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THE MOLYBDENUM SPECTRA MO I-XLII

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Abstract

A good amount of experimental data has poured in the last few years on the spectra of highly and very highly ionized molybdenum atoms, because of their importance in Tokamak and nuclear fusion studies. The spectra of Mo I-XXV, XXX-XXXIV and XL-XLII are now known in the literature, although many of them fragmentarily.

From our laboratory, significant contributions are made to Mo VI-XII. The existing information on transitions and energy levels is presented in this review together with level diagrams.

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Introduction

Molybdenum is a hard metal with the following characteristics:

Melting point 2610 °C; boiling point 5560 °C; heat of vaporization 123 (K-cal/g-atom); heat of fusion 6.6 (K-cal/g-atom); specific heat 0.061 (cal/g/°C); thermal conductance 0.35 (cal/cm^2/cm/°C/sec); electrical conductance 0.19 (microhoms)$^{-1}$; electronegativity 1.3 (Pauling's) covelent radius 1.30 Å; atomic radius 1.39 Å ionic radius 0.68 (+4) Å; atomic volume 9.4 (W/d); the first ionization energy 166 (K-cal/g-mole) and density 10.2 (g/ml).

It is therefore, useful in a variety of ways for different metallurgical and engineering purposes. It is found in small abundance in our sun and other stars.

Molybdenum is used, along with Tungston (W) in plasma machines, particularly in Tokamak, as container (Furth 1975, Group TFR 1974, 75, Hinnov 1976) due to its specific metallic properties. This fact enhanced the importance of spectroscopic studies of molybdenum in the form of ionized atoms in the last decade. In recent years, the prospects of achieving nuclear fusion as a great source of energy have brightened up; molybdenum is a suitable material for the pallets to be used. The international commission for fusion studies have, therefore, recommended as complete and accurate investigation of all molybdenum spectra, among others, as possible.

Studies in these spectra wre started by one of us in Paris

(1963) continued in Lund (Sweden, 1968-69) and developed as a group activity at Aligarh since 1969 with the help of material assistance of Lund University and the theoretical calculations performed at Loss Alamos (U.S.A.).

In the present review, we describe briefly the present knowledge of various molybdenum spectra.

The First Two Spectra of Molybdenum: Mo I & Mo II

Molybdenum belongs to the 2nd transition period of elements. The spectrum of neutral molybdenum atom as described in A.E.L. vol. 3 (Moore 1958) is based on the work of Kiess first alone, then with Harvey and finally with Trees. The ground configuration of this atom of 42 electrons is $4d^5\ 5s$ with $^7S_3$ as ground-most level. Known excited configurations include $4d^6$, $4d^5\ nl$ ($l = 0, 1, 2$ and $n \geq 5$), $4d^4\ 5s\ nl$ ($l = 0, 1$). 7500 lines of this spectrum have been recorded from 2000 to 11850 Å of which about 80% are classified.

Singly ionized molybdenum atom (Mo II) has naturally 41 electrons, and is, therefore, isoelectronic with neutral niobium atom (Nb I). The ground configuration of Mo II is $4d^5$ with $^6S_{5/2}$

as ground-most level; fourteen of the sixteen expected terms of $4d^5$ are found out. All the known excited configurations of the spectrum are obtained by adding one electron to the parent configuration $4d^4$. More than 2600 lines of Mo II covering the spectral region 2000 - 6000 Å are classified by Kiess.

No addition to the data reported in A.E.L. Vol. 3(Moore 1958) on MoI and MoII is known.

The Doubly Ionized Molybdenum Atom (MoIII)

A doubly ionized molybdenum atom is isoelectronic with Zr I; and contains 40 electrons. The ground configuration is $4d^4$ with $^5D_0$ as ground-most level. The ion is therefore, diamagnetic (J=0).

The analysis of Mo III was started by V.R. Rao and persuade by Rico and Catalán. Rico has made important additions to the A.E.L. data in 1965. Now the stage of knowledge of this spectrum is such that the eight singlet terms are the only glaring omission from the ground configuration $4d^4$. Among the excited ones, $4d^3$ 5s, 5p are known in detail, with some information on $4d^3$ 6s. The presently known data on terms and their levels are collected in Table I and plotted to the scale in Fig. 1. The line list extends over 500-4800 Å.

