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

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Received February 15, 1990; revised manuscript received August 6, 1990

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].

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# 2. Brief Comments on Each Copper Ion

### Cu X (Ca sequence)

Ground state: $1s^22s^22p^63s^23p^63d^2\ {}^3F_2$

Classification of emission lines from the $3p^63d^2-3p^53d^3$ 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 $3p^63d^2-3p^63d4f$ transitions in the wavelength range of 86.1–88.0 Å using vacuum spark observations. They identified the transitions, ${}^1D_2-{}^1D^o_2$, ${}^1F^o_3$ and ${}^3F-{}^3F^o$, ${}^3G^o$. Tabulated wavelengths are from improved measurements by Even-Zohar and Fraenkel (1968)[25], who classified 5 new lines due to the ${}^3P-{}^3D^o$, ${}^1D_2-{}^3D^o_3$ and ${}^3F_4-{}^3F^o_3$ transitions. Their wavelength uncertainty is ±0.005 Å.

### Cu XI (K sequence)

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

The transition arrays, $3p^63d\ {}^2D-3p^53d^2\ {}^2P^o, {}^2D^o, {}^2F^o$ in the range of 134.9–150.4 Å were first identified and measured by Goldsmith and Fraenkel (1970)[34] with an uncertainty of ±0.005 Å in a vacuum spark. Ramonas and Ryabtsev (1980)[59] remeasured the spectrum in a wider range with a wavelength uncertainty of ±0.003 Å using low-inductance vacuum sparks. They classified 16 lines in the range of 108−185 Å, 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 Å with an uncertainty of ±0.005 Å, in agreement with those of Ref. 59. The wavelengths are adopted from Ref. 59. The line at 147.742 Å is classified as the $3p^63d\ ^2D_{5/2}-3p^5(^2P^\circ)3d^2(^3F)\ ^2F^\circ_{7/2}$ transition in Ref. 59, but in Ref. 45 it is given as $3p^63d\ ^2D_{5/2}-3p^5(^2P^\circ)3d^2(^1G)\ ^2F^\circ_{7/2}$. We have adopted the designations of Ref. 59.

The $3p^63d\ ^2D-3p^64f\ ^2F^\circ$ 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 $3p^63d\ ^2D-3p^6nf\ ^2F^\circ$ ($n=4$ to 6) at 78 Å, 63 Å, and 57 Å. These wavelengths have an uncertainty of ±0.01 Å.

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

### Cu XII (Ar sequence)

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

Sugar *et al.* (1987)[65] gave the spin-forbidden $3p^6\ ^1S-3p^53d\ ^3D^\circ_1$ transition as 174.739±0.005 Å and the allowed transition $3p^6\ ^1S_0-3p^53d\ ^1P^\circ_1$ at 139.175±0.005 Å. 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 $3p^6\ ^1S_0-3p^54s\ (^3/_2,^1/_2)^\circ_1$, $(^1/_2,^1/_2)^\circ_1$, and $3p^54d\ (^3/_2,^5/_2)^\circ_1$, $(^1/_2,^3/_2)^\circ_1$ transitions in the range of 55−69 Å. The uncertainty of the wavelengths is ±0.01 Å.

Swartz *et al.* (1976)[72] identified 13 lines as the $3p^53d-3p^54f$ transitions in the range of 70−81 Å with a high-voltage vacuum spark.

### Cu XIII (Cl sequence)

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

The magnetic-dipole transition within the ground configuration, $3s^23p^5\ ^2P^\circ_{3/2}-^2P^\circ_{1/2}$ at 3500.4±0.3 Å (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 $3p^5\ ^2P^\circ-3p^4(^3P)3d\ ^2D$ multiplet and the $3p^5\ ^2P^\circ_{3/2}-3p^4(^3P)3d\ ^2P_{3/2}$ transition in the range of 138−145 Å with a three-electrode vacuum spark. New measurements of the $3p^5-3p^43d$ transitions in the range of 138−151 Å were provided by Kaufman *et al.* (1989)[46] in a laser-produced plasma. The uncertainty of the wavelengths is ±0.005 Å. The authors have communicated to us that the line at 148.318 Å should be removed in Ref. 46.

Fawcett and Hayes (1975)[26] observed two lines due to the transitions $3s^23p^4(^3P)3d\ ^4F_{9/2}-3s^23p^4(^3P)4f\ ^4G^\circ_{11/2}$ at 66.18±0.05 Å and $(^3P)\ ^4D_{7/2}-(^3P)\ ^4F^\circ_{9/2}$ at 65.24±0.05 Å 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±0.3 Å (in air) was identified by Denne *et al.* (1983)[17], and the intercombination $^3P_1-^1S_0$ transition at 1190.4±0.5 Å was assigned by Roberts *et al.* (1987)[62]. Both were observed in tokamak discharges.

Fawcett and Hayes (1975)[26] first identified the $3s^23p^4\ ^3P_2-3s^23p^3(^4S^\circ)3d\ ^3D^\circ_3$ transition at 148.30 ± 0.03 Å in a laser-produced plasma. Recently, Sugar and Kaufman (1986)[63] reported measurements of the $3s^23p^4-3s3p^5$ transitions in the range of 250−302 Å and the $3s^23p^4-3s^23p^33d$ transitions in the range of 140−189 Å. 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 ±0.007 Å.

Fawcett and Hayes (1975)[26] also identified the transitions $3s^23p^33d\ ^3G^\circ_5-3s^23p^34f\ ^3H_6$ at 61.70±0.05 Å and $^5D^\circ_4-^5F_5$ at 61.08±0.05 Å.

### Cu XV (P sequence)

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

Denne *et al.* (1983)[17] and Denne *et al.* (1984)[18] identified the two magnetic-dipole transitions $3s^23p^3\ ^4S^\circ_{3/2}-^2D^\circ_{5/2}$ and $^4S^\circ_{3/2}-^2P^\circ_{3/2}$ in tokamak discharges. Their wavelengths of 2085.3±0.2 Å (in air) and 944.6±0.2 Å 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 $^4S^\circ_{3/2}-(^3P)\ ^4P_{5/2}$ and $^2D^\circ_{5/2}-(^3P)\ ^2F_{7/2}$ lines at 161.34±0.03 Å and 154.67±0.03 Å. New measurements and classifications by Sugar and Kaufman (1986)[63] included seven lines in the range of 154.7−172.8 Å. Wavelengths were measured in a laser-produced plasma with an uncertainty of ±0.01 Å. All the wavelengths tabulated have been reduced by 0.02 Å, as suggested by them (1987)[66]. Hutton *et al.* (1987)[41] reported observations in a beam-foil spectrum of the $3s^23p^3-3s3p^4$, $3s^23p^23d$ lines in the range of 154−297 Å. 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 $3s^23p^23d\ ^2G_{9/2}-3s^23p^24f\ ^2H^\circ_{11/2}$ at 57.52±0.01 Å and $^4F_{9/2}-^4G^\circ_{11/2}$ 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 $3s^23p^2\ ^3P_2-3s^23p3d\ ^3D^\circ_3$ 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 $3s^23p^2-3s3p^3$ array and for 11 lines of $3s^23p^2-3s^23p3d$ 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 $3s^23p^2\ ^3P_{2,1}-3s3p^3\ ^5S^\circ_2$ 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 $3s^23p3d-3s^23p4f$ and $3s^23p^2-3s^23p4d$ 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 $3s^23p^2-3s^23p4s$ transitions from Ref. 47 and the $3s3p^3-3s^23p4f$ transitions tentatively identified in Ref. 44. It should be noted, however, that the wavelengths of 52.85 Å and 52.18 Å for the $3s^23p^2\ ^3P_{2,1}-3s^23p4s\ ^3P^\circ_2$ transitions in Ref. 47 lead to an incorrect $^3P$ ground term splitting.

### Cu XVII (Al sequence)

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

Hinnov *et al.* (1982)[36] and Denne *et al.* (1983)[17] observed the $3s^23p\ ^2P^\circ_{1/2}-^2P^\circ_{3/2}$ 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 $3s^23p\ ^2P^\circ-3s3p^2\ ^4P$ 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 $3s^23p\ ^2P^\circ_{3/2}-3s3p^2\ ^2P_{3/2}$ and $3s^23p-3s^23d$ ($^2P^\circ_{3/2}-^2D_{5/2}$, $^2P^\circ_{1/2}-^2D_{3/2}$) transitions. An extended analysis of the $3s^23p-3s3p^2$, $3s3p^2-3p^3$, and $3s^23p-3s^23d$ 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 $3s3p^2\ ^4P_{1/2}-3p^3\ ^4S^\circ_{3/2}$ 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 $3s3p^2-3s3p3d$ 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 $3s^23d-3s^24f$, $3s3p^2-3s3p4s$, $3s3p3d-3s3p4f$, $3s^23p-3s^24s$, $3s^24d$ 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 $3s3p\ ^3P^\circ_1-^3P^\circ_2$ 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 $3s3p-3s3d$ in addition to the $3s^2\ ^1S_0-3s3p\ ^1P^\circ_1$ resonance transition were classified by Fawcett and Hayes (1975)[26]. Finkenthal *et al.* (1982)[33] identified the $3s^2\ ^1S_0-3s3p\ ^3P^\circ_1$ 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, $3s3p-3p^2$, $3s^2-3s3p$, and $3s3p-3s3d$, in the range of 185−270 Å. In a subsequent paper of Sugar and Kaufman (1986)[64] the arrays $3p^2-3p3d$ and $3s3d-3p3d$ 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: $3s3p\ ^1P^\circ_1 - 3p^2\ ^3P_2$ at 346.44 Å, $3s3p\ ^3P^\circ_2 - 3p^2\ ^1D_2$ at 274.01 Å, and $3p^2\ ^1D_2 - 3p3d\ ^3F^\circ_2$ at 228.16 Å, are taken. These wavelengths have an uncertainty of $\pm 0.02$ 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 $272.30 \pm 0.2$ Å and $198.56 \pm 0.05$ Å corresponding to the $3s3d\ ^3D_2 - 3p3d\ ^3D^\circ_2$ and $3s3p\ ^3P^\circ_2 - 3s3d\ ^3D_1$ 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 $3p3d - 3d^2$ 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 $3s^2 - 3s4p$, $3s3p - 3s4s$, $3s3p - 3snd$ $(n=4,5)$, and $3s3d - 3snf$ $(n=4,5)$. The measurement was performed in a low-inductance vacuum spark and the wavelengths have an uncertainty of $\pm 0.01$ Å. The identifications were extended by Kastner *et al.* (1978)[44] to include the $3p3d - 3p4f$ transitions in the range of 48.8 − 51.5 Å with a similar light source. It should be noted that the $3p3d\ ^3F^\circ_3 - 3p4f\ ^3F_4$ 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 $^3F^\circ_2 - ^3G_3$ 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 $2p^63s^2\ ^1S_0 - 2p^53s^23d\ ^1P^\circ_1$ inner-shell transition at 11.774 Å. The observation was made with a low-inductance vacuum spark with an uncertainty of $\pm 0.01$ Å.

### Cu XIX (Na sequence)

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

The $n=3-3$ transitions were first observed by Feldman *et al.* (1971)[32] in a low-inductance vacuum spark. They classified the $3s\ ^2S_{1/2} - 3p\ ^2P^\circ_{3/2}$ resonance transition at 273.34 Å and the $3p\ ^2P^\circ - 3d\ ^2D$ 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 $\pm 0.007$ Å, which are adopted in the present compilation.

Jupén *et al.* (1988)[43] ascribed the line at $210.70 \pm 0.05$ Å measured by Buchet-Poulizac and Buchet (1988)[15] in a beam-foil spectrum to the core-excited $2p^53s3p\ ^4D_{7/2} - 2p^53s3d\ ^4F^\circ_{9/2}$ transition.

Kononov *et al.* (1977)[50] identified the $4f\ ^2F^\circ - 5g\ ^2G$ doublet at 111 Å and Kononov *et al.* (1979)[51] reported the $4d\ ^2D - 5f\ ^2F^\circ$ doublet and the $4p\ ^2P^\circ_{3/2} - 5d\ ^2D_{5/2}$ and $4s\ ^2S_{1/2} - 5p\ ^2P^\circ_{3/2}$ transitions in the range of 85 − 103 Å with an uncertainty of $\pm 0.005$ Å. The $4f\ ^2F^\circ - 5g\ ^2G$ and $4d\ ^2D - 5f\ ^2F^\circ$ doublets were remeasured by Sugar and Kaufman (1986)[63] in a laser-produced plasma with an uncertainty of $\pm 0.01$ 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 $\pm 0.01$ Å. Fawcett and Hayes (1975)[26] and Khan (1978)[47] identified the $3d\ ^2D - 4p\ ^2P^\circ$ 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 $3d\ ^2D - 7f\ ^2F^\circ$ 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 $3d\ ^2D - 8f\ ^2F^\circ$ doublet at 25.175 Å and 25.142 Å in Ref. 32 is tentative.

Feldman and Cohen (1967)[31] identified the resonance line $2p^63s\ ^2S_{1/2} - 2p^53s^2\ ^2P^\circ_{3/2}$ at $13.11 \pm 0.01$ Å using a low-inductance vacuum spark.

### Cu XX (Ne sequence)

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

Twelve lines of the $2s^22p^53s - 2s^22p^53p$ array in the range of 163 − 341 Å and 12 lines of the $2s^22p^53p - 2s^22p^53d$ 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 $\pm 0.05$ Å. For the weak line at 163.6 Å it is $\pm 0.1$ Å.

Feldman *et al.* (1967)[29] classified seven resonance transitions from the $2s^22p^53s$, $2s^22p^53d$, and $2s2p^63p$ $J=1$ levels to the ground $2s^22p^6\ ^1S_0$ 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 $2p^6 - 2p^54d$ transitions and by Swartz *et al.* (1971)[71] for the $2p^6 - 2p^54s$, $2p^55d$ and $2p^56d$ 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: $2s^22p^6\ ^1S_0 - 2s^22p^54d\ (^3/_2,^3/_2)^\circ_1$ at 9.274 Å, $2s^22p^6\ ^1S_0 - 2s2p^64p\ (^1/_2,^1/_2)^\circ_1$ at 8.400 Å, and $2s^22p^6\ ^1S_0 - 2s2p^64p\ (^1/_2,^3/_2)^\circ_1$ at 8.385 Å. The uncertainty of the wavelengths is $\pm 0.005$ Å. The $2s^22p^6 - 2s2p^64p$ transitions are also identified by Hutcheon *et al.* (1980)[39].

### Cu XXI (F sequence)

Ground state: $1s^22s^22p^5\ ^2P^o_{3/2}$

The magnetic-dipole transition within the ground $2s^22p^5$ configuration, $^2P^o_{3/2}-^2P^o_{1/2}$ at $592.3\pm0.3$ Å, was observed in a tokamak discharge by Hinnov *et al.* (1982)[36].

Buchet-Poulizac and Buchet (1988)[15] identified eight lines of the $2s^22p^43s-2s^22p^43p$ array in the range of 279 – 346 Å and seven lines of the $2s^22p^43p-2s^22p^43d$ array in the range of 245 – 264 Å in a beam-foil spectrum. The uncertainty of the wavelengths is $\pm0.05$ Å except for blended lines at 279.40 Å and 257.50 Å, for which it is $\pm0.2$ Å.

Kononov *et al.* (1977)[50] first identified the $2s^22p^5\ ^2P^o-2s2p^6\ ^2S$ transitions at $90.353\pm0.01$ Å and $78.388\pm0.01$ Å 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 $\pm0.02$ Å and $\pm0.01$ Å, respectively. Tabulated wavelengths are taken from Ref. 63. The values have been reduced by 0.02 Å, as suggested by Sugar and Kaufman (1987)[66].

The $2p^5-2p^43s$ and $2p^43d$ transition arrays in the ranges of 11.7 – 12.2 Å and 10.8 – 11.4 Å 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 Å and 11.352 Å. Wavelengths in Refs. 35 and 39 have uncertainties of $\pm0.005$ Å and $\pm0.002$ Å, respectively.

Gordon *et al.* (1980)[35] also identified the $2s^22p^5-2s2p^53p$ transitions in the range of 9.9 – 10.4 Å.

The $2p^5-2p^44s$ and $2p^44d$ lines were observed by Gordon *et al.* (1980)[35] and Hutcheon *et al.* (1980)[40] in the ranges of 8.6 – 9 Å and 8.5 – 8.8 Å. They are mostly blends and their classifications are given with question marks.

### Cu XXII (O sequence)

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

Two magnetic-dipole transitions within the ground $2s^22p^4$ configuration, $^3P_2-^3P_1$ at $657.7\pm0.3$ Å and $^3P_2-^1D_2$ at $420.0\pm0.3$ Å, were observed by Hinnov *et al.* (1982)[36] in a tokamak discharge.

The $2s^22p^4-2s2p^5$ transitions were identified and measured by Kononov *et al.* (1977)[50] and Behring *et al.* (1985)[6], and the $2s2p^5\ ^1P^o_1-2p^6\ ^1S_0$ 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: $2s^22p^4\ ^1D_2-2s2p^5\ ^3P^o_2$ at $114.974\pm0.015$ Å and $2s2p^5\ ^3P^o_1-2p^6\ ^1S_0$ at $74.383\pm0.015$ Å, in addition to the earlier identifications. For the $2s^22p^4\ ^3P_2-2s2p^5\ ^1P^o_1$ intercombination transition the wavelength of $65.43\pm0.01$ Å is adopted from Kononov *et al.*, because it gives an consistent value of the $^1P^o_1$ with the lines at 93.302 Å and 77.512 Å.

The $2p^4-2p^33s, 2p^33d$ and $2p^34d$ transitions were classified by Gordon *et al.* (1980)[35] in the ranges of 11 – 12 Å, 10.3 – 10.6 Å, and 8.0 – 8.4 Å. The uncertainty of the wavelengths is $\pm0.005$ Å. Many of the lines are multiply classified. Three lines at 11.573 Å, 10.611 Å, and 8.125 Å 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: $1s^22s^22p^3\ ^4S^o_{3/2}$

Hinnov *et al.* (1982)[36] observed two magnetic-dipole transitions between the ground $2s^22p^3$ levels, $^4S^o_{3/2}-^2D^o_{3/2}$ at $585.0\pm0.3$ Å and $^4S^o_{3/2}-^2D^o_{5/2}$ at $434.8\pm0.3$ Å, in a tokamak plasma.

The $2s^22p^3-2s2p^4$ transitions were identified by Kononov *et al.* (1977)[50] and also by Behring *et al.* (1985)[6] with laser-produced plasmas. For the $2s2p^4-2p^5$ transitions, only the $^2D_{5/2}-^2P^o_{3/2}$ at 96.762 Å was reported in Ref. 6. With a more complete laser excitation Ekberg *et al.* (1987)[23] identified two lines at 80.057 Å and 70.073 Å as the $2s^22p^3\ ^4S^o_{3/2}-2s2p4\ ^2D_{3/2},^2S_{1/2}$ spin-forbidden transitions in addition to 12 lines of the $2s^22p^3-2s2p^4$ array and four lines of the $2s2p^4-2p^5$ array. The wavelengths adopted from Ref. 23 have an uncertainty of $\pm0.015$ Å.

### Cu XXIV (C sequence)

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

Hinnov *et al.* (1982)[36] identified the magnetic-dipole transitions between the ground $2s^22p^2$ levels, $^3P_1-^3P_2$ at 1776.0 Å, $^3P_0-^3P_1$ at 756.9 Å, and $^3P_{2,1}-^1D_2$ at 540.0 Å and 414.1 Å, in a tokamak plasma. The wavelengths have an uncertainty of $\pm0.3$ Å.

Ekberg *et al.* (1987)[23] reported lines of the $2s^22p^2-2s2p^3$ and $2s2p^3-2p^4$ arrays, including the $2s^22p^2\ ^3P_2-2s2p^3\ ^1D^o_2$ spin-forbidden transition at 82.195 Å. The uncertainty of the wavelengths is $\pm0.015$ Å.

### Cu XXV (B sequence)

Ground state: $1s^22s^22p\ ^2P^o_{1/2}$

The magnetic-dipole transition $2s^22p\ ^2P^o_{1/2}-^3P^o_{3/2}$ at $522.8\pm0.3$ Å was observed in a tokamak plasma by Hinnov *et al.* (1982)[36].

Ekberg *et al.* (1987)[23] identified the $2s2p^2\ ^4P-2p^3\ ^4S°$ 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 $2p^3\ ^4S°$ 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 $2s2p\ ^3P_1^o-^3P_2^o$ 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 $2s2p\ ^{3,1}P_1^o$ 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)[15] of the $2s2p-2p^2$ transitions in the range of 113–173 Å, including the spin-forbidden transition $^3P_2^o-^1D_2$ 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 $1s^22s\ ^2S_{1/2}-1s^22p\ ^2P_{1/2,3/2}^o$ 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 $3d\ ^2D_{5/2}-4p\ ^2P_{3/2}^o$, $3d\ ^2D-4f\ ^2F°$, $3p\ ^2P°-4d\ ^2D$, and $3s\ ^2S_{1/2}-4p\ ^2P_{3/2}^o$ transitions in the wavelength range of 24.2–25.9 Å with an uncertainty of ±0.010 Å and the $2p\ ^2P°-3s\ ^2S$, $2p\ ^2P°-3d\ ^2D$, and $2s\ ^2S-3p\ ^2P°$ 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 $1s^22p\ ^2P_{3/2}^o-1s2pnp\ ^2D_{5/2}$ $(n=3,4)$ 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 $1s^2\ ^1S_0-1s2p\ ^1P_1^o$ resonance line was observed at 1.47758±0.00007 Å by Aglitsky *et al.* (1988)[3]. The earlier measurements are less accurate. The $1s^2\ ^1S_0-1snp\ ^{3,1}P_1^o$ $(n=3$ 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 $1s^2\ ^1S_0-1s2p\ ^3P_{2,1}^o$ at 1.4805±0.001 Å and 1.4840±0.0005 Å and also the transitions $1s2p\ ^1P_1^o-2p^2\ ^1S_0$, $^1D_2$ 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

Principal ionization energy of the tabulated ions in $cm^{-1}$ (eV).

λ(Å)

Wavelength of listed spectral lines in Angstrom units ($10^{-8}$ cm).

C,T

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

- $^{C}$ wavelength calculated from energy level data using the Ritz combination principle.
- $^{T}$ wavelength classification is tentative.

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 "°" 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.

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.

Int

Approximate intensity of a spectral line, generally visually estimated from the blackness (or density) of the line on photographic plates.

*f*

This column indicates magnetic dipole transitions denoted by M1.

*A*

Radiative transition probability in $s^{-1}$. The notation 4.19+2 denotes $4.19\times10^2$.

Acc

Accuracy estimate for the transition probability as follows: A 3%, B 10%, C 25%, D 50%, E>50%.

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:

- ° reference from which the adopted wavelength value is taken
- $^{\Delta}$ 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)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | References |
|---|---|---|---|---|---|---|
| 154.591 | $3p^63d^2\ ^3F_2$ | $3p^5(^2P^\circ)3d^3(^2H)\ ^3G^\circ_3$ | 0 | 646870 | 4 | 27 |
| 154.363 | $_3$ | $_4$ | 2486 | 650310 | 3 | 27 |
| 153.767 | $_4$ | $_5$ | 5487 | 655820 | 6 | 27 |
| 153.711 | $3p^63d^2\ ^1G_4$ | $3p^5(^2P^\circ)3d^3(^2G)\ ^1H^\circ_5$ | | | 4 | 27 |
| 140.071 | $3p^63d^2\ ^3F_2$ | $3p^5(^2P^\circ)3d^3(^4F)\ ^3F^\circ_2$ | 0 | 713920 | 7 | 27 |
| 139.868 | $_3$ | $_3$ | 2486 | 717450 | 6 | 27 |
| 139.771 | $_4$ | $_4$ | 5487 | 720940 | 7 | 27 |
| 137.036 | $3p^63d^2\ ^1G_4$ | $3p^5(^2P^\circ)3d^3(^2H)\ ^1G^\circ_4$ | | | 6 | 27 |
| 133.034 | $3p^63d^2\ ^3F_4$ | $3p^5(^2P^\circ)3d^3(^4F)\ ^3D^\circ_3$ | 5487 | 757170 | 7 | 27 |
| 132.478 | $_3$ | $_2$ | 2486 | 757330 | 5 | 27 |
| 132.240 | $_2$ | $_1$ | 0 | 756200 | 3 | 27 |
| 88.032 | $3p^63d^2\ ^3P_2$ | $3p^63d4f\ ^3D^\circ_3$ | 30600+X | 1166550+X | 12 | 25 |
| 88.020 | $_1$ | $_2$ | | | 6 | 25 |
| 87.983 | $_0$ | $_1$ | | | 4 | 25 |
| 87.932 | $3p^63d^2\ ^1D_2$ | $3p^63d4f\ ^1D^\circ_2$ | 23900+X | 1161140+X | 10 | 5,25° |
| 87.703 | $3p^63d^2\ ^1D_2$ | $3p^63d4f\ ^1F^\circ_3$ | 23900+X | 1164110 | 10 | 5,25° |

Cu X (Ca sequence) Ionization Energy = 1871000 cm$^{-1}$ (232 eV) – Continued

| λ (Å) | Classification | | Energy Levels (cm$^{-1}$) | | Int. | References |
|---|---|---|---|---|---|---|
| 87.516 | $3p^63d^2\ ^1D_2$ | $3p^63d4f\ ^3D^o_3$ | 23900+X | 1166550+X | 5 | 25 |
| 87.135 | $3p^63d^2\ ^3F_4$ | $3p^63d4f\ ^3F^o_3$ | 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 | $3p^63d^2\ ^3F_4$ | $3p^63d4f\ ^3G^o_4$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^5(^2P^o)3d^2(^1G)\ ^2F^o_{7/2}$ | 4060 | 546595 | 40 | 59 |
| 180.001 | $3p^63d\ ^2D_{5/2}$ | $3p^5(^2P^o)3d^2(^1D)\ ^2F^o_{7/2}$ | 4060 | 559612 | 100 | 59 |
| 171.875 | 3/2 | 5/2 | 0 | 581818 | 50 | 59 |
| 150.369 | $3p^63d\ ^2D_{5/2}$ | $3p^5(^2P^o)3d^2(^3F)\ ^2F^o_{5/2}$ | 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 | $3p^63d\ ^2D_{3/2}$ | $3p^5(^2P^o)3d^2(^3P)\ ^2P^o_{1/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^5(^2P^o)3d^2(^3F)\ ^2D^o_{5/2}$ | 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 | $3p^63d\ ^2D_{3/2}$ | $3p^64p\ ^2P^o_{1/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^64f\ ^2F^o_{7/2}$ | 4060 | 1273300 | 13 | 4,25° |
| 78.542 | 3/2 | 5/2 | 0 | 1273200 | 12 | 4,25° |
| 76.256 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^3P^o)4s\ ^2P^o_{3/2}$ | 4060 | 1315420 | 2 | 38 |
| 76.022 | 3/2 | 3/2 | 0 | 1315420 | 0 | 38 |
| 75.866 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^3F^o)4s\ ^4F^o_{7/2}$ | 4060 | 1322170 | 1 | 38 |
| 75.472 | 3/2 | 5/2 | 0 | 1324990 | 1 | 38 |
| 75.325 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^3F^o)4s\ ^2F^o_{7/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^3D^o)4s\ ^4D^o_{7/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^1F^o)4s\ ^2F^o_{7/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^53d(^3D^\circ)4s\ ^2D^\circ_{3/2}$ | 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 | $3p^63d\ ^2D_{5/2}$ | $3p^65f\ ^2F^\circ_{7/2}$ | 4060 | 1586400 | 4 | 25 |
| 63.038 | $_{3/2}$ | $_{5/2}$ | 0 | 1586300 | 4 | 25 |
| 57.047 | $3p^63d\ ^2D_{5/2}$ | $3p^66f\ ^2F^\circ_{7/2}$ | 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 | $3p^6\ ^1S_0$ | $3p^53d\ ^3D^\circ_1$ | 0 | 572282 | 5 | 65 |
| 139.175 | $3p^6\ ^1S_0$ | $3p^53d\ ^1P^\circ_1$ | 0 | 718520 | 300 | 25,34,65° |
| 80.666 | $3p^53d\ ^1P^\circ_1$ | $3p^5(^2P^\circ_{1/2})4f\ ^1/_2[^5/_2]_2$ | 718520 | 1958200? | 2 | 72 |
| 73.734 | $3p^53d\ ^1F^\circ_3$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^7/_2]_4$ | | | 3 | 72 |
| 72.821 | $3p^53d\ ^3D^\circ_3$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^7/_2]_4$ | | | 7 | 72 |
| 72.572 | $3p^53d\ ^1F^\circ_3$ | $3p^5(^2P^\circ_{1/2})4f\ ^1/_2[^7/_2]_4$ | | | 10 | 72 |
| 72.373 | $3p^53d\ ^3D^\circ_2$ | $3p^5(^2P^\circ_{1/2})4f\ ^1/_2[^7/_2]_3$ | | | 6 | 72 |
| 71.948 | $3p^53d\ ^1D^\circ_2$ | $3p^5(^2P^\circ_{1/2})4f\ ^1/_2[^5/_2]_3$ | | | 6 | 72 |
| 71.700 | $3p^53d\ ^3F^\circ_2$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^7/_2]_3$ | | | 4 | 72 |
| 71.609 | $3p^53d\ ^3F^\circ_3$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^9/_2]_4$ | | | 7 | 72 |
| 71.530 | $_4$ | $_5$ | | | 8 | 72 |
| 71.033 | $3p^53d\ ^3P^\circ_2$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^3/_2]_2$ | | | 4 | 72 |
| 70.656 | $_1$ | $_1$ | | | 5 | 72 |
| 70.551 | $_1$ | $_2$ | | | 6 | 72 |
| 70.804 | $3p^53d\ ^3P^\circ_2$ | $3p^5(^2P^\circ_{3/2})4f\ ^3/_2[^5/_2]_3$ | | | 4 | 72 |
| 69.128 | $3p^6\ ^1S_0$ | $3p^54s\ (^3/_2,^1/_2)^\circ_1$ | 0 | 1446600 | 3 | 25 |
| 67.882 | $3p^6\ ^1S_0$ | $3p^54s\ (^1/_2,^1/_2)^\circ_1$ | 0 | 1473100 | 3 | 25 |
| 56.333 | $3p^6\ ^1S_0$ | $3p^54d\ (^3/_2,^5/_2)^\circ_1$ | 0 | 1775200 | 0 | 25 |
| 55.466 | $3p^6\ ^1S_0$ | $3p^54d\ (^1/_2,^3/_2)^\circ_1$ | 0 | 1802900 | 0 | 25 |

Cu XIII (Cl sequence) Ionization Energy = 3234000 $cm^{-1}$ (401 eV)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | *f* | *A* ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 3500.4 | $3s^23p^5\ ^2P^o_{3/2}$ | $3s^23p^5\ ^2P^o_{1/2}$ | 0 | 28560 | | M1 | 4.19+2 | C | 17°,36,78* |
| 150.638 | $3s^23p^5\ ^2P^o_{3/2}$ | $3s^23p^4(^1D)3d\ ^2S_{1/2}$ | 0 | 663840 | 10 | | | | 46 |
| 144.720 | $3s^23p^5\ ^2P^o_{3/2}$ | $3s^23p^4(^3P)3d\ ^2P_{3/2}$ | 0 | 690990 | 20 | | | | 34,46° |
| 143.756 | $3s^23p^5\ ^2P^o_{1/2}$ | $3s^23p^4(^3P)3d\ ^2D_{3/2}$ | 28560 | 724240 | 200bl | | | | 34,46° |
| 142.963 | 3/2 | 5/2 | 0 | 699480 | 200 | | | | 34,46° |
| 138.065 | 3/2 | 3/2 | 0 | 724240 | 20 | | | | 34,46° |
| 66.18 | $3s^23p^4(^3P)3d\ ^4F_{9/2}$ | $3s^23p^4(^3P)4f\ ^4G^o_{11/2}$ | | | | | | | 26 |
| 65.24 | $3s^23p^4(^3P)3d\ ^4D_{7/2}$ | $3s^23p^4(^3P)4f\ ^4F^o_{9/2}$ | | | | | | | 26 |

Cu XIV (S sequence) Ionization Energy = 3508000 $cm^{-1}$ (435 eV)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | *f* | *A* ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 4183.4 | $3s^23p^4\ ^3P_2$ | $3s^23p^4\ ^3P_1$ | 0 | 23897 | | M1 | 2.83+2 | C | 17,62°,78* |
| 1190.4 | $3s^23p^4\ ^3P_1$ | $3s^23p^4\ ^1S_0$ | 23897 | 107902 | | M1 | 4.01+3 | C | 46a,62,78* |
| 302.406 | $3s^23p^4\ ^3P_1$ | $3s3p^5\ ^3P^o_2$ | 23897 | 354570 | 1 | | | | 46a°,63 |
| 282.038 | 2 | 2 | 0 | 354570 | 1 | | | | 46a°,63 |
| 250.429 | $3s^23p^4\ ^1D_2$ | $3s3p^5\ ^1P^o_1$ | 52540 | 451850 | 1 | | | | 46a°,63 |
| 159.997 | $3s^23p^4\ ^3P_1$ | $3s^23p^3(^2D^o)3d\ ^3P^o_2$ | 23897 | 648960 | 10 | | | | 46a° |
| 154.080 | 2 | 2 | 0 | 648960 | 50 | | | | 46a°,63 |
| 152.466 | $3s^23p^4\ ^1S_0$ | $3s^23p^3(^2P^o)3d\ ^1P^o_1$ | 107902 | 763830 | 20 | | | | 46a°.63 |
| 151.938 | $3s^23p^4\ ^1D_2$ | $3s^23p^3(^2D^o)3d\ ^1D^o_2$ | 52540 | 710700 | 5 | | | | 46a°,63 |
| 150.836 | $3s^23p^4\ ^3P_1$ | $3s^23p^3(^4S^o)3d\ ^3D^o_2$ | 23897 | 686870 | 20 | | | | 46a°,63 |
| 148.318 | 2 | 3 | 0 | 674230 | 200bl | | | | 26,46a°,63 |
| 148.309 | $3s^23p^4\ ^1D_2$ | $3s^23p^3(^2D^o)3d\ ^1F^o_3$ | 52540 | 726770 | 200bl | | | | 46a° |
| 140.580 | $3s^23p^4\ ^1D_2$ | $3s^23p^3(^2P^o)3d\ ^1P^o_1$ | 52540 | 763830 | 10 | | | | 46a°,63 |
| 61.70 | $3s^23p^3(^2D^o)3d\ ^3G^o_5$ | $3s^23p^3(^2D^o)4f\ ^3H_6$ | | | | | | | 26 |
| 61.08 | $3s^23p^33d\ ^5D^o_4$ | $3s^23p^34f\ ^5F_5$ | | | 1 | | | | 26 |

Cu XV (P sequence) Ionization Energy = 3903000 $cm^{-1}$ (484 eV)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | $f$ | $A$ ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 2085.3 | $3s^23p^3\ ^4S^o_{3/2}$ | $3s^23p^3\ ^2D^o_{3/2}$ | 0 | 47940 | | M1 | 2.81+2 | C | 17,18°,78* |
| 944.6 | $3s^23p^3\ ^4S^o_{3/2}$ | $3s^23p^3\ ^2P^o_{3/2}$ | 0 | 105865 | | M1 | 1.03+3 | C | 17,18°,78* |
| 296.6 | $3s^23p^3\ ^4S^o_{3/2}$ | $3s3p^4\ ^4P_{5/2}$ | 0 | 337100 | | | | | 41 |
| 238.1 | $3s^23p^3\ ^2D^o_{5/2}$ | $3s3p^4\ ^2P_{3/2}$ | 57803 | 477800 | | | | | 41 |
| 163.274 | $3s^23p^3\ ^2P^o_{1/2}$ | $3s^23p^2(^1D)3d\ ^2P_{3/2}$ | 91106 | 703573 | 2 | | | | 41,68° |
| 161.852 | $3s^23p^3\ ^2D^o_{5/2}$ | $3s^23p^2(^1D)3d\ ^2D_{5/2}$ | 57803 | 675651 | 5 | | | | 41,68° |
| 160.143 | $_{3/2}$ | $_{3/2}$ | 47940 | 672380 | 10 | | | | 41,68° |
| 161.381 | $3s^23p^3\ ^4S^o_{3/2}$ | $3s^23p^2(^3P)3d\ ^4P_{5/2}$ | 0 | 619652 | 40 | | | | 26,41,68° |
| 159.677 | $_{3/2}$ | $_{3/2}$ | 0 | 626264 | 1 | | | | 41,68° |
| 157.9 | $_{3/2}$ | $_{1/2}$ | 0 | 633300 | | | | | 41,68° |
| 158.944 | $3s^23p^3\ ^2P^o_{3/2}$ | $3s^23p^2(^3P)3d\ ^2D_{5/2}$ | 105962 | 735114 | 10 | | | | 41,68° |
| 155.1 | $_{1/2}$ | $_{3/2}$ | 90950 | 735639 | | | | | 41 |
| 154.713 | $3s^23p^3\ ^2D^o_{5/2}$ | $3s^23p^2(^3P)3d\ ^2F_{7/2}$ | 57803 | 704207 | 200 | | | | 26,41,68° |
| 57.52 | $3s^23p^2(^1D)3d\ ^2G_{9/2}$ | $3s^23p^2(^1D)4f\ ^2H^o_{11/2}$ | | | 1 | | | | 26 |
| 57.44 | $3s^23p^23d\ ^4F_{9/2}$ | $3s^23p^24f\ ^4G^o_{11/2}$ | | | 1 | | | | 26 |

