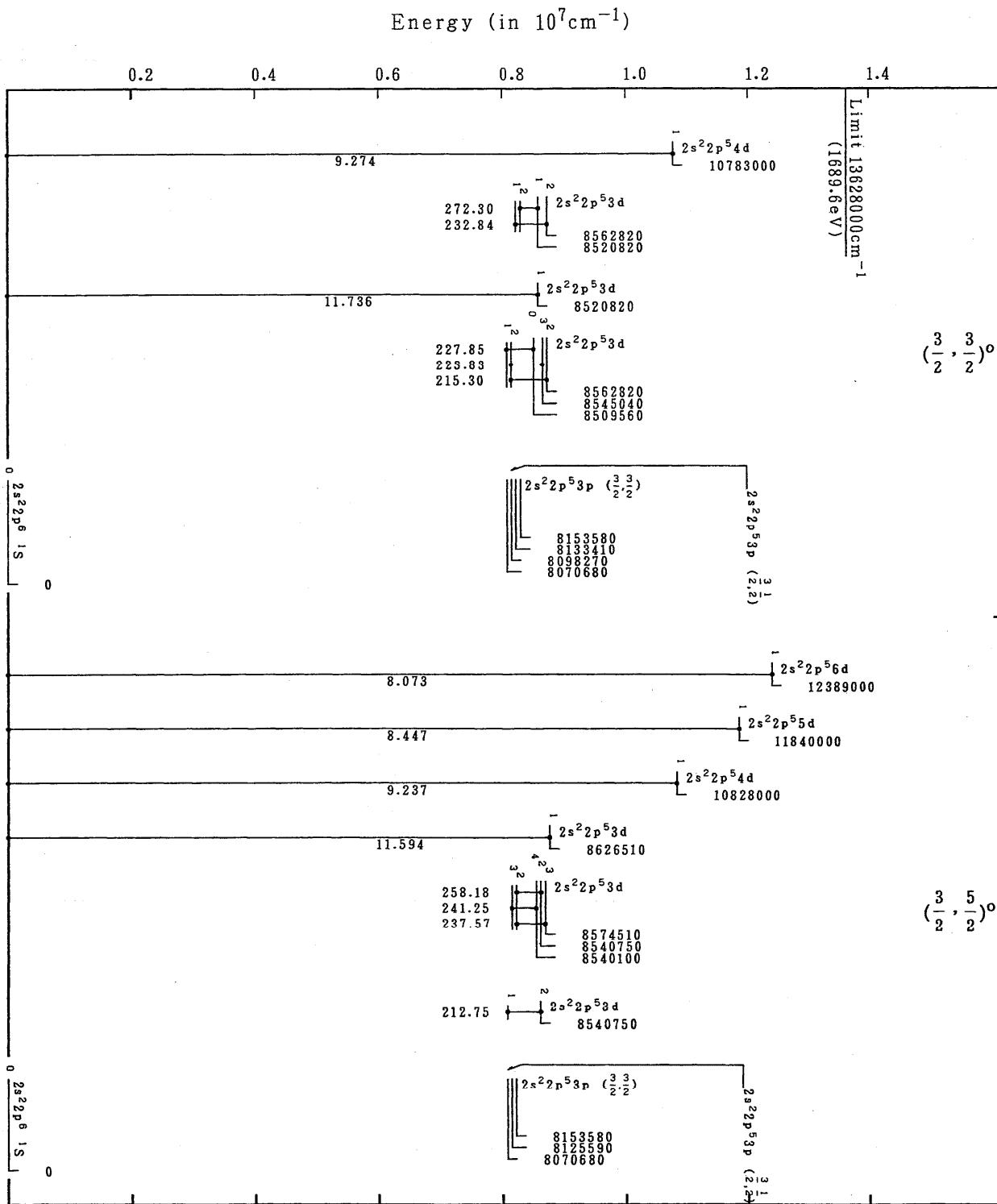
Grotrian diagrams for Cu xix (Na sequence) — Continued

Energy (in 10^7 cm^{-1})

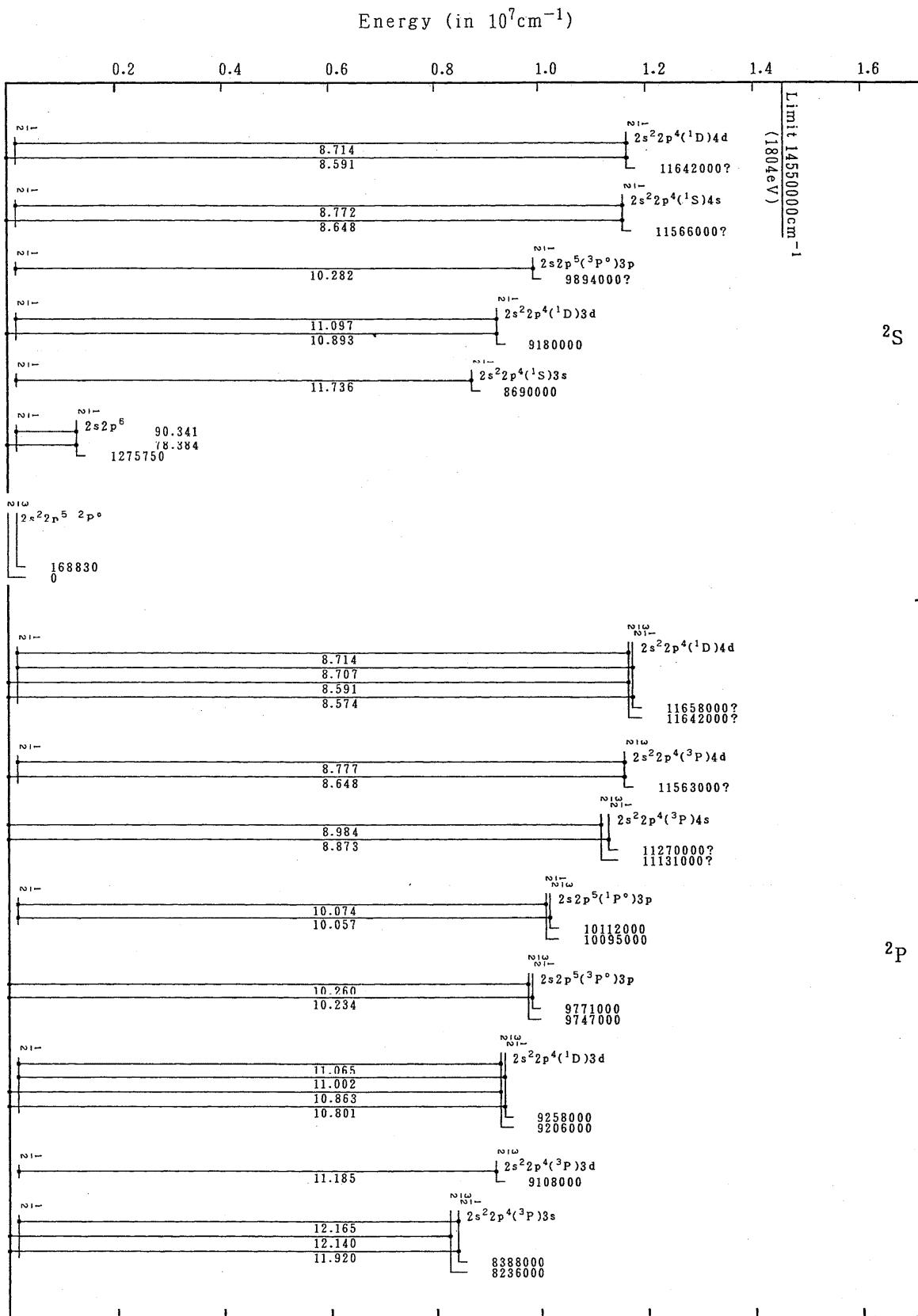
Grotrian diagrams for Cu xx (Ne sequence)



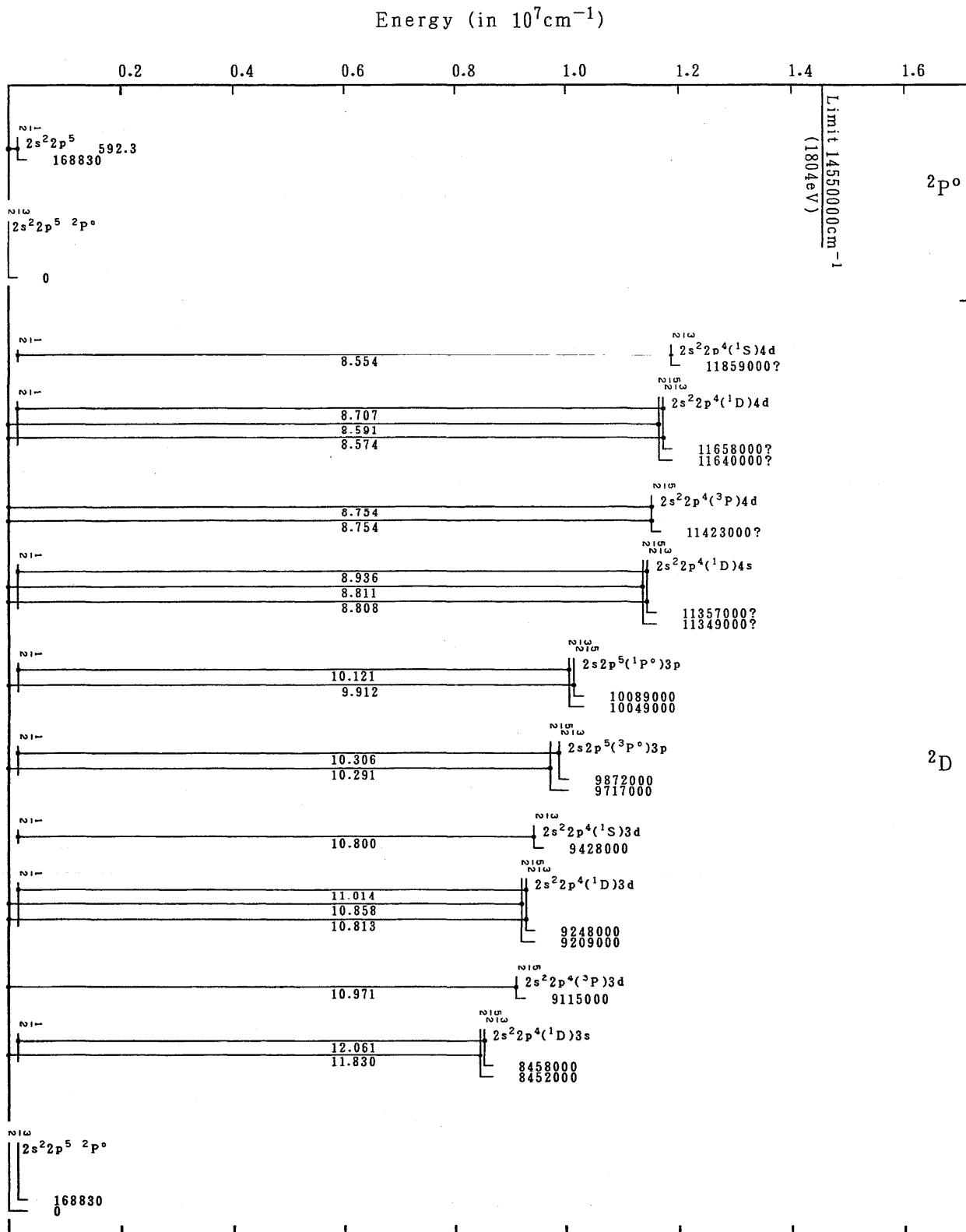
Grotrian diagrams for Cu XX (Ne sequence) — Continued