The Three and Four Times Ionized Molybdenum Atom(Mo IV & Mo V)

Mo IV is isoelectronic with neutral Yttrium (YI) with 39 electrons. The A.E.L. data on this spectrum covers fragments of three configurations $4d^3$ $^4F_{3/2}$ is the ground state; some information exists on $4d^2(^3F)$ 5s and $4d^2(^3F)$ 5p ^4G, ^4F, ^4D.

The work is by the Eliason and is based on 40 lines identification between 856 and 2141 Å. No additional information on this spectrum is known to us. A.E.L. data is reproduced in Table II and plotted in Fig. 2.

A four times ionized molybdenum atom (Mo V) is isoelectronic with SrI; it contains 38 electrons. This spectrum was worked out by Trawick, in 1935 (410-2160 Å) and this is completely reported in A.E.L. No additional data is yet available.

The knowledge of Mo V is far from being complete. Even the ground configuration $4d^2$ is known to the extent of triplet terms, ^3F and ^3P only. Known excited configurations are all made up by the addition, to one 4d electron, of a 5s, 5p, 5d or 5f. Out of these 4d5d and 4d4f configurations are only partly known.

The energy level data is reproduced in Table III from A.E.L. and plotted in Fig. 3.

<u>The Five Times Ionized Molybdenum Atom (MoVI)</u>

This simple 1-electron Rb I-like spectrum with 4d $^2D_{3/2}$ as ground level was first studied by Trawick (1955) and followed by Charles (1950). A.E.L. reports therefore, sixteen classified lines of this spectrum combining seven terms in the range of 260-1595 Å. Six of these terms have been confirmed since then with small improvement in level values; only 6p ^2P term is revised by Romanov and Striganov (1969) who have published a detailed investigation of this spectrum. The spectral region

of their investigation has been 2200 - 6800 Å, and covers large l values up to i (l = 6). Edlén applied his polarization formula to connect most of these levels with the ground term through a more accurate ionization potential value (1976,78 and private communication).

Edlén also predicted the unperturbed position of a number of unobserved levels of Mo VI and hence of the unobserved lines connected with them. We have included in Table IV all the levels that have been so far obtained in our laboratory (Singh 1977); though some of them require confirmation. All the levels are plotted in Fig. 4.

The Six Times Ionized Molybdenum Atom (MoVII)

The six times ionized molybdenum atom has KrI-like structure. In the ground state, all the sub-shells are full hence a $^1S_0$ level results. Most of the excited configurations are made of the addition of one nl electron to the parent $4p^5$ configuration, that gives rise to an inverted term $^2P_{3/2,1/2}$ only. The structure of the excited configurations shows instead of the LS situation, a marked pair coupling particularly in case of the additional electron being s; $4p^5ns$ obeys to what is called s j coupling and is the same thing as jj or sk in this case. Theoretical calculations predict a dominant pair-coupling also in some other cases like $4p^5np$, but a confused situation prevails for large l values of the external electron like nd. In this last case LS notation are retained as nothing better is available.

The unsplitted ground term with j = 0 does not naturally combine with any other excited level except those for which J = 1. In case of the excited states discussed above, it has to be either s or d configuration that gives rise to two or three resonance transitions respectively. The observation of more than one strong transition in either case is itself a sufficient indicator to the fact that LS-coupling is not a good approximation here. In fact these resonance transitions are so strong that they stand out in dense spectra. Some resonance transitions have also been observed from the internally excited $4s4p^6 5p\ ^{1,3}P_1$ levels.

The structure of the next excited states in the conventional LS-coupling would have been

$4p^5ns$ $(n \geq 5)$: $^3P_{2,1,0}$, $^1P_1$

$4p^5np$ $(n \geq 5)$: $^1S_0$, $^1P_1$, $^1D_2$; $^3S_1$, $^3P_{2,1,0}$, $^3D_{3,2,1}$

$4p^5nd$ $(n \geq 4)$: $^1P_1$, $^1D_2$, $^1F_3$, $^3P_{2,1,0}$, $^3D_{3,2,1}$, $^3F_{4,3,2}$

$4p^5nf$: $^1D_2$, $^1F_3$, $^1G_4$, $^3D_{3,2,1}$, $^3F_{4,3,2}$, $^3G_{5,4,3}$

$4s\ 4p^6ns$: $^1S_0$, $^3S_1$

$4s\ 4p^6\ np$: $^1P_1$, $^3P_{0,1,2}$

$4s\ 4p^6\ nd$: $^1D_2$, $^3D_{1,2,3}$

$4s\ 4p^6nf$: $^1F_3$, $^3F_{2,3,4}$

We will give in the Table 5 and Fig. 5 concerned notations more appropriate to the physical situation.