Cu XVI (Si sequence) Ionization Energy = 4194000 $cm^{-1}$ (520 eV)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | $f$ | $A$ ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 5375.8 | $3s^23p^2\ ^3P_0$ | $3s^23p^2\ ^3P_1$ | 0 | 18596.7 | | M1 | 1.07+2 | C | 17,78* |
| 2544.7 | $3s^23p^2\ ^3P_2$ | $3s^23p^2\ ^1D_2$ | 32747 | 72035 | | M1 | 3.28+2 | C | 16°,17,78* |
| 1871.3 | $_1$ | $_2$ | 18596.7 | 72035 | | M1 | 3.32+2 | C | 62,78* |
| 952.8 | $3s^23p^2\ ^3P_1$ | $3s^23p^2\ ^1S_0$ | 18596.7 | 123550 | | M1 | 3.81+3 | C | 17,78* |
| 410.46 | $3s^23p^2\ ^3P_2$ | $3s3p^3\ ^5S^o_2$ | 32747 | 276430 | | | | | 73,74,75° |
| 387.56 | $_1$ | $_2$ | 18596.7 | 276430 | bl | | | | 73,74,75° |
| 298.162 | $3s^23p^2\ ^3P_2$ | $3s3p^3\ ^3D^o_3$ | 32747 | 368118 | 1 | | | | 63,70° |
| 291.705 | $_1$ | $_2$ | 18596.7 | 361409 | 2 | | | | 63,70° |
| 276.821 | $_0$ | $_1$ | 0 | 361244 | 2 | | | | 63,70° |
| 261.247 | $3s^23p^2\ ^3P_2$ | $3s3p^3\ ^3P^o_1$ | 32730 | 415501 | 1 | | | | 63,70° |
| 259.857 | $_2$ | $_2$ | 32730 | 417557 | 3 | | | | 63,70° |
| 251.954 | $_1$ | $_1$ | 18596.7 | 415501 | 1 | | | | 63,70° |
| 210.385 | $3s^23p^2\ ^1D_2$ | $3s3p^3\ ^1P^o_1$ | 72016 | 547335 | 10 | | | | 63,70° |
| 209.160 | $3s^23p^2\ ^3P_2$ | $3s3p^3\ ^3S^o_1$ | 32730 | 510826 | 10 | | | | 63,70° |
| 203.155 | $_1$ | $_1$ | 18596.7 | 510826 | 10 | | | | 63,70° |
| 195.766 | $_0$ | $_1$ | 0 | 510826 | 5 | | | | 63,70° |
| 192.461 | $3s^23p^2\ ^1D_2$ | $3s^23p3d\ ^3P^o_2$ | 72016 | 591646 | 1 | | | | 70 |
| 184.613 | $3s^23p^2\ ^1D_2$ | $3s^23p3d\ ^1D^o_2$ | 72016 | 613690 | 20 | | | | 63,70° |

Cu XVI (Si sequence) Ionization Energy = 4194000 $cm^{-1}$ (520 eV) — Continued

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | $f$ | $A$ ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 178.959 | $3s^23p^2\ ^3P_2$ | $3s^23p3d\ ^3P^o_2$ | 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 | $3s^23p^2\ ^1S_0$ | $3s^23p3d\ ^1P^o_1$ | 123550 | 698524 | 2 | | | | 63,70° |
| 168.879 | $3s^23p^2\ ^3P_2$ | $3s^23p3d\ ^3D^o_3$ | 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 | $3s^23p^2\ ^3P_1$ | $3s^23p3d\ ^1D^o_2$ | 18596.7 | 613690 | 1 | | | | 63,70° |
| 164.228 | $3s^23p^2\ ^1D_2$ | $3s^23p3d\ ^1F^o_3$ | 72016 | 680933 | 10 | | | | 63,70° |
| 154.271 | $3s^23p^2\ ^3P_2$ | $3s^23p3d\ ^1F^o_3$ | 32730 | 680933 | 5 | | | | 70 |
| 56.06$^T$ | $3s^23p3d\ ^3D^o_3$ | $3s^23p4f\ ^3F_4$ | 624870 | 2409000? | | | | | 44 |
| 55.46$^T$ | $3s^23p3d\ ^3P^o_0$ | $3s^23p4f\ ^3D_1$ | 617805 | 2421000? | | | | | 44 |
| 54.48 | $3s^23p3d\ ^3F^o_3$ | $3s^23p4f\ ^3G_4$ | 534500? | 2370000 | 200 | | | | 44°,47$^{\Delta}$ |
| 54.24 | $_4$ | $_5$ | 553300? | 2397000 | 100 | | | | 44°,47$^{\Delta}$ |
| 53.52 | $3s^23p^2\ ^1D_2$ | $3s^23p4s\ ^1P^o_1$ | 72016 | 1940000 | 300 | | | | 47 |
| 52.85 | $3s^23p^2\ ^3P_2$ | $3s^23p4s\ ^3P^o_2$ | 32730 | 1930000 | 350 | | | | 47 |
| 52.18 | $_1$ | $_2$ | 18596.7 | 1930000 | 350 | | | | 47 |
| 52.41$^T$ | $3s3p^3\ ^1D^o_2$ | $3s^23p4f\ ^3G_3$ | 464200? | 2372000? | | | | | 44 |
| 52.08$^T$ | $3s3p^3\ ^1D^o_2$ | $3s^23p4f\ ^1F_3$ | 464200? | 2384000? | | | | | 44 |
| 45.90 | $3s^23p^2\ ^1S_0$ | $3s^23p4d\ ^1P^o_1$ | 123550 | 2302000 | | | | | 44 |
| 45.24 | $3s^23p^2\ ^1D_2$ | $3s^23p4d\ ^1F^o_3$ | 72016 | 2282000 | 300 | | | | 44°,47$^{\Delta}$ |
| 45.21 | $3s^23p^2\ ^3P_2$ | $3s^23p4d\ ^3D^o_3$ | 32730 | 2244000 | 350 | | | | 44°,47$^{\Delta}$ |
| 44.98 | $_1$ | $_2$ | 18596.7 | 2242000 | 350 | | | | 44°,47$^{\Delta}$ |
| 44.63$^T$ | $_0$ | $_1$ | 0 | 2241000? | | | | | 44 |
| 44.67 | $3s^23p^2\ ^3P_2$ | $3s^23p4d\ ^3F^o_3$ | 32730 | 2271000 | | | | | 44 |
| 44.47$^T$ | $3s^23p^2\ ^3P_1$ | $3s^23p4d\ ^3P^o_0$ | 18596.7 | 2267000? | | | | | 44 |

Cu XVII (Al sequence) Ionization Energy = 4490000 $cm^{-1}$ (557 eV)

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | $f$ | $A$ ($s^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 3007.6 | $3s^23p\ ^2P^o_{1/2}$ | $3s^23p\ ^2P^o_{3/2}$ | 0 | 33239 | | M1 | 3.30+2 | C | 17°,36,78* |
| 410.6 | $3s^23p\ ^2P^o_{3/2}$ | $3s3p^2\ ^4P_{1/2}$ | 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 | $3s^23p\ ^2P^o_{3/2}$ | $3s3p^2\ ^2D_{5/2}$ | 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. | $f$ | $A$ (s$^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 239.462 | $3s3p^2\ ^4P_{5/2}$ | $3p^3\ ^4S^\circ_{3/2}$ | 307708 | 725320 | 5 | | | | 67 |
| 230.675 | $_{3/2}$ | $_{3/2}$ | 291810 | 725320 | 2 | | | | 15,67° |
| 223.170 | $_{1/2}$ | $_{3/2}$ | 277231 | 725320 | 1 | | | | 54,63$^{A}$,67° |
| 224.841 | $3s^23p\ ^2P^\circ_{1/2}$ | $3s3p^2\ ^2S_{1/2}$ | 0 | 444759 | 10 | | | | 15,63,67° |
| 223.823 | $3s^23p\ ^2P^\circ_{3/2}$ | $3s3p^2\ ^2P_{1/2}$ | 33239 | 480016 | 10 | | | | 15,63,67° |
| 218.716 | $_{3/2}$ | $_{3/2}$ | 33239 | 490467 | 100 | | | | 15,26,63, 67° |
| 208.328 | $_{1/2}$ | $_{1/2}$ | 0 | 480016 | 3 | | | | 67 |
| 203.881 | $_{1/2}$ | $_{3/2}$ | 0 | 490467 | 5 | | | | 15,63,67° |
| 200.40 | $3s3p^2\ ^2D_{5/2}$ | $3s3p3d\ ^2D^\circ_{5/2}$ | 377783 | 876785? | | | | | 15 |
| 188.19 | $3s3p^2\ ^2D_{5/2}$ | $3s3p3d\ ^2F^\circ_{5/2}$ | 377783 | 909161? | bl | | | | 15 |
| 180.70 | $_{5/2}$ | $_{7/2}$ | 377783 | 931186? | bl | | | | 15 |
| 184.855 | $3s^23p\ ^2P^\circ_{3/2}$ | $3s^23d\ ^2D_{3/2}$ | 33239 | 574180 | 5 | | | | 63,67° |
| 183.485 | $_{3/2}$ | $_{5/2}$ | 33239 | 578243 | 100 | | | | 15,26,63, 67° |
| 174.168 | $_{1/2}$ | $_{3/2}$ | 0 | 574180 | 50 | | | | 15,26,63, 67° |
| 180.70 | $3s3p^2\ ^4P_{5/2}$ | $3s3p3d\ ^4D^\circ_{7/2}$ | 307708 | 861003? | bl | | | | 15 |
| 176.98 | $_{3/2}$ | $_{5/2}$ | 291810 | 856728? | | | | | 15 |
| 52.76 | $3s^23d\ ^2D_{5/2}$ | $3s^24f\ ^2F^\circ_{7/2}$ | 578243 | 2474000 | 350 | | | | 47 |
| 52.59 | $_{3/2}$ | $_{5/2}$ | 574180 | 2476000 | 450 | | | | 47 |
| 51.16 | $3s3p^2\ ^2D_{5/2}$ | $3s3p4s\ ^2P^\circ_{3/2}$ | 377783 | 2332000 | 600 | | | | 47 |
| 51.16 | $3s3p3d\ ^4F^\circ_{7/2}$ | $3s3p4f\ ^4G_{9/2}$ | | | 600 | | | | 47 |
| 50.98 | $_{5/2}$ | $_{7/2}$ | | | 550 | | | | 47 |
| 50.81 | $_{9/2}$ | $_{11/2}$ | | | 450 | | | | 47 |
| 50.17 | $3s^23p\ ^2P^\circ_{3/2}$ | $3s^24s\ ^2S_{1/2}$ | 33239 | 2026000 | 450 | | | | 47 |
| 49.90 | $3s3p^2\ ^4P_{5/2}$ | $3s3p4s\ ^4P^\circ_{3/2}$ | 307600 | 2312000 | 350 | | | | 47 |
| 48.89 | $_{3/2}$ | $_{5/2}$ | 291692 | 2337000 | 350 | | | | 47 |
| 43.31 | $3s^23p\ ^2P^\circ_{3/2}$ | $3s^24d\ ^2D_{5/2}$ | 33239 | 2342000 | 500 | | | | 47 |
| 42.81 | $_{1/2}$ | $_{3/2}$ | 0 | 2336000 | 400 | | | | 47 |

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 |
|---|---|---|---|---|---|---|---|---|---|
| 3941.6 | $3s3p\ ^3P^\circ_1$ | $3s3p\ ^3P^\circ_2$ | 289401 | 314753 | | M1 | 2.16+2 | C | 17,78* |
| 430.44 | $3s3d\ ^1D_2$ | $3p3d\ ^1D^\circ_2$ | 917020 | 1149319 | 2 | | | | 53 |
| 395.67 | $3s3p\ ^1P^\circ_1$ | $3p^2\ ^1D_2$ | 426987 | 679710 | 4 | | | | 53 |
| 346.44 | $3s3p\ ^1P^\circ_1$ | $3p^2\ ^3P_2$ | 426987 | 715608 | 2 | | | | 53 |
| 345.542 | $3s^2\ ^1S_0$ | $3s3p\ ^3P^\circ_1$ | 0 | 289401 | | | | | 15,33,69° |
| 334.002 | $3s3d\ ^3D_1$ | $3p3d\ ^3F^\circ_2$ | 818630 | 1118029 | 1 | | | | 15,69° |
| 317.563 | $_2$ | $_3$ | 820704 | 1135602 | 5 | | | | 15,69° |
| 300.417 | $_3$ | $_4$ | 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 | $3s3d\ ^3D_1$ | $3p3d\ ^1D^\circ_2$ | 818630 | 1149319 | 1 | | | | 69 |
| 275.813 | $3s3d\ ^3D_2$ | $3p3d\ ^3D^\circ_1$ | 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 | $3s3p\ ^3P^\circ_2$ | $3p^2\ ^1D_2$ | 314753 | 679710 | 5 | | | | 53 |
| 256.202 | 1 | 2 | 289401 | 679710 | 3 | | | | 69 |
| 272.120 | $3s3d\ ^1D_2$ | $3p3d\ ^1F^\circ_3$ | 917020 | 1284495 | 30 | | | | 15,53,64,69° |
| 270.316 | $3s3p\ ^3P^\circ_2$ | $3p^2\ ^3P_1$ | 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 | $3s3p\ ^1P^\circ_1$ | $3p^2\ ^1S_0$ | 426987 | 804139 | 10 | | | | 53,69° |
| 261.820 | $3s3d\ ^1D_2$ | $3p3d\ ^1P^\circ_1$ | 917020 | 1298970 | 3 | | | | 53,69° |
| 257.464 | $3s3d\ ^3D_2$ | $3p3d\ ^3P^\circ_2$ | 820704 | 1209104 | 2 | | | | 69 |
| 256.612 | 1 | 1 | 818630 | 1208326 | 2 | | | | 69 |
| 240.028 | $3p3d\ ^1F^\circ_3$ | $3d^2\ ^1G_4$ | 1284495 | 1701113 | 10 | | | | 61,69° |
| 234.199 | $3s^2\ ^1S_0$ | $3s3p\ ^1P^\circ_1$ | 0 | 426987 | 500 | | | | 15,26,69° |
| 228.16 | $3p^2\ ^1D_2$ | $3p3d\ ^3F^\circ_2$ | 679710 | 1118029 | 2 | | | | 53 |
| 223.170 | $3p3d\ ^3P^\circ_2$ | $3d^2\ ^3F_3$ | 1209104 | 1657191 | 20 | | | | 69 |
| 219.410 | $3p3d\ ^3D^\circ_3$ | $3d^2\ ^3F_4$ | 1205542 | 1661315 | 10 | | | | 61,69° |
| 213.087 | 2 | 3 | 1187907 | 1657191 | 5 | | | | 69 |
| 212.551 | 1 | 2 | 1183252 | 1653727 | 2 | | | | 69 |
| 212.939 | $3p^2\ ^1D_2$ | $3p3d\ ^1D^\circ_2$ | 679710 | 1149319 | 10 | | | | 15,69° |
| 204.110 | $3p^2\ ^3P_2$ | $3p3d\ ^3D^\circ_3$ | 715608 | 1205542 | 200bl | | | | 69 |
| 198.718 | 1 | 2 | 684689 | 1187907 | 100 | | | | 69 |
| 192.954 | 0 | 1 | 664977 | 1183252 | 50 | | | | 15,69° |
| 204.072 | $3s3p\ ^1P^\circ_1$ | $3s3d\ ^1D_2$ | 426987 | 917020 | 30 | | | | 15,26,69° |
| 202.962 | $3p^2\ ^3P_2$ | $3p3d\ ^3P^\circ_1$ | 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 | $3p^2\ ^1S_0$ | $3p3d\ ^1P^\circ_1$ | 804139 | 1298970 | 30 | | | | 53,69° |
| 198.56 | $3s3p\ ^3P^\circ_2$ | $3s3d\ ^3D_1$ | 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 | $3p3d\ ^3F^\circ_4$ | $3d^2\ ^3F_4$ | 1156841 | 1661315 | 10 | | | | 69 |
| 191.723 | 3 | 3 | 1135602 | 1657191 | 30 | | | | 69 |
| 190.174 | $3p^2\ ^1D_2$ | $3p3d\ ^3D^\circ_3$ | 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 | $3p^2$ $^3P_2$ | $3p3d$ $^1F^o_3$ | 715608 | 1284495 | 5 | | | | 64,69° |
| 165.349 | $3p^2$ $^1D_2$ | $3p3d$ $^1F^o_3$ | 679710 | 1284495 | 10 | | | | 15,64,69° |
| 51.496[T] | $3p3d$ $^1P^o_1$ | $3p4f$ $^1D_2$ | 1298970 | 3240900? | | | | | 44 |
| 51.287 | $3p3d$ $^1F^o_3$ | $3p4f$ $^1G_4$ | 1284495 | 3234300? | | | | | 44 |
| 50.118 | $3p3d$ $^3D^o_1$ | $3p4f$ $^3F_2$ | 1183252 | 3178500? | | | | | 44 |
| 50.067 | 3 | 4 | 1205542 | 3202900 | | | | | 44°,47 |
| 49.862 | $3p3d$ $^3D^o_2$ | $3p4f$ $^3D_3$ | 1187907 | 3193400 | | | | | 44 |
| 49.769 | $3p3d$ $^3P^o_1$ | $3p4f$ $^3D_2$ | 1208326 | 3217600 | | | | | 44 |
| 49.639 | 1 | 1 | 1208326 | 3222900 | bl | | | | 44 |
| 49.639 | 0 | 1 | 1208022 | 3222900 | bl | | | | 44°,47 |
| 49.558 | $3s3d$ $^3D_3$ | $3s4f$ $^3F^o_4$ | 823970 | 2841800 | 4 | | | | 32°,44 |
| 49.490 | 2 | 3 | 820704 | 2841300 | 4 | | | | 32[Δ],44° |
| 49.452 | 1 | 2 | 818630 | 2840800 | 3 | | | | 32°,44 |
| 49.395 | $3p3d$ $^1D^o_2$ | $3p4f$ $^1F_3$ | 1149319 | 3173800 | | | | | 44 |
| 49.010 | $3p3d$ $^3F^o_3$ | $3p4f$ $^3G_4$ | 1135602 | 3176000 | | | | | 44°,47 |
| 48.885 | 2 | 3 | 1118029 | 3163600 | bl | | | | 44 |
| 48.885 | 4 | 5 | 1156841 | 3202500 | bl | | | | 44°,47 |
| 47.585 | $3s3p$ $^3P^o_2$ | $3s4s$ $^3S_1$ | 314753 | 2416400 | 3 | | | | 32 |
| 47.012 | 1 | 1 | 289401 | 2416400 | 2 | | | | 32 |
| 46.781 | 0 | 1 | 279816 | 2416400 | 1 | | | | 32 |
| 41.173 | $3s3p$ $^3P^o_2$ | $3s4d$ $^3D_2$ | 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 | $3s^2$ $^1S_0$ | $3s4p$ $^1P^o_1$ | 0 | 2572300 | 5 | | | | 32 |
| 35.294 | $3s3d$ $^3D_3$ | $3s5f$ $^3F^o_4$ | 823970 | 3657300 | 3 | | | | 32 |
| 35.256 | 2 | 3 | 820704 | 3657100 | 2 | | | | 32 |
| 35.238 | 1 | 2 | 818630 | 3656500 | 2 | | | | 32 |
| 30.325 | $3s3p$ $^3P^o_2$ | $3s5d$ $^3D_3$ | 314753 | 3612400 | 5 | | | | 32 |
| 30.104 | 1 | 2 | 289401 | 3611200 | 4 | | | | 32 |
| 30.019 | 0 | 1 | 279816 | 3611000 | 3 | | | | 32 |
| 11.774 | $2p^63s^2$ $^1S_0$ | $2p^53s^23d$ $^1P^o_1$ | 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 | $2p^63s$ $^2S_{1/2}$ | $2p^63p$ $^2P^o_{1/2}$ | 0 | 329436 | 200 | 15,60°,63[Δ] |
| 273.354 | 1/2 | 3/2 | 0 | 365826 | 150 | 15,32,51[Δ],60°, 63 |
| 224.237 | $2p^63p$ $^2P^o_{3/2}$ | $2p^63d$ $^2D_{3/2}$ | 365826 | 811791 | 100 | 15,32,51[Δ],60°, 63 |
| 221.369 | 3/2 | 5/2 | 365826 | 817560 | 450 | 15,32,51[Δ],60°, 63 |
| 207.312 | 1/2 | 3/2 | 329436 | 811791 | 350 | 15,32,51[Δ],60°, 63 |

Cu XIX (Na sequence) Ionization Energy = 5408660 $cm^{-1}$ (670.588 eV) – Continued

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | References |
|---|---|---|---|---|---|---|
| 210.70 | $2p^53s3p$ $^4D_{7/2}$ | $2p^53s3d$ $^4F^{\circ}_{9/2}$ | | | | 15,43° |
| 111.353 | $2p^64f$ $^2F^{\circ}_{7/2}$ | $2p^65g$ $^2G_{9/2}$ | 2925400 | 3823400 | 350 | 15,50,51°,63 |
| 111.274 | $_{5/2}$ | $_{7/2}$ | 2924400 | 3823100 | 250 | 50,51°,63 |
| 103.179 | $2p^64d$ $^2D_{5/2}$ | $2p^65f$ $^2F^{\circ}_{7/2}$ | 2849500 | 3818700 | 150 | 51°,63 |
| 102.960 | $_{3/2}$ | $_{5/2}$ | 2847000 | 3818100 | 100 | 51°,63 |
| 90.990 | $2p^64p$ $^2P^{\circ}_{3/2}$ | $2p^65d$ $^2D_{5/2}$ | 2681600 | 3780600 | 50 | 51 |
| 85.90 | $2p^64s$ $^2S_{1/2}$ | $2p^65p$ $^2P^{\circ}_{3/2}$ | 2535440 | 3699300 | 20 | 51 |
| 53.889 | $2p^63d$ $^2D_{3/2}$ | $2p^64p$ $^2P^{\circ}_{1/2}$ | 811791 | 2667490 | 100 | 26,47,51° |
| 53.643 | $_{5/2}$ | $_{3/2}$ | 817560 | 2681600 | 200 | 26,47,51° |
| 47.442 | $2p^63d$ $^2D_{5/2}$ | $2p^64f$ $^2F^{\circ}_{7/2}$ | 817560 | 2925400 | 1000 | 21,51^Δ,60°,63 |
| 47.335 | $_{3/2}$ | $_{5/2}$ | 811791 | 2924400 | 850 | 21,51^Δ,60°,63 |
| 46.090 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^64s$ $^2S_{1/2}$ | 365826 | 2535440 | 300 | 28,32,51°,63 |
| 45.332 | $_{1/2}$ | $_{1/2}$ | 329436 | 2535440 | 200 | 32,51° |
| 40.298 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^64d$ $^2D_{3/2}$ | 365826 | 2847000 | 200 | 32,51° |
| 40.263 | $_{3/2}$ | $_{5/2}$ | 365826 | 2849500 | 650 | 28,32,51° |
| 39.725 | $_{1/2}$ | $_{3/2}$ | 329436 | 2847000 | 550 | 28,32,51° |
| 37.488 | $2p^63s$ $^2S_{1/2}$ | $2p^64p$ $^2P^{\circ}_{1/2}$ | 0 | 2667490 | 350 | 28,32,51° |
| 37.293 | $_{1/2}$ | $_{3/2}$ | 0 | 2681600 | 450 | 28,32,51° |
| 33.317 | $2p^63d$ $^2D_{5/2}$ | $2p^65f$ $^2F^{\circ}_{7/2}$ | 817560 | 3818700 | 6 | 28,32° |
| 33.266 | $_{3/2}$ | $_{5/2}$ | 811791 | 3818100 | 300 | 28,32,51° |
| 29.277 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^65d$ $^2D_{5/2}$ | 365826 | 3780600 | 9 | 28,32° |
| 28.987 | $_{1/2}$ | $_{3/2}$ | 329436 | 3779300 | 180 | 28,32,51° |
| 28.674 | $2p^63d$ $^2D_{5/2}$ | $2p^66f$ $^2F^{\circ}_{7/2}$ | 817560 | 4305000 | 150 | 28,32,51° |
| 28.631 | $_{3/2}$ | $_{5/2}$ | 811791 | 4304500 | 100 | 32,51° |
| 27.075 | $2p^63s$ $^2S_{1/2}$ | $2p^65p$ $^2P^{\circ}_{1/2}$ | 0 | 3693400 | 100 | 32,51° |
| 27.032 | $_{1/2}$ | $_{3/2}$ | 0 | 3699300 | 150 | 32,51° |
| 26.452 | $2p^63d$ $^2D_{5/2}$ | $2p^67f$ $^2F^{\circ}_{7/2}$ | 817560 | 4598000 | 70 | 32°,51^Δ |
| 26.416 | $_{3/2}$ | $_{5/2}$ | 811791 | 4597400 | 70 | 32°,51^Δ |
| 25.526 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^66d$ $^2D_{5/2}$ | 365826 | 4283400 | 150 | 32,51° |
| 25.297 | $_{1/2}$ | $_{3/2}$ | 329436 | 4282500 | 100 | 32,51° |
| 25.175^T | $2p^63d$ $^2D_{5/2}$ | $2p^68f$ $^2F^{\circ}_{7/2}$ | 817560 | 4789800? | 1 | 32 |
| 25.142^T | $_{3/2}$ | $_{5/2}$ | 811791 | 4789200? | | 32 |
| 23.704 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^67d$ $^2D_{5/2}$ | 365826 | 4584500 | 10 | 32 |
| 23.503 | $_{1/2}$ | $_{3/2}$ | 329436 | 4584200 | 10 | 32 |
| 23.621 | $2p^63s$ $^2S_{1/2}$ | $2p^66p$ $^2P^{\circ}_{1/2}$ | 0 | 4233500 | 1 | 32 |
| 23.599 | $_{1/2}$ | $_{3/2}$ | 0 | 4237500 | 10 | 32 |
| 22.661 | $2p^63p$ $^2P^{\circ}_{3/2}$ | $2p^68d$ $^2D_{5/2}$ | 365826 | 4778800 | | 32 |
| 22.475 | $_{1/2}$ | $_{3/2}$ | 329436 | 4778800 | 1 | 32 |
| 13.11 | $2p^63s$ $^2S_{1/2}$ | $2p^53s^2$ $^2P^{\circ}_{3/2}$ | 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 | $2s^22p^53s\ (^3/_2,^1/_2)^\circ_2$ | $2s^22p^53p\ (^3/_2,^1/_2)_1$ | 7777270 | 8070680 | | 14 |
| 330.44 | $_1$ | $_2$ | 7795650 | 8098270 | | 14 |
| 311.53 | $_2$ | $_2$ | 7777270 | 8098270 | | 14 |
| 328.69 | $2s^22p^53s\ (^1/_2,^1/_2)^\circ_1$ | $2s^22p^53p\ (^1/_2,^1/_2)_1$ | 7955050 | 8259280 | | 14 |
| 317.63 | $_0$ | $_1$ | 7943950 | 8259280 | | 14 |
| 296.07 | $2s^22p^53s\ (^3/_2,^1/_2)^\circ_1$ | $2s^22p^53p\ (^3/_2,^3/_2)_1$ | 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 | $2s^22p^53s\ (^1/_2,^1/_2)^\circ_1$ | $2s^22p^53p\ (^1/_2,^3/_2)_1$ | 7955050 | 8301150 | | 14 |
| 284.70 | $_1$ | $_2$ | 7955050 | 8306290 | | 14 |
| 272.30 | $2s^22p^53p\ (^3/_2,^3/_2)_2$ | $2s^22p^53d\ (^3/_2,^3/_2)^\circ_1$ | 8153580 | 8520820 | | 14 |
| 232.84 | $_1$ | $_2$ | 8133410 | 8562820 | | 14 |
| 258.18 | $2s^22p^53p\ (^3/_2,^3/_2)_2$ | $2s^22p^53d\ (^3/_2,^5/_2)^\circ_2$ | 8153580 | 8540750 | | 14 |
| 241.25 | $_3$ | $_4$ | 8125590 | 8540100 | | 14 |
| 237.57 | $_2$ | $_3$ | 8153580 | 8574510 | | 14 |
| 247.00 | $2s^22p^53p\ (^1/_2,^3/_2)_2$ | $2s^22p^53d\ (^1/_2,^3/_2)^\circ_2$ | 8306290 | 8711110 | | 14 |
| 238.52 | $2s^22p^53p\ (^1/_2,^3/_2)_1$ | $2s^22p^53d\ (^1/_2,^5/_2)^\circ_2$ | 8301150 | 8720400 | | 14 |
| 237.57 | $_2$ | $_3$ | 8306290 | 8727220 | | 14 |
| 227.85 | $2s^22p^53p\ (^3/_2,^1/_2)_1$ | $2s^22p^53d\ (^3/_2,^3/_2)^\circ_0$ | 8070680 | 8509560 | | 14 |
| 223.83 | $_2$ | $_3$ | 8098270 | 8545040 | | 14 |
| 215.30 | $_2$ | $_2$ | 8098270 | 8562820 | | 14 |
| 212.75 | $2s^22p^53p\ (^3/_2,^1/_2)_1$ | $2s^22p^53d\ (^3/_2,^5/_2)^\circ_2$ | 8070680 | 8540750 | | 14 |
| 163.6 | $2s^22p^53s\ (^3/_2,^1/_2)^\circ_1$ | $2s^22p^53p\ (^1/_2,^1/_2)_0$ | 7795650 | 8406900 | | 14 |
| 12.827 | $2s^22p^6\ ^1S_0$ | $2s^22p^53s\ (^3/_2,^1/_2)^\circ_1$ | 0 | 7795650 | 9 | 8,29,35° |
| 12.570 | $2s^22p^6\ ^1S_0$ | $2s^22p^53s\ (^1/_2,^1/_2)^\circ_1$ | 0 | 7955050 | 6 | 8,29,35° |
| 11.736 | $2s^22p^6\ ^1S_0$ | $2s^22p^53d\ (^3/_2,^3/_2)^\circ_1$ | 0 | 8520820 | 7 | 8,29,35° |
| 11.594 | $2s^22p^6\ ^1S_0$ | $2s^22p^53d\ (^3/_2,^5/_2)^\circ_1$ | 0 | 8626510 | 10 | 8,29,35° |
| 11.383 | $2s^22p^6\ ^1S_0$ | $2s^22p^53d\ (^1/_2,^3/_2)^\circ_1$ | 0 | 8787010 | 8 | 8,29,35° |
| 10.653 | $2s^22p^6\ ^1S_0$ | $2s2p^63p\ (^1/_2,^1/_2)^\circ_1$ | 0 | 9387000 | 5 | 8,29,35°,71 |
| 10.597 | $2s^22p^6\ ^1S_0$ | $2s2p^63p\ (^1/_2,^3/_2)^\circ_1$ | 0 | 9436000 | 4 | 8,29,35°,71 |
| 9.521 | $2s^22p^6\ ^1S_0$ | $2s^22p^54s\ (^3/_2,^1/_2)^\circ_1$ | 0 | 10504000 | 1 | 8,35°,39,71$^{\Delta}$ |
| 9.375 | $2s^22p^6\ ^1S_0$ | $2s^22p^54s\ (^1/_2,^1/_2)^\circ_1$ | 0 | 10667000 | 1 | 8,35°,39,71$^{\Delta}$ |
| 9.274 | $2s^22p^6\ ^1S_0$ | $2s^22p^54d\ (^3/_2,^3/_2)^\circ_1$ | 0 | 10783000 | | 35 |
| 9.237 | $2s^22p^6\ ^1S_0$ | $2s^22p^54d\ (^3/_2,^5/_2)^\circ_1$ | 0 | 10828000 | | 8,30,35° |
| 9.106 | $2s^22p^6\ ^1S_0$ | $2s^22p^54d\ (^1/_2,^3/_2)^\circ_1$ | 0 | 10984000 | | 8,30,35° |
| 8.447 | $2s^22p^6\ ^1S_0$ | $2s^22p^55d\ (^3/_2,^5/_2)^\circ_1$ | 0 | 11840000 | 1 | 8,35°,71$^{\Delta}$ |
| 8.400 | $2s^22p^6\ ^1S_0$ | $2s2p^64p\ (^1/_2,^1/_2)^\circ_1$ | 0 | 11905000 | | 35°,39 |
| 8.385 | $2s^22p^6\ ^1S_0$ | $2s2p^64p\ (^1/_2,^3/_2)^\circ_1$ | 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 | $2s^22p^6\ ^1S_0$ | $2s^22p^55d\ (^1/_2,^3/_2)^\circ_1$ | 0 | 12002000 | 1 | 8,35°,71$^{\Delta}$ |
| 8.073 | $2s^22p^6\ ^1S_0$ | $2s^22p^56d\ (^3/_2,^5/_2)^\circ_1$ | 0 | 12389000 | 1 | 8,35°,71$^{\Delta}$ |
| 7.972 | $2s^22p^6\ ^1S_0$ | $2s^22p^56d\ (^1/_2,^3/_2)^\circ_1$ | 0 | 12544000 | | 8,35° |