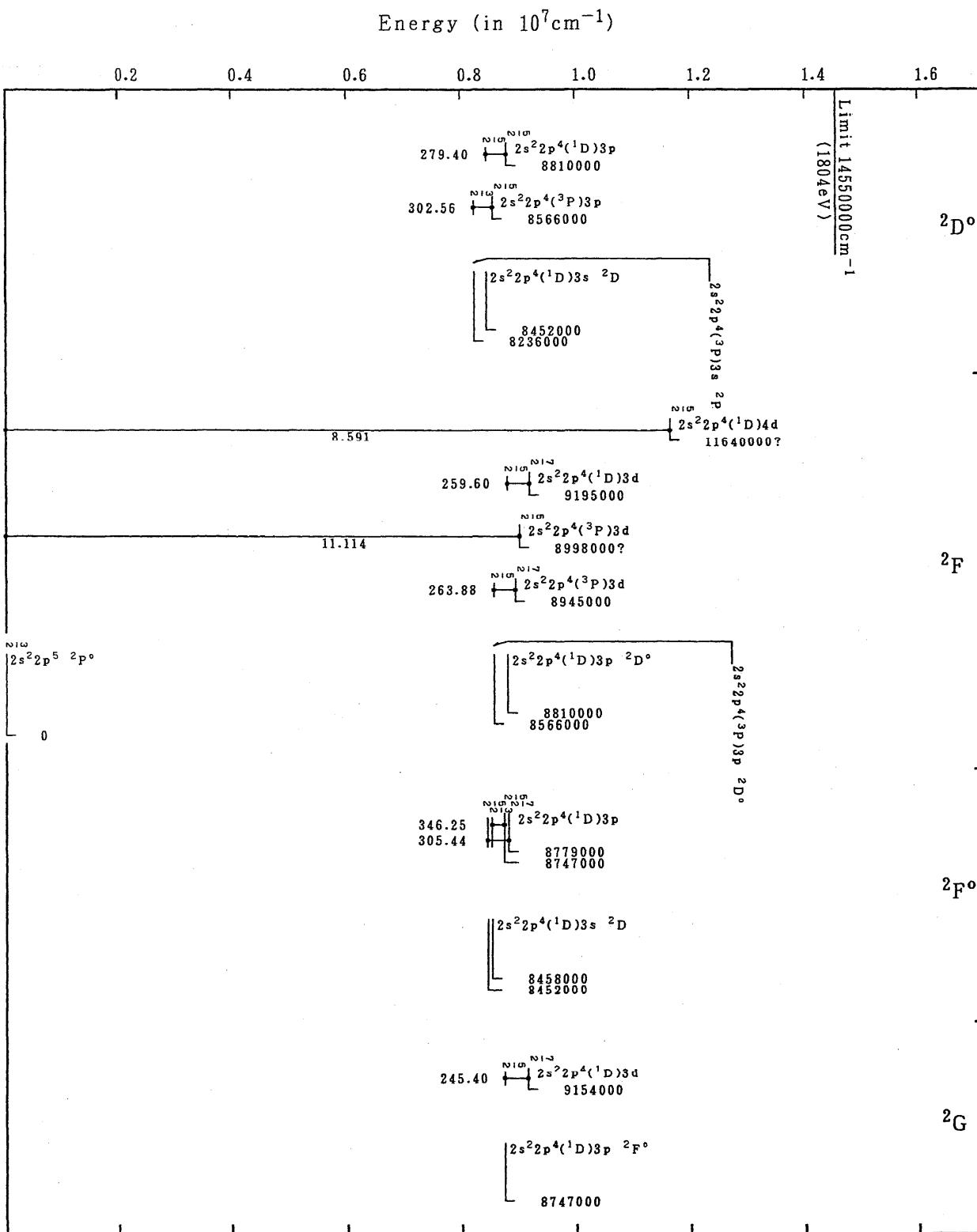
Grotrian diagrams for Cu xx (Ne sequence) — Continued



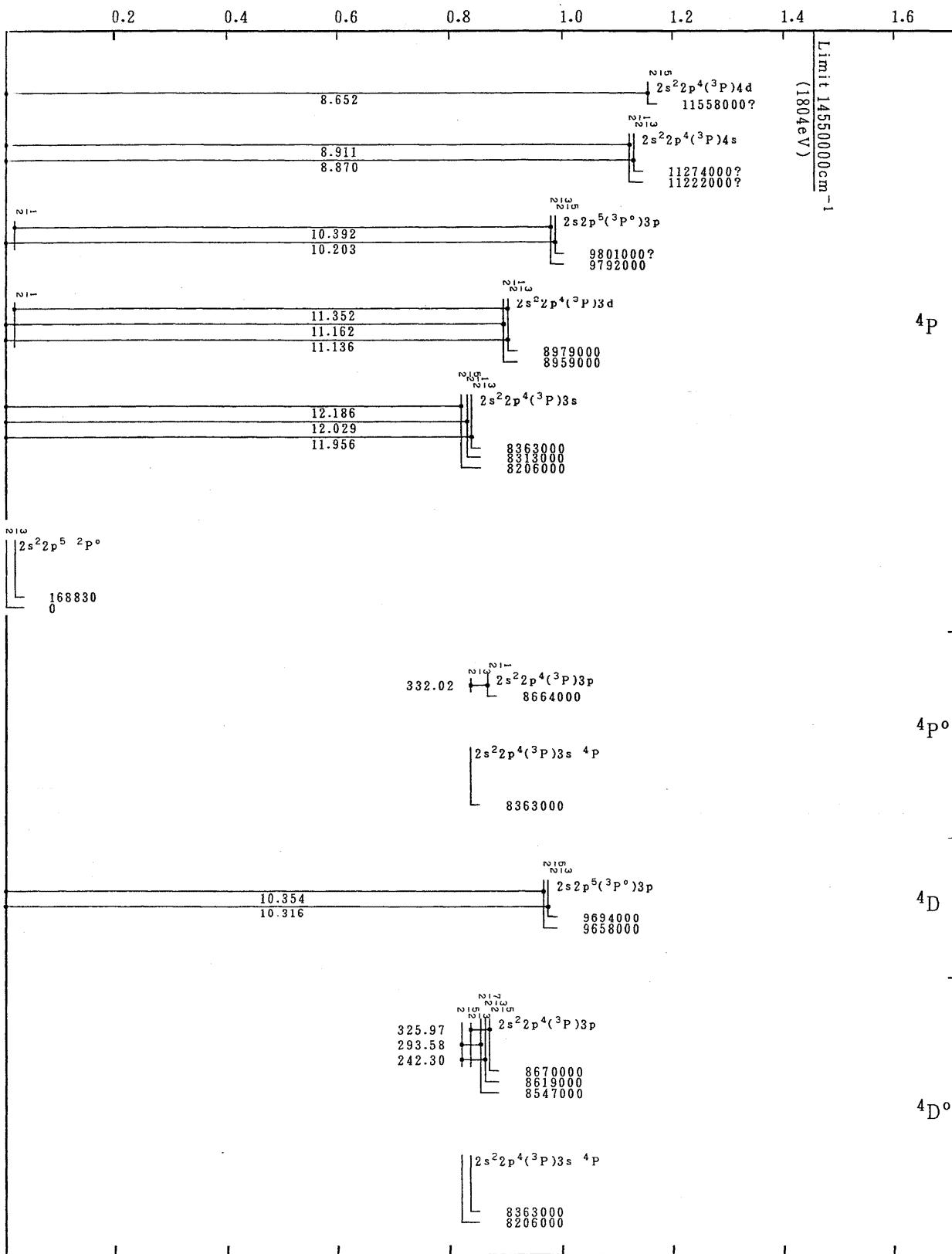
Grotrian diagrams for Cu xxI (F sequence)



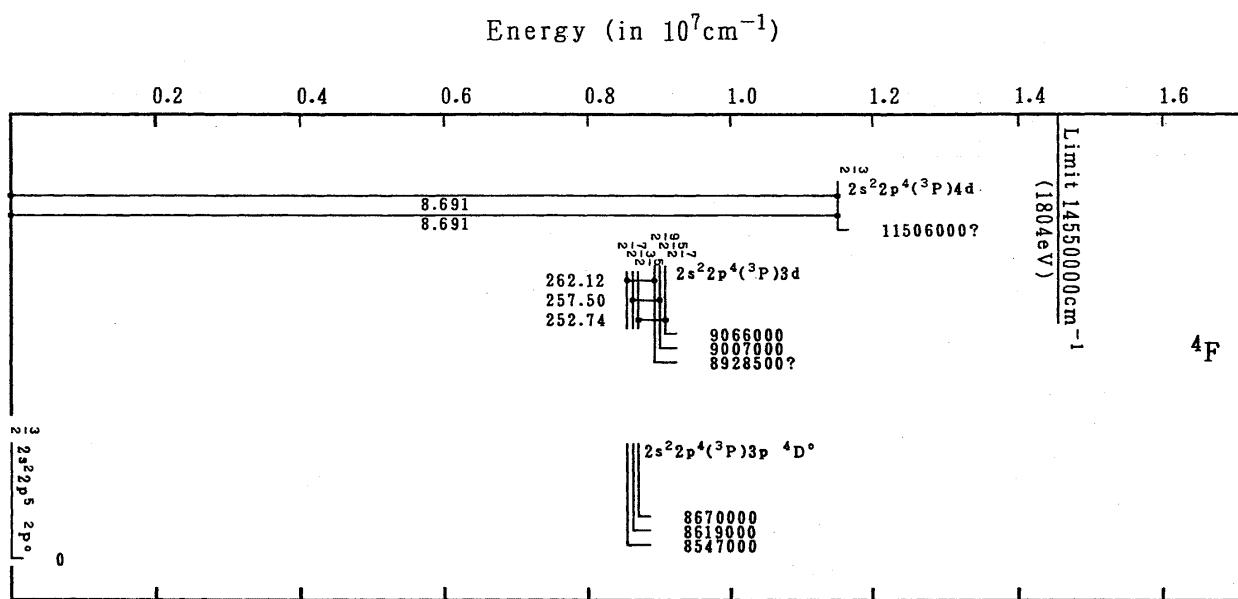
Grotrian diagrams for Cu xxI (F sequence) — Continued