The first work on Mo VII was due to Charles (1950) who identified five resonance lines correctly, establishing $^{1,3}P_1$ levels of 5s, 6s and 5d $^3D_1$ related to the ground level. Chaghtai extended his work (1969,70) followed by Reader and Epstein (1972). This established J = 1 levels of ns ($n \leq 10$) and nd ($n \leq 6$) as given in Table 5 and plotted on Fig. 5.

In our laboratory it is attempted to identify transitions between ns and $n'p$ ($n, n' = 5-7$) configurations so as to find out their complete level structure (Singh 1977). These levels are plotted in Fig. 5, although they need confirmation.

Mo VII spectrum has been studied from about 100 to 2500 Å.

The Seven Times Ionized Molybdenum Atom (MoVIII)

The seven times ionized molybdenum atom is isoelectronic with the halogen Br I. There is an inverted doublet $^2P_{3/2,1/2}$ as ground term arising out of the configuration $4p^5$. Most of the excited levels are formed of the parent configuration $4p^4$, which consists of one inverted triplet and two singlets namely $^3P_{2,1,0}$, $^1D_2$, $^1S_1$ in order of increasing energy. The ground levels combine with nd and ns configurations only, but the internally excited 4s $4p^6$ $^2S_{1/2}$ level also gives strong resonance transitions that become most prominent for ionizations greater than two times. In case of $4p^4ns$, the structure shows pair coupling eminently, where as 4d structure could retain an LS or LS-like character.

The first work on Mo VIII was published by Charles (1950) who reported the resonance transitions from 4s $4p^6$, $4p^4 4d$ and $4p^4 5s$ configurations. His work was revised by Chaghtai (1969,70),

followed by Ekberg et al (1972). The higher configurations namely $4p^4 5d$, 6d and $4p^4$ 6s, 7s have been studied only by Chaghtai et al in our laboratory (1975), but no work has been reported on transitions between the different excited configurations yet. The observed energy levels are assembled in Table 6. and the different configurations are plotted in Fig. 6.

The study of Mo VIII covers the wavelength region 100-475 Å.

The Ninth Spectra of Molybdenum (Mo IX)

The study of eight times ionized molybdenum atom was initiated by Chaghtai (1969-70) but it was performed in detail only at Aligarh mainly by Khatoon (1976,78,78A,79). Mo IX with 34 electrons is isoelectronic with Se I. The ground configuration $4p^4$ breaks up into an inverted triplet $^3P_{2,0,1}$ and two singlets $^1D_2$, $^1S_0$. The anomalous order of levels in ^3P is in accordance with the Condon and Shortley theory of mixed coupling; it has been observed by Chaghtai for the first time in the spectra XVI-Mo XI (1973,69,70). Excited configurations studied are 4d, 5d, 6d, and 5s, 6s, 7s with the common parent terms $4p^3$ ($^4S_{3/2}$, $^2D_{1/2}$ and $^2P_{1/2,3/2}$).

Internally excited levels $^3P_{0,1,2}$ and $^1P_1$ arising out of 4s $4p^5$ have been established by Reader and Acquista (1976). All the studies of Mo IX are based on the identification of transitions to the ground levels from 92 Å-364 Å.

Observed energy levels of Mo IX are assembled in Table 7 and plotted in Fig. 7.

The Tenth Spectra of Molybdenum (Mo X)

The As I-like spectrum of Mo X with 33 electrons was studied for the first time at Aligarh (Rahimullah et al. 1976,78 Khatoon

1979); the ground configuration $4p^3$ of this ion splits up into $^4S_{3/2}$, $^2D_{3/2,5/2}$, $^2P_{1/2,3/2}$ and these levels combine with those of $4p^2nd$, ns. Excited configurations $4p^2nd$ have been studied for n = 4 - 6 and $4p^2$ ns for n = 5 - 7. As the structure of p^2 is $^3P_{0,1,2}$, $^1D_2$, $^1S_0$, there result, ^4P, ^2P, ^2D and ^2S terms for each p^2ns; all these terms and their levels are found out for the reported $4p^2ns$ configurations. In case of $4p^2nd$, rather a large number of terms result, all of which have not been determined so far. Reader and Acquista (1981) confirmed our $4s^24p^3$ - $4s^24p^25s$ analysis and added to it resonance transitions from $4s4p^4$ configuration, establishing all the eight levels.

The studies of Mo X cover the wavelength region 82-474 Å. All the observed energy levels are assembled in table 8 and plotted in Fig. 8.