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 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^5\ ^2P^\circ_{1/2}$ | 0 | 168830 | | M1 | 8.62+4 | C | 36,78* |
| 346.25 | $2s^22p^4(^1D)3s\ ^2D_{3/2}$ | $2s^22p^4(^1D)3p\ ^2F^\circ_{5/2}$ | 8458000 | 8747000 | | | | | 15 |
| 305.44 | 5/2 | 7/2 | 8452000 | 8779000 | | | | | 15 |
| 332.02 | $2s^22p^4(^3P)3s\ ^4P_{3/2}$ | $2s^22p^4(^3P)3p\ ^4P^\circ_{1/2}$ | 8363000 | 8664000 | | | | | 15 |
| 325.97 | $2s^22p^4(^3P)3s\ ^4P_{3/2}$ | $2s^22p^4(^3P)3p\ ^4D^\circ_{5/2}$ | 8363000 | 8670000 | | | | | 15 |
| 293.58 | 5/2 | 7/2 | 8206000 | 8547000 | | | | | 15 |
| 242.30 | 5/2 | 3/2 | 8206000 | 8619000 | | | | | 15 |
| 302.56 | $2s^22p^4(^3P)3s\ ^2P_{3/2}$ | $2s^22p^4(^3P)3p\ ^2D^\circ_{5/2}$ | 8236000 | 8566000 | | | | | 15 |
| 279.40 | $2s^22p^4(^1D)3s\ ^2D_{5/2}$ | $2s^22p^4(^1D)3p\ ^2D^\circ_{5/2}$ | 8452000 | 8810000 | bl | | | | 15 |
| 263.88 | $2s^22p^4(^3P)3p\ ^2D^\circ_{5/2}$ | $2s^22p^4(^3P)3d\ ^2F_{7/2}$ | 8566000 | 8945000 | | | | | 15 |
| 262.12 | $2s^22p^4(^3P)3p\ ^4D^\circ_{7/2}$ | $2s^22p^4(^3P)3d\ ^4F_{9/2}$ | 8547000 | 8928500? | | | | | 15 |
| 257.50 | 3/2 | 5/2 | 8619000 | 9007000 | bl | | | | 15 |
| 252.74 | 5/2 | 7/2 | 8670000 | 9066000 | | | | | 15 |
| 259.60 | $2s^22p^4(^1D)3p\ ^2D^\circ_{5/2}$ | $2s^22p^4(^1D)3d\ ^2F_{7/2}$ | 8810000 | 9195000 | | | | | 15 |
| 250.48 | $2s^22p^4(^3P)3p\ ^4P^\circ_{5/2}$ | $2s^22p^4(^3P)3d\ ^4D_{7/2}$ | | | | | | | 15 |
| 245.40 | $2s^22p^4(^1D)3p\ ^2F^\circ_{5/2}$ | $2s^22p^4(^1D)3d\ ^2G_{7/2}$ | 8747000 | 9154000 | | | | | 15 |
| 90.341 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^6\ ^2S_{1/2}$ | 168830 | 1275750 | 30 | | | | 6,50,63° |
| 78.384 | 3/2 | 1/2 | 0 | 1275750 | 100 | | | | 6,50,63° |
| 12.186 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^4(^3P)3s\ ^4P_{5/2}$ | 0 | 8206000 | | | | | 35°,39 |
| 12.029 | 3/2 | 1/2 | 0 | 8313000 | | | | | 39 |
| 11.956 | 3/2 | 3/2 | 0 | 8363000 | 6 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 12.165 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^3P)3s\ ^2P_{1/2}$ | 168830 | 8388000 | 5 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 12.140 | 3/2 | 3/2 | 0 | 8236000 | 7 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 11.920 | 3/2 | 1/2 | 0 | 8388000 | 4 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 12.061 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1D)3s\ ^2D_{3/2}$ | 168830 | 8458000 | 7 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 11.830 | 3/2 | 5/2 | 0 | 8452000 | 8 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 11.736 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1S)3s\ ^2S_{1/2}$ | 168830 | 8690000 | | | | | 35 |
| 11.352 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^3P)3d\ ^4P_{3/2}$ | 168830 | 8979000 | | | | | 39 |
| 11.162 | 3/2 | 1/2 | 0 | 8959000 | 7 | | | | 9,10$^{\Delta}$,11, 35°,39 |
| 11.136 | 3/2 | 3/2 | 0 | 8979000 | 10 | | | | 9,10$^{\Delta}$,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 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^3P)3d\ ^2P_{3/2}$ | 168830 | 9108000 | 6 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 11.114 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^4(^3P)3d\ ^2F_{5/2}$ | 0 | 8998000? | | | | | 35°,39 |
| 11.097 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1D)3d\ ^2S_{1/2}$ | 168830 | 9180000 | 45 | | | | 9,$10^{\Delta}$,11,35° |
| 10.893 | 3/2 | 1/2 | 0 | 9180000 | 14 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 11.065 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1D)3d\ ^2P_{3/2}$ | 168830 | 9206000 | 12 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 11.002 | 1/2 | 1/2 | 168830 | 9258000 | 12 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.863 | 3/2 | 3/2 | 0 | 9206000 | 28 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.801 | 3/2 | 1/2 | 0 | 9258000 | 16 | | | | 9,$10^{\Delta}$,11,39° |
| 11.014 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1D)3d\ ^2D_{3/2}$ | 168830 | 9248000 | 14 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.858 | 3/2 | 5/2 | 0 | 9209000 | 28 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.813 | 3/2 | 3/2 | 0 | 9248000 | 16 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.971 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^4(^3P)3d\ ^2D_{5/2}$ | 0 | 9115000 | 14 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.800 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1S)3d\ ^2D_{3/2}$ | 168830 | 9428000 | 5 | | | | 9,$10^{\Delta}$,11, 35°,39 |
| 10.392 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^5(^3P^\circ)3p\ ^4P_{3/2}$ | 168830 | 9792000 | | | | | 35 |
| 10.203 | 3/2 | 5/2 | 0 | 9801000? | | | | | 35 |
| 10.354 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s2p^5(^3P^\circ)3p\ ^4D_{5/2}$ | 0 | 9658000 | | | | | 35 |
| 10.316 | 3/2 | 3/2 | 0 | 9694000 | | | | | 35 |
| 10.306 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^5(^3P^\circ)3p\ ^2D_{3/2}$ | 168830 | 9872000 | | | | | 35 |
| 10.291 | 3/2 | 5/2 | 0 | 9717000 | | | | | 35 |
| 10.282 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^5(^3P^\circ)3p\ ^2S_{1/2}$ | 168830 | 9894000? | | | | | 35 |
| 10.260 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s2p^5(^3P^\circ)3p\ ^2P_{3/2}$ | 0 | 9747000 | | | | | 35 |
| 10.234 | 3/2 | 1/2 | 0 | 9771000 | | | | | 35 |
| 10.121 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^5(^1P^\circ)3p\ ^2D_{3/2}$ | 168830 | 10049000 | | | | | 35 |
| 9.912 | 3/2 | 5/2 | 0 | 10089000 | | | | | 35 |
| 10.074 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s2p^5(^1P^\circ)3p\ ^2P_{1/2}$ | 168830 | 10095000 | | | | | 35 |
| 10.057 | 1/2 | 3/2 | 168830 | 10112000 | | | | | 35 |
| 8.984 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^4(^3P)4s\ ^2P_{3/2}$ | 0 | 11131000? | | | | | 35 |
| 8.873 | 3/2 | 1/2 | 0 | 11270000? | | | | | 40 |
| 8.936 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^1D)4s\ ^2D_{3/2}$ | 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 | $2s^22p^5\ ^2P^\circ_{3/2}$ | $2s^22p^4(^3P)4s\ ^4P_{1/2}$ | 0 | 11222000? | | | | | 40 |
| 8.870 | 3/2 | 3/2 | 0 | 11274000? | | | | | 35 |
| 8.777 | $2s^22p^5\ ^2P^\circ_{1/2}$ | $2s^22p^4(^3P)4d\ ^2P_{3/2}$ | 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 | $2s^22p^5\ ^2P^o_{1/2}$ | $2s^22p^4(^1S)4s\ ^2S_{1/2}$ | 168830 | 11566000? | | | | | 40 |
| 8.648 | $_{3/2}$ | $_{1/2}$ | 0 | 11566000? | | | | | 40 |
| 8.754 | $2s^22p^5\ ^2P^o_{3/2}$ | $2s^22p^4(^3P)4d\ ^2D_{5/2}$ | 0 | 11423000? | | | | | 35 |
| 8.754 | $_{3/2}$ | $_{3/2}$ | 0 | 11423000? | | | | | 35 |
| 8.714 | $2s^22p^5\ ^2P^o_{1/2}$ | $2s^22p^4(^1D)4d\ ^2S_{1/2}$ | 168830 | 11642000? | | | | | 40 |
| 8.591 | $_{3/2}$ | $_{1/2}$ | 0 | 11642000? | | | | | 35°,40 |
| 8.714 | $2s^22p^5\ ^2P^o_{1/2}$ | $2s^22p^4(^1D)4d\ ^2P_{3/2}$ | 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 | $2s^22p^5\ ^2P^o_{1/2}$ | $2s^22p^4(^1D)4d\ ^2D_{3/2}$ | 168830 | 11658000? | | | | | 35°,40 |
| 8.591 | $_{3/2}$ | $_{5/2}$ | 0 | 11640000? | | | | | 35 |
| 8.574 | $_{3/2}$ | $_{3/2}$ | 0 | 11658000? | | | | | 40 |
| 8.691 | $2s^22p^5\ ^2P^o_{3/2}$ | $2s^22p^4(^3P)4d\ ^4F_{3/2}$ | 0 | 11506000? | | | | | 35°,40 |
| 8.691 | $_{3/2}$ | $_{5/2}$ | 0 | 11506000? | | | | | 35 |
| 8.652 | $2s^22p^5\ ^2P^o_{3/2}$ | $2s^22p^4(^3P)4d\ ^4P_{5/2}$ | 0 | 11558000? | | | | | 35 |
| 8.591 | $2s^22p^5\ ^2P^o_{3/2}$ | $2s^22p^4(^1D)4d\ ^2F_{5/2}$ | 0 | 11640000? | | | | | 35 |
| 8.554 | $2s^22p^5\ ^2P^o_{1/2}$ | $2s^22p^4(^1S)4d\ ^2D_{3/2}$ | 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 | $2s^22p^4\ ^3P_2$ | $2s^22p^4\ ^3P_1$ | 0 | 151990 | | M1 | 6.78+4 | C | 36,78* |
| 420.0 | $2s^22p^4\ ^3P_2$ | $2s^22p^4\ ^1D_2$ | 0 | 237950 | | M1 | 6.52+4 | C | 36,78* |
| 114.974 | $2s^22p^4\ ^1D_2$ | $2s2p^5\ ^3P^o_2$ | 237950 | 1107710 | 3 | | | | 23° |
| 104.620 | $2s^22p^4\ ^3P_1$ | $2s2p^5\ ^3P^o_2$ | 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 | $2s2p^5\ ^1P^o_1$ | $2p^6\ ^1S_0$ | 1528080 | 2546610 | 10 | | | | 23°,58 |
| 93.302 | $2s^22p^4\ ^1S_0$ | $2s2p^5\ ^1P^o_1$ | 456290 | 1528080 | 4 | | | | 23°,50 |
| 77.512 | $2s^22p^4\ ^1D_2$ | $2s2p^5\ ^1P^o_1$ | 237950 | 1528080 | 30 | | | | 6,23°,50 |
| 74.383 | $2s2p^5\ ^3P^o_1$ | $2p^6\ ^1S_0$ | 1202170 | 2546610 | 1 | | | | 23 |
| 65.43 | $2s^22p^4\ ^3P_2$ | $2s2p^5\ ^1P^o_1$ | 0 | 1528080 | 2 | | | | 23^Δ,49,50° |
| 11.621 | $2s^22p^4\ ^3P_1$ | $2s^22p^3(^4S^o)3s\ ^3S^o_1$ | 151990 | 8758000? | | | | | 35 |
| 11.416 | $_2$ | $_1$ | 0 | 8758000? | | | | | 35 |
| 11.573 | $2s^22p^4\ ^1D_2$ | $2s^22p^3(^2D^o)3s\ ^3D^o_2$ | 237950 | 8876000? | | | | | 35 |
| 11.468 | $2s^22p^4\ ^1D_2$ | $2s^22p^3(^2D^o)3s\ ^1D^o_2$ | 237950 | 8958000? | | | | | 35 |
| 11.468 | $2s^22p^4\ ^1S_0$ | $2s^22p^3(^2P^o)3s\ ^1P^o_1$ | 456290 | 9177000? | | | | | 35 |

Cu XXII (O sequence) Ionization Energy = 15450000 cm$^{-1}$ (1916 eV) – Continued

| λ (Å) | Classification | | Energy Levels (cm$^{-1}$) | | Int. | $f$ | $A$ (s$^{-1}$) | Acc. | References |
|---|---|---|---|---|---|---|---|---|---|
| 11.466 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2D^\circ)3s$ $^3D^\circ_2$ | 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 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3s$ $^3P^\circ_1$ | 237950 | 9049000? | | | | | 35 |
| 11.198 | $_2$ | $_2$ | 237950 | 9166000? | | | | | 35 |
| 11.266 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2P^\circ)3s$ $^3P^\circ_0$ | 151990 | 9028000? | | | | | 35 |
| 11.097 | $_1$ | $_2$ | 151990 | 9166000? | | | | | 35 |
| 11.185 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3s$ $^1P^\circ_1$ | 237950 | 9177000? | | | | | 35 |
| 10.611 | $2s^22p^4$ $^3P_2$ | $2s^22p^3(^4S^\circ)3d$ $^3D^\circ_3$ | 0 | 9424000? | | | | | 35 |
| 10.611 | $2s^22p^4$ $^1S_0$ | $2s^22p^3(^2P^\circ)3d$ $^1P^\circ_1$ | 456290 | 9880000? | | | | | 35 |
| 10.611 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3d$ $^3F^\circ_3$ | 237950 | 9666000? | | | | | 35 |
| 10.597 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2D^\circ)3d$ $^1F^\circ_3$ | 237950 | 9675000? | | | | | 35 |
| 10.560 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3d$ $^3P^\circ_2$ | 237950 | 9708000? | | | | | 35 |
| 10.406 | $2s^22p^4$ $^3P_2$ | $2s^22p^3(^2D^\circ)3d$ $^3D^\circ_3$ | 0 | 9610000? | | | | | 35 |
| 10.406 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3d$ $^1D^\circ_2$ | 237950 | 9848000? | | | | | 35 |
| 10.406 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)3d$ $^1F^\circ_3$ | 237950 | 9848000? | | | | | 35 |
| 10.392 | $2s^22p^4$ $^3P_2$ | $2s^22p^3(^2D^\circ)3d$ $^3P^\circ_2$ | 0 | 9623000? | | | | | 35 |
| 10.374 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2P^\circ)3d$ $^3P^\circ_1$ | 151990 | 9791000? | | | | | 35 |
| 10.342 | $2s^22p^4$ $^3P_2$ | $2s^22p^3(^2P^\circ)3d$ $^3F^\circ_3$ | 0 | 9666000? | | | | | 35 |
| 10.316 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2P^\circ)3d$ $^3D^\circ_2$ | 151990 | 9846000? | | | | | 35 |
| 8.385 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^4S^\circ)4d$ $^3D^\circ_2$ | 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 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2D^\circ)4d$ $^1D^\circ_2$ | 237950 | 12314000? | | | | | 35 |
| 8.281 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2D^\circ)4d$ $^1F^\circ_3$ | 237950 | 12314000? | | | | | 35 |
| 8.275 | $2s^22p^4$ $^1S_0$ | $2s^22p^3(^2P^\circ)4d$ $^1P^\circ_1$ | 456290 | 12541000? | | | | | 35 |
| 8.275 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2D^\circ)4d$ $^3D^\circ_2$ | 151990 | 12237000? | | | | | 35 |
| 8.125 | $_2$ | $_3$ | 0 | 12308000? | | | | | 35 |
| 8.222 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)4d$ $^3F^\circ_3$ | 237950 | 12400000? | | | | | 35 |
| 8.171 | $2s^22p^4$ $^3P_2$ | $2s^22p^3(^2D^\circ)4d$ $^3F^\circ_3$ | 0 | 12238000? | | | | | 35 |
| 8.171 | $2s^22p^4$ $^3P_1$ | $2s^22p^3(^2P^\circ)4d$ $^3P^\circ_2$ | 151990 | 12390000? | | | | | 35 |
| 8.086 | $_1$ | $_1$ | 151990 | 12519000? | | | | | 35 |
| 8.125 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)4d$ $^1F^\circ_3$ | 237950 | 12546000? | | | | | 35 |
| 8.125 | $2s^22p^4$ $^1D_2$ | $2s^22p^3(^2P^\circ)4d$ $^3D^\circ_2$ | 237950 | 12532000? | | | | | 35 |
| 8.125 | $2s^22p^4$ $^3P_0$ | $2s^22p^3(^2P^\circ)4d$ $^3D^\circ_1$ | 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 | $2s^22p^3\ ^2D^o_{3/2}$ | $2s^22p^3\ ^2D^o_{5/2}$ | 170860 | 230070 | | M1 | 1.49+3 | C | 37,78* |
| 585.0 | $2s^22p^3\ ^4S^o_{3/2}$ | $2s^22p^3\ ^2D^o_{3/2}$ | 0 | 170860 | | M1 | 6.40+4 | C | 36,78* |
| 434.8 | $_{3/2}$ | $_{5/2}$ | 0 | 230070 | | M1 | 7.98+3 | C | 36,78* |
| 111.071 | $2s^22p^3\ ^4S^o_{3/2}$ | $2s2p^4\ ^4P_{5/2}$ | 0 | 900330 | 4bl | | | | 23° |
| 98.848 | $_{3/2}$ | $_{3/2}$ | 0 | 1011650 | 4bl | | | | 6,23° |
| 96.485 | $_{3/2}$ | $_{1/2}$ | 0 | 1036430 | 70 | | | | 6,23° |
| 108.519 | $2s^22p^3\ ^2P^o_{1/2}$ | $2s2p^4\ ^2D_{3/2}$ | 327900 | 1249110 | 1 | | | | 23° |
| 99.243 | $2s2p^4\ ^2P_{3/2}$ | $2p^5\ ^2P^o_{1/2}$ | 1485340 | 2492890 | 4bl | | | | 23 |
| 96.845 | $2s2p^4\ ^2D_{5/2}$ | $2p^5\ ^2P^o_{3/2}$ | 1283940 | 2316720 | 5bl | | | | 6,23° |
| 93.667 | $_{3/2}$ | $_{3/2}$ | 1249110 | 2316720 | 2 | | | | 23 |
| 80.400 | $_{3/2}$ | $_{1/2}$ | 1249110 | 2492890 | 1 | | | | 23 |
| 94.888 | $2s^22p^3\ ^2D^o_{5/2}$ | $2s2p^4\ ^2D_{5/2}$ | 230070 | 1283940 | 10bl | | | | 6,23°,50 |
| 92.728 | $_{3/2}$ | $_{3/2}$ | 170860 | 1249110 | 5 | | | | 6,23°,50 |
| 91.000 | $2s^22p^3\ ^2P^o_{1/2}$ | $2s2p^4\ ^2S_{1/2}$ | 327900 | 1427080 | 5 | | | | 6,23° |
| 83.340 | $2s^22p^3\ ^2P^o_{3/2}$ | $2s2p^4\ ^2P_{1/2}$ | 446780 | 1646680 | 15bl | | | | 6,23°,50 |
| 80.057 | $2s^22p^3\ ^4S^o_{3/2}$ | $2s2p^4\ ^2D_{3/2}$ | 0 | 1249110 | 1 | | | | 23 |
| 79.664 | $2s^22p^3\ ^2D^o_{5/2}$ | $2s2p^4\ ^2P_{3/2}$ | 230070 | 1485340 | 20 | | | | 6,23°,50 |
| 76.076 | $_{3/2}$ | $_{3/2}$ | 170860 | 1485340 | 1 | | | | 23 |
| 67.759 | $_{3/2}$ | $_{1/2}$ | 170860 | 1646680 | 2 | | | | 23 |
| 79.615 | $2s^22p^3\ ^2D^o_{3/2}$ | $2s2p^4\ ^2S_{1/2}$ | 170860 | 1427080 | 5 | | | | 6,23° |
| 70.073 | $2s^22p^3\ ^4S^o_{3/2}$ | $2s2p^4\ ^2S_{1/2}$ | 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 | $2s^22p^2\ ^3P_1$ | $2s^22p^2\ ^3P_2$ | 132120 | 188430 | | M1 | 1.57+3 | C | 36,78* |
| 756.9 | $_0$ | $_1$ | 0 | 132120 | | M1 | 3.55+4 | C | 36,78* |
| 540.0 | $2s^22p^2\ ^3P_2$ | $2s^22p^2\ ^1D_2$ | 188430 | 373620 | | M1 | 5.78+4 | C | 36,78* |
| 414.1 | $_1$ | $_2$ | 132120 | 373620 | | M1 | 6.53+4 | C | 36,78* |
| 120.442 | $2s^22p^2\ ^3P_2$ | $2s2p^3\ ^3D^o_3$ | 188430 | 1018700 | 2 | | | | 23 |
| 119.572 | $_1$ | $_2$ | 132120 | 968440 | 3 | | | | 23 |
| 104.292 | $_0$ | $_1$ | 0 | 958850 | 3 | | | | 23 |
| 105.859 | $2s2p^3\ ^1P^o_1$ | $2p^4\ ^1S_0$ | 1573500 | 2518200 | 2 | | | | 23 |
| 105.760 | $2s2p^3\ ^3P^o_2$ | $2p^4\ ^3P_1$ | 1196100 | 2141600 | 4 | | | | 23 |
| 100.637 | $_0$ | $_1$ | 1147900 | 2141600 | 3 | | | | 23 |
| 103.702 | $2s2p^3\ ^3D^o_3$ | $2p^4\ ^3P_2$ | 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 | $2s^22p^2\ ^3P_2$ | $2s2p^3\ ^3P^o_2$ | 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 | $2s^22p^2\ ^1D_2$ | $2s2p^3\ ^1D^o_2$ | 373620 | 1404900 | 8 | | | | 23 |
| 94.888 | $2s^22p^2\ ^1S_0$ | $2s2p^3\ ^1P^o_1$ | 519650 | 1573500 | 10bl | | | | 23 |
| 87.128 | $2s^22p^2\ ^3P_2$ | $2s2p^3\ ^3S^o_1$ | 188430 | 1335700 | 7 | | | | 6,23° |
| 83.084 | $_1$ | $_1$ | 132120 | 1335700 | 1 | | | | 6,23° |
| 83.340 | $2s^22p^2\ ^1D_2$ | $2s2p^3\ ^1P^o_1$ | 373620 | 1573500 | 15bl | | | | 23 |
| 82.195 | $2s^22p^2\ ^3P_2$ | $2s2p^3\ ^1D^o_2$ | 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 | $2s^22p\ ^2P^o_{1/2}$ | $2s^22p\ ^2P^o_{3/2}$ | 0 | 191280 | | M1 | 6.26+4 | C | 36,78* |
| 117.507 | $2s2p^2\ ^4P_{5/2}$ | $2p^3\ ^4S^o_{3/2}$ | 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 | $1s^22s2p\ ^3P^o_1$ | $1s^22s2p\ ^3P^o_2$ | 438970 | 593290 | | M1 | 4.74+4 | C | 36,78* |
| 227.808 | $1s^22s^2\ ^1S_0$ | $1s^22s2p\ ^3P^o_1$ | 0 | 438970 | | | | | 17a° |
| 173.34 | $1s^22s2p\ ^1P^o_1$ | $1s^22p^2\ ^1D_2$ | 899390 | 1477200 | | | | | 13 |
| 158.70 | $1s^22s2p\ ^3P^o_2$ | $1s^22p^2\ ^3P_1$ | 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 | $1s^22s2p\ ^1P^o_1$ | $1s^22p^2\ ^1S_0$ | 899390 | 1716100 | | | | | 13 |
| 113.14 | $1s^22s2p\ ^3P^o_2$ | $1s^22p^2\ ^1D_2$ | 593290 | 1477200 | | | | | 13 |
| 111.186 | $1s^22s^2\ ^1S_0$ | $1s^22s2p\ ^1P^o_1$ | 0 | 899390 | | | | | 13,17a°,36 |
| 27.395 | $1s^22p3d\ ^3F^o_3$ | $1s^22p4f\ ^3G_4$ | 12156000 | 15806000 | 1 | | | | 12 |
| 27.013 | $_4$ | $_5$ | | | 1 | | | | 12 |
| 27.182 | $1s^22s3d\ ^3D_3$ | $1s^22s4f\ ^3F^o_4$ | 11672000? | 15351000 | 1 | | | | 12 |
| 9.746 | $1s^22p^2\ ^1S_0$ | $1s^22p3s\ ^1P^o_1$ | 1716100 | 11977000 | 30 | | | | 7,12° |
| 9.520 | $1s^22p^2\ ^3P_1$ | $1s^22p3s\ ^3P^o_0$ | 1223400 | 11728000 | | | | | 7 |
| 9.520 | $1s^22p^2\ ^1D_2$ | $1s^22p3s\ ^1P^o_1$ | 1477200 | 11977000 | | | | | 7 |
| 9.489 | $1s^22s2p\ ^1P^o_1$ | $1s^22s3s\ ^1S_0$ | 899390 | 11439000 | 1 | | | | 12 |

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 | $1s^22p^2\ ^1D_2$ | $1s^22p3d\ ^3P^o_2$ | 1477200 | 12144000 | 3 | | | | 7,12° |
| 9.359 | $1s^22s2p\ ^3P^o_2$ | $1s^22s3s\ ^3S_1$ | 593290 | 11278000 | 15 | | | | 7,12° |
| 9.324 | $1s^22p^2\ ^1S_0$ | $1s^22p3d\ ^1P^o_1$ | 1716100 | 12441000 | 6 | | | | 7,12° |
| 9.233 | $1s^22p^2\ ^1D_2$ | $1s^22p3d\ ^1D^o_2$ | 1477200 | 12308000 | | | | | 7 |
| 9.194 | $1s^22p^2\ ^3P_2$ | $1s^22p3d\ ^3F^o_3$ | 1279600 | 12156000 | 12 | | | | 12 |
| 9.194 | $1s^22s2p\ ^1P^o_1$ | $1s^22s3d\ ^1D_2$ | 899390 | 11777000 | 12 | | | | 8,12° |
| 9.149 | $1s^22p^2\ ^3P_1$ | $1s^22p3d\ ^3D^o_2$ | 1223400 | 12154000 | 3 | | | | 7,12° |
| 9.042 | 2 | 3 | 1279600 | 12339000 | 10bl | | | | 12 |
| 9.026 | 0 | 1 | 1095600 | 12175000 | 20 | | | | 12 |
| 9.131 | $1s^22p^2\ ^1D_2$ | $1s^22p3d\ ^1F^o_3$ | 1477200 | 12428000 | 10 | | | | 12 |
| 9.026 | $1s^22s2p\ ^3P^o_2$ | $1s^22s3d\ ^3D_3$ | 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 | $1s^22p^2\ ^3P_2$ | $1s^22p3d\ ^1F^o_3$ | 1279600 | 12428000 | 8 | | | | 7,12° |
| 8.970 | $1s^22p^2\ ^3P_1$ | $1s^22p3d\ ^3P^o_1$ | 1223400 | 12372000 | 8 | | | | 12 |
| 8.970 | $1s^22s2p\ ^1P^o_1$ | $1s^22p3p\ ^1P_1$ | 899390 | 12049000 | 8 | | | | 7,12° |
| 8.773 | $1s^22s2p\ ^1P^o_1$ | $1s^22p3p\ ^1D_2$ | 899390 | 12293000 | 5 | | | | 7,12° |
| 8.661 | $1s^22s^2\ ^1S_0$ | $1s^22s3p\ ^1P^o_1$ | 0 | 11546000 | 3 | | | | 12 |
| 8.691[a] | $1s^22s^2\ ^1S_0$ | $1s^22s3p\ ^3P^o_1$ | 0 | 11546000 | 3 | | | | 12 |
| 8.618 | $1s^22s2p\ ^3P^o_2$ | $1s^22p3p\ ^3P_2$ | 593330 | 12197000 | 12 | | | | 7,12° |
| 8.551 | $1s^22s2p\ ^3P^o_2$ | $1s^22p3p\ ^1D_2$ | 593330 | 12293000 | 3 | | | | 7,12° |

[a]Given 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 | $1s^22s\ ^2S_{1/2}$ | $1s^22p\ ^2P^o_{1/2}$ | 0 | 444899 | | 36,48°, 79° |
| 153.507 | 1/2 | 3/2 | 0 | 651432 | 4 | 12▲,36,48°,79° |
| 25.893 | $1s^23d\ ^2D_{5/2}$ | $1s^24p\ ^2P^o_{3/2}$ | 11967000 | 15828000 | 1 | 12 |
| 25.646 | $1s^23d\ ^2D_{5/2}$ | $1s^24f\ ^2F^o_{7/2}$ | 11967000 | 15866000 | 7 | 12 |
| 25.543 | 3/2 | 5/2 | 11947000 | 15862000 | 6 | 12 |
| 25.291 | $1s^23p\ ^2P^o_{3/2}$ | $1s^24d\ ^2D_{5/2}$ | 11903000 | 15857000 | 3 | 12 |
| 24.943 | 1/2 | 3/2 | 11841000 | 15850000 | 1 | 12 |
| 24.291 | $1s^23s\ ^2S_{1/2}$ | $1s^24p\ ^2P^o_{3/2}$ | 11711000 | 15828000 | 1 | 12 |
| 9.042 | $1s^22p\ ^2P^o_{3/2}$ | $1s^23s\ ^2S_{1/2}$ | 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 | $1s^22p\ ^2P^\circ_{3/2}$ | $1s^23d\ ^2D_{3/2}$ | 651432 | 11947000 | 2 | 12 |
| 8.837 | $_{3/2}$ | $_{5/2}$ | 651432 | 11967000 | 25 | 12 |
| 8.691 | $_{1/2}$ | $_{3/2}$ | 444899 | 11947000 | 15 | 12 |
| 8.445 | $1s^22s\ ^2S_{1/2}$ | $1s^23p\ ^2P^\circ_{1/2}$ | 0 | 11841000 | 10 | 12 |
| 8.401 | $_{1/2}$ | $_{3/2}$ | 0 | 11903000 | 20 | 12 |
| 1.272 | $1s^22p\ ^2P^\circ_{3/2}$ | $1s2p3p\ ^2D_{5/2}$ | 651432 | 79260000 | | 1 |
| 1.213 | $1s^22p\ ^2P^\circ_{3/2}$ | $1s2p4p\ ^2D_{5/2}$ | 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$^{C}$ | $1s2s\ ^3S_1$ | $1s2p\ ^3P^\circ_0$ | 67035105 | 67303025 | | 20 |
| 347.767$^{C}$ | $_1$ | $_1$ | 67035105 | 67322654 | | 20 |
| 206.756$^{C}$ | $_1$ | $_2$ | 67035105 | 67518768 | | 20 |
| 283.237$^{C}$ | $1s2s\ ^1S_0$ | $1s2p\ ^1P^\circ_1$ | 67324766 | 67677827 | | 20 |
| 155.588$^{C}$ | $1s2s\ ^3S_1$ | $1s2p\ ^1P^\circ_1$ | 67035105 | 67677827 | | 20 |
| 52.0725$^{C}$ | $1s4p\ ^1P^\circ_1$ | $1s5s\ ^1S_0$ | 83830300 | 85750700 | | 77 |
| 51.3769$^{C}$ | $1s4p\ ^3P^\circ_1$ | $1s5s\ ^3S_1$ | 83787900 | 85734300 | | 77 |
| 50.3373$^{C}$ | $1s4s\ ^1S_0$ | $1s5p\ ^1P^\circ_1$ | 83786500 | 85773100 | | 77 |
| 50.0726$^{C}$ | $1s4s\ ^3S_1$ | $1s5p\ ^3P^\circ_1$ | 83754400 | 85751500 | | 77 |
| 24.0835$^{C}$ | $1s3p\ ^1P^\circ_1$ | $1s4s\ ^1S_0$ | 79634283 | 83786500 | | 19,77 |
| 23.6863$^{C}$ | $1s3p\ ^3P^\circ_1$ | $1s4s\ ^3S_1$ | 79532544 | 83754400 | | 19,77 |
| 23.2557$^{C}$ | $1s3s\ ^1S_0$ | $1s4p\ ^1P^\circ_1$ | 79530270 | 83830300 | | 19,77 |
| 23.0695$^{C}$ | $1s3s\ ^3S_1$ | $1s4p\ ^3P^\circ_1$ | 79453169 | 83787900 | | 19,77 |
| 16.3494$^{C}$ | $1s3p\ ^1P^\circ_1$ | $1s5s\ ^1S_0$ | 79634283 | 85750700 | | 19,77 |
| 16.1245$^{C}$ | $1s3p\ ^3P^\circ_1$ | $1s5s\ ^3S_1$ | 79532544 | 85734300 | | 19,77 |
| 16.0184$^{C}$ | $1s3s\ ^1S_0$ | $1s5p\ ^1P^\circ_1$ | 79530270 | 85773100 | | 19,77 |
| 15.8772$^{C}$ | $1s3s\ ^3S_1$ | $1s5p\ ^3P^\circ_1$ | 79453169 | 85751500 | | 19,77 |
| 8.43708$^{C}$ | $1s2p\ ^1P^\circ_1$ | $1s3s\ ^1S_0$ | 67677827 | 79530270 | | 19,20 |
| 8.24367$^{C}$ | $1s2p\ ^3P^\circ_1$ | $1s3s\ ^3S_1$ | 67322654 | 79453169 | | 19,20 |
| 8.12380$^{C}$ | $1s2s\ ^1S_0$ | $1s3p\ ^1P^\circ_1$ | 67324766 | 79634283 | | 19,20 |
| 8.00164$^{C}$ | $1s2s\ ^3S_1$ | $1s3p\ ^3P^\circ_1$ | 67035105 | 79532544 | | 19,20 |
| 6.20784$^{C}$ | $1s2p\ ^1P^\circ_1$ | $1s4s\ ^1S_0$ | 67677827 | 83786500 | | 20,77 |
| 6.08578$^{C}$ | $1s2p\ ^3P^\circ_1$ | $1s4s\ ^3S_1$ | 67322654 | 83754400 | | 20,77 |
| 6.05857$^{C}$ | $1s2s\ ^1S_0$ | $1s4p\ ^1P^\circ_1$ | 67324766 | 83830300 | | 20,77 |

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

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | References |
|---|---|---|---|---|---|---|
| 5.96915$^C$ | $1s2s\ ^3S_1$ | $1s4p\ ^3P^o_1$ | 67035105 | 83787900 | | 20,77 |
| 5.53315$^C$ | $1s2p\ ^1P^o_1$ | $1s5s\ ^1S_0$ | 67677827 | 85750700 | | 20,77 |
| 5.43134$^C$ | $1s2p\ ^3P^o_1$ | $1s5s\ ^3S_1$ | 67322654 | 85734300 | | 20,77 |
| 5.42054$^C$ | $1s2s\ ^1S_0$ | $1s5p\ ^1P^o_1$ | 67324766 | 85773100 | | 20,77 |
| 5.34291$^C$ | $1s2s\ ^3S_1$ | $1s5p\ ^3P^o_1$ | 67035105 | 85751500 | | 20,77 |
| 1.48538$^C$ | $1s^2\ ^1S_0$ | $1s2p\ ^3P^o_1$ | 0 | 67322654 | | 1,20,76 |
| 1.48107$^C$ | 0 | 2 | 0 | 67518768 | | 20,76 |
| 1.47759$^C$ | $1s^2\ ^1S_0$ | $1s2p\ ^1P^o_1$ | 0 | 67677827 | | 1,3,20,52,56, 57,76 |
| 1.4343 | $1s2p\ ^1P^o_1$ | $2p^2\ ^1D_2$ | 67677827 | 137400000 | | 76 |
| 1.4302 | $1s2p\ ^1P^o_1$ | $2p^2\ ^1S_0$ | 67677827 | 137600000 | | 76 |
| 1.25735$^C$ | $1s^2\ ^1S_0$ | $1s3p\ ^3P^o_1$ | 0 | 79532544 | | 1,19 |
| 1.25574$^C$ | $1s^2\ ^1S_0$ | $1s3p\ ^1P^o_1$ | 0 | 79634283 | | 1,19 |
| 1.19349$^C$ | $1s^2\ ^1S_0$ | $1s4p\ ^3P^o_1$ | 0 | 83787900 | | 1,77 |
| 1.19289$^C$ | $1s^2\ ^1S_0$ | $1s4p\ ^1P^o_1$ | 0 | 83830300 | | 1,77 |
| 1.16616$^C$ | $1s^2\ ^1S_0$ | $1s5p\ ^3P^o_1$ | 0 | 85751500 | | 1,77 |
| 1.16587$^C$ | $1s^2\ ^1S_0$ | $1s5p\ ^1P^o_1$ | 0 | 85773100 | | 1,77 |

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

| λ (Å) | Classification | | Energy Levels ($cm^{-1}$) | | Int. | References |
|---|---|---|---|---|---|---|
| 385.0671$^C$ | $2s\ ^2S_{1/2}$ | $2p\ ^2P^o_{3/2}$ | 69902760 | 70162455 | | 42 |
| 7.770236$^C$ | $2p\ ^2P^o_{3/2}$ | $3d\ ^2D_{5/2}$ | 70162455 | 83032077 | | 24,42 |
| 7.631439$^C$ | $2s\ ^2S_{1/2}$ | $3p\ ^2P^o_{3/2}$ | 69902760 | 83006449 | | 24,42 |
| 5.760688$^C$ | $2p\ ^2P^o_{3/2}$ | $4d\ ^2D_{5/2}$ | 70162455 | 87521643 | | 24,42 |
| 5.679217$^C$ | $2s\ ^2S_{1/2}$ | $4p\ ^2P^o_{3/2}$ | 69902760 | 87510822 | | 24,42 |
| 5.144289$^C$ | $2p\ ^2P^o_{3/2}$ | $5d\ ^2D_{5/2}$ | 70162455 | 89601488 | | 24,42 |
| 5.077872$^C$ | $2s\ ^2S_{1/2}$ | $5p\ ^2P^o_{3/2}$ | 69902760 | 89596047 | | 24,42 |
| 1.430694$^C$ | $1s\ ^2S_{1/2}$ | $2p\ ^2P^o_{1/2}$ | 0 | 69896140 | | 2,42 |
| 1.425264$^C$ | 1/2 | 3/2 | 0 | 70162455 | | 2,42 |
| 1.204726$^C$ | $1s\ ^2S_{1/2}$ | $3p\ ^2P^o_{3/2}$ | 0 | 83006449 | | 24 |
| 1.142716$^C$ | $1s\ ^2S_{1/2}$ | $4p\ ^2P^o_{3/2}$ | 0 | 87510822 | | 24 |
| 1.116121$^C$ | $1s\ ^2S_{1/2}$ | $5p\ ^2P^o_{3/2}$ | 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.