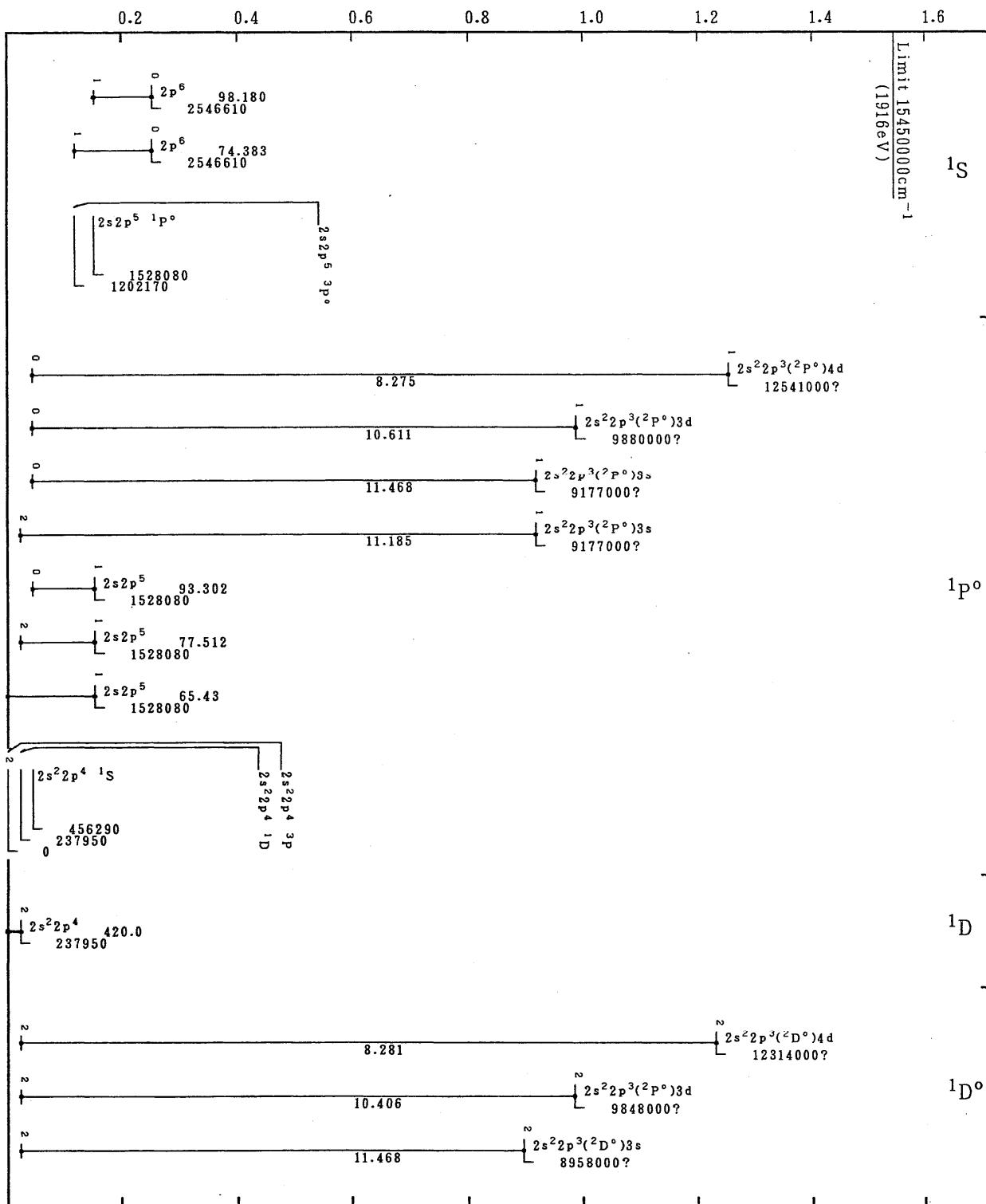
Grotrian diagrams for Cu xxI (F sequence) — Continued

Energy (in 10^7 cm^{-1})

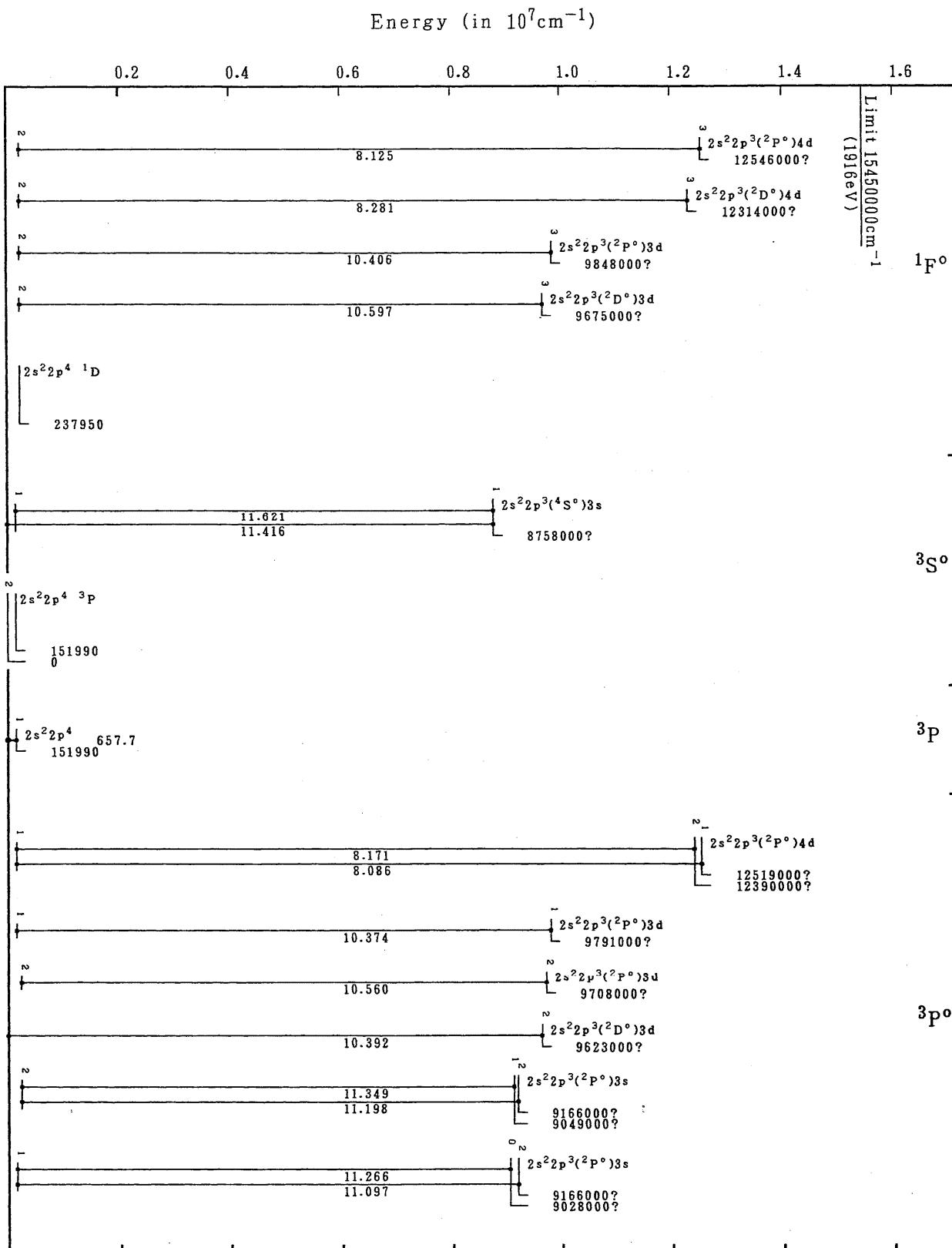
Grotrian diagrams for Cu xxi (F sequence) — Continued



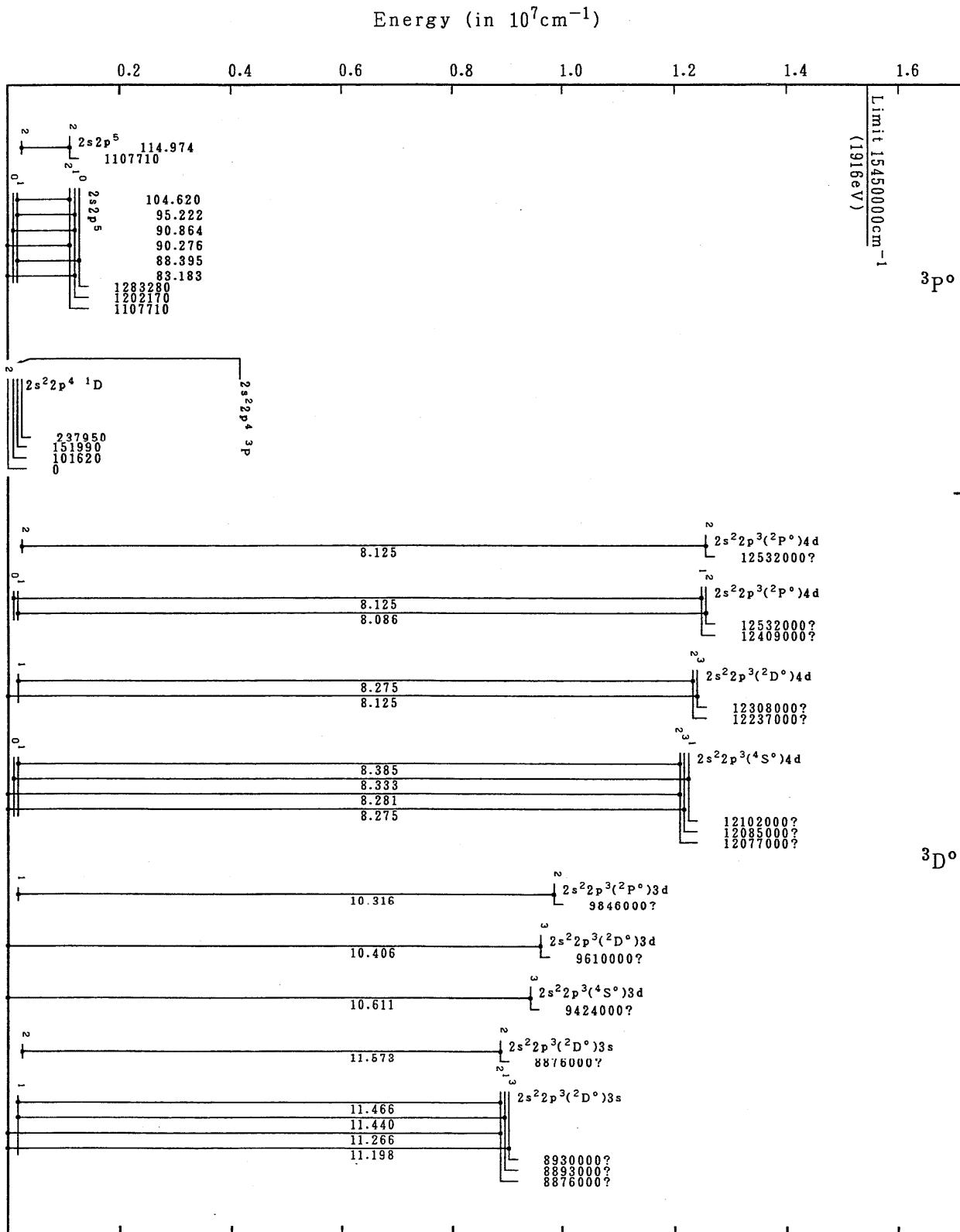
Grotrian diagrams for Cu XXI (F sequence) — Continued

Energy (in 10^7 cm^{-1})

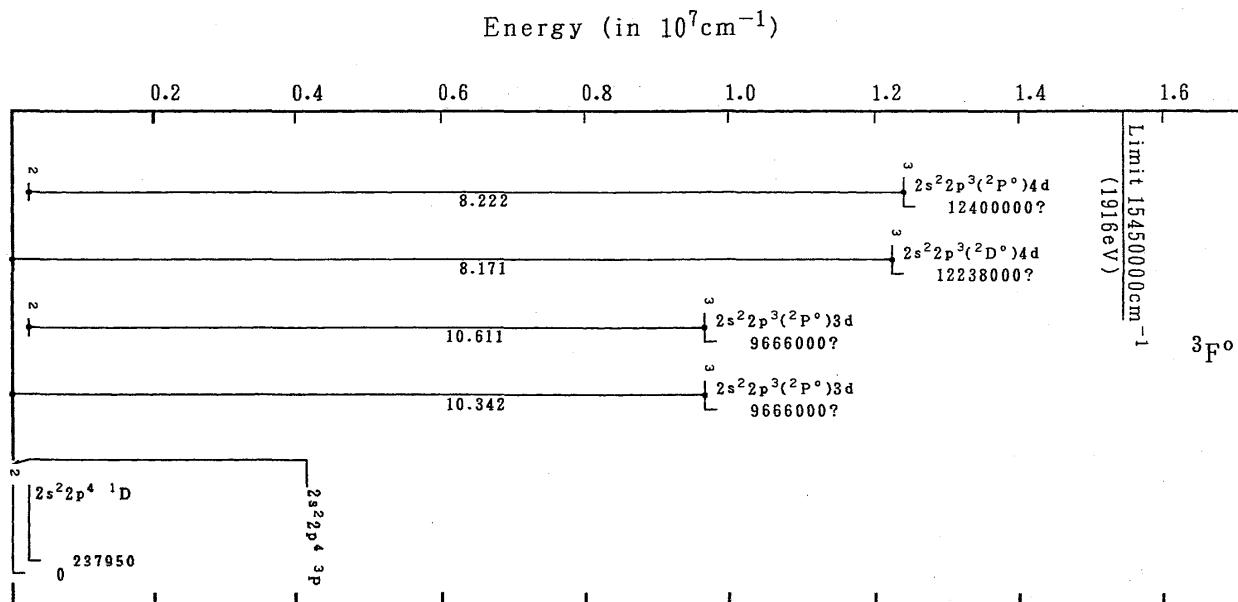
Grotrian diagrams for Cu xxii (O sequence)



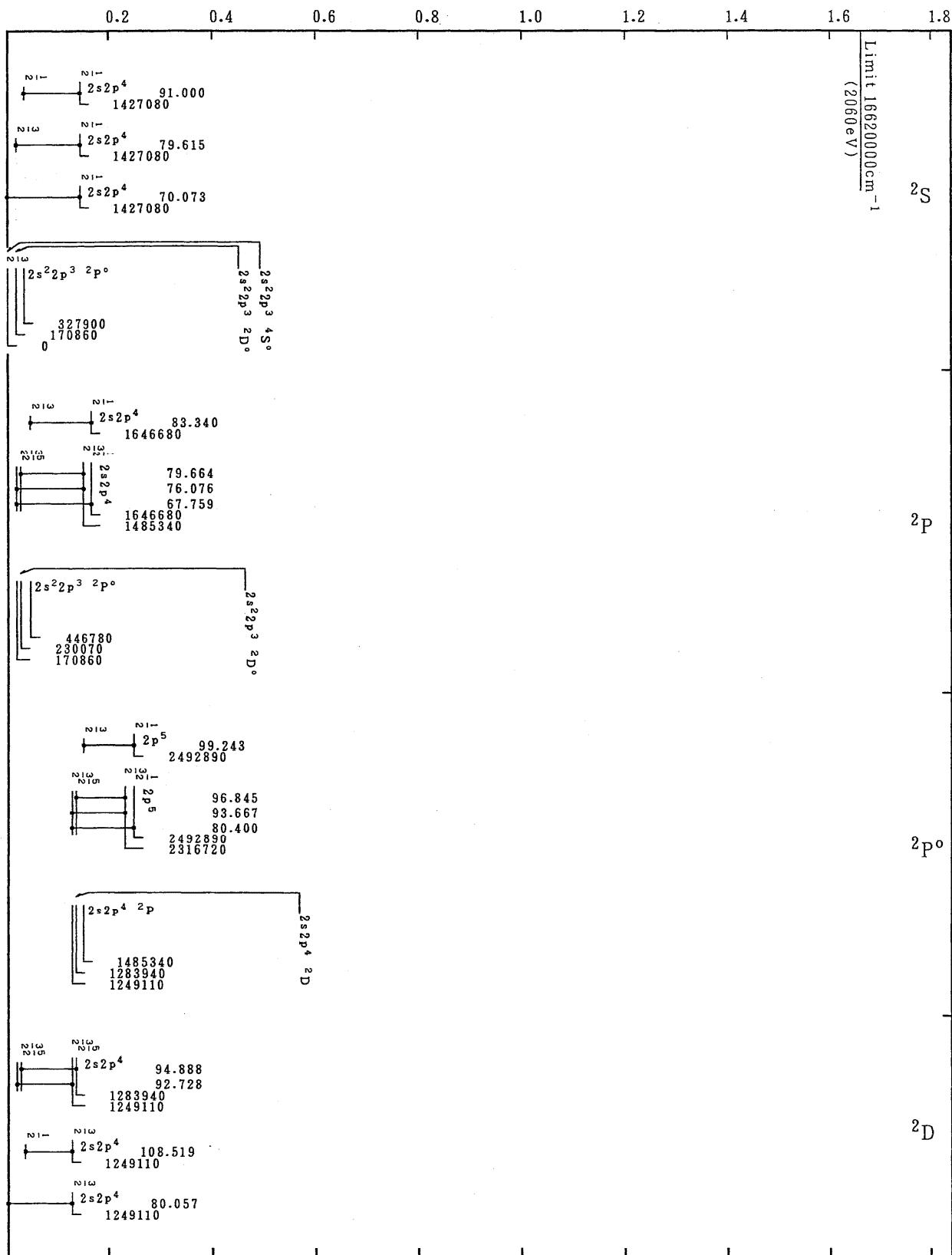
Grotrian diagrams for Cu xxii (O sequence) — Continued



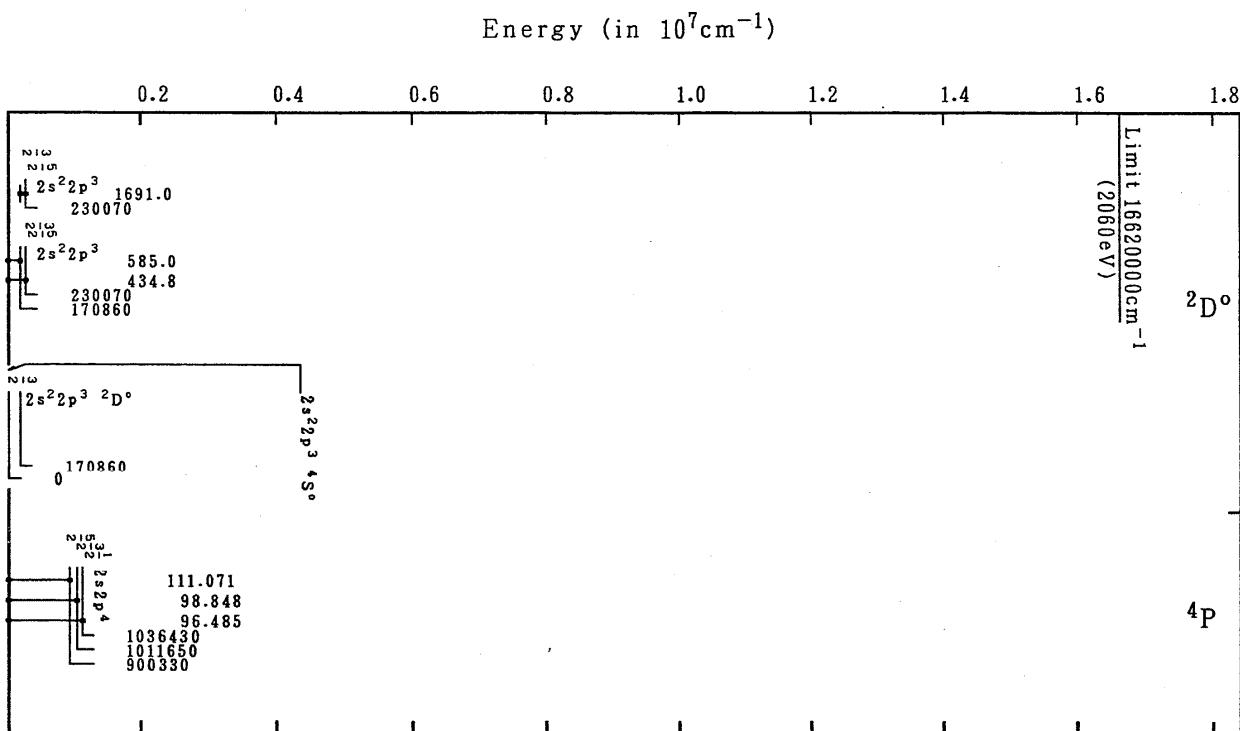
Grotrian diagrams for Cu xxii (O sequence) — Continued



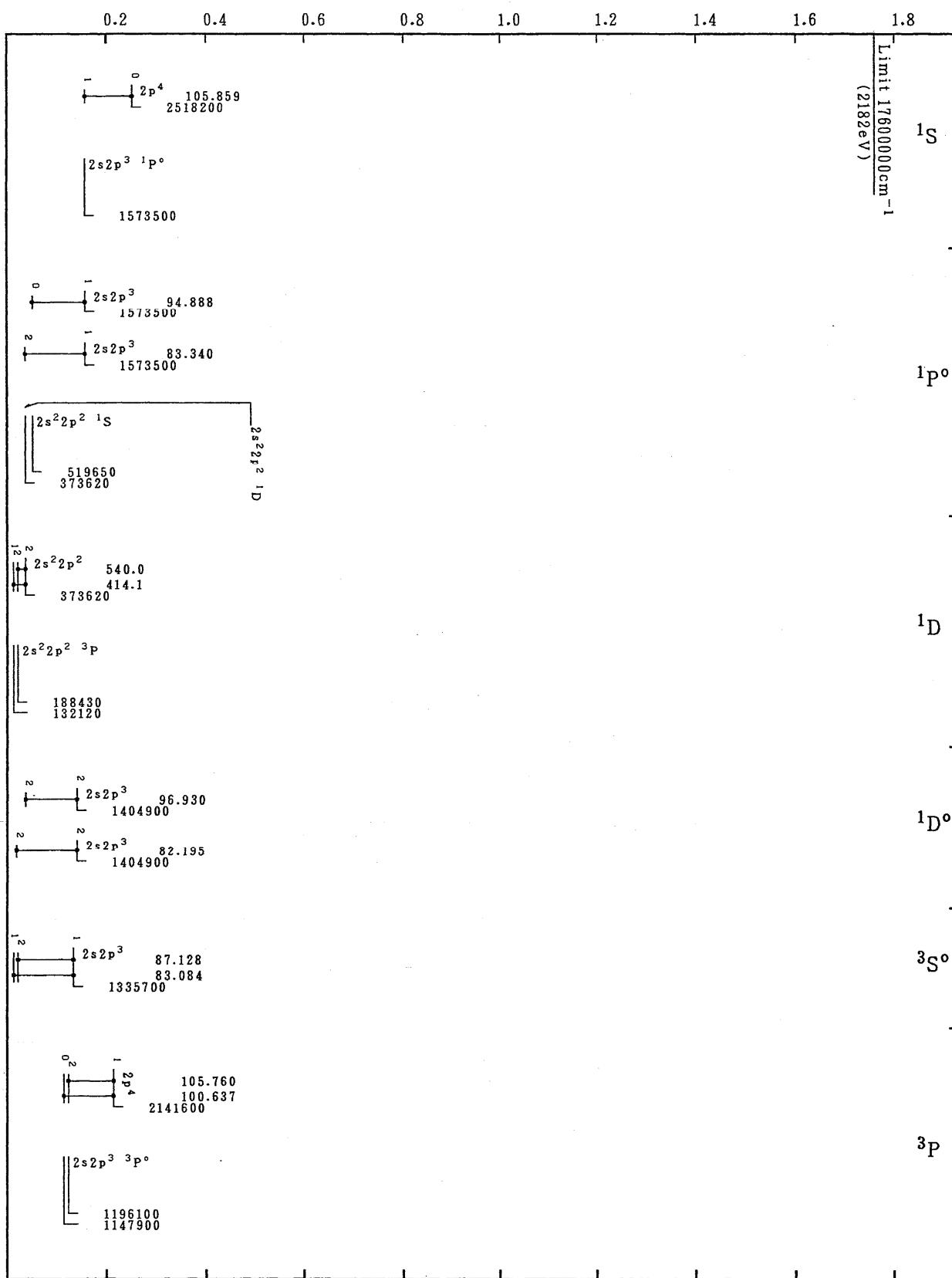
Grotrian diagrams for Cu xxii (O sequence) - Continued