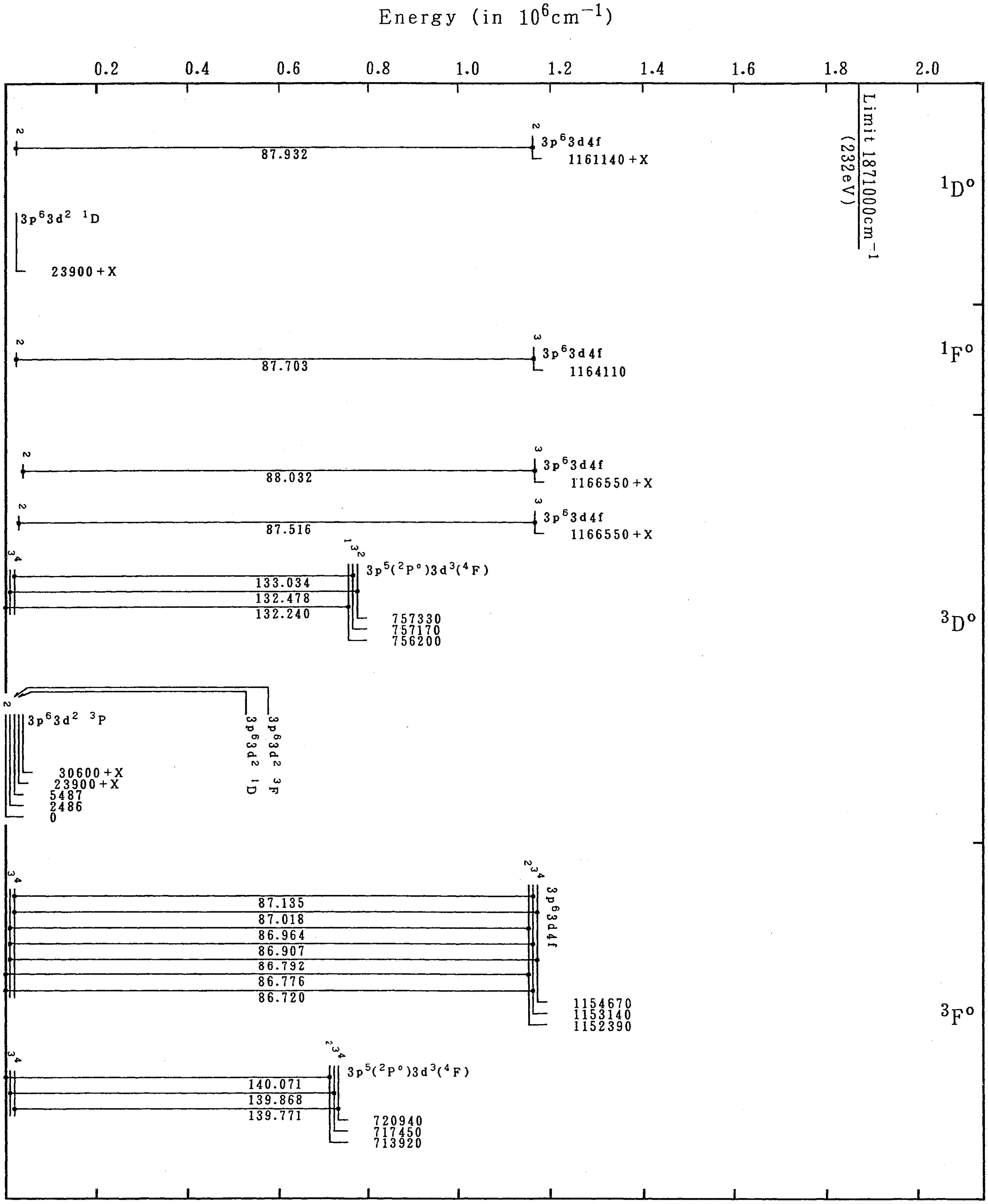
Horizontal lines

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

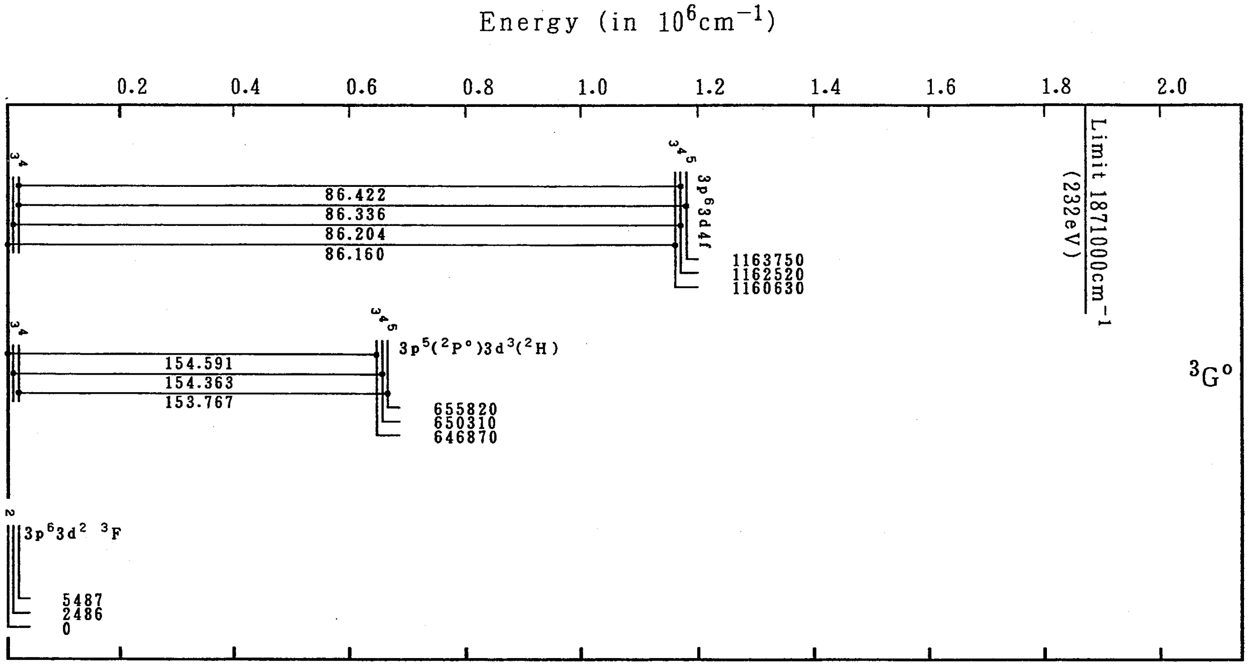
Limit

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

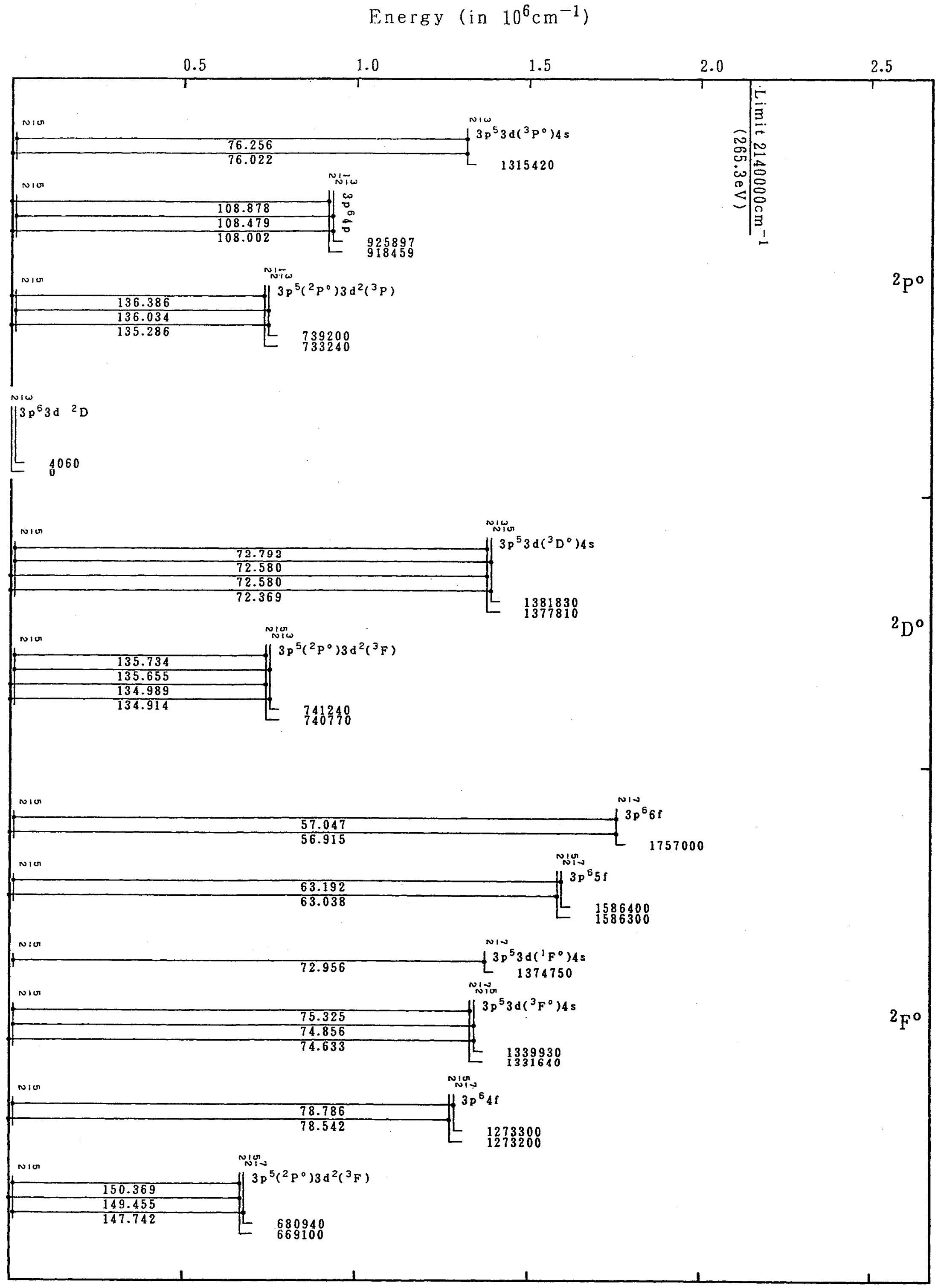
## 6. Grotrian Diagrams for Cu x–Cu xxix



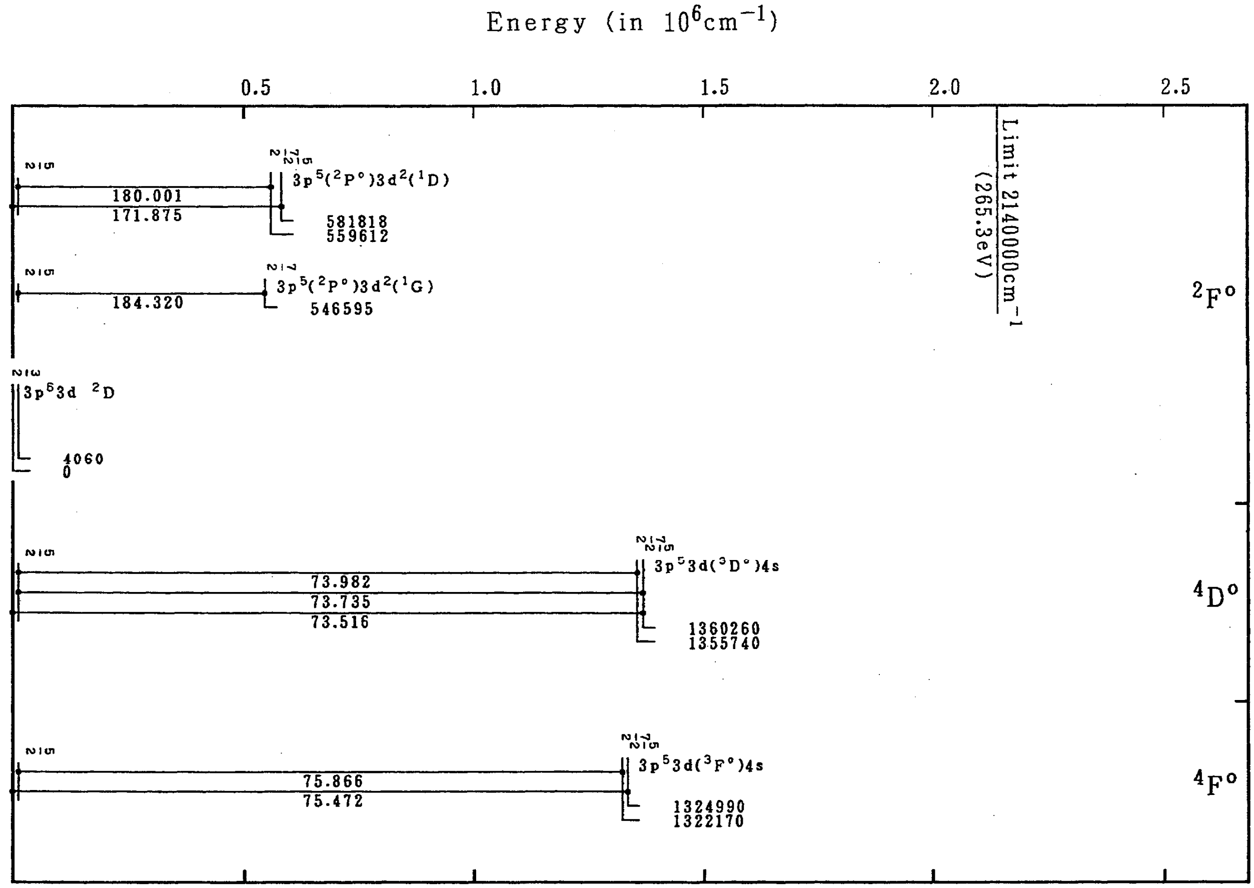

Grotrian diagrams for Cu x (Ca sequence)



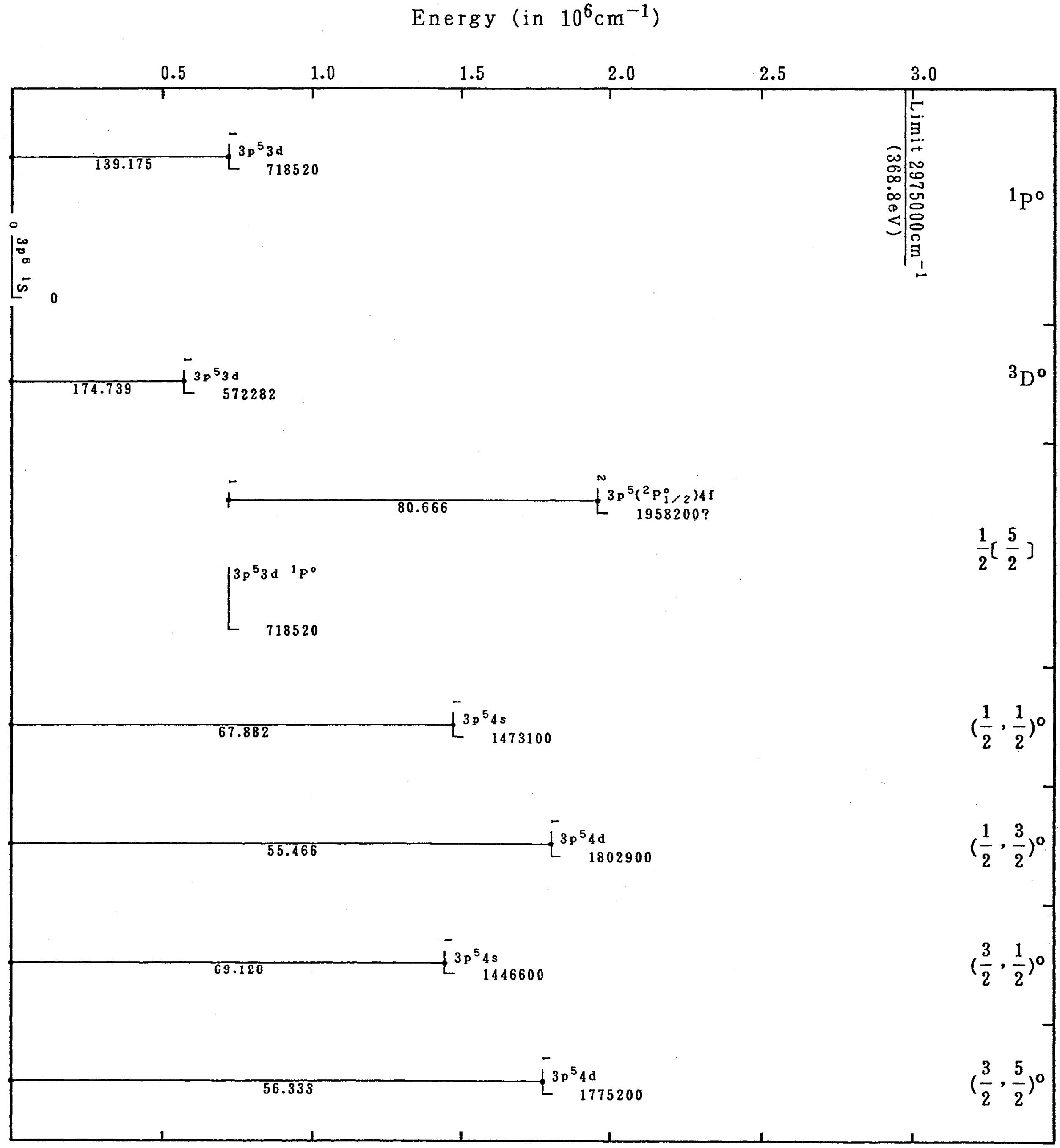

Grotrian diagrams for Cu X (Ca sequence) – Continued



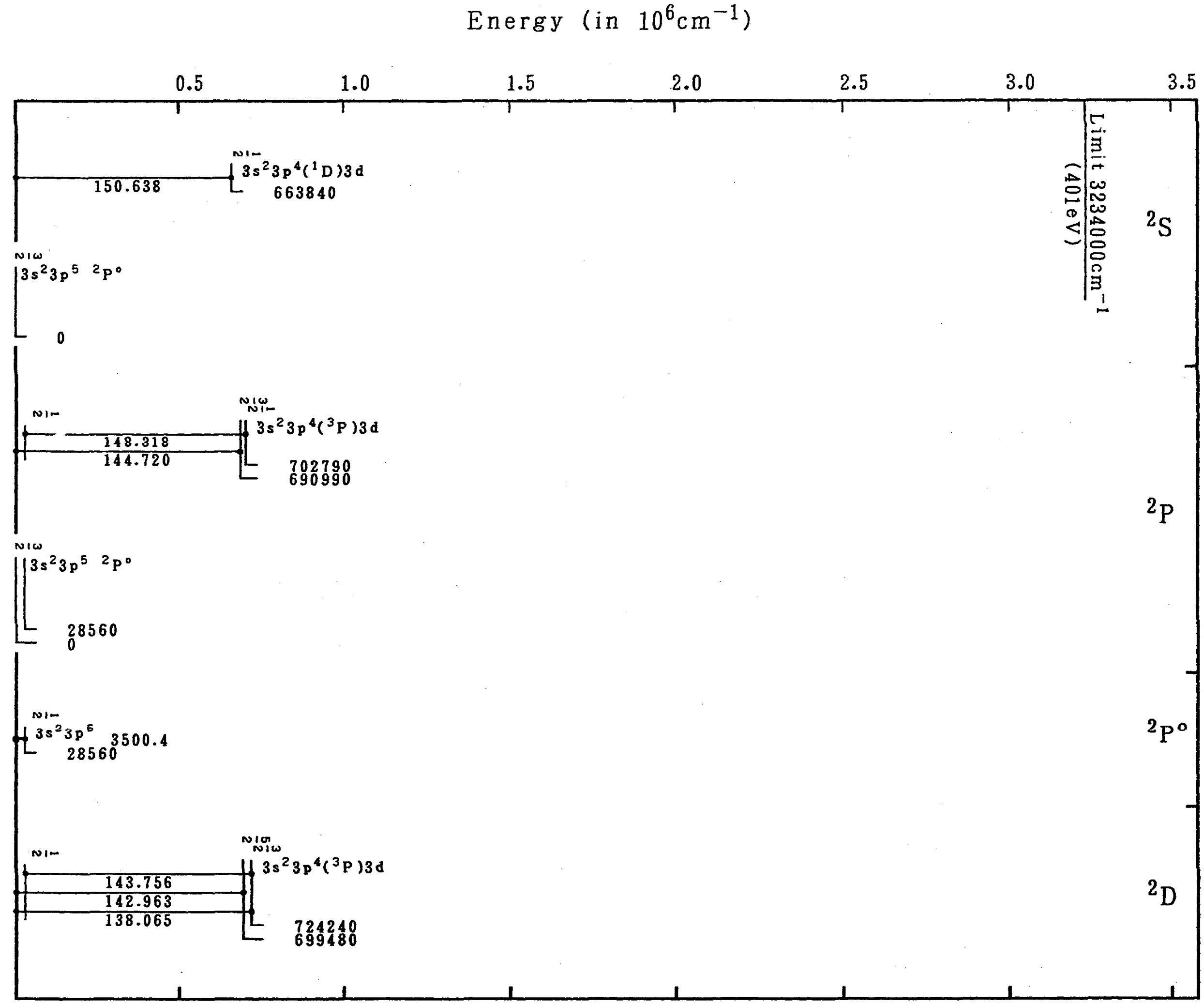

Grotrian diagrams for Cu XI (K sequence)



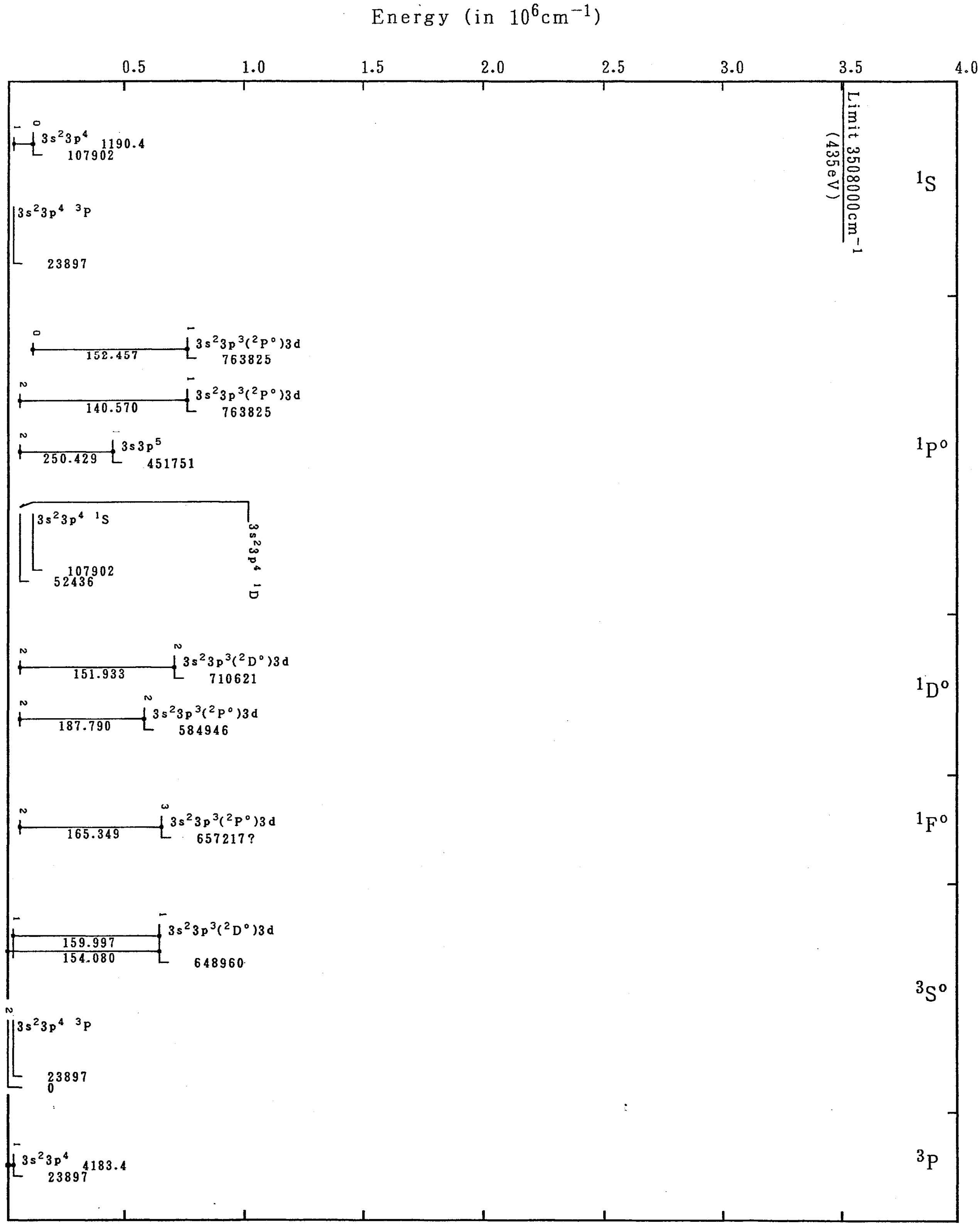

Grotrian diagrams for Cu XI (K sequence) – Continued



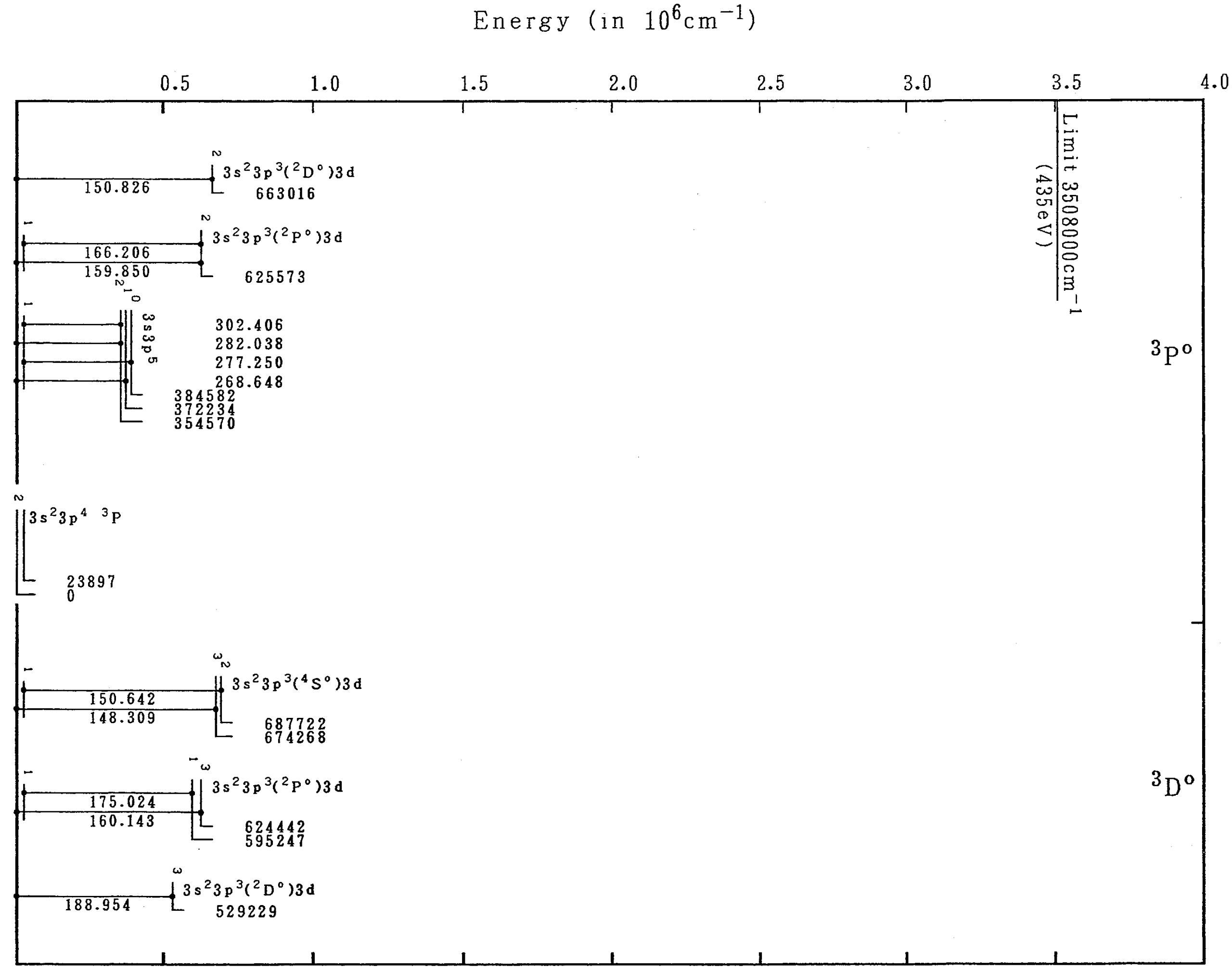

Grotrian diagrams for Cu XII (Ar sequence)



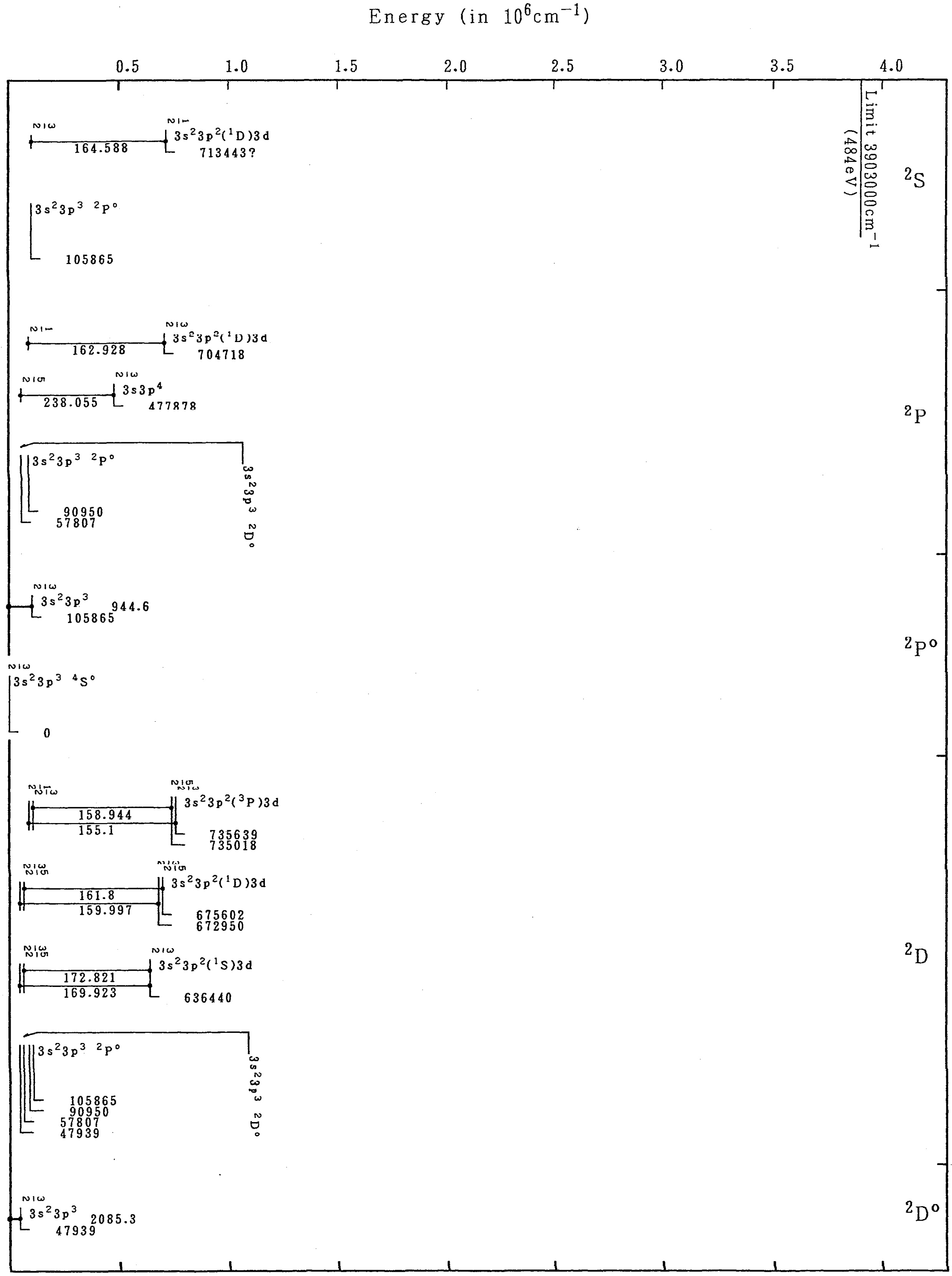

Grotrian diagrams for Cu XIII (Cl sequence)



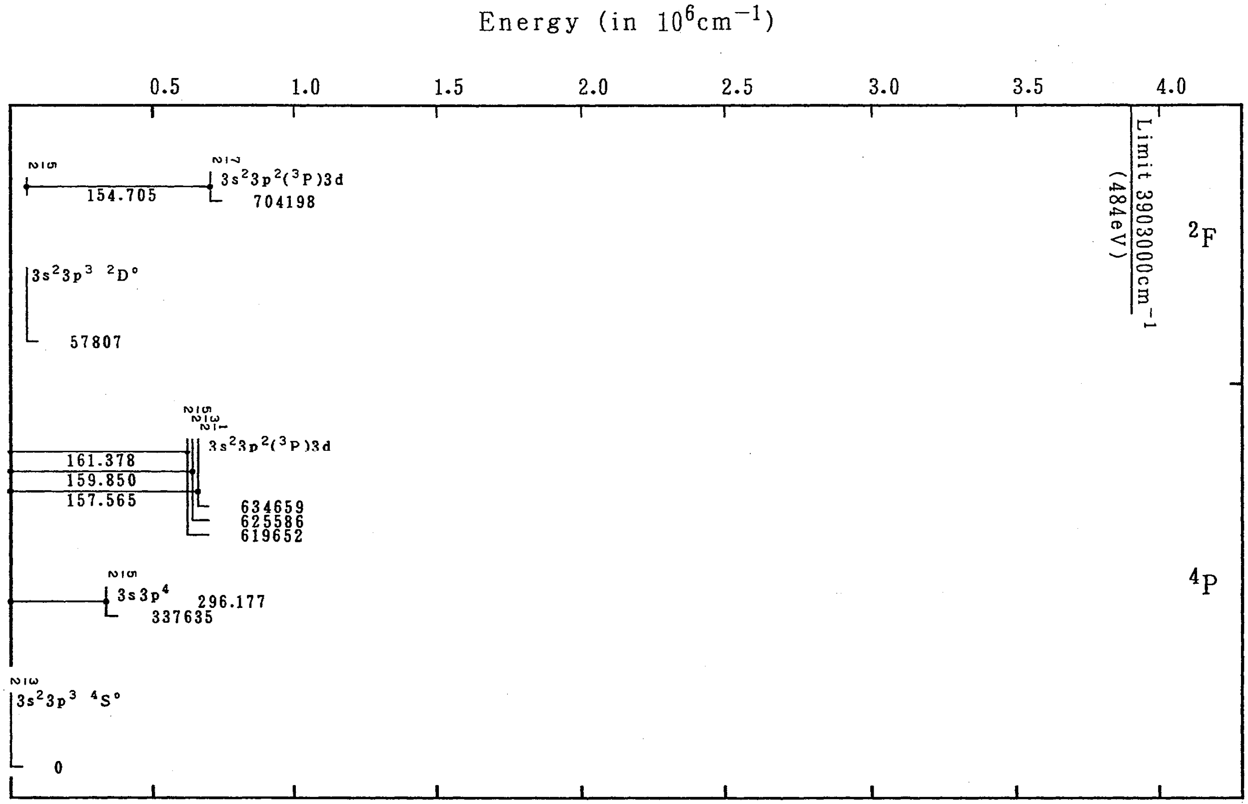

Grotrian diagrams for Cu XIV (S sequence)



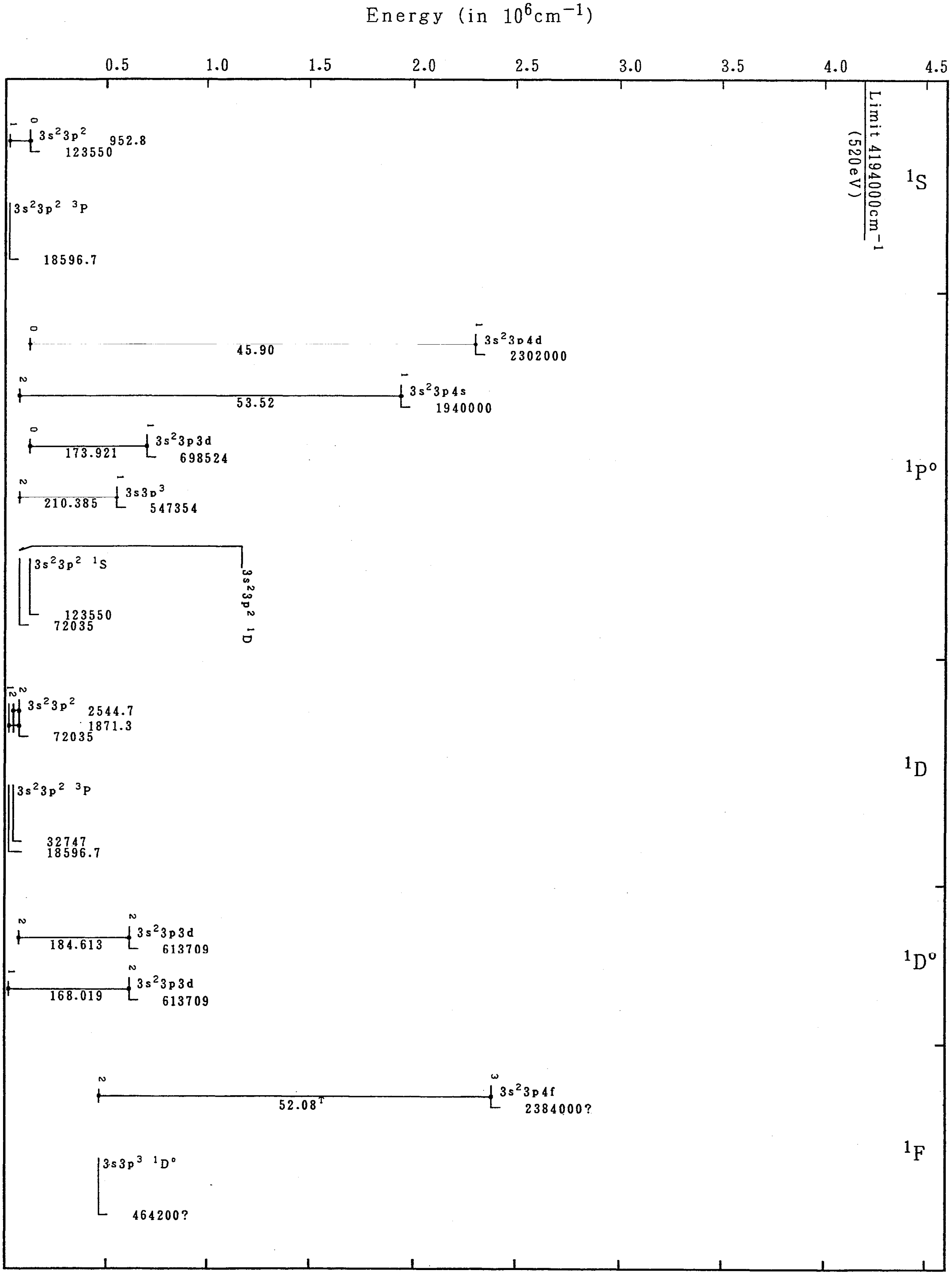

Grotrian diagrams for Cu XIV (S sequence) – Continued



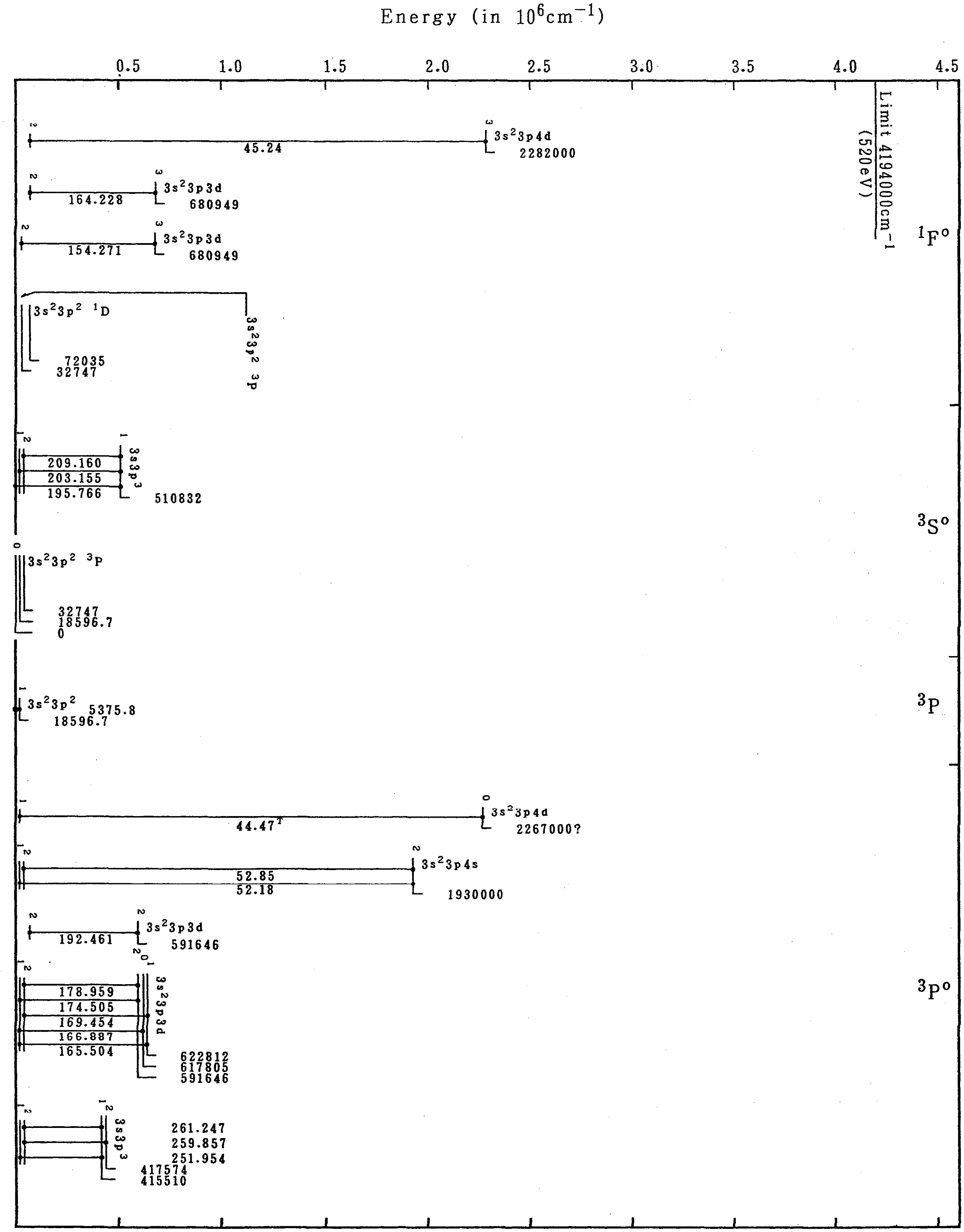

Grotrian diagrams for Cu XV (P sequence)



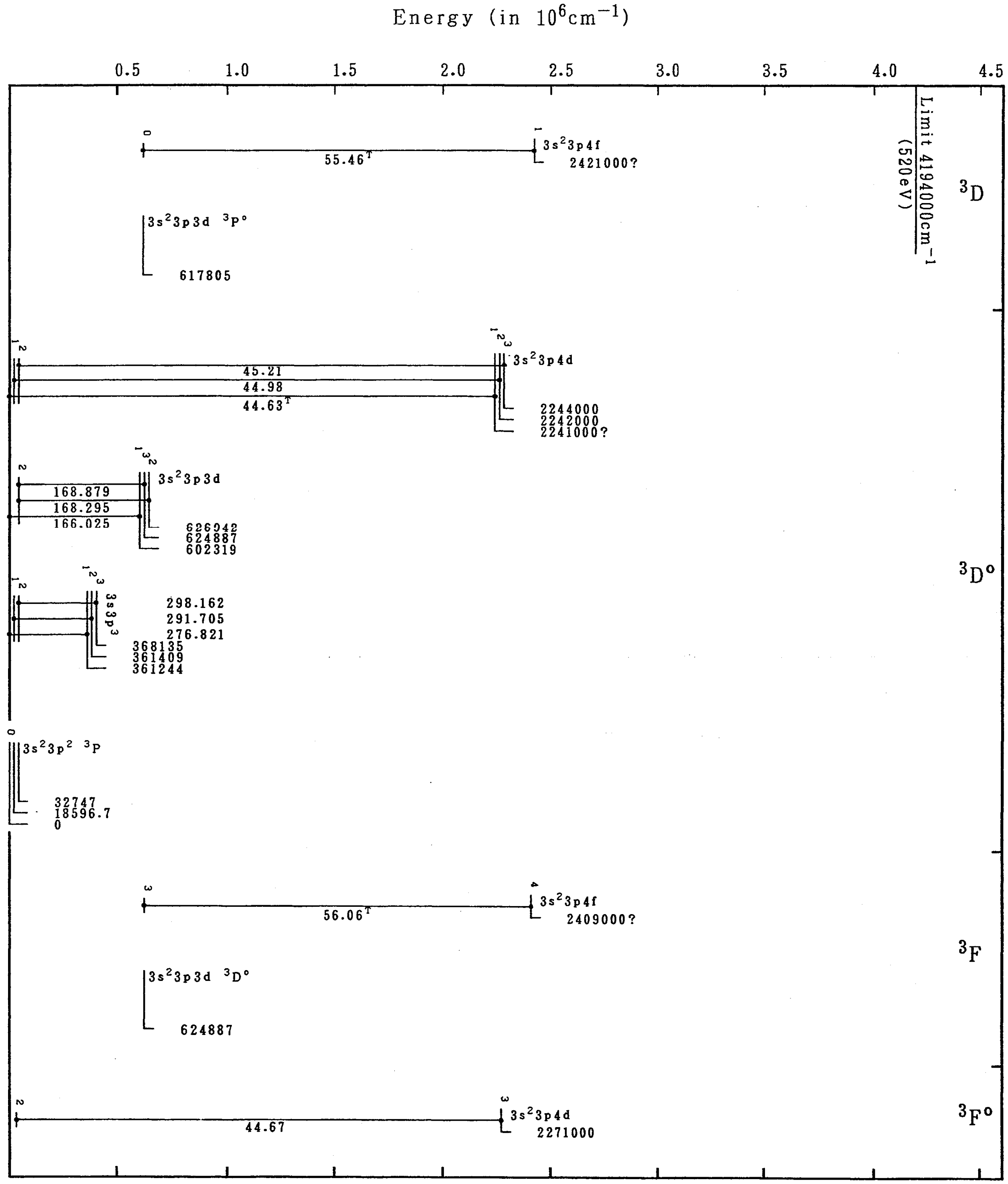

Grotrian diagrams for Cu XV (P sequence) – Continued



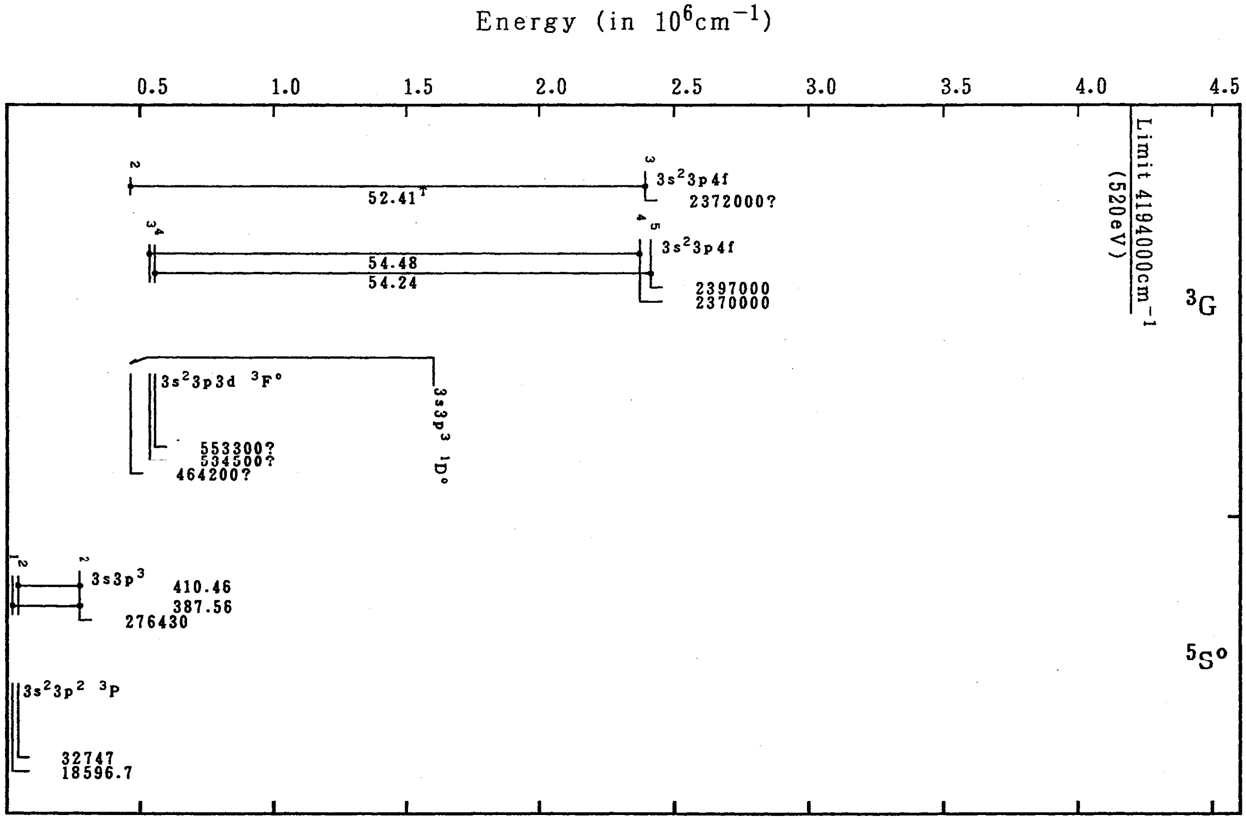

Grotrian diagrams for Cu XVI (Si sequence)



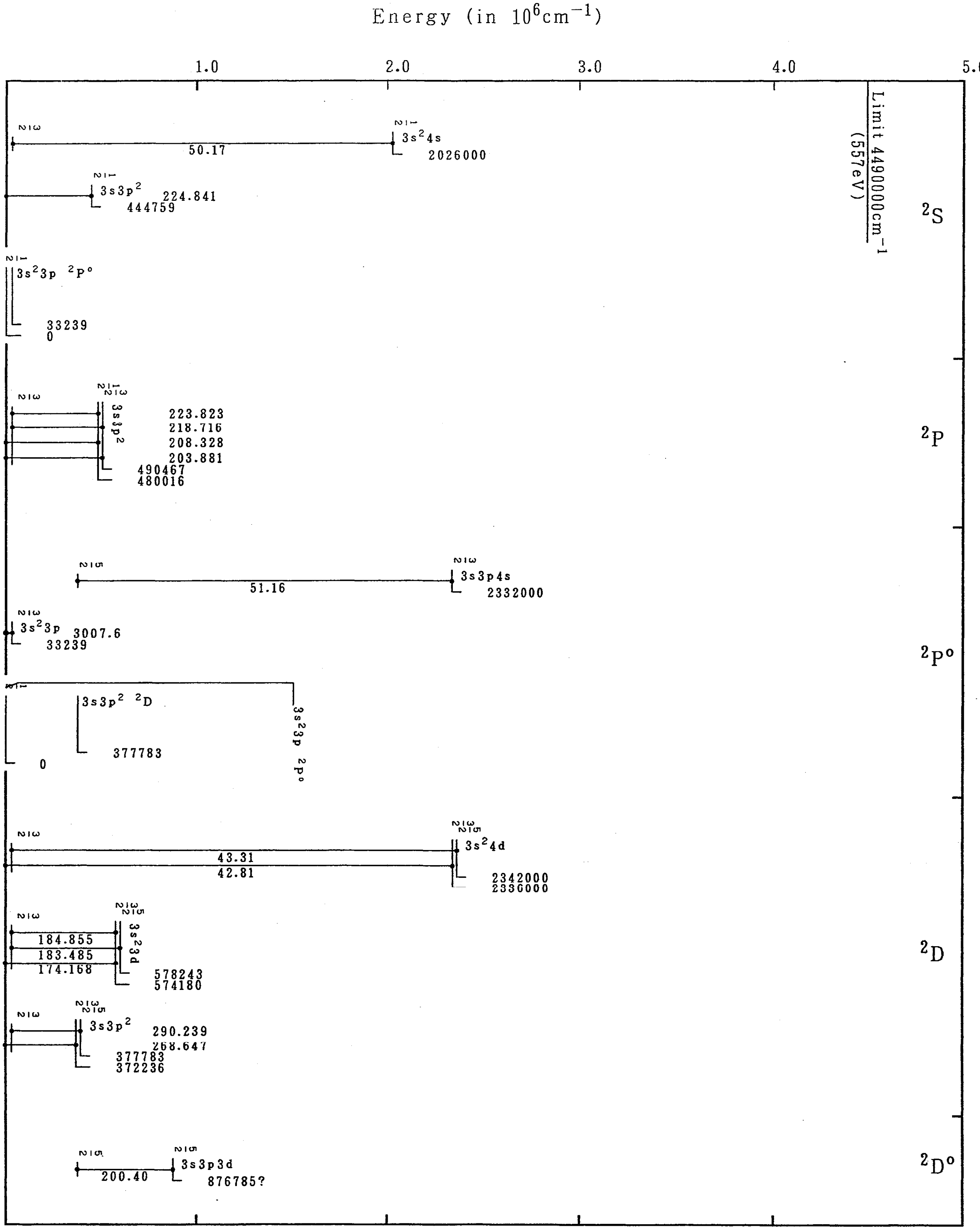

Grotrian diagrams for Cu XVI (Si sequence) – Continued



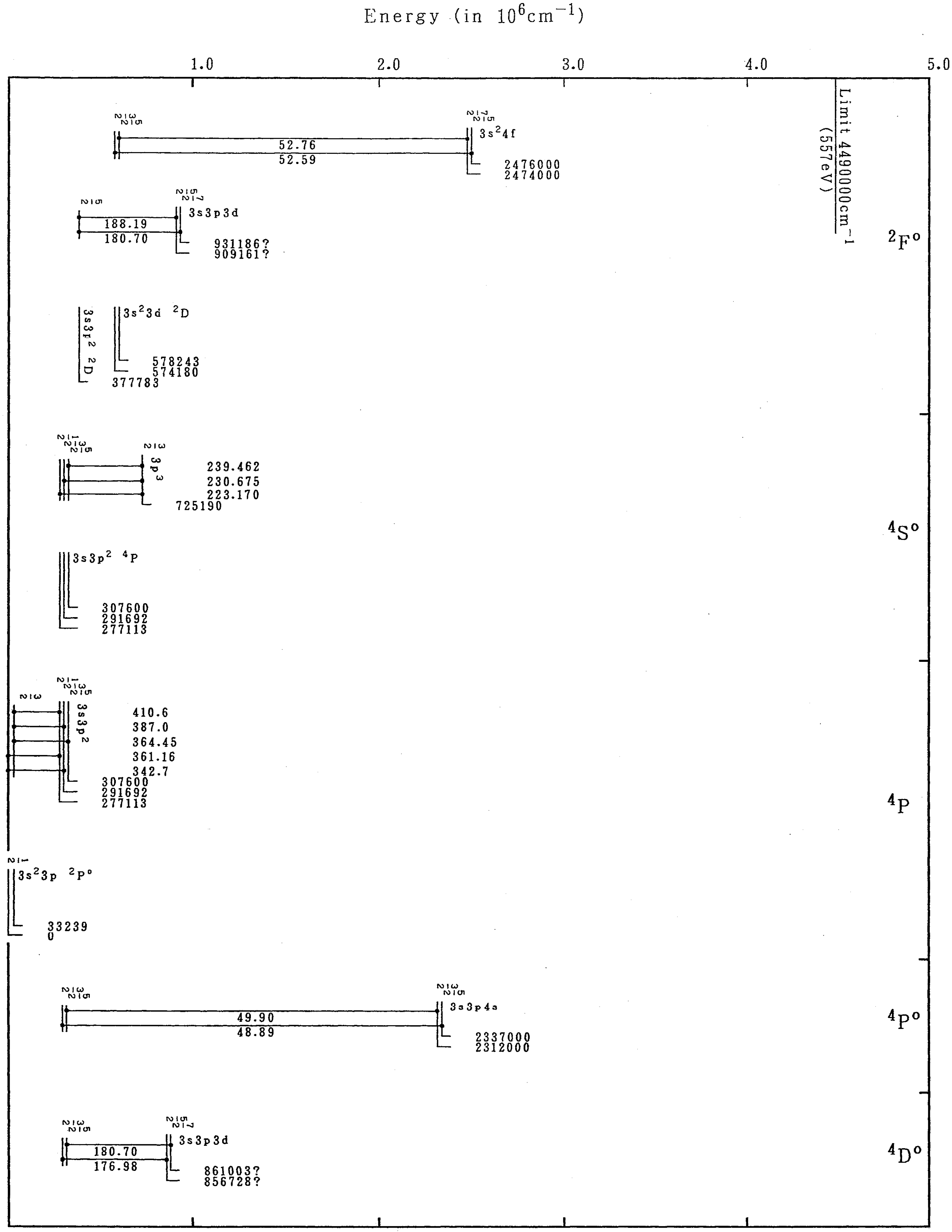

Grotrian diagrams for Cu XVI (Si sequence) – Continued



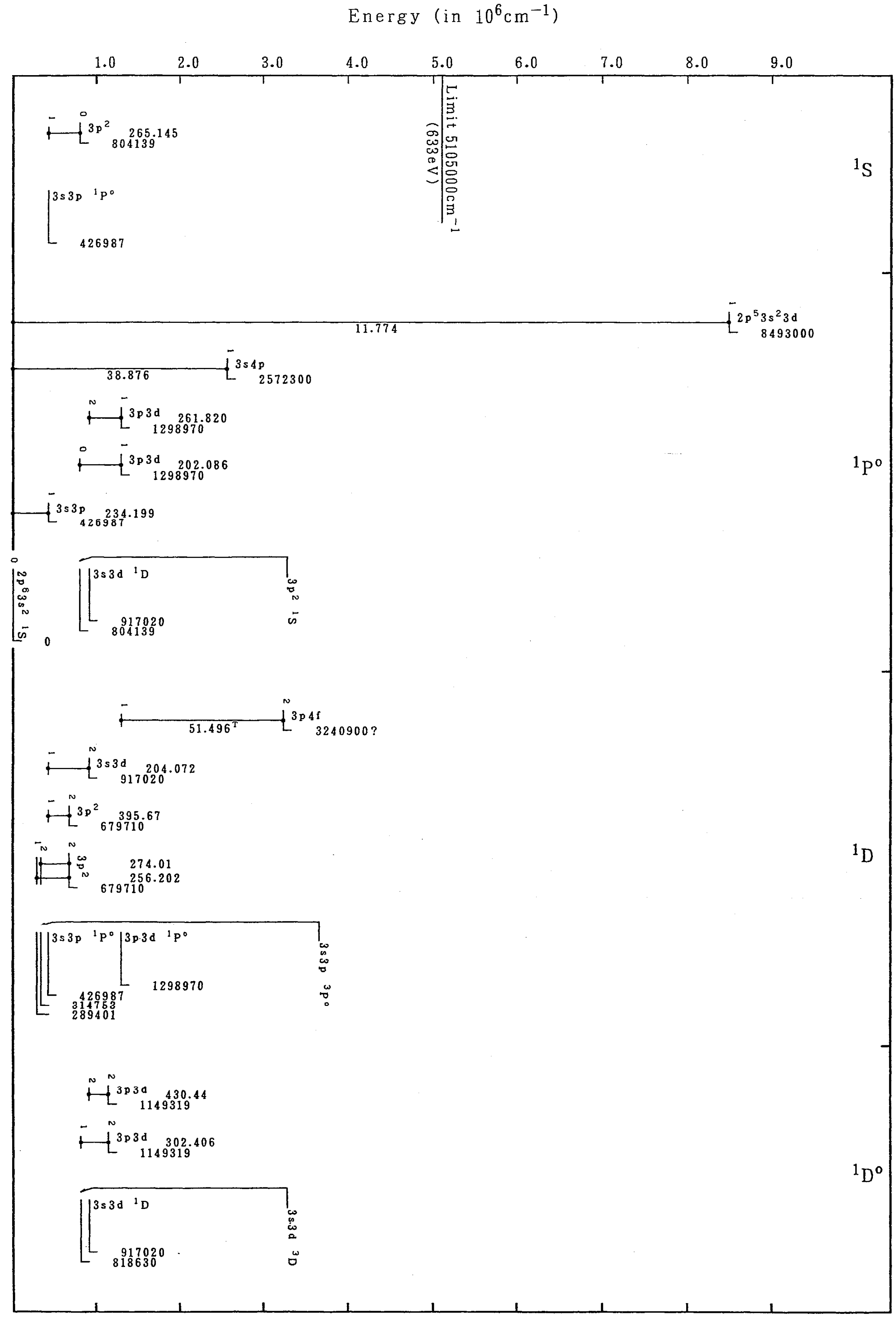

Grotrian diagrams for Cu XVI (Si sequence) – Continued



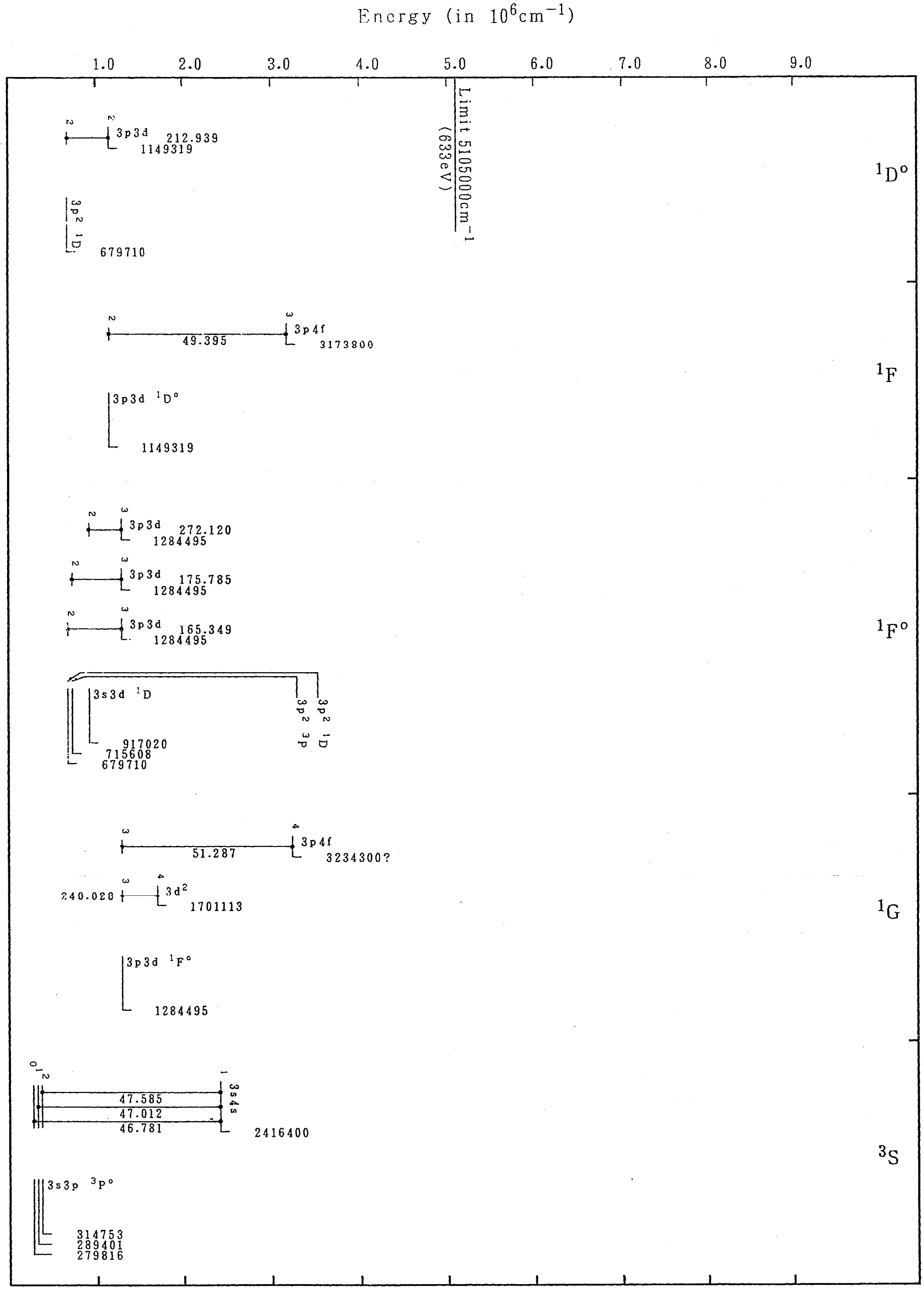

Grotrian diagrams for Cu XVII (Al sequence)



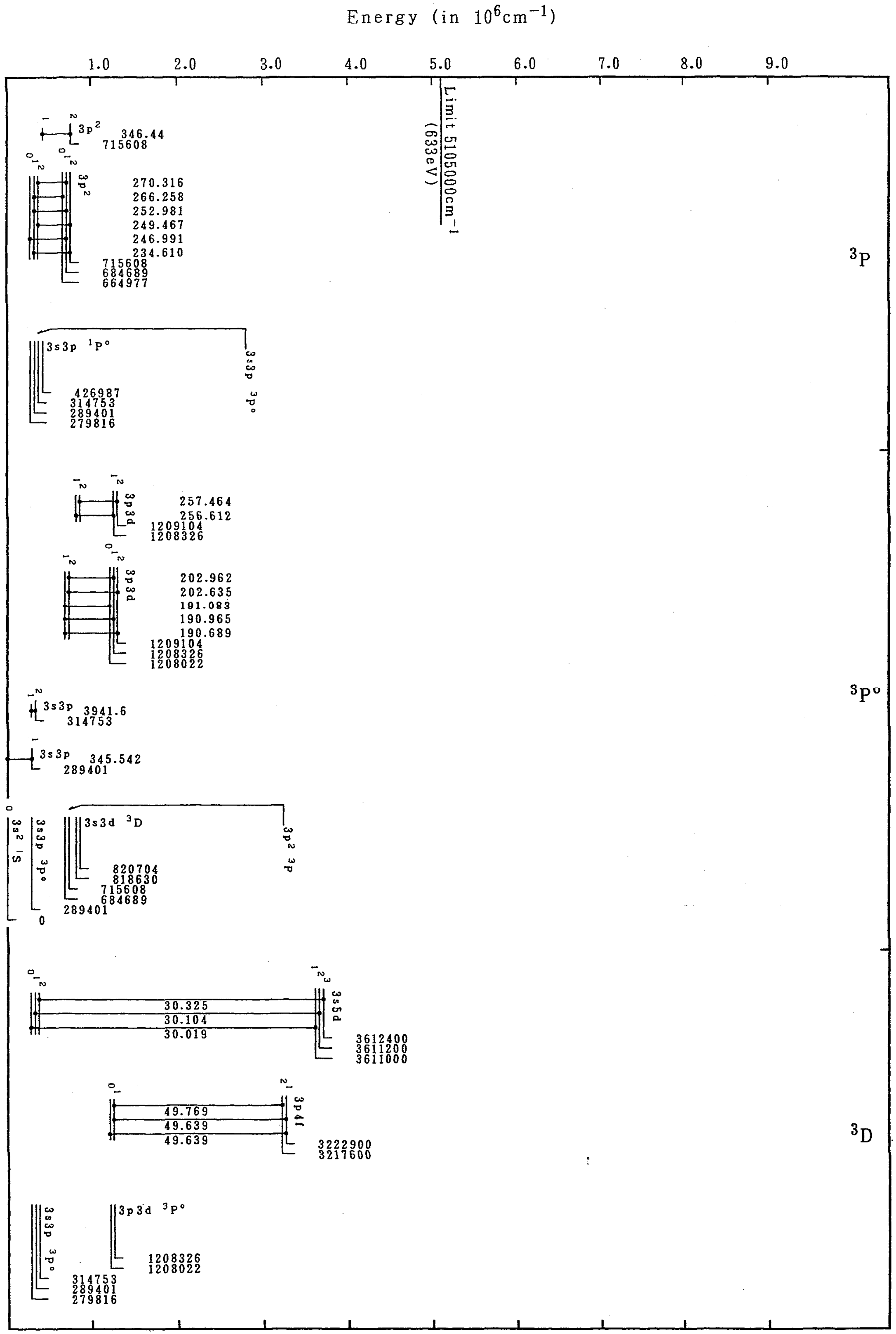

Grotrian diagrams for Cu XVII (Al sequence) – Continued



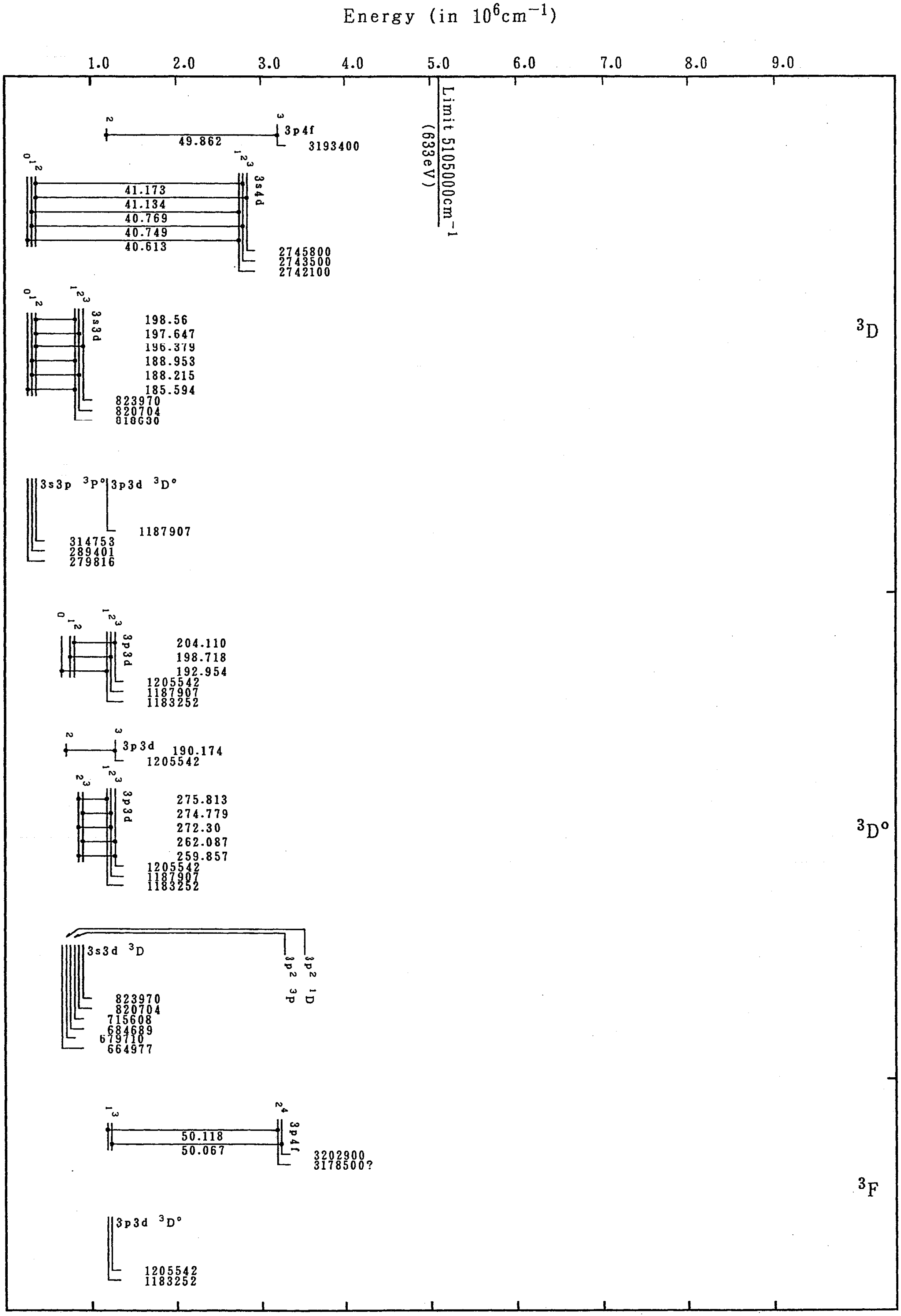

Grotrian diagrams for Cu XVIII (Mg sequence)