Energy (in 10^7 cm^{-1})

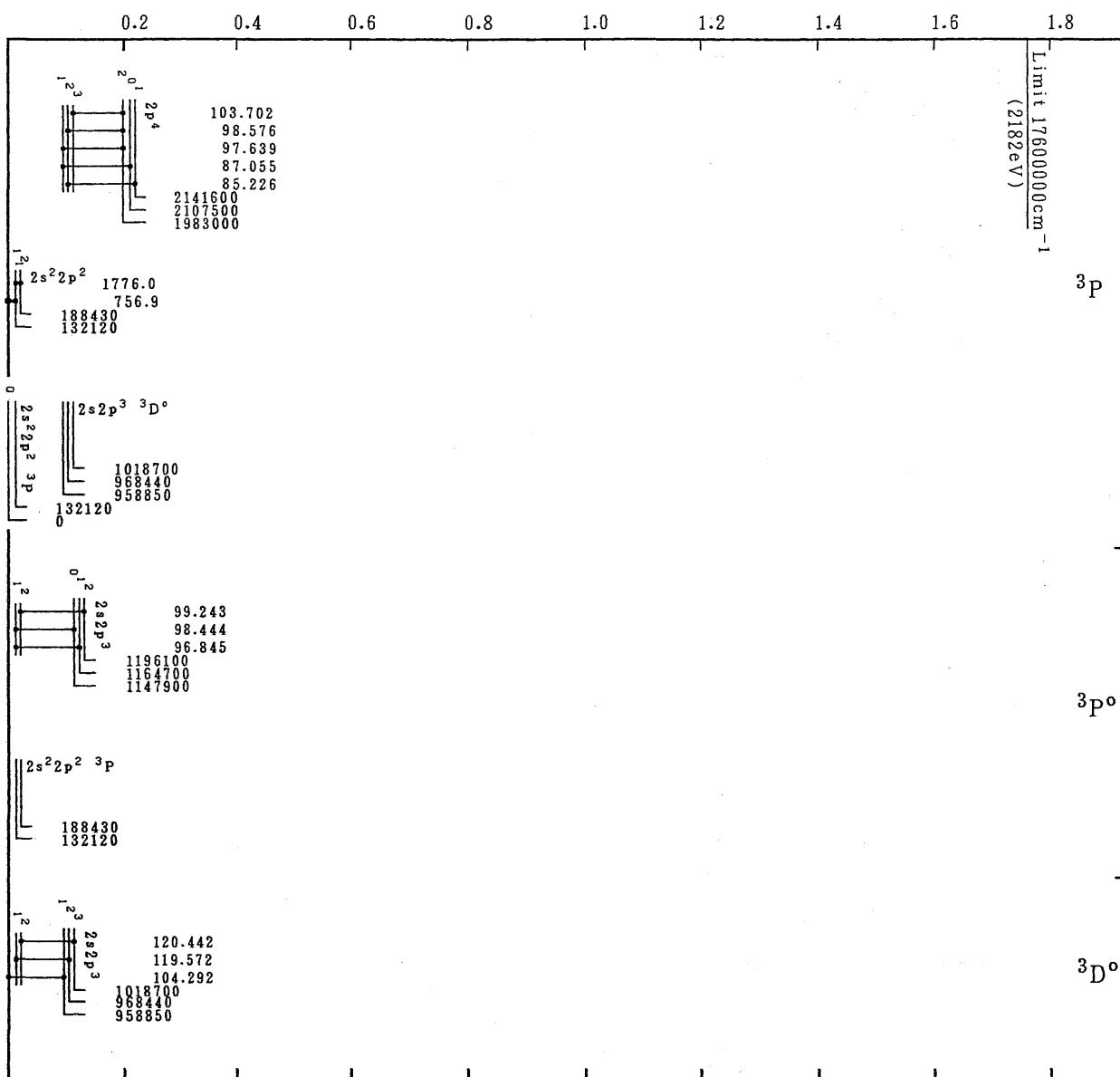
Grotrian diagrams for Cu xxIII (N sequence)



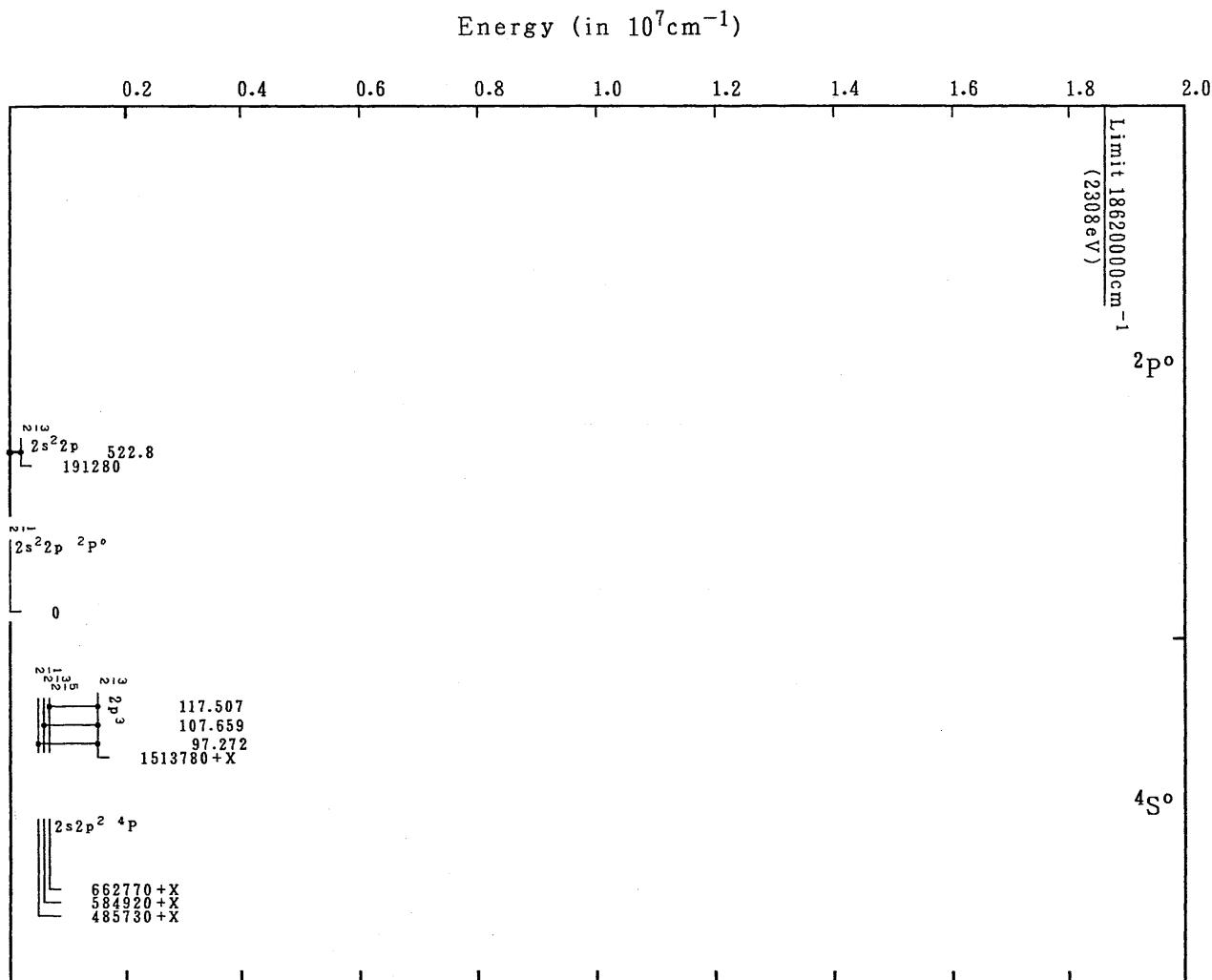
Grotrian diagrams for Cu xxiii (N sequence) – Continued

Energy (in 10^7 cm^{-1})

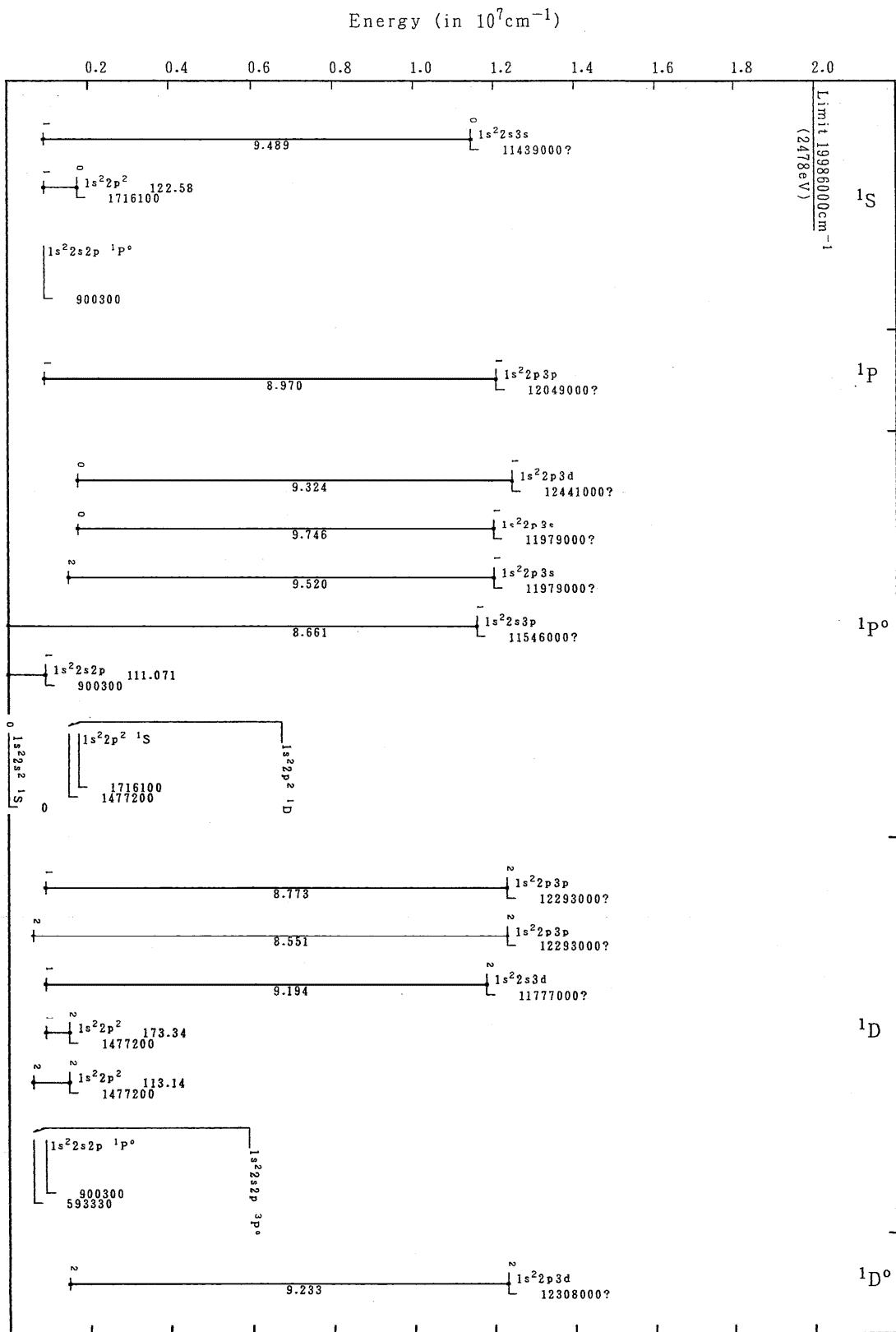
Grotrian diagrams for Cu xxiv (C sequence)

Energy (in 10^7 cm^{-1})

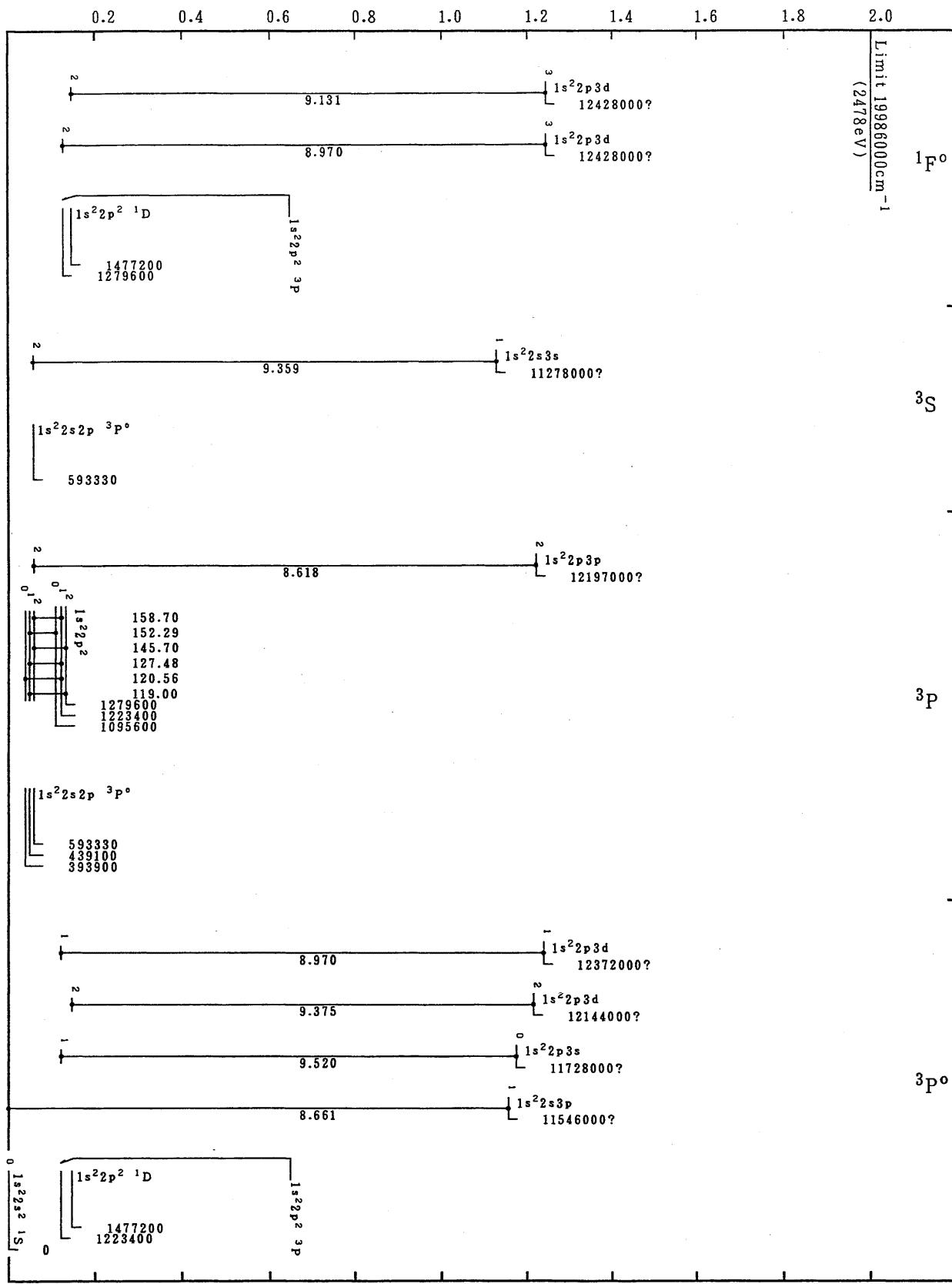
Grotrian diagrams for Cu xxiv (C sequence) — Continued



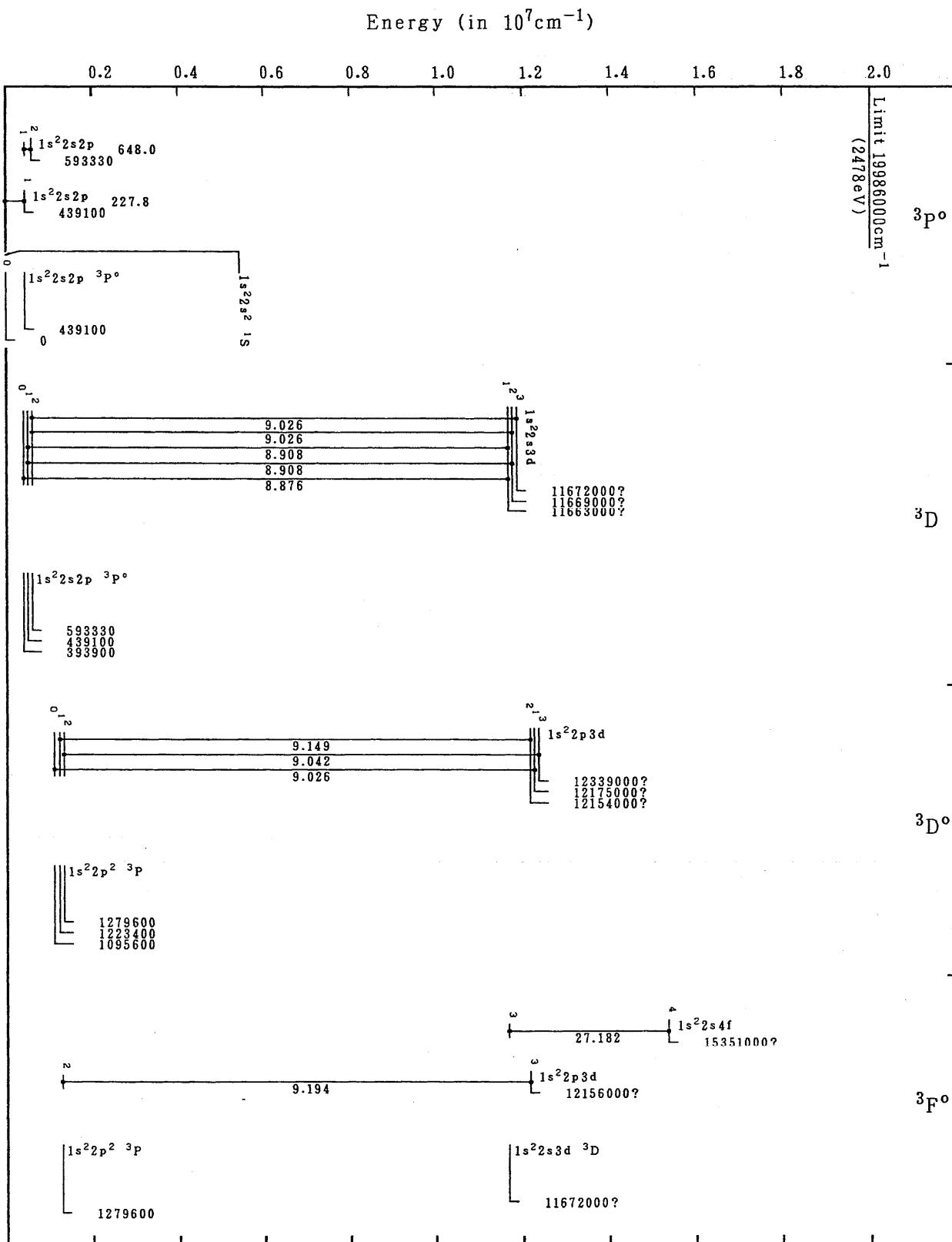
Grotrian diagrams for Cu xxv (B sequence)



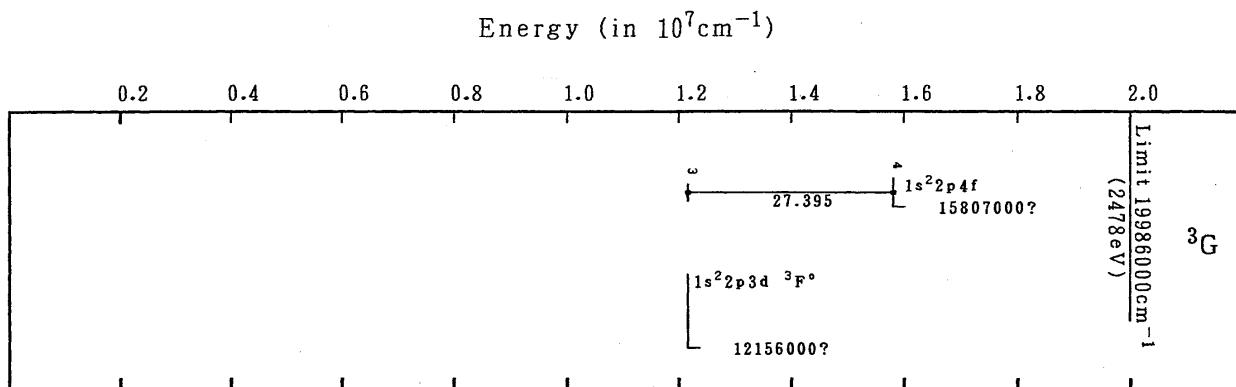
Grotrian diagrams for Cu xxvi (Be sequence)