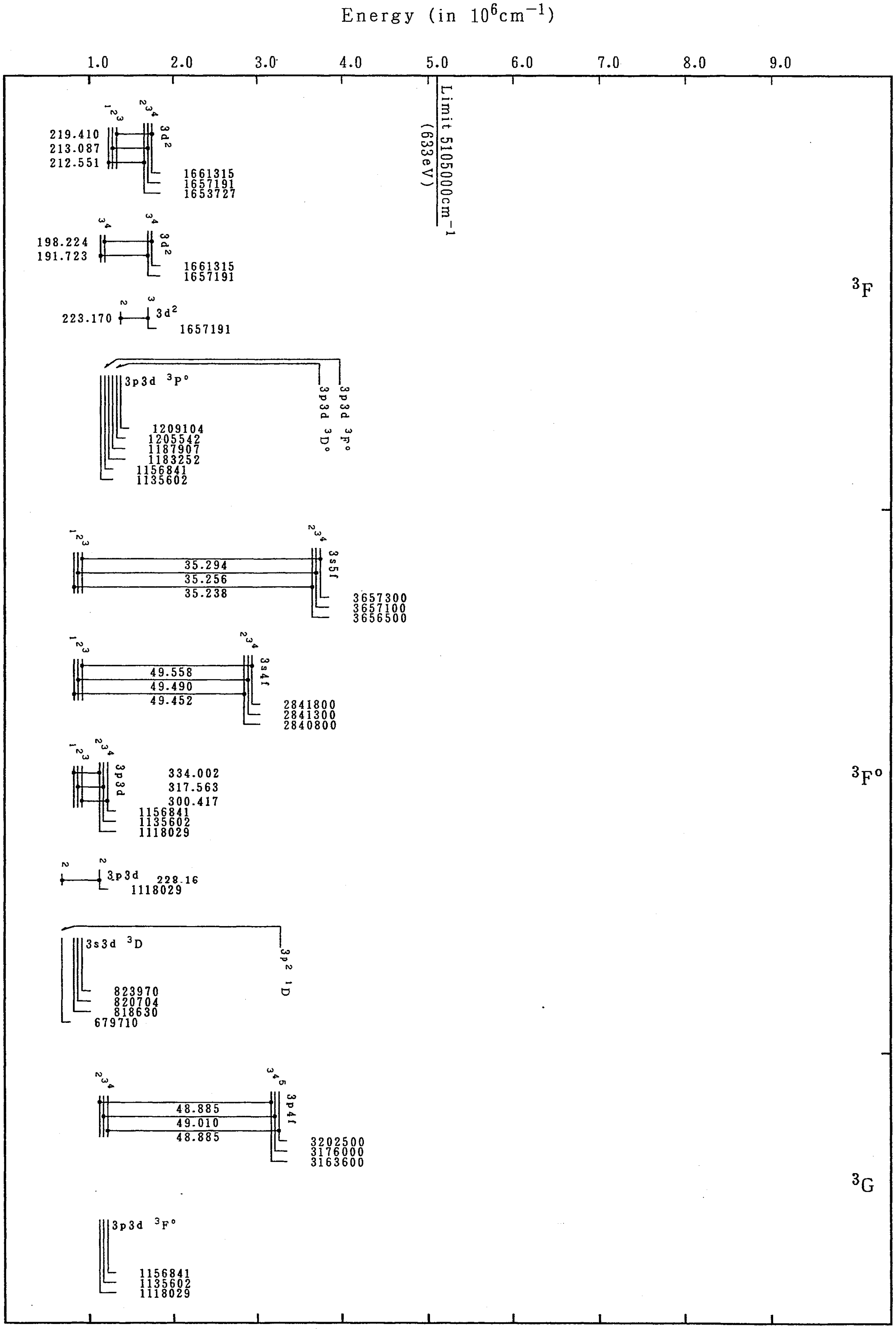

Grotrian diagrams for Cu XVIII (Mg sequence) — Continued



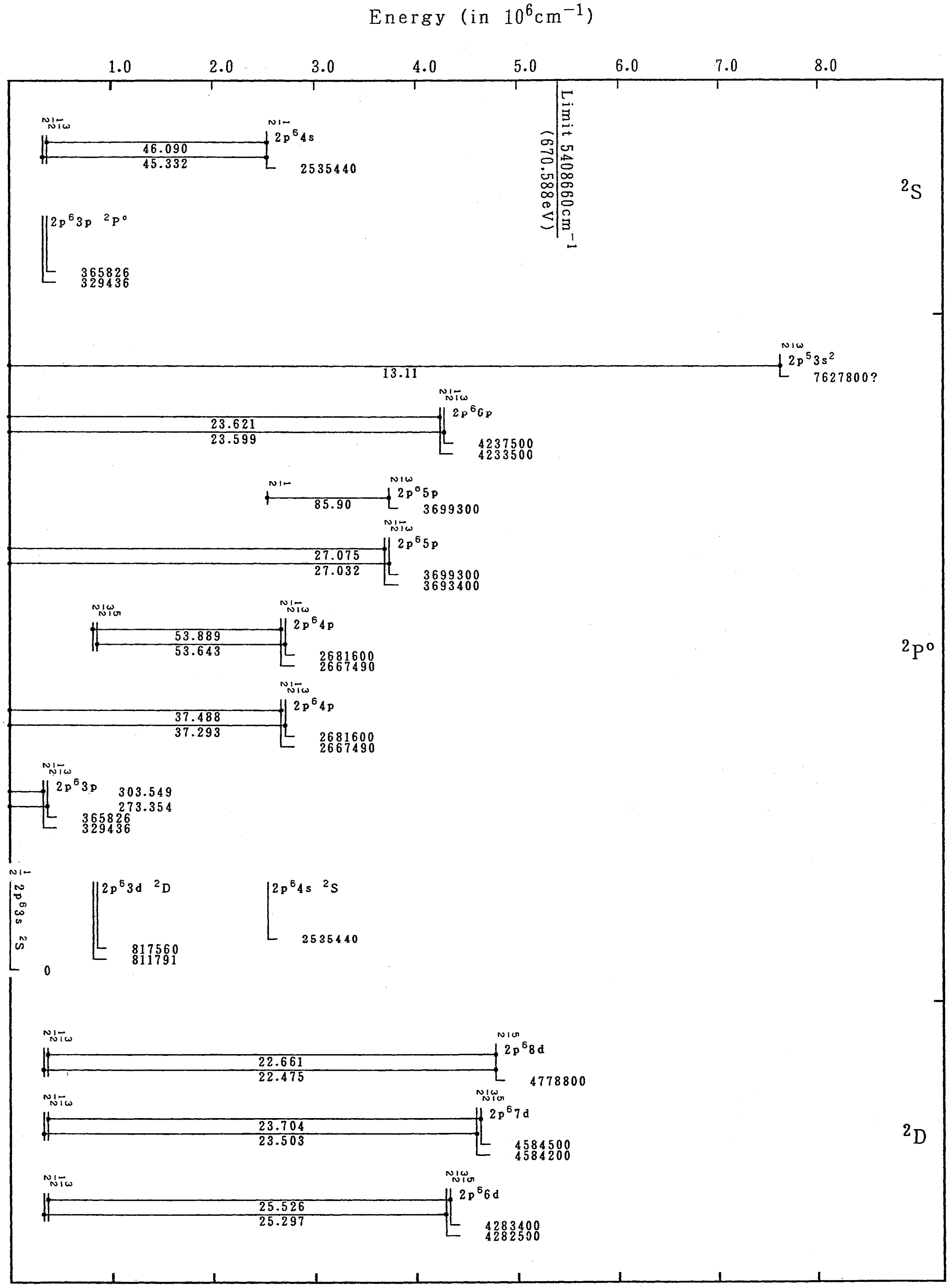

Grotrian diagrams for Cu XVIII (Mg sequence) – Continued



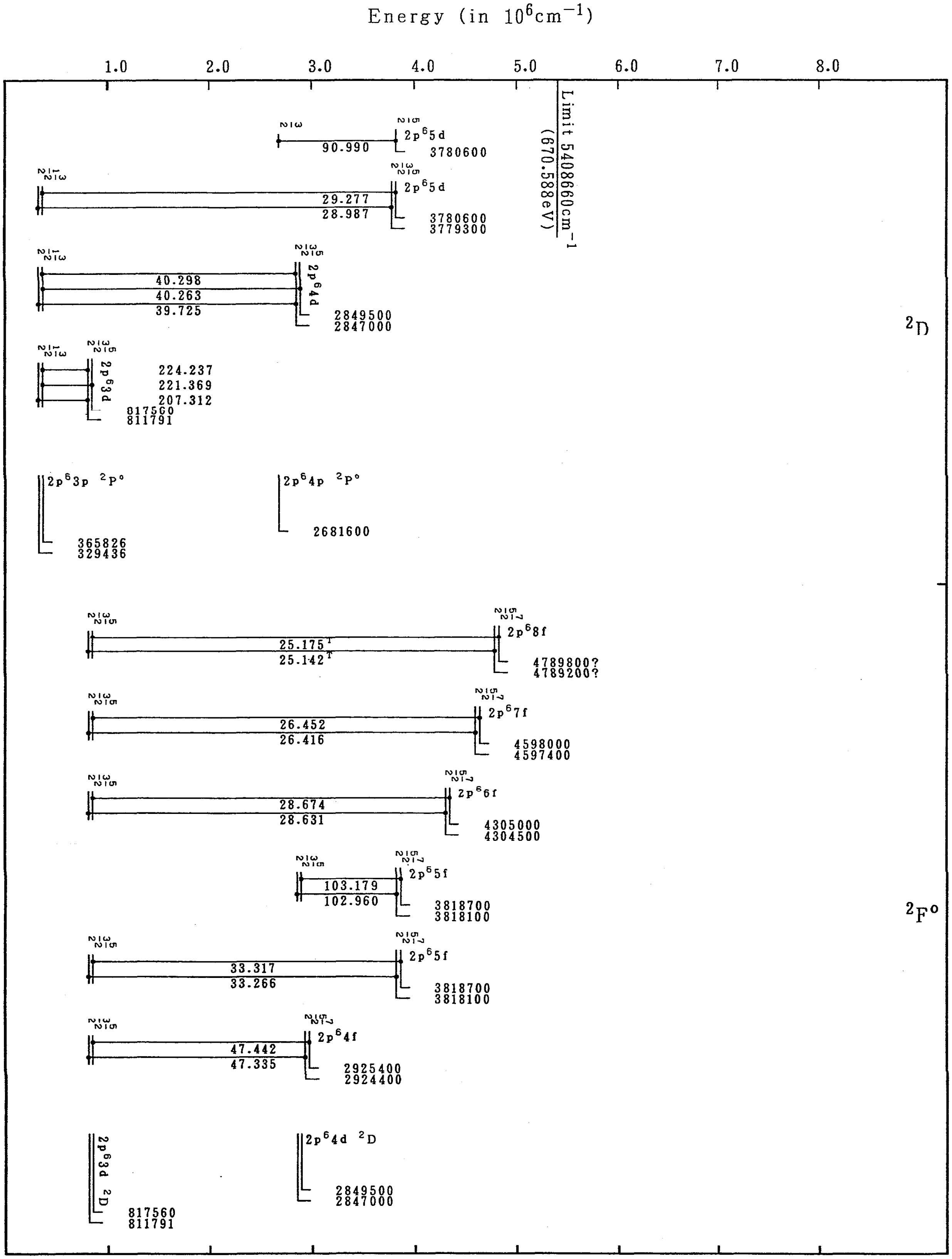

Grotrian diagrams for Cu XVIII (Mg sequence) — Continued



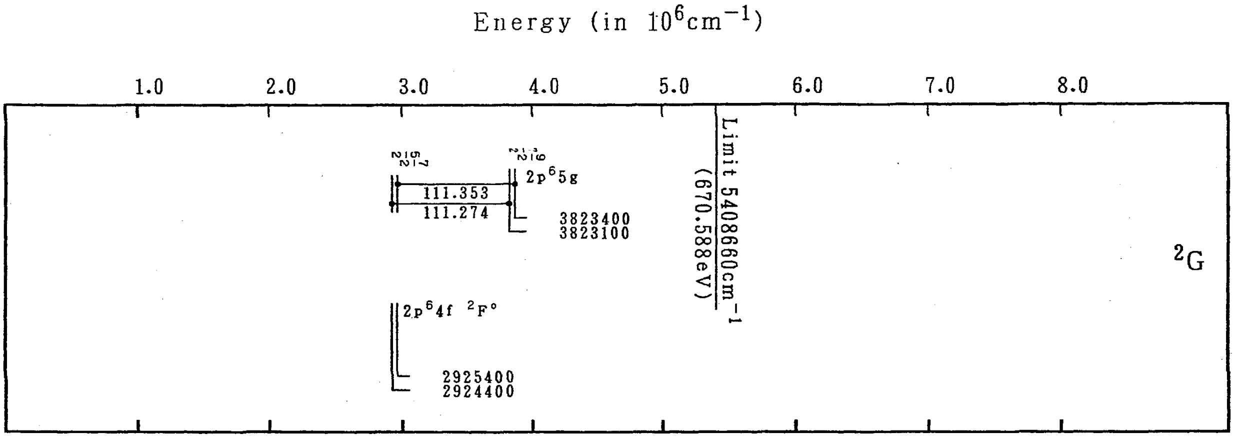

Grotrian diagrams for Cu XVIII (Mg sequence) — Continued



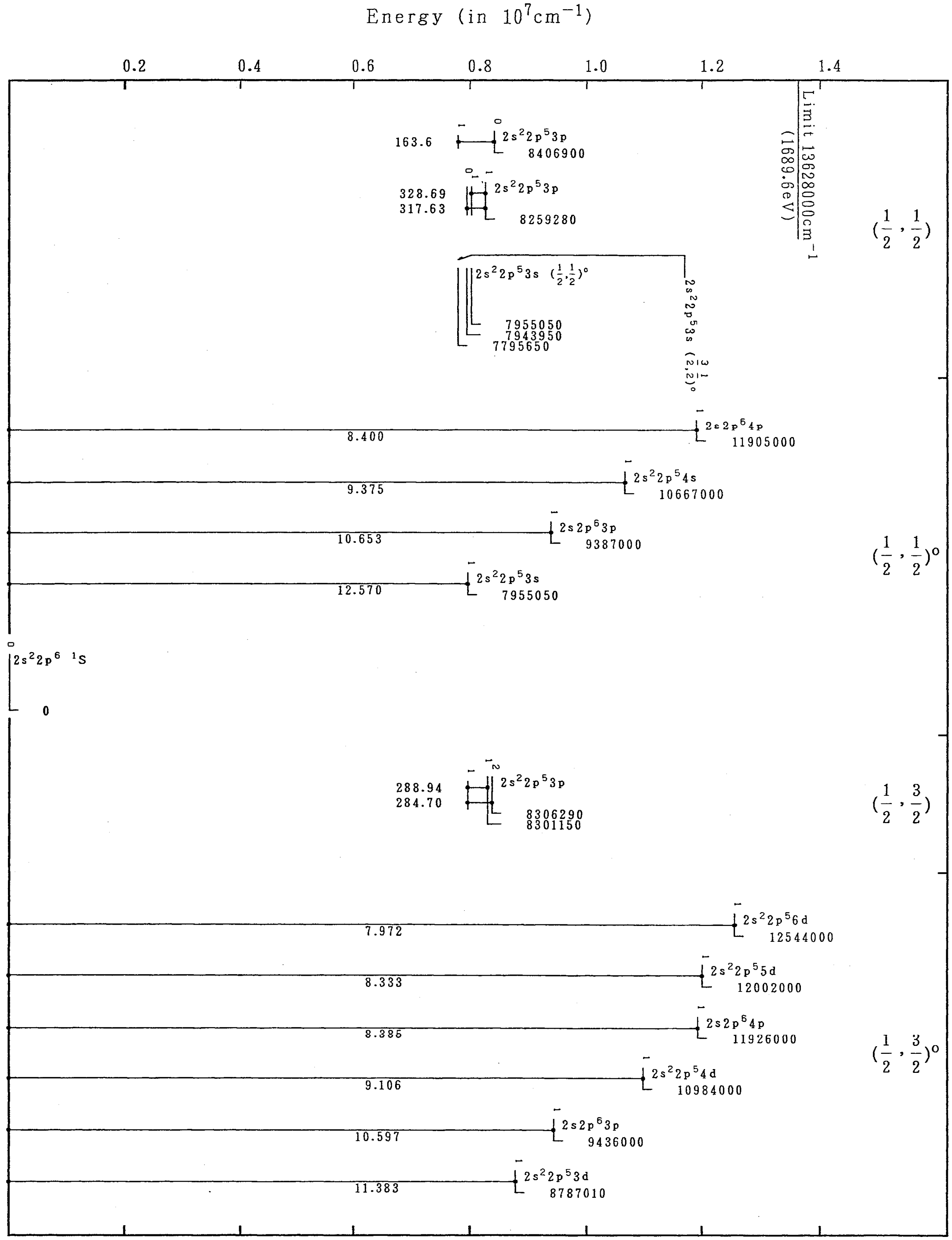

Grotrian diagrams for Cu XIX (Na sequence)



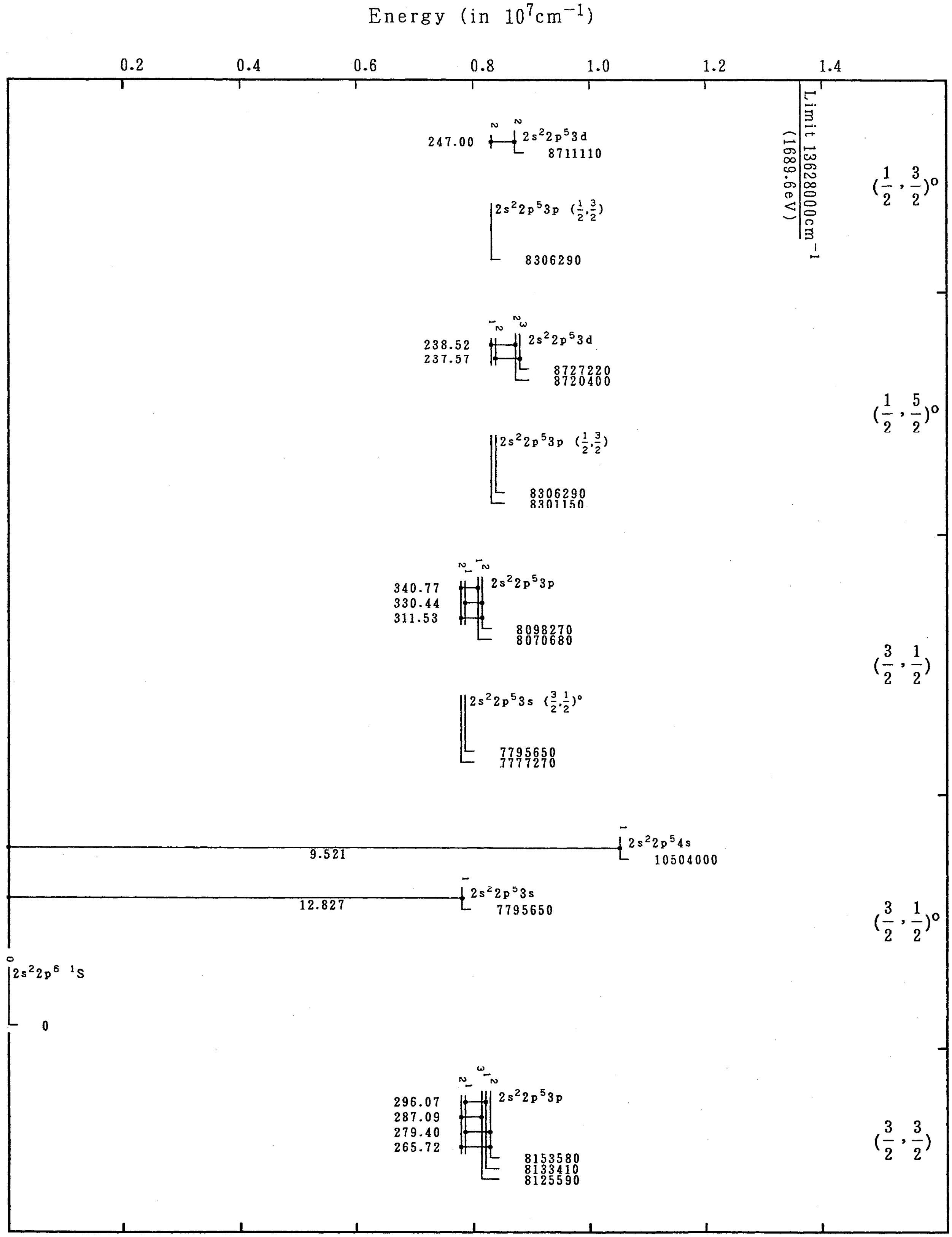

Grotrian diagrams for Cu XIX (Na sequence) – Continued



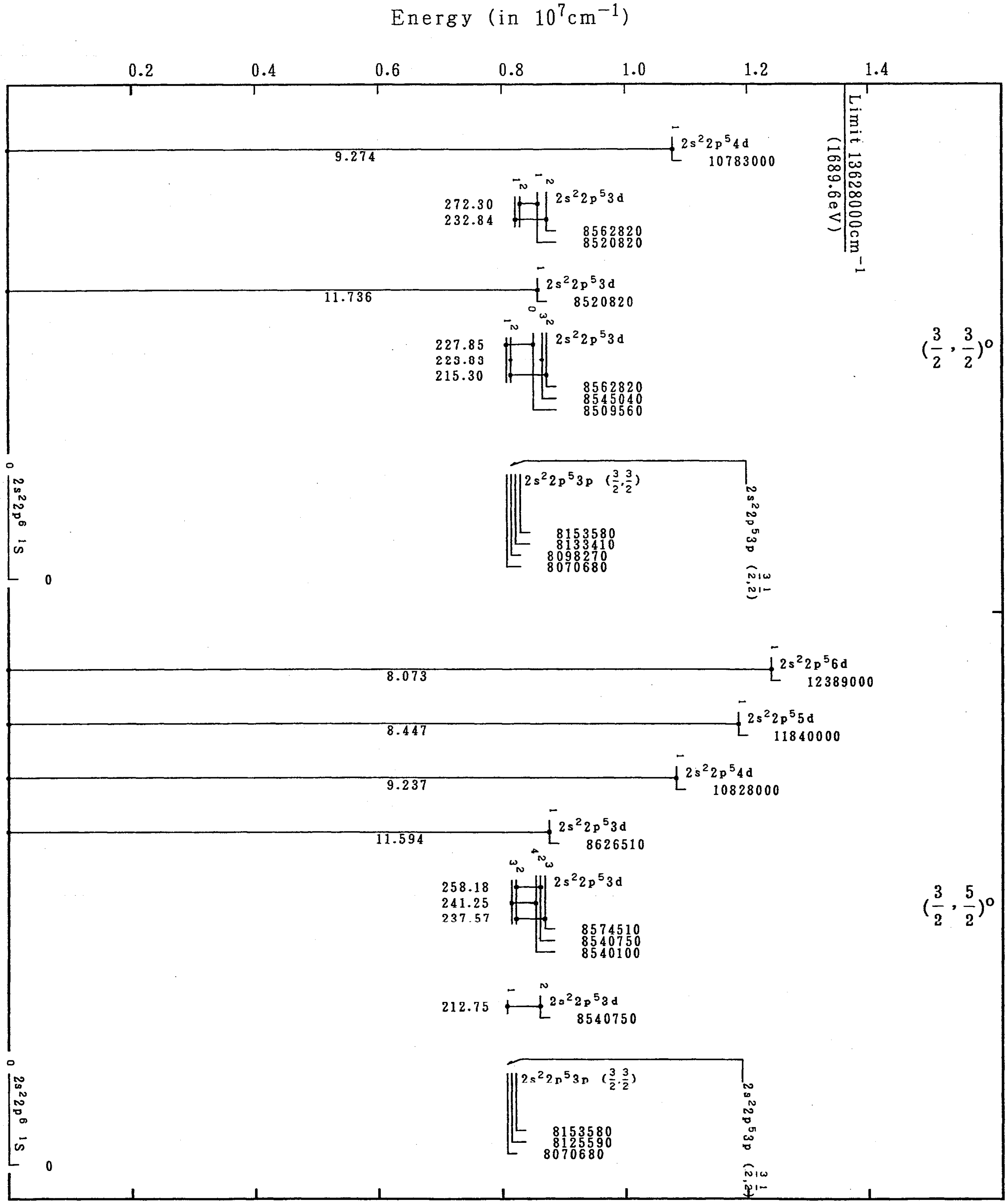

Grotrian diagrams for Cu XIX (Na sequence) — Continued



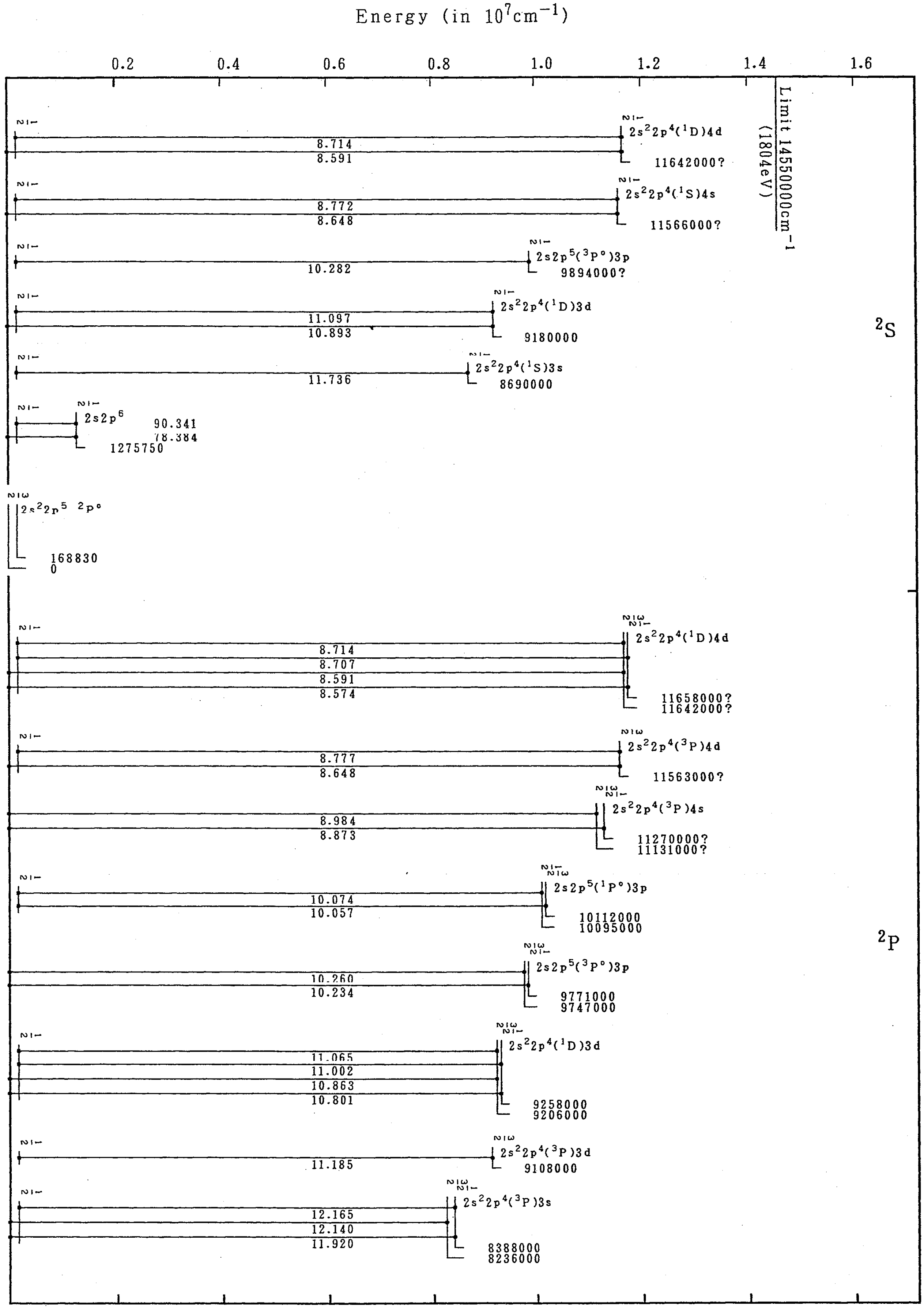

Grotrian diagrams for Cu xx (Ne sequence)



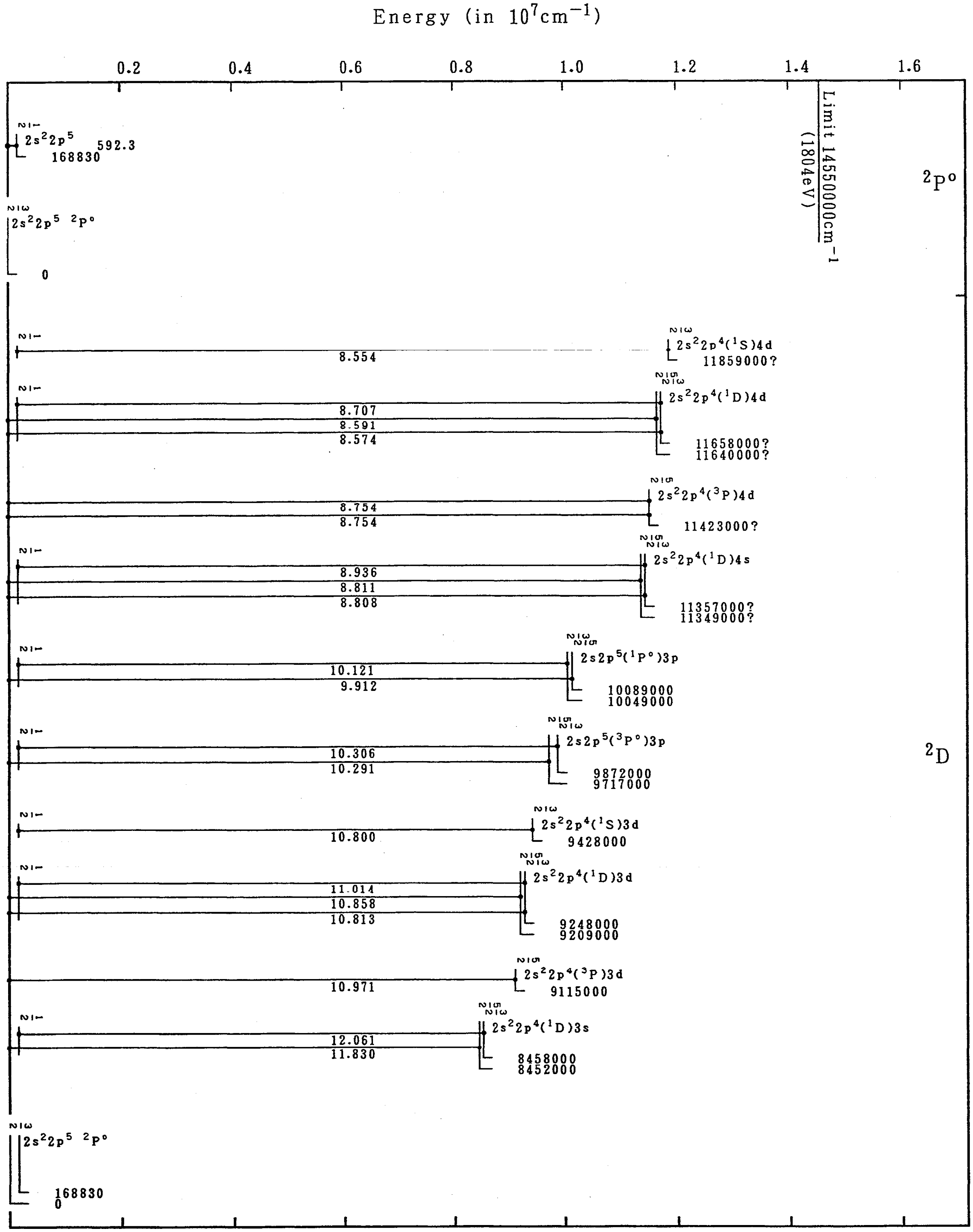

Grotrian diagrams for Cu XX (Ne sequence) — Continued



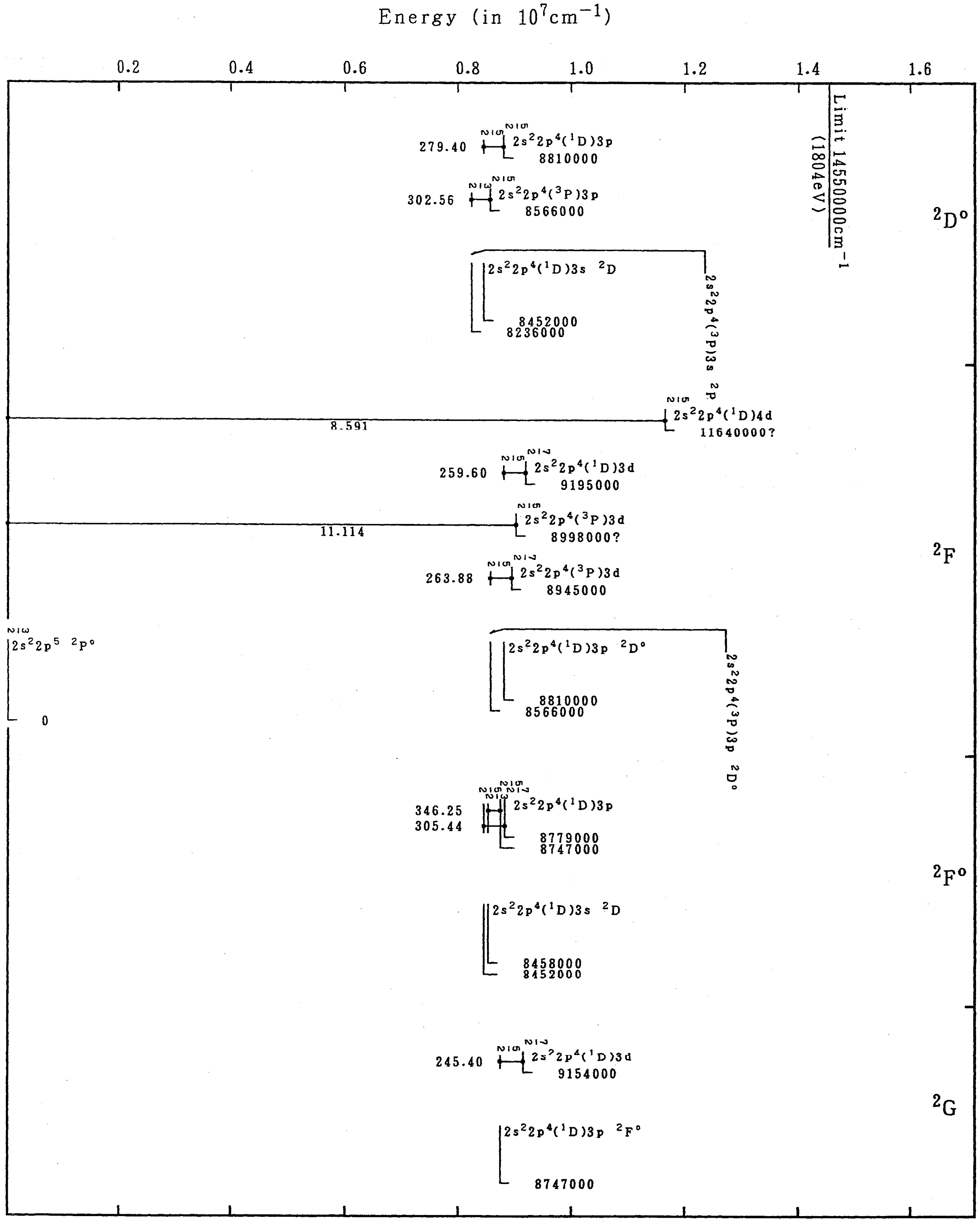

Grotrian diagrams for Cu XX (Ne sequence) — Continued



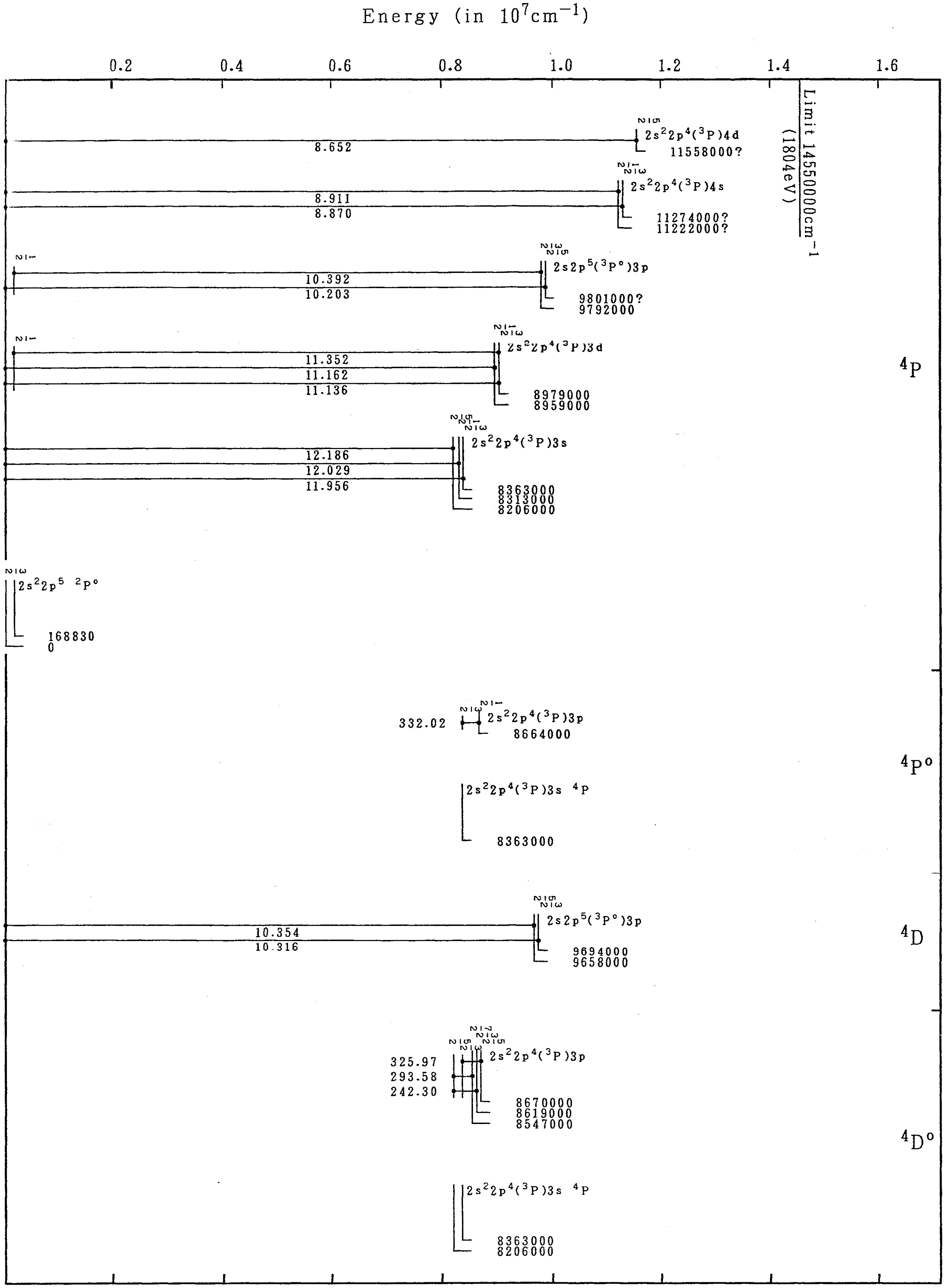

Grotrian diagrams for Cu XXI (F sequence)