Energy (in 10^7 cm^{-1})

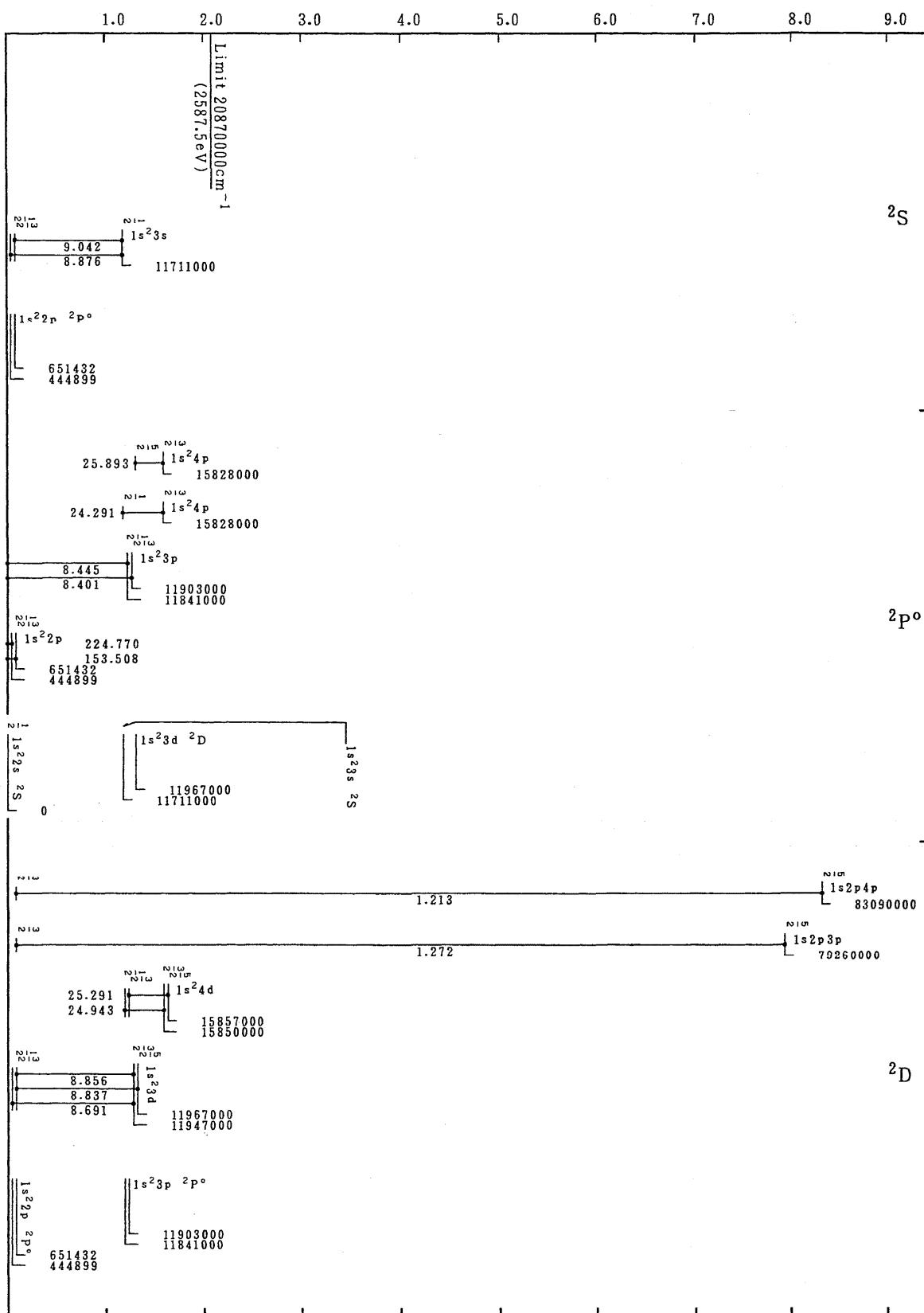
Grotian diagrams for Cu xxvi (Be sequence) — Continued



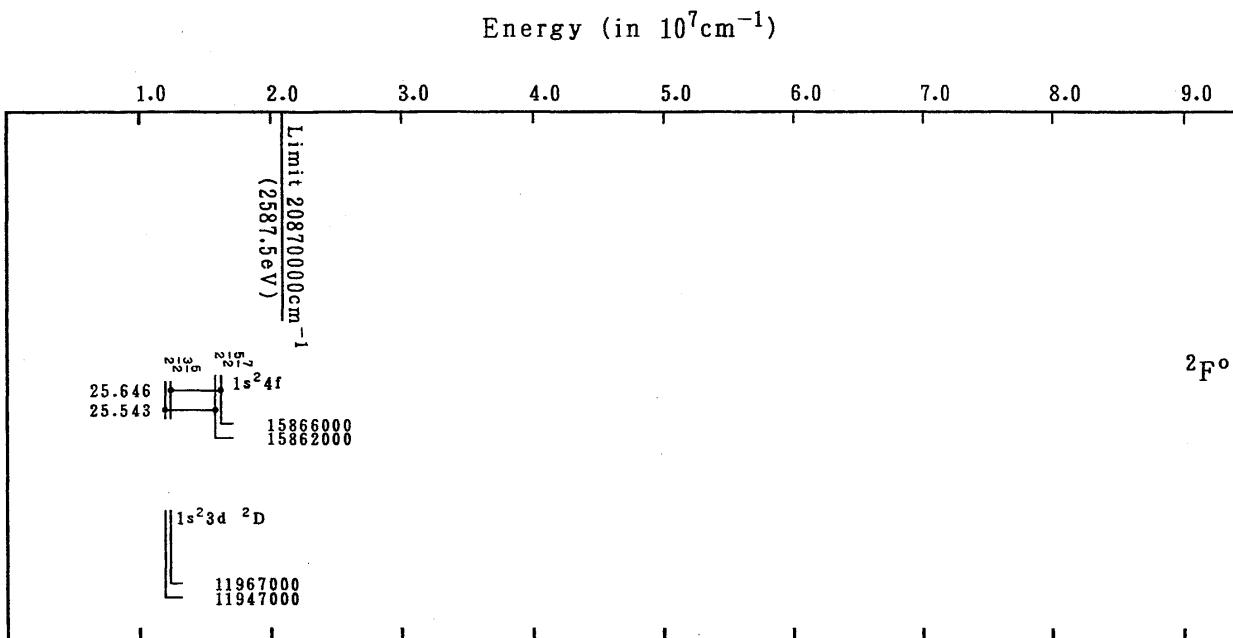
Grotrian diagrams for Cu xxvi (Be sequence) — Continued



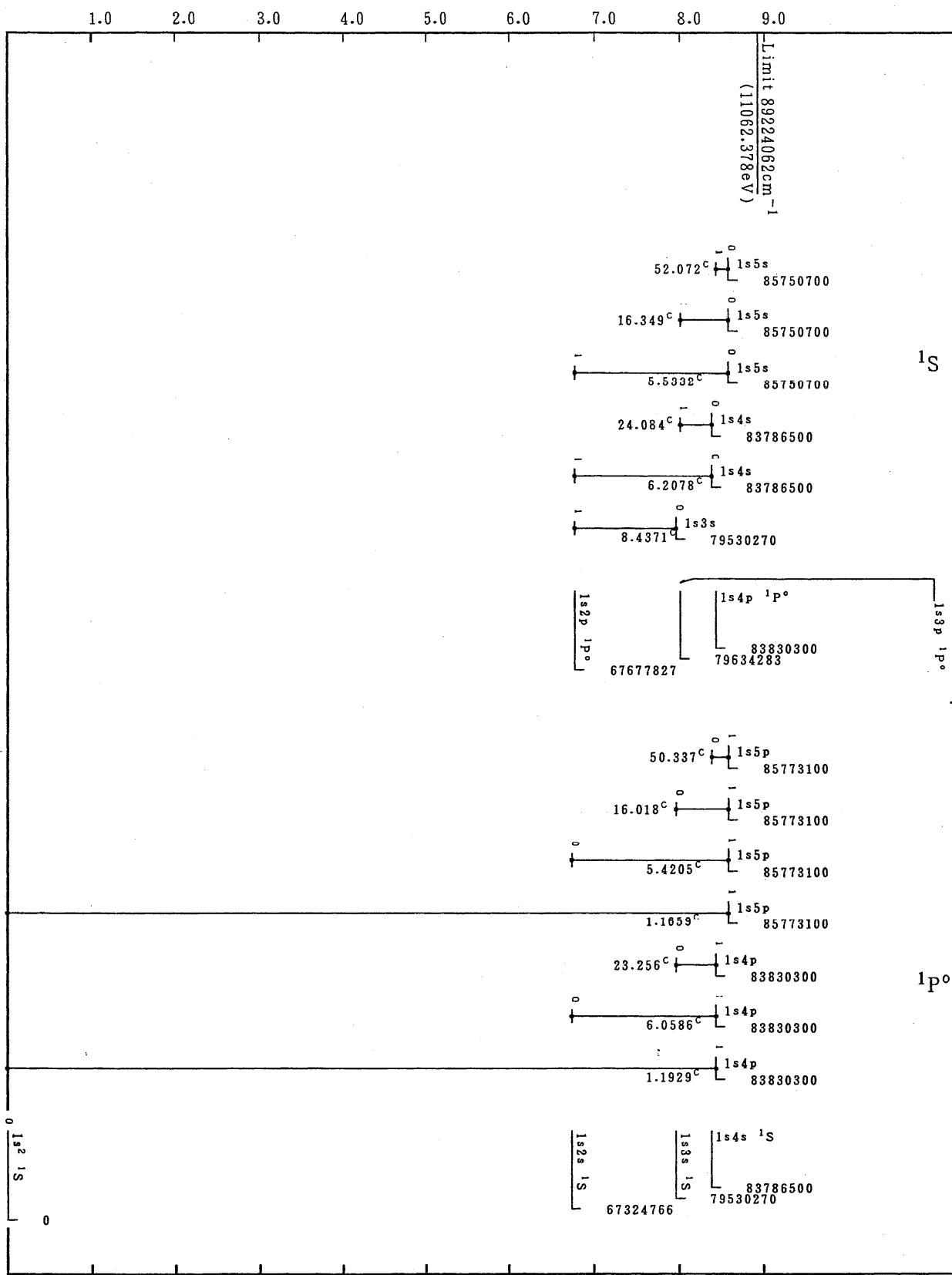
Grotrian diagrams for Cu xxvi (Be sequence) — Continued

Energy (in 10^7 cm^{-1})

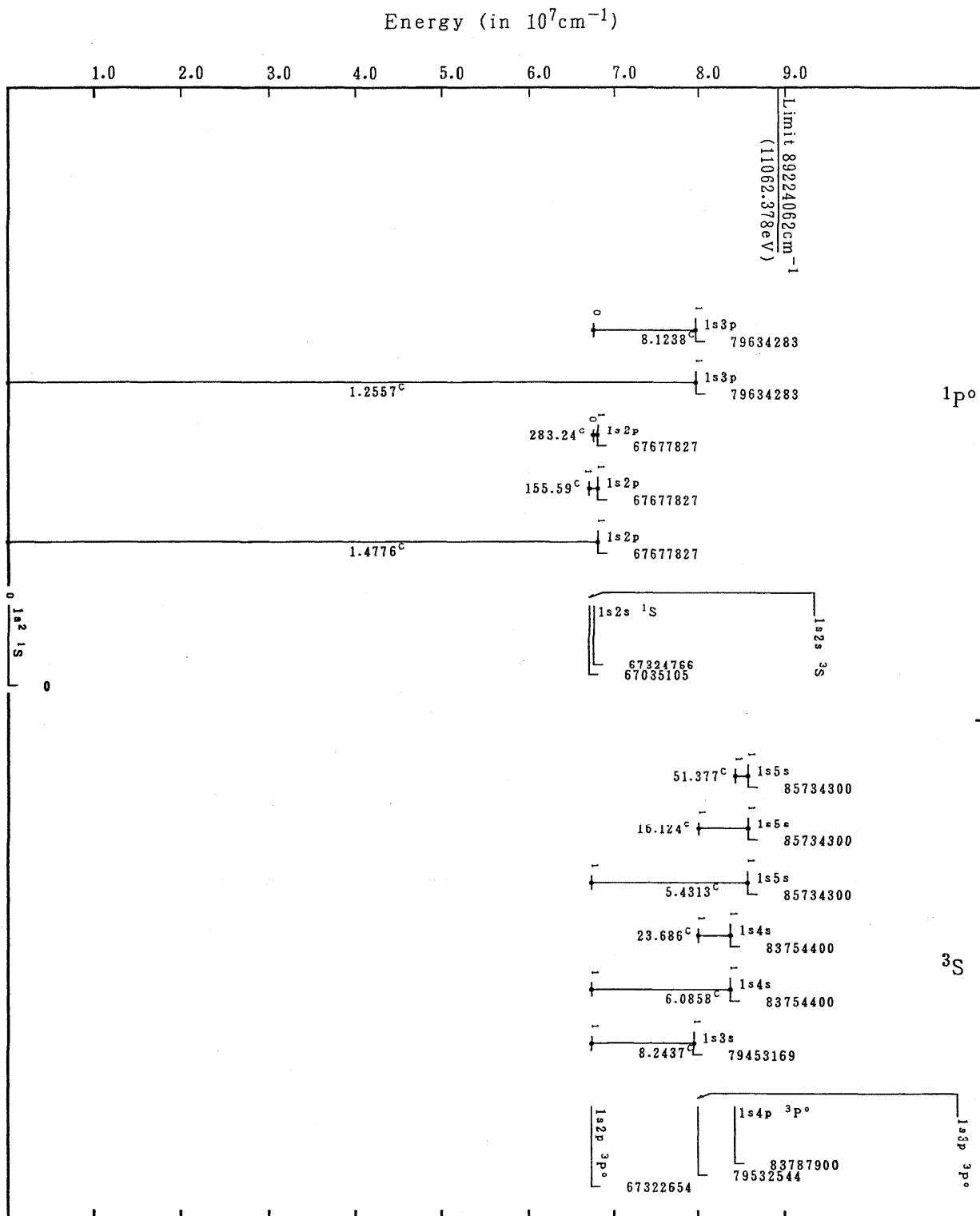
Grotrian diagrams for Cu xxvii (Li sequence)



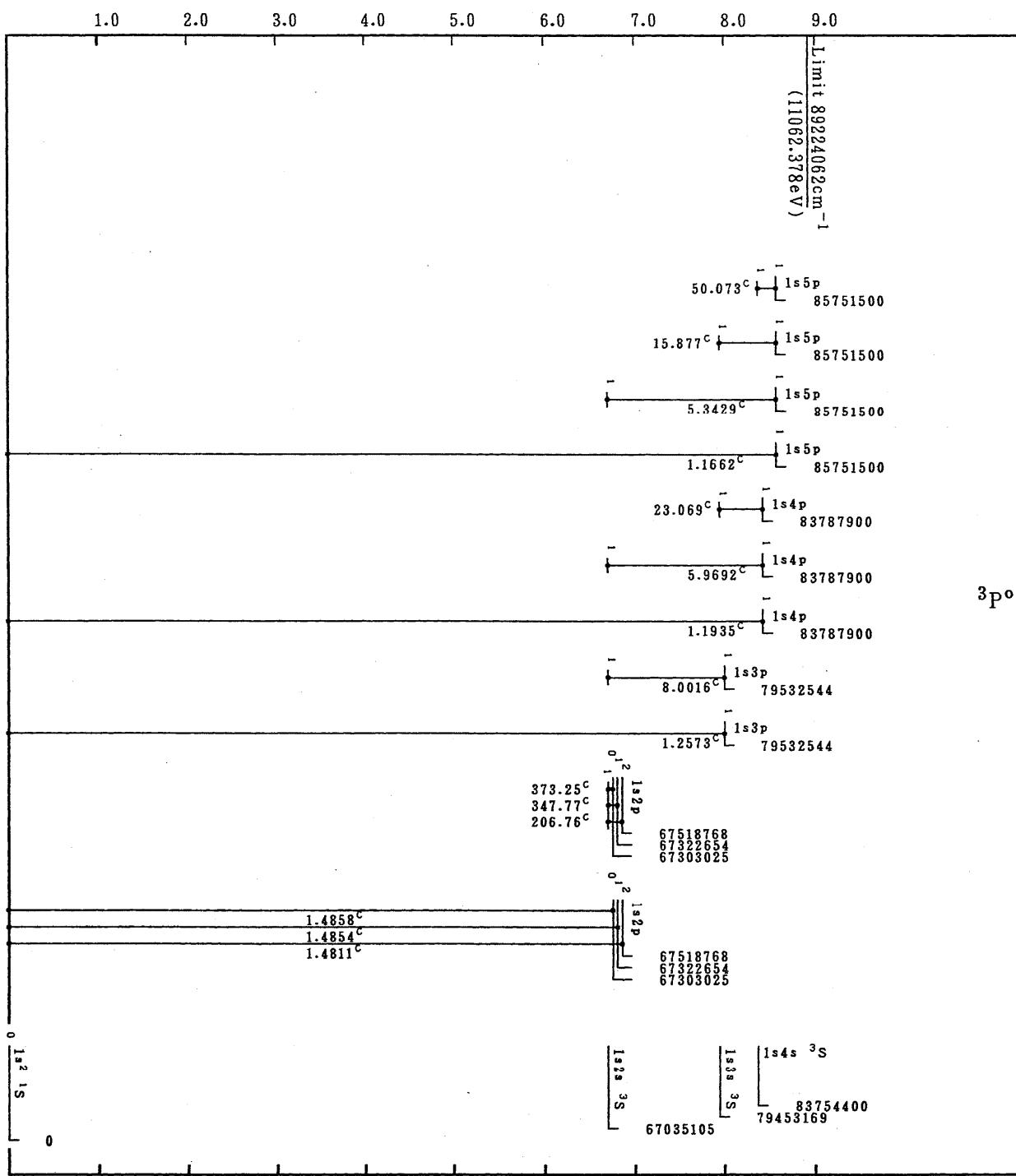
Grotrian diagrams for Cu xxvii (Li sequence) — Continued

Energy (in 10^7 cm^{-1})

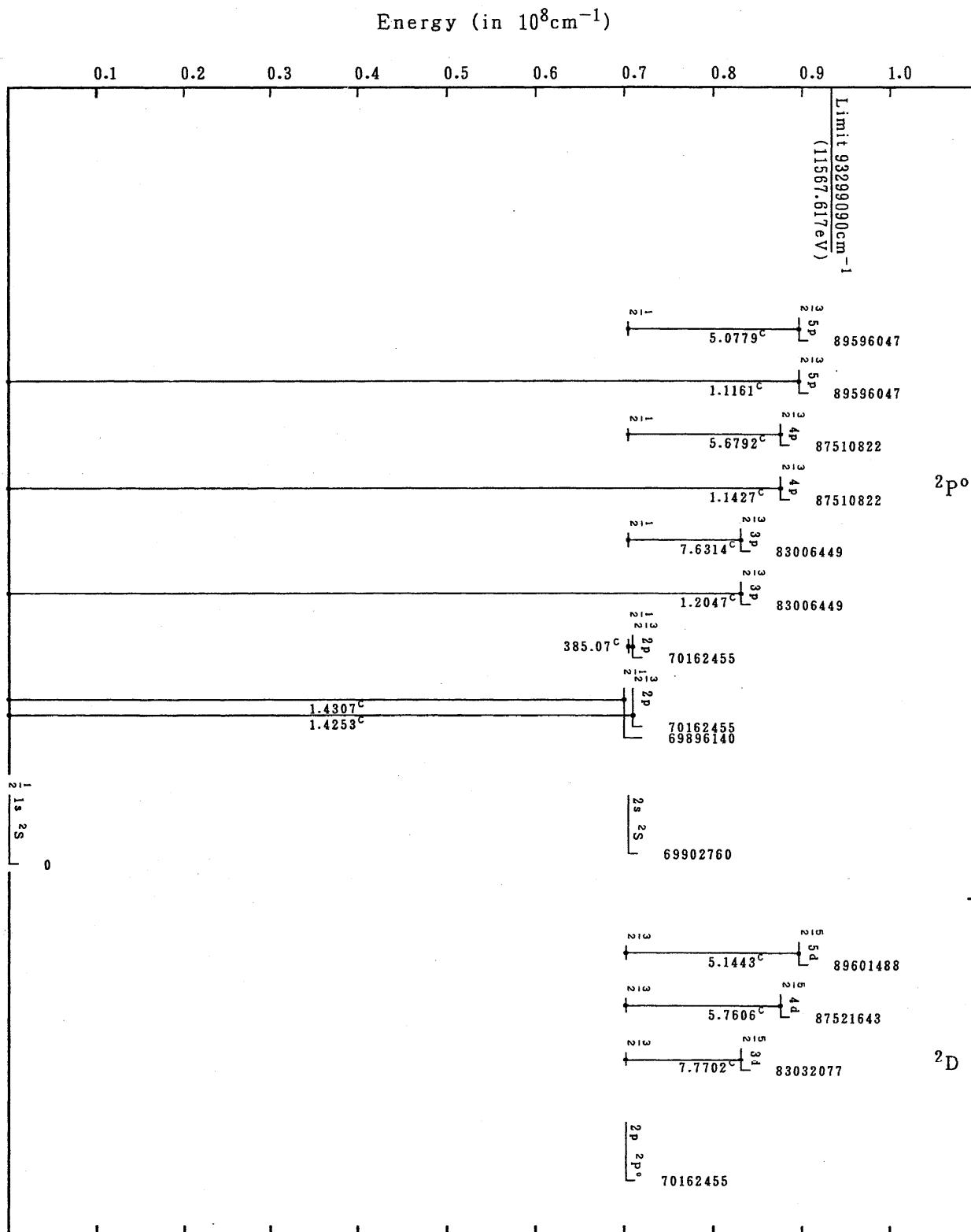
Grotrian diagrams for Cu xxviii (He sequence)



Grotrian diagrams for Cu xxviii (He sequence) – Continued

Energy (in 10^7 cm^{-1})

Grotrian diagrams for Cu xxviii (He sequence) — Continued



Grotrian diagrams for Cu xxix (H sequence)

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