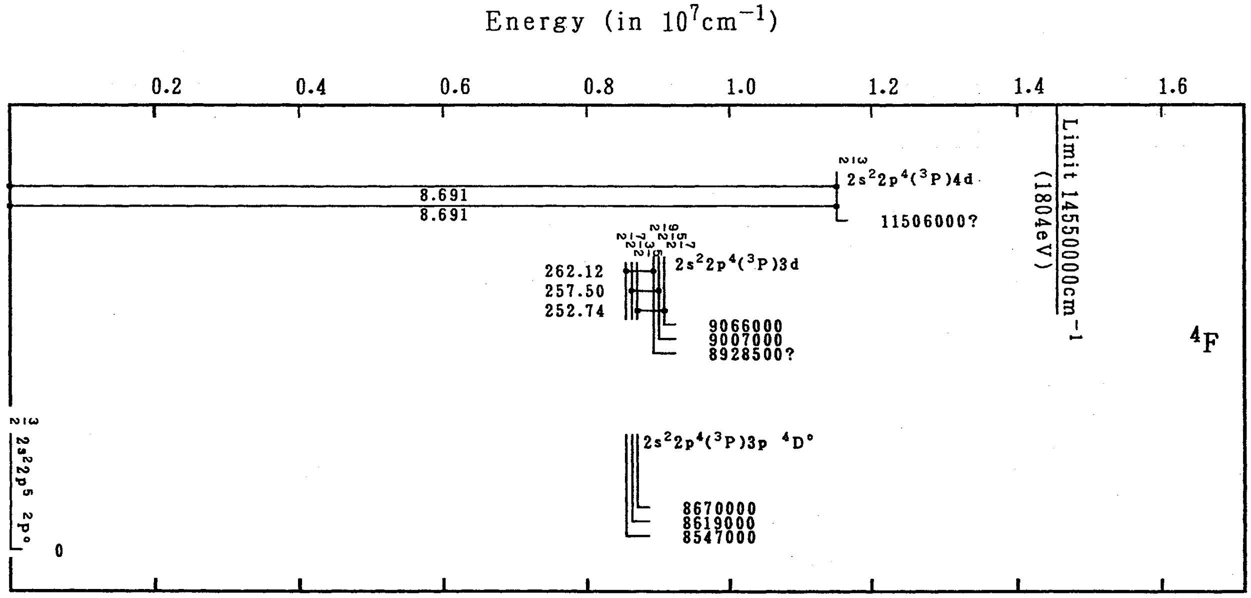

Grotrian diagrams for Cu XXI (F sequence) — Continued



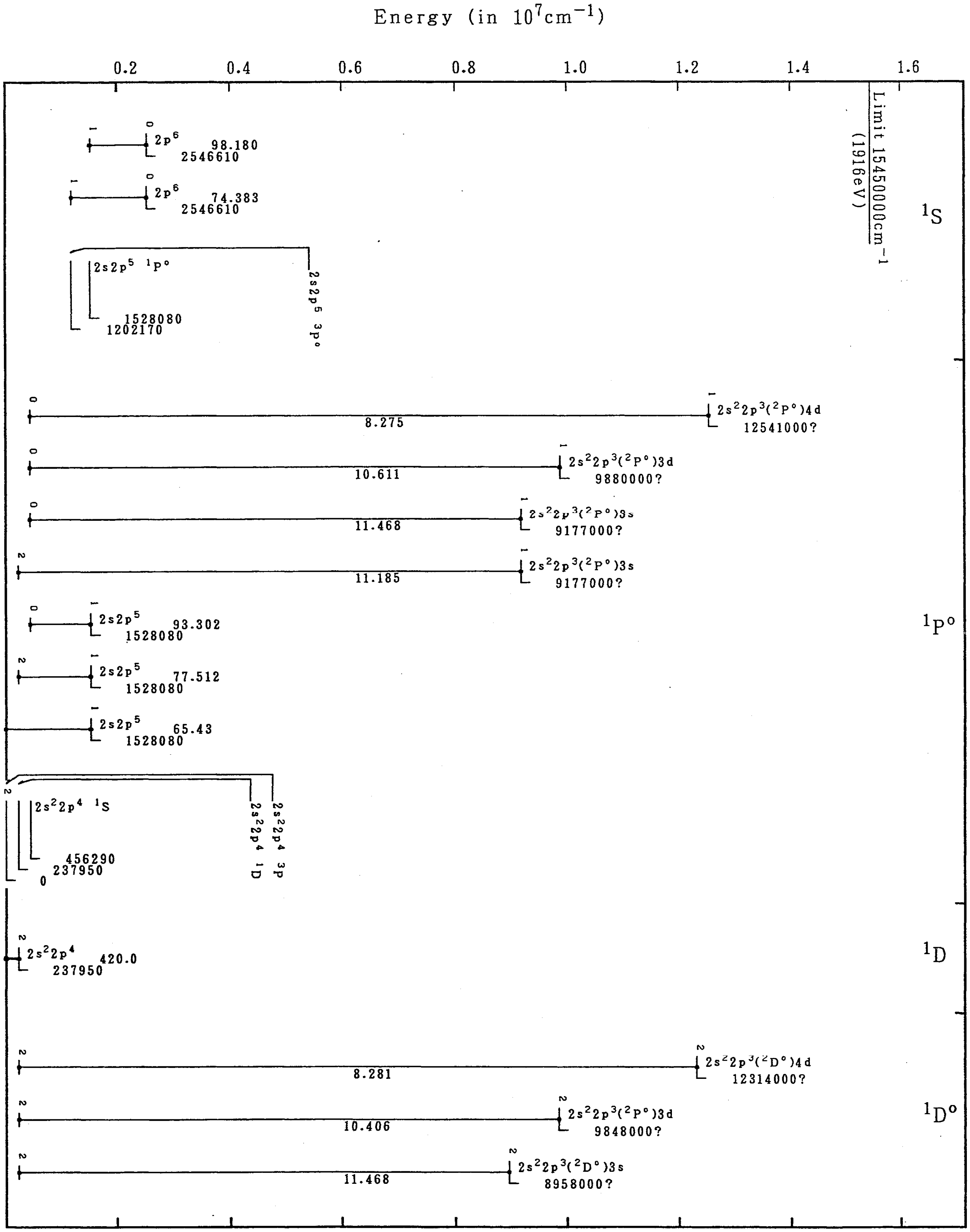

Grotrian diagrams for Cu XXI (F sequence) — Continued



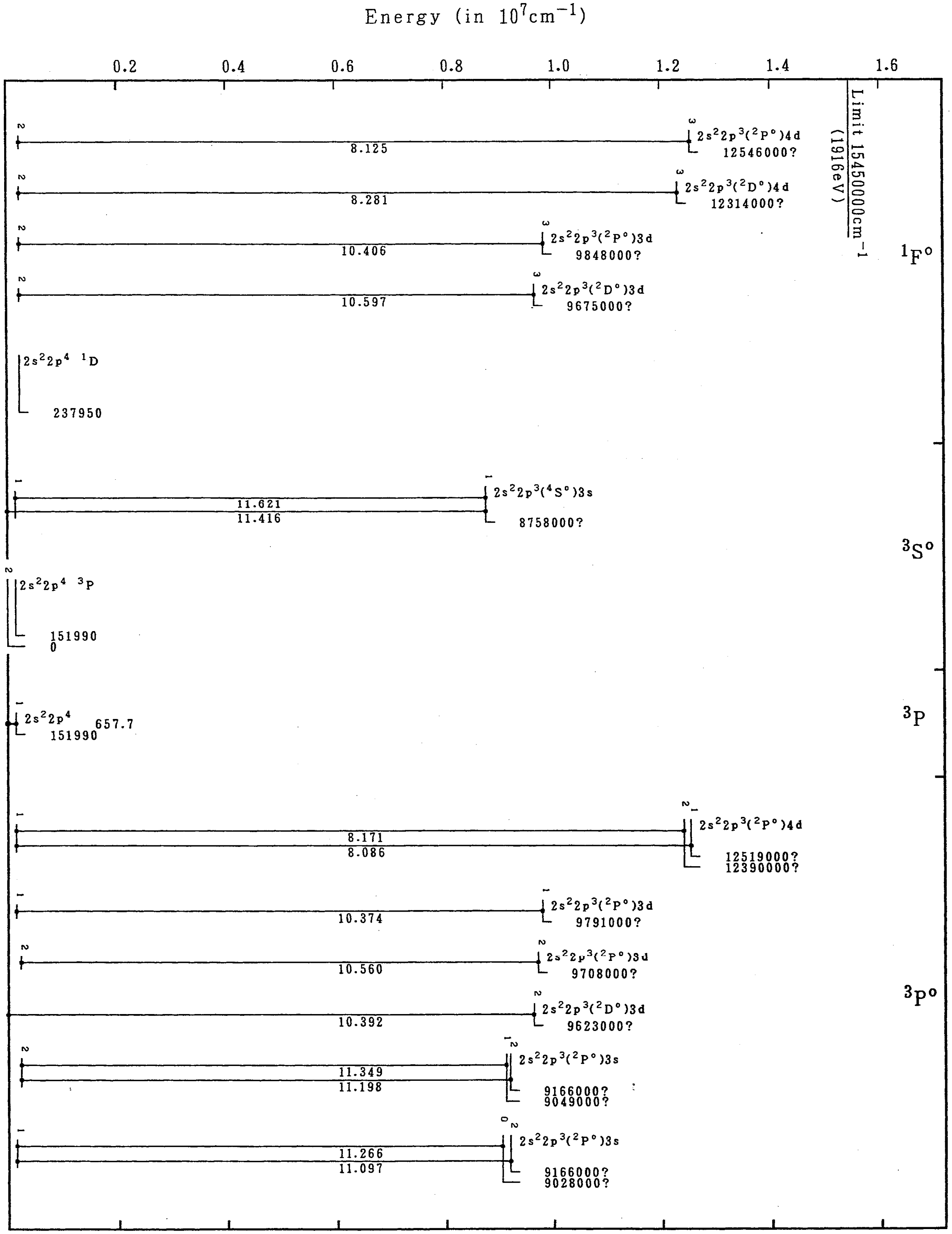

Grotrian diagrams for Cu XXI (F sequence) — Continued



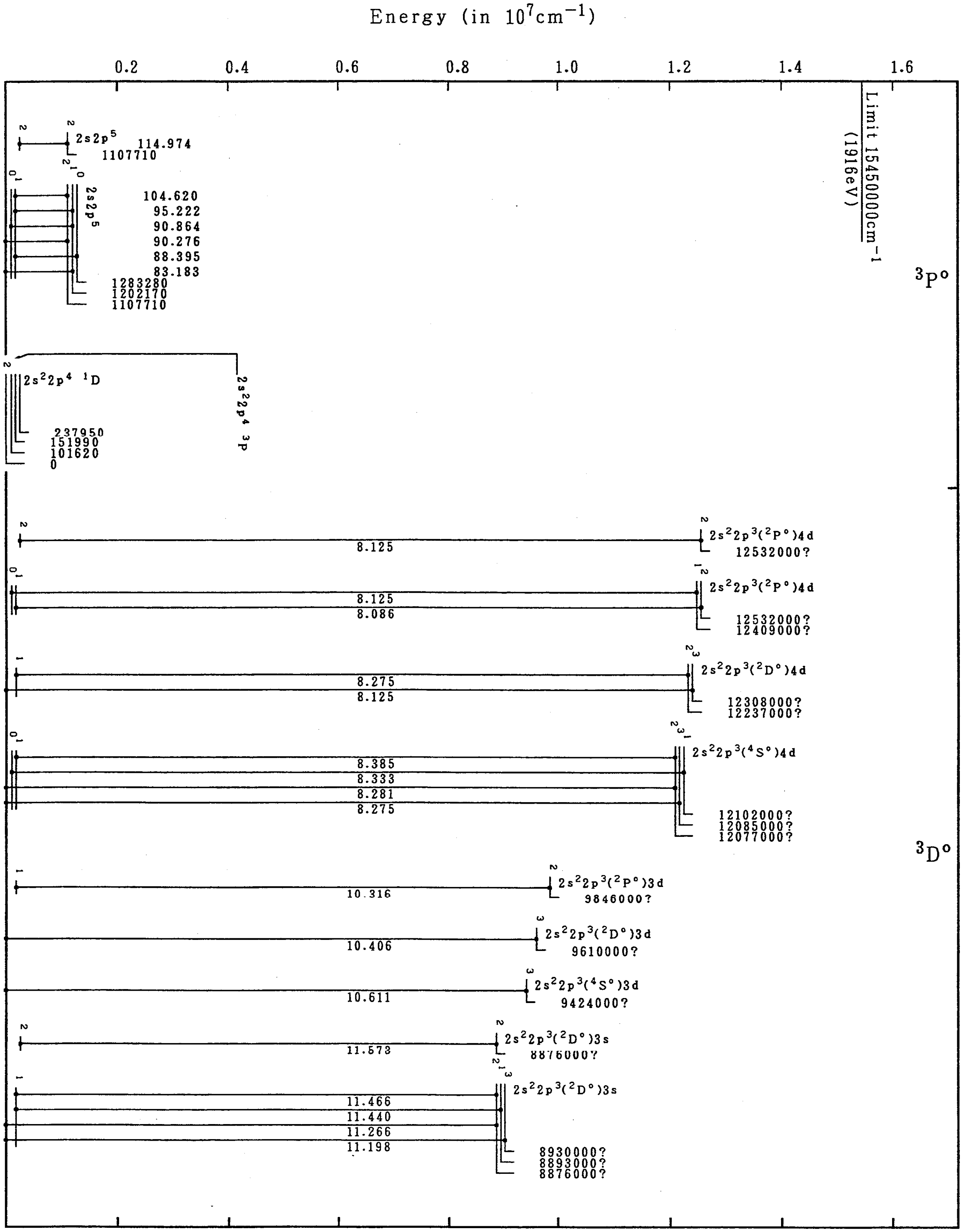

Grotrian diagrams for Cu XXI (F sequence) — Continued



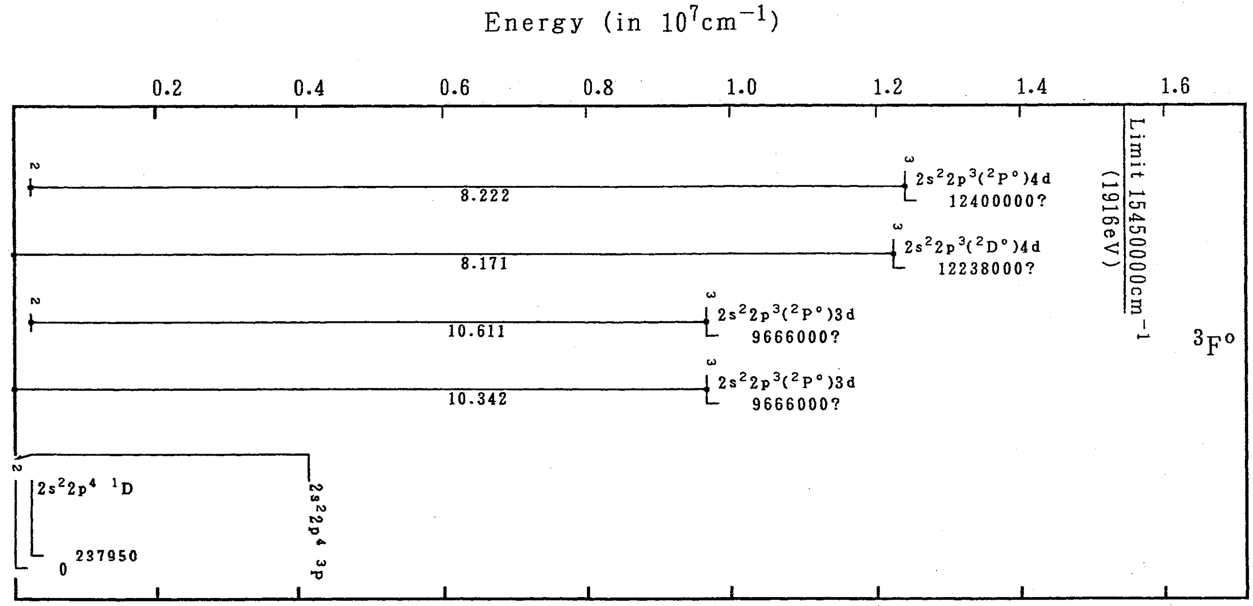

Grotrian diagrams for Cu XXII (O sequence)



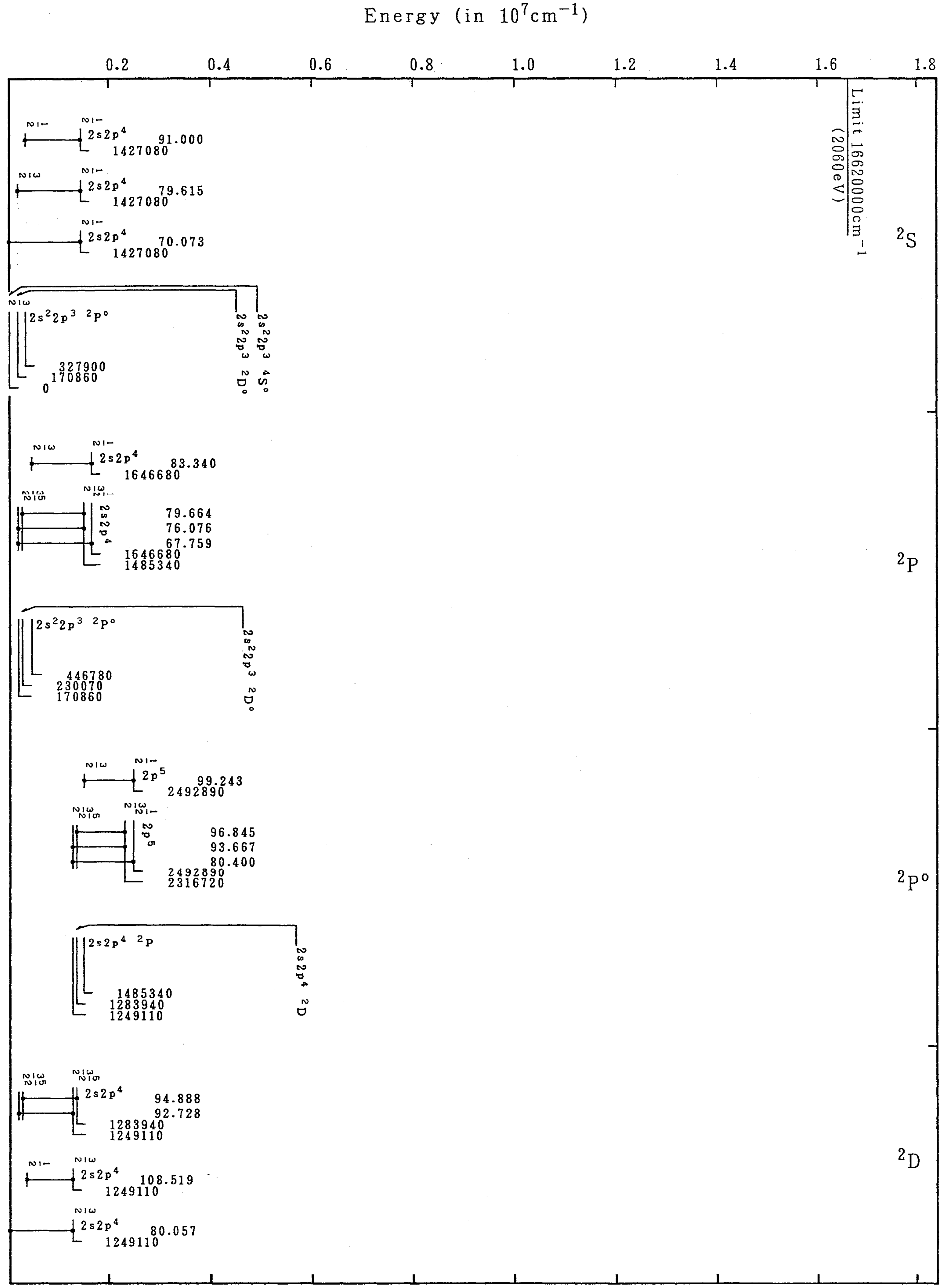

Grotrian diagrams for Cu XXII (O sequence) — Continued



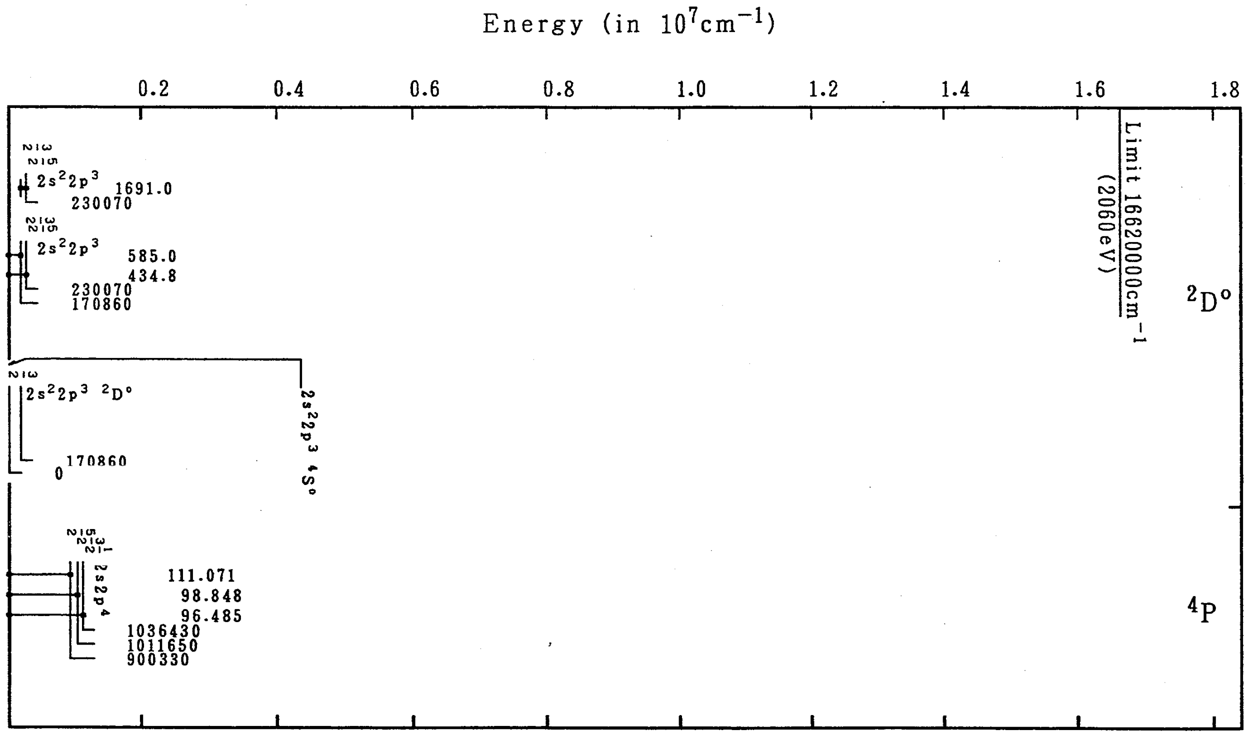

Grotrian diagrams for Cu XXII (O sequence) — Continued



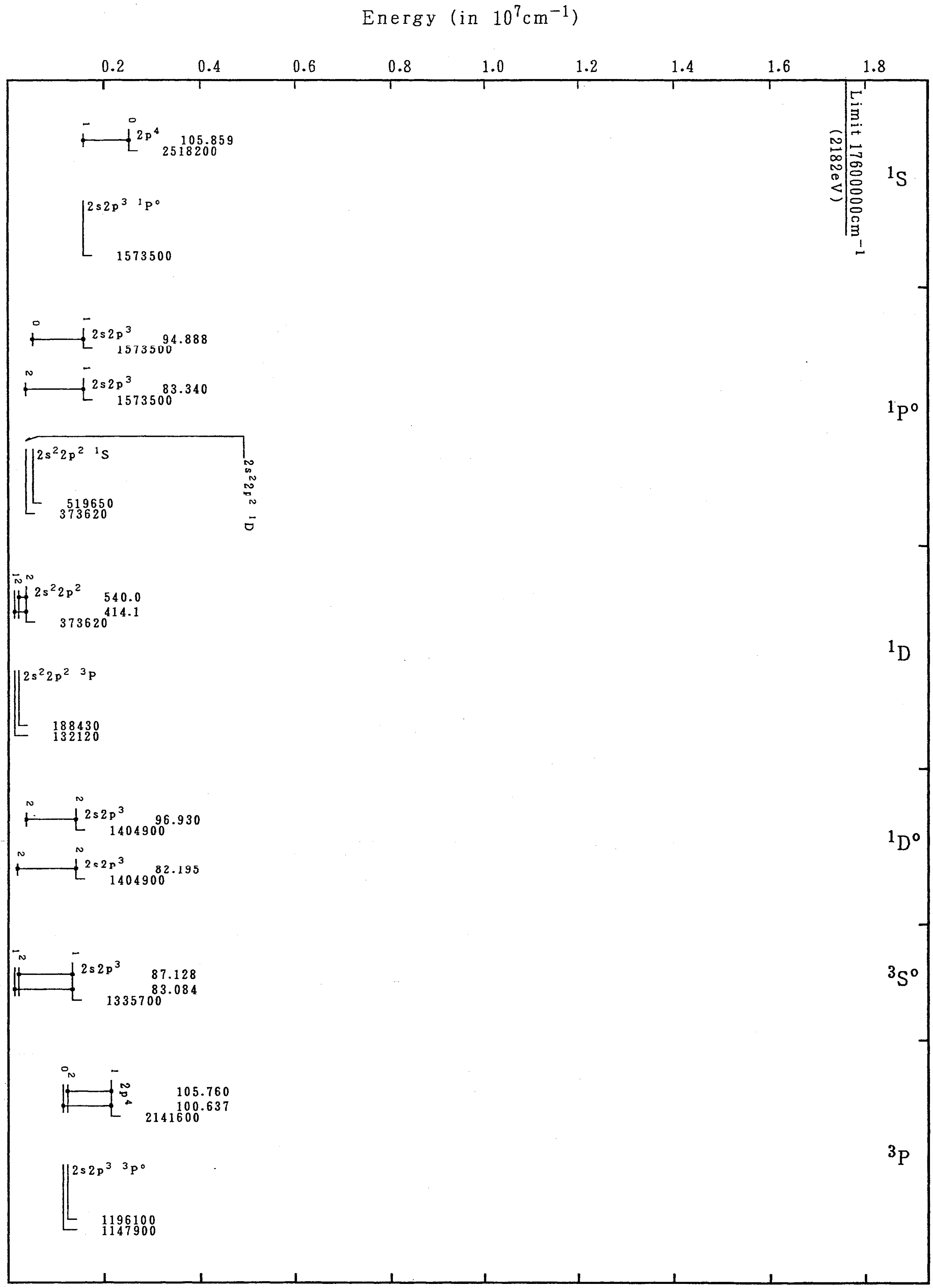

Grotrian diagrams for Cu XXII (O sequence) — Continued



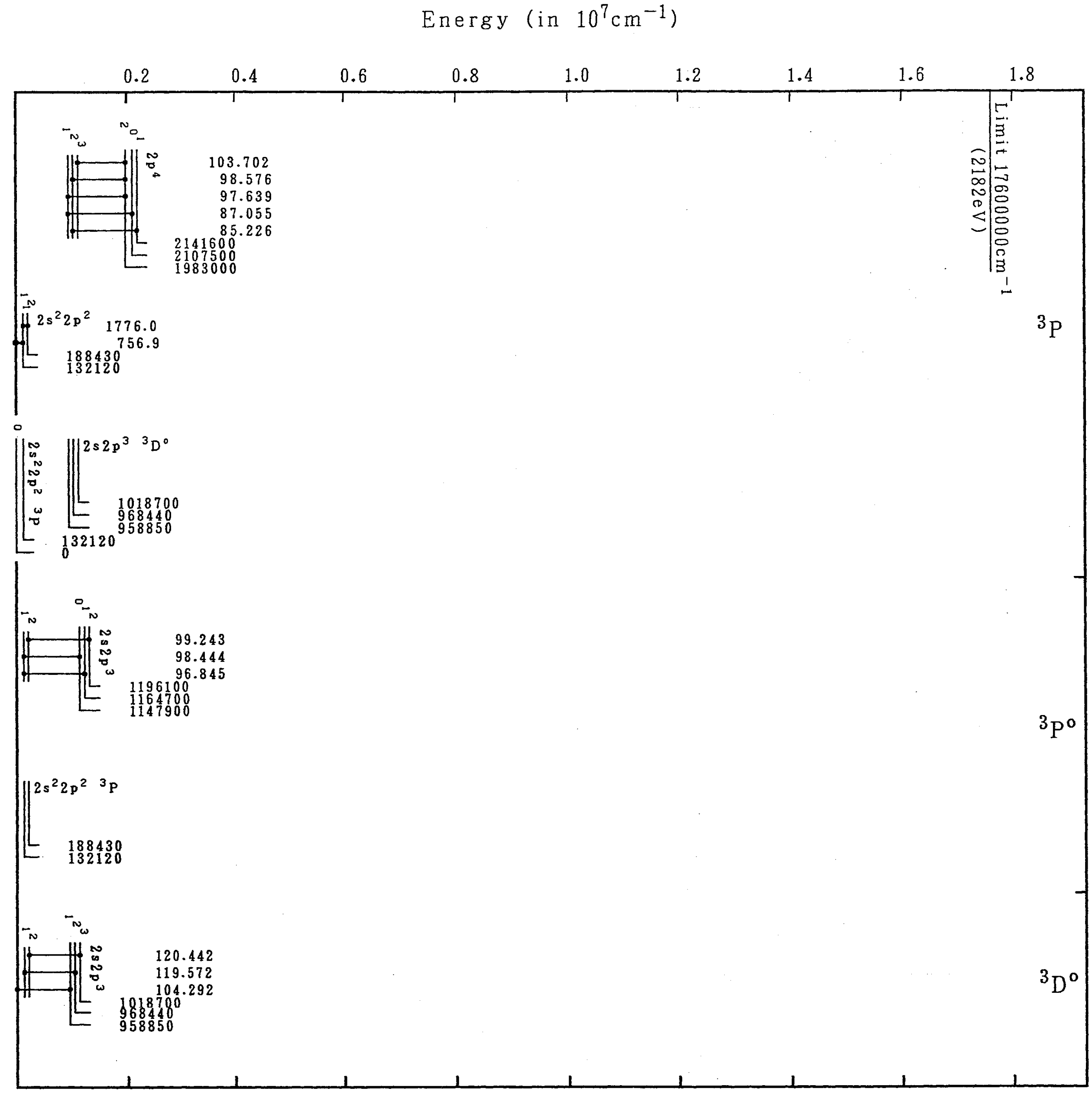

Grotrian diagrams for Cu XXIII (N sequence)



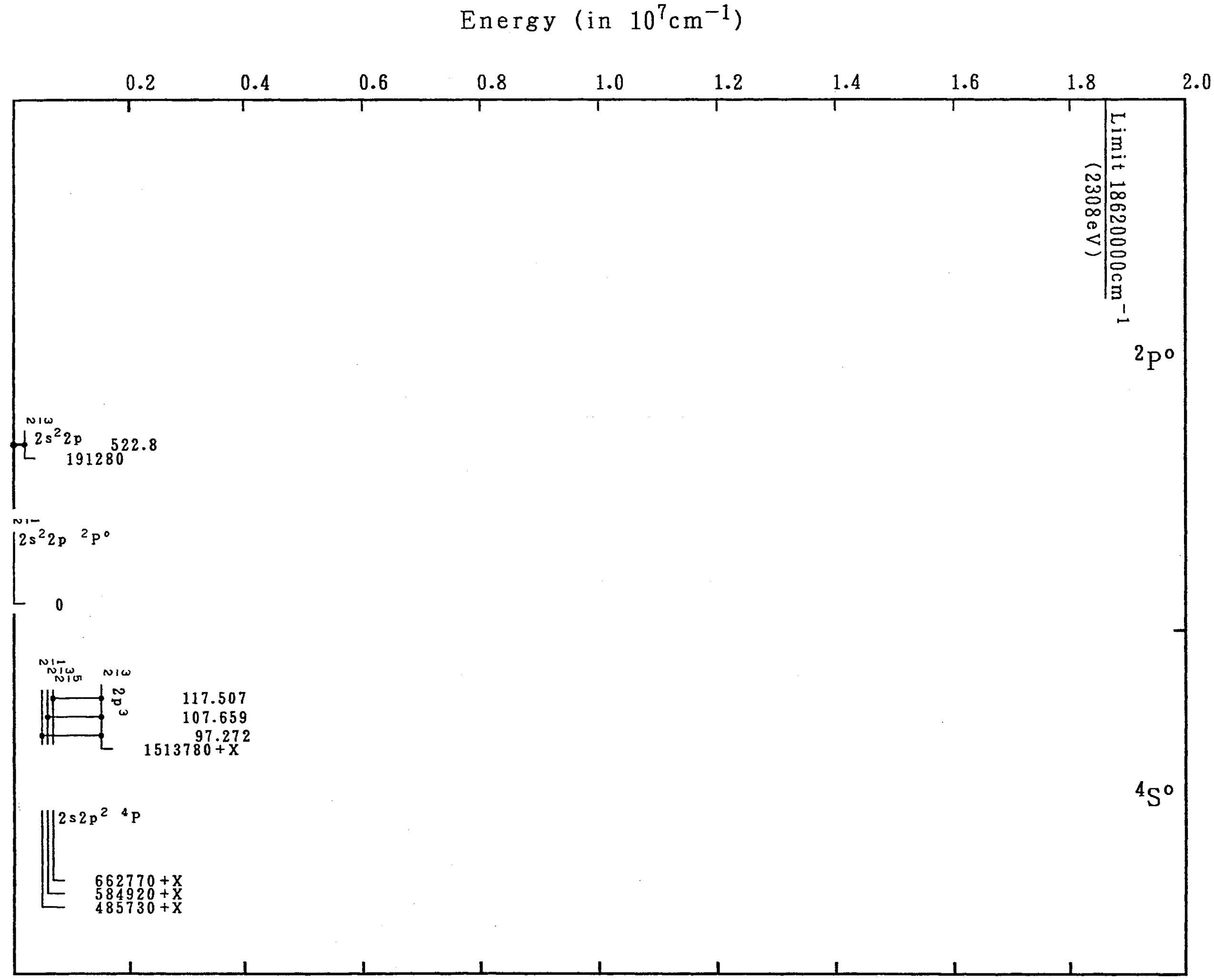

Grotrian diagrams for Cu XXIII (N sequence) — Continued



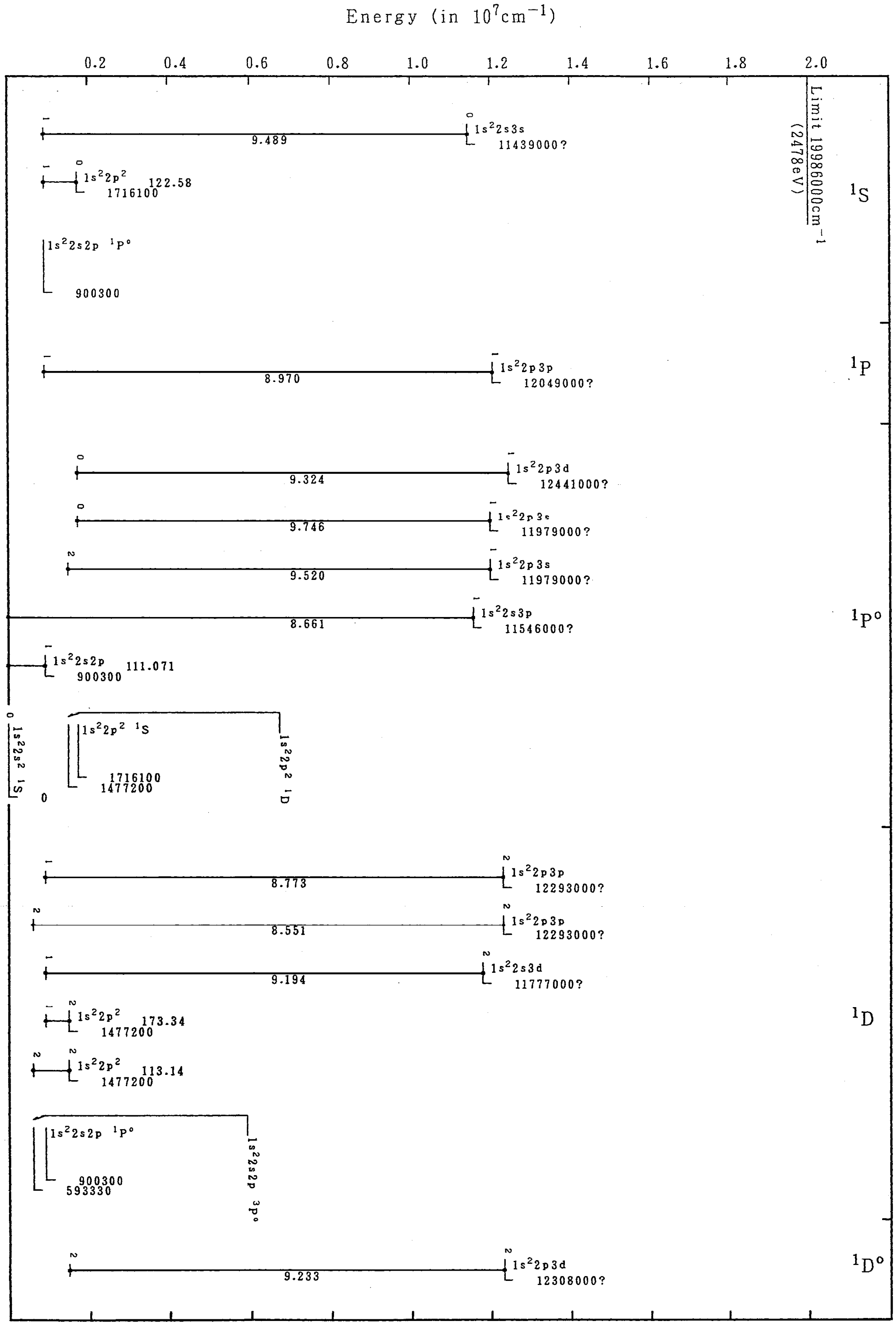

Grotrian diagrams for Cu XXIV (C sequence)



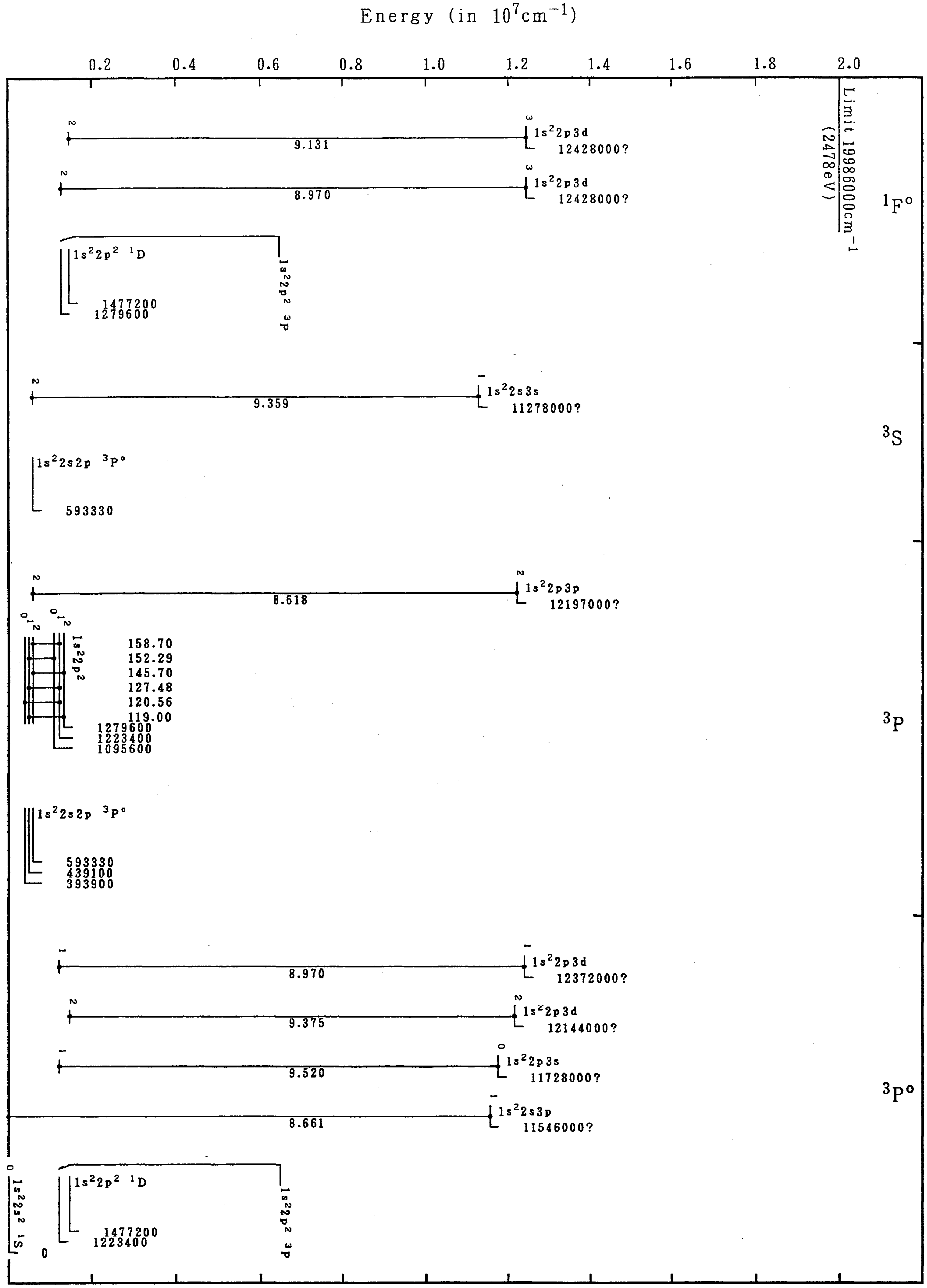

Grotrian diagrams for Cu XXIV (C sequence) – Continued



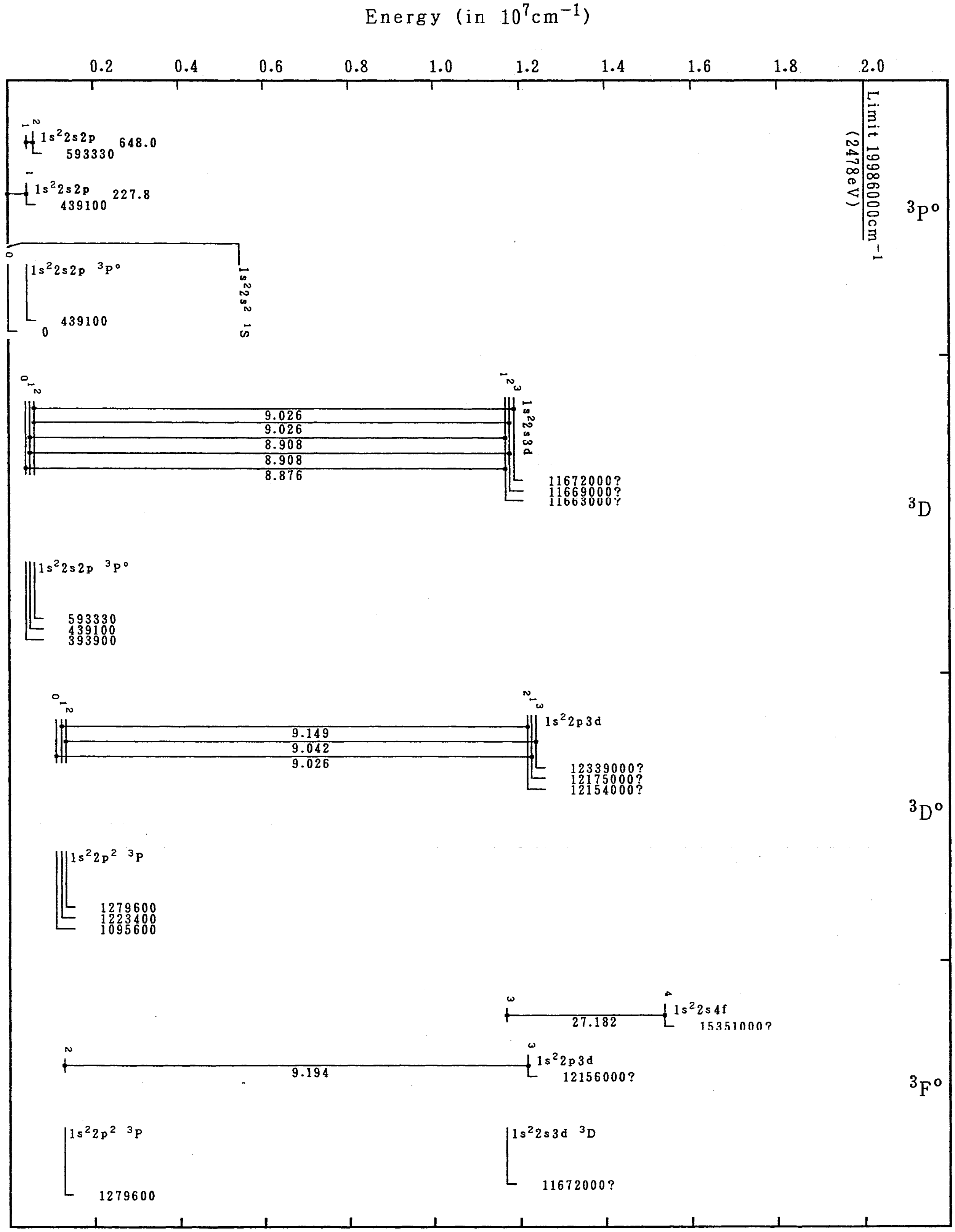

Grotrian diagrams for Cu XXV (B sequence)



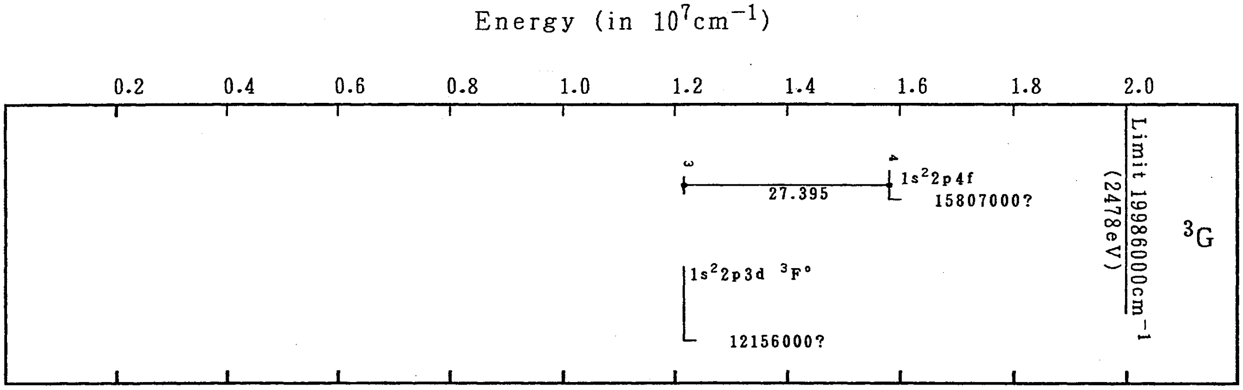

Grotrian diagrams for Cu XXVI (Be sequence)



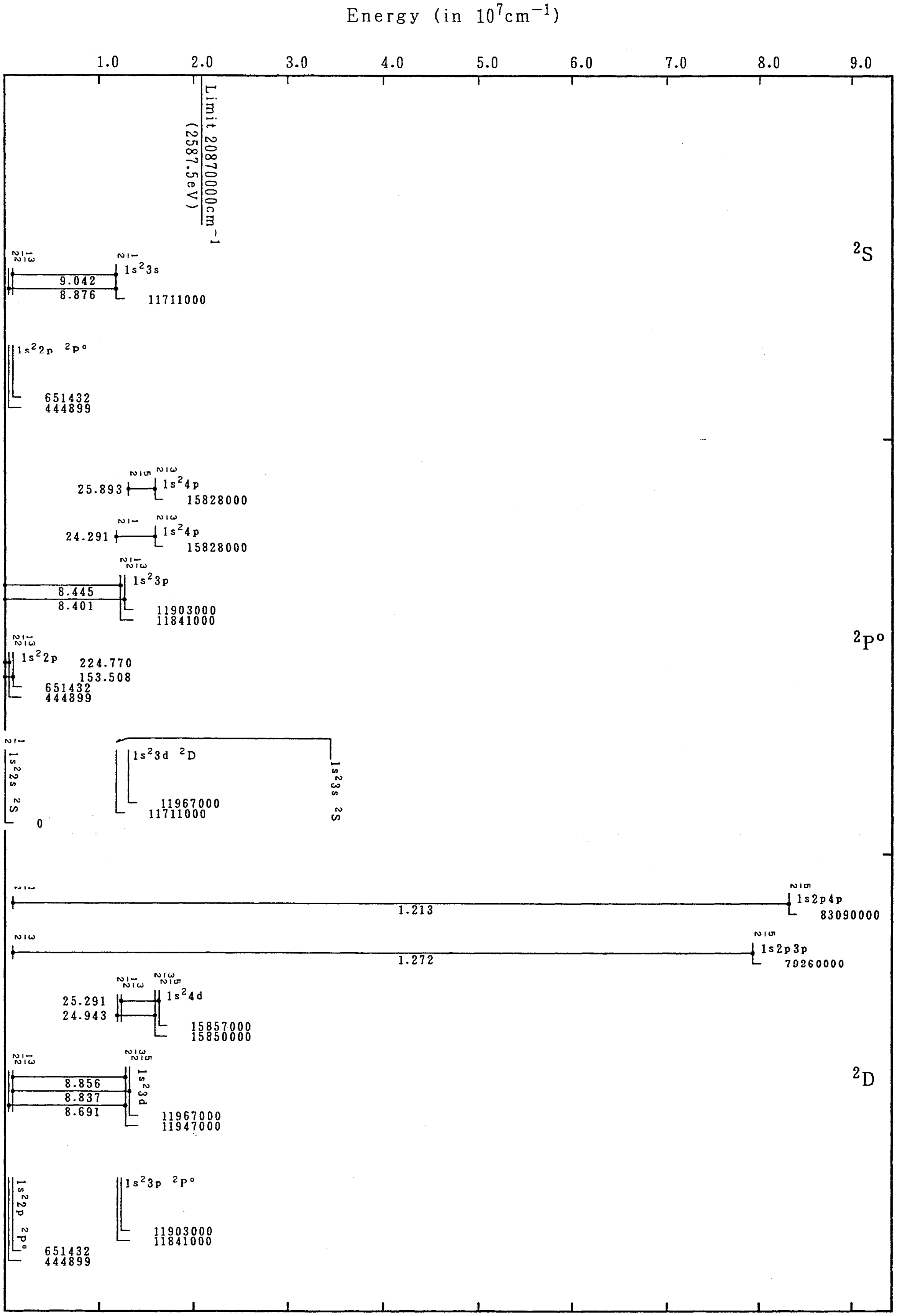

Grotrian diagrams for Cu XXVI (Be sequence) — Continued



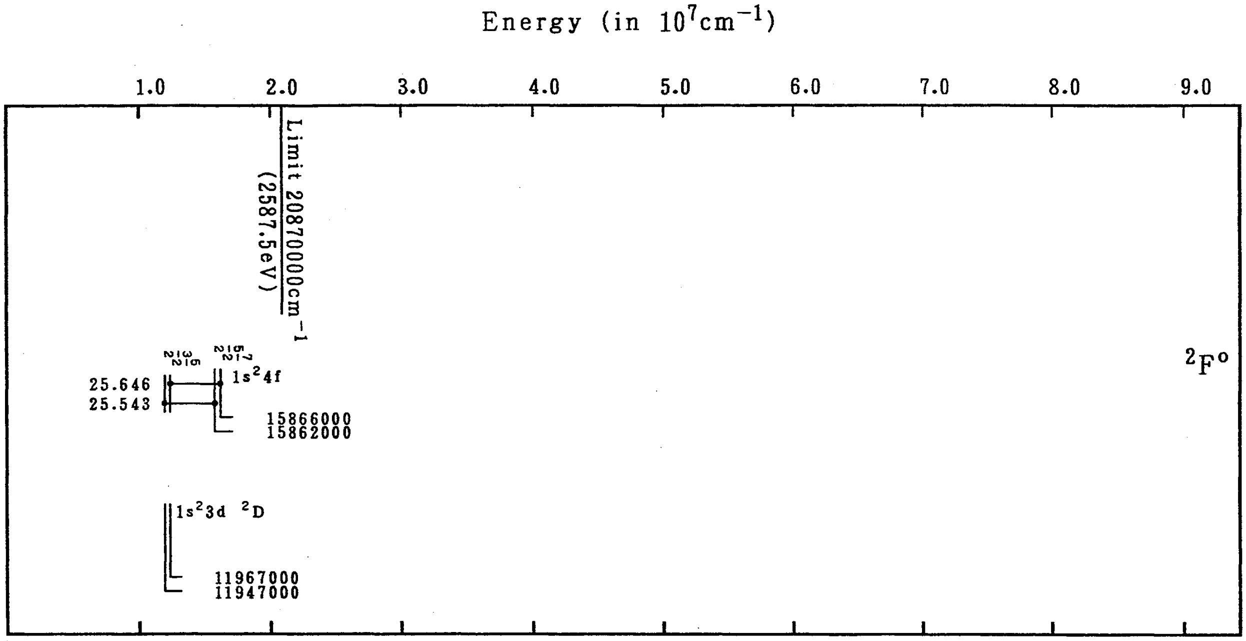

Grotrian diagrams for Cu XXVI (Be sequence) – Continued



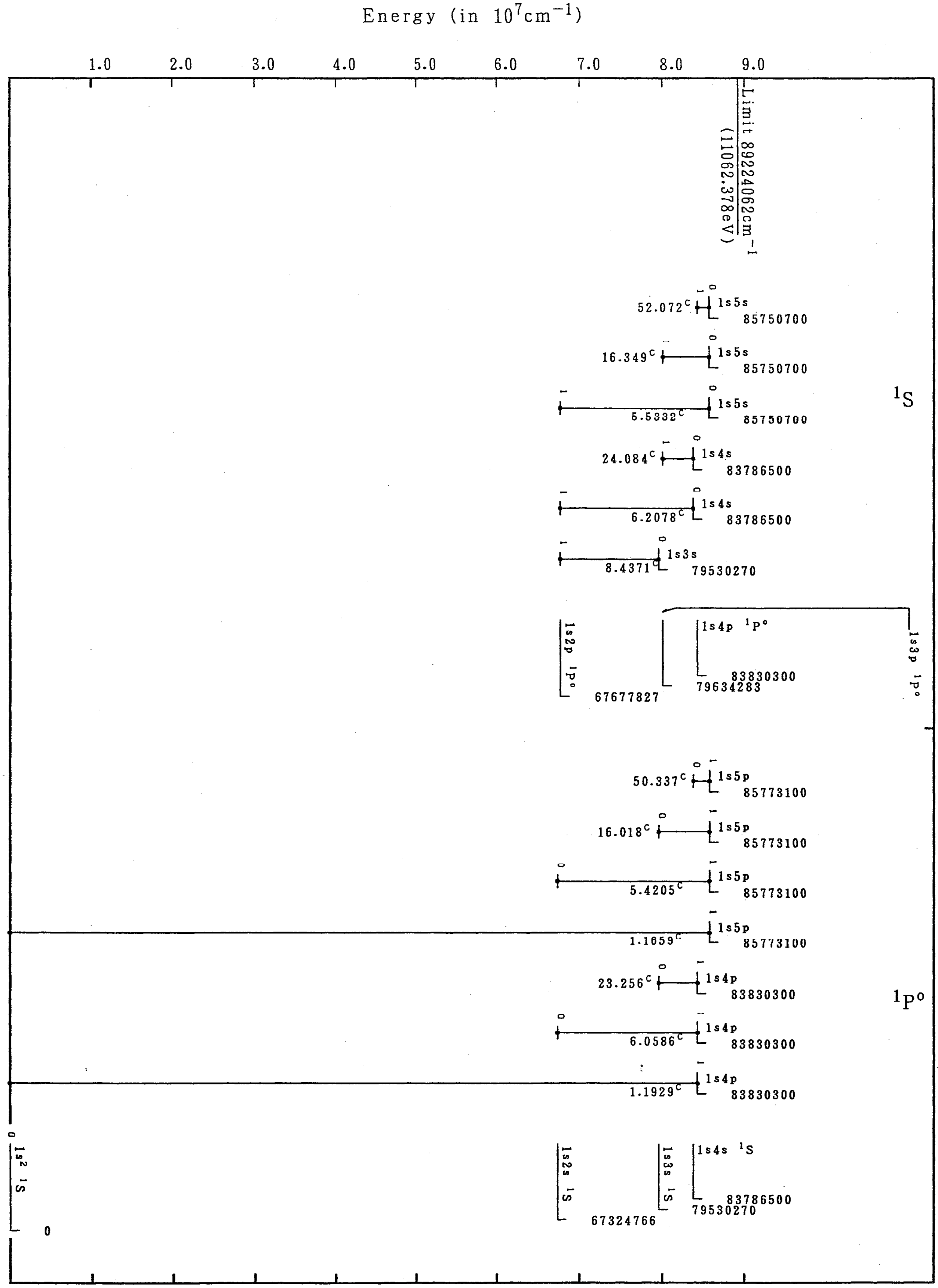

Grotrian diagrams for Cu XXVI (Be sequence) — Continued



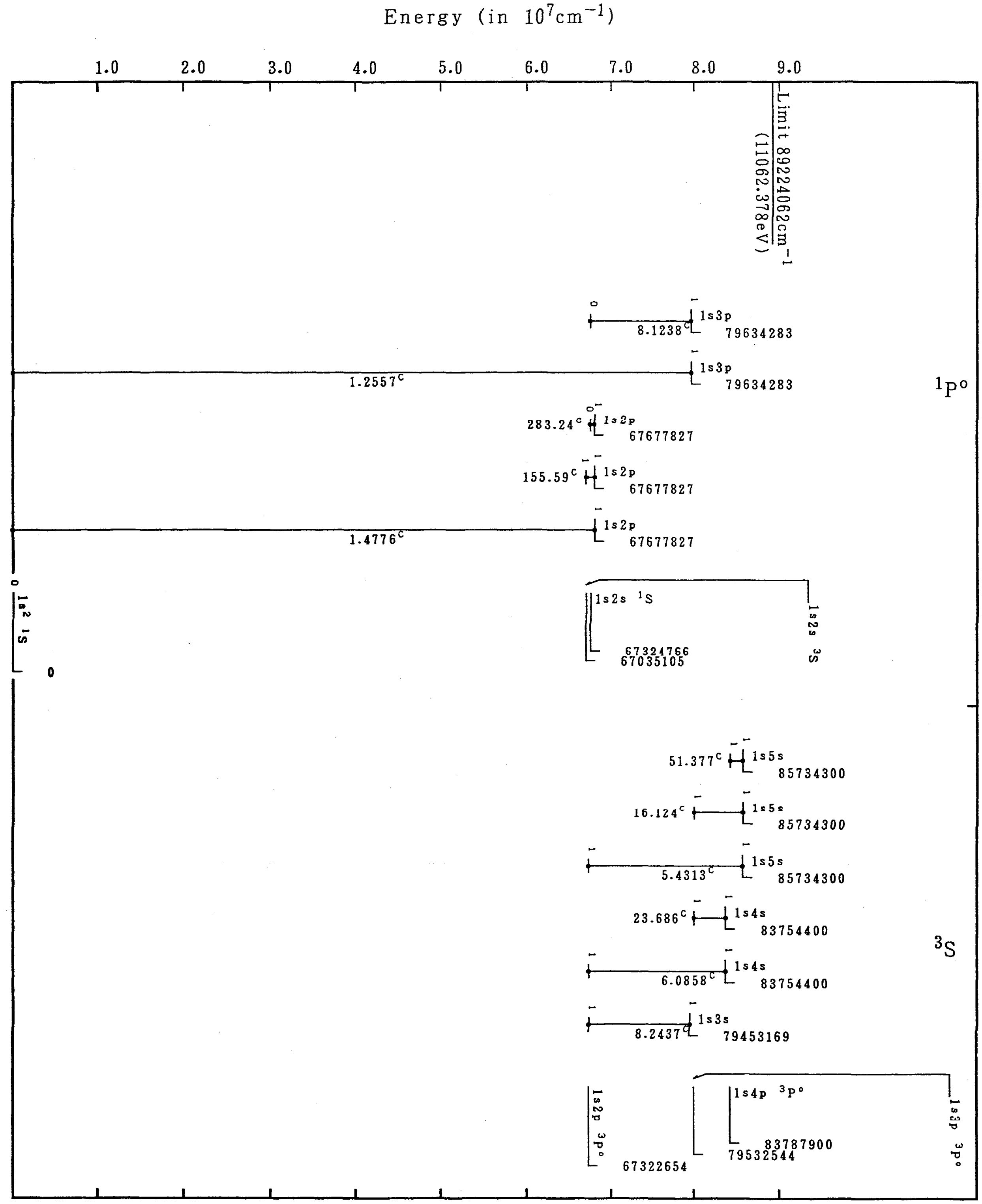

Grotrian diagrams for Cu XXVII (Li sequence)



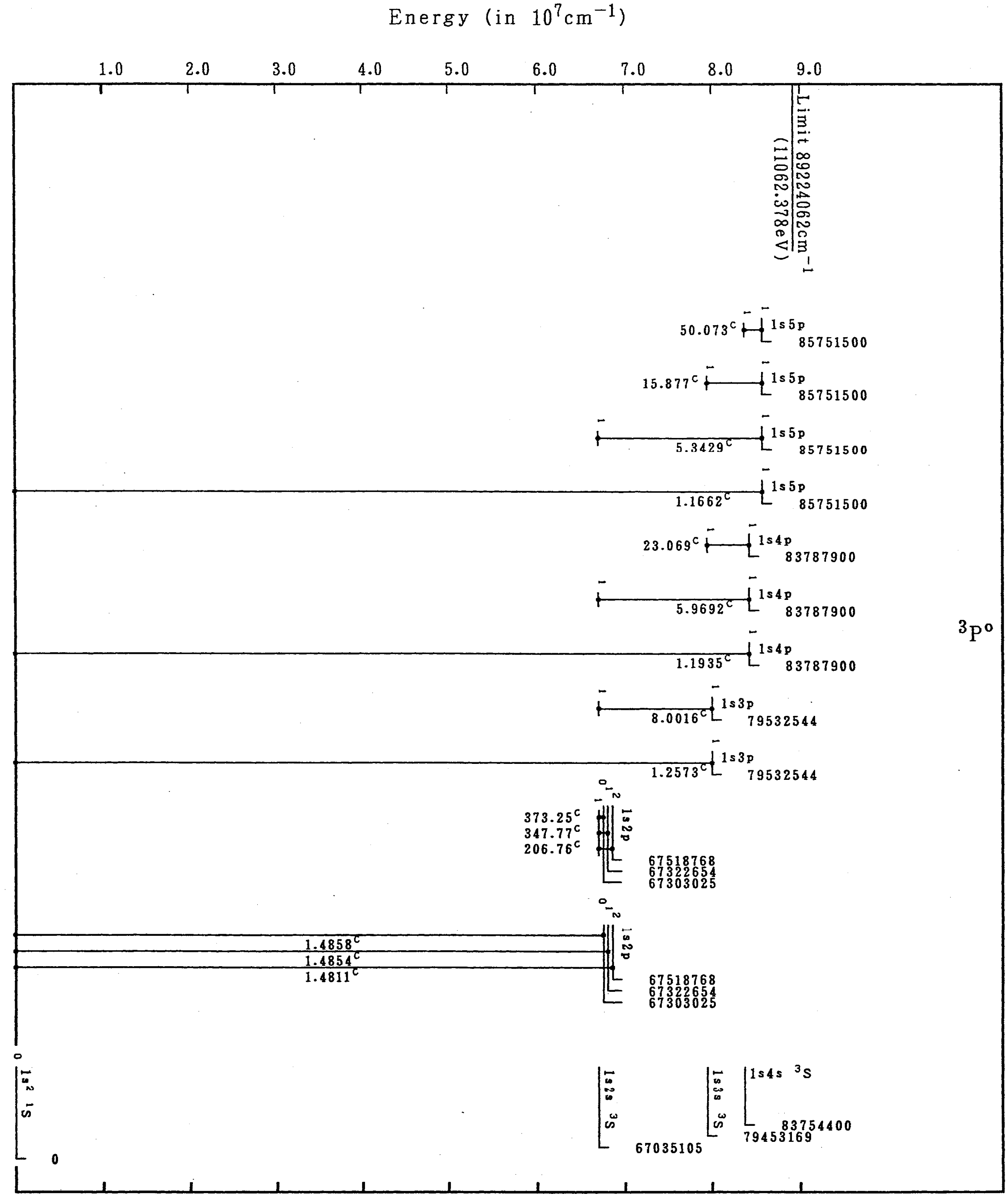

Grotrian diagrams for Cu XXVII (Li sequence) — Continued



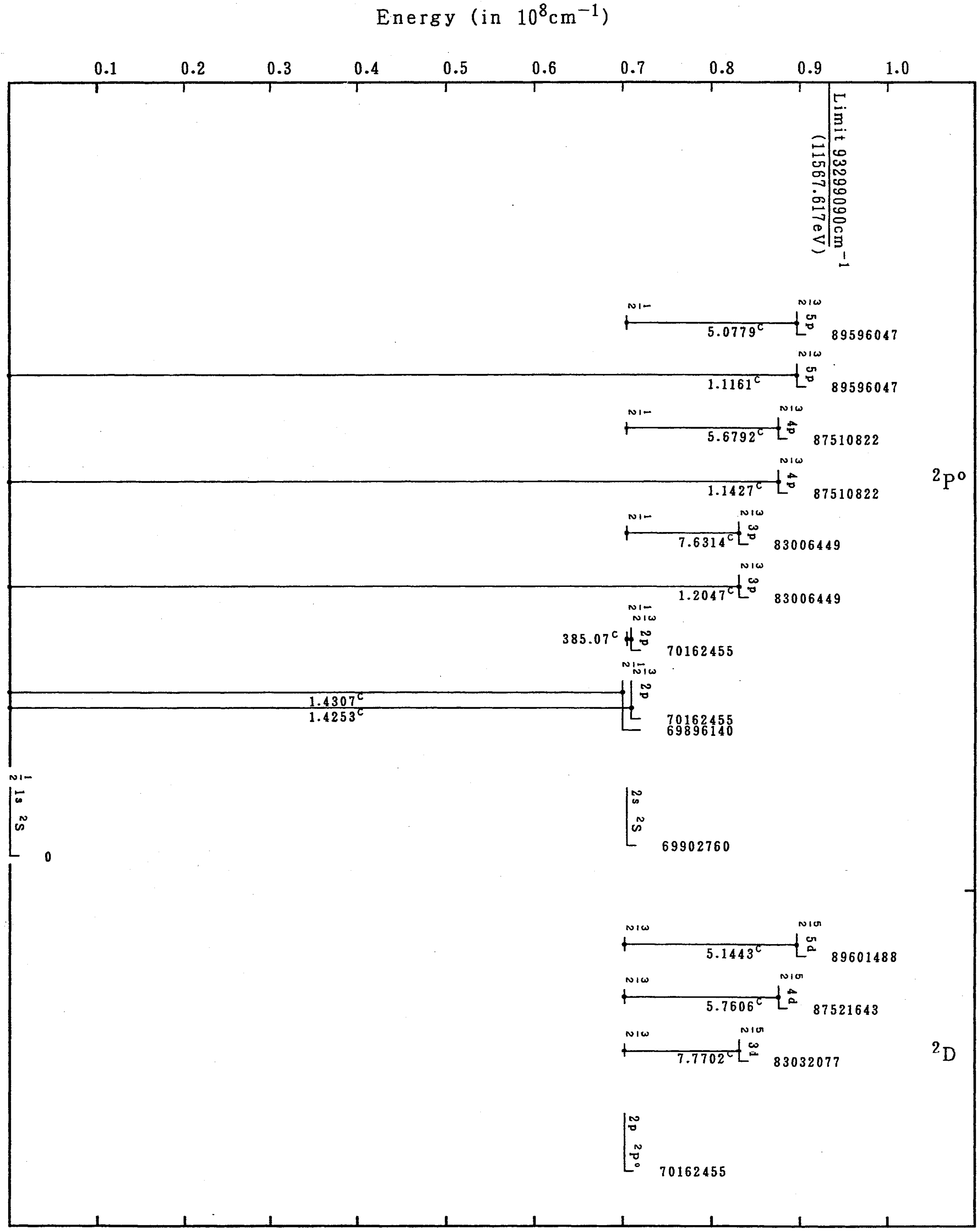

Grotrian diagrams for Cu XXVIII (He sequence)




Grotrian diagrams for Cu XXVIII (He sequence) – Continued




Grotrian diagrams for Cu XXVIII (He sequence) – Continued




Grotrian diagrams for Cu XXIX (H sequence)

## 7. Acknowledgments

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

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