<u>The Ten Times Ionized Molybdenum Atom (Mo XI)</u>

Mo XI with 32 electrons is isoelectronic with neutral Ge and, therefore, generally exhibits a simple two-electrons spectrum with $4p^2$ as ground configuration. The detailed structure of this spectrum can be easily guessed from the above described situations and hence is not repeated.

The spectrum is studied exclusively at Aligarh by Rahimullah et al (1976,78). The knowledge of the ground configuration $4s^24p^2$ ($^3P_{0,1,2}$, $^1D_2$, $^1S_0$) and the excited configurations 4p 4d and 4p5s is complete except for the $^3F_4$ level of 4p4d that does not combine with ground levels. $^1P_1$ and $^3S_1$ levels of the internally excited 4s $4p^3$ configuration are also established.

The data is reported in Table 9 and plotted in Fig. 9. Wavelengths are comprised in the region 189-331 Å.

The Twelfth spectrum of Molybdenum Atom (Mo XII)

The spectrum of eleven times ionized molybdenum atom is Ga I-like and is, therefore, in part a 1-electron spectrum and in part a 3-electron system. As the ionization involved is high, the internally excited $4s4p^2$ and $4p^3$ configurations, which belong to the same shell as the ground state $4s^24p$, descend so much that the former becomes the lower-most excited configuration and the latter one not too highly placed.

Mo XII is analysed in our laboratory only (Khatoon, 1978), except for identifications of two 4p-5d lines by Alexander et al. (1971). The ground term $4s^24p\ ^2P_{1/2,3/2}$ and the excited $4s^24d\ ^2D_{3/2,5/2}$ are firmly established. The $4s4p^2$ configuration is known to the extent of ^4P, ^2S, ^2P terms, which are fully determined. Other configurations and their terms, whose study is attempted are $4p^3$ (^4S, ^2D, ^2P) and $4s^25d\ ^2D$, but they need to be confirmed.

The spectrum has been studied from 238 to 430 Å. The observed levels are assembled in Table 10 and plotted in Fig.10.

The spectra of Mo XIII

In this spectrum, Alexander et al (1971) were the first to report five transitions; two of them permitted us to determine the $4s4p\ ^{1,3}P_1$ levels with respect to the ground $4s^2\ ^1S_0$ level; the $^1S_0$- $^1P_1$ transition has also been traced in Tokamak emission by Hinnov (1976). Burkhalter et al. (1980) reported two resonance transitions $3d^{10}4s^2$ - $3d^94s^25p\ ^3D_1$, $^1P_1$ and Wyart et al confirmed them (1981).

The derived five levels are assembled in table 12 and plotted in Fig. 12. The few other reported lines, not useful in this respect, are given in table 20.

Fourteenth Spectrum of Molybdenum (Mo XIV)

A thirteen-times ionized molybdenum atom has 29 electrons and is isoelectronic with Cu I (Z=29). The ground configuration is $3d^{10}$ 4s and except for $3d^{9}4s4p$, $3d^{9}4p^{2}$, all the known excited configurations are of the type $3d^{10}nl$. Alexander et al. (1971) were the first to record the spectrum of Mo XIV in the region 45-350 Å with a low inductance spark; they identified the strong 4s-5p, 4s-6p, 4p-5s, 4p-5d and 4d-5f transitions. In 1972, Hinnov et al. spotted the 4s-4p resonance doublet on the Princeton S.T. Tokamak machine.

In July 1977, Curtis et al published a paper on Mo XIV (35 - 184 Å) based on Edlén's old recording. This deals with identification of 4s-7p, 4p-6s, 4p-7s, 4p-8s, 4f-5g, 4f-6g and 4d-5p transitions, along with life time determination of the states involved. Wavelength accuracy of this work is limited to ± 0.5 or ± 0.2 Å only, and the reported identification differ in case of 4d-5p, 4f-5g and 4f-6g from the paper on this spectrum by Reader et al. (1979), presumably because of the spectrum measurement difficulty that Curtis et al met with in the longer wavelength region these lines are situated in.

In view of the accurate measurement of Reader et al., we are reporting the consolidated data from their paper (Table 11, Fig. 11) and have borrowed this review of Mo XIV also from there. These transitions lie in the spectral region 70 - 630 Å.

Three additional papers have appeared in the last two years on Mo XIV transitions observed in the 50-54 Å region; they are authored by Burkhalter et al (1980), Klapisch et al (1981) and Wyart et al (1981). The transitions involved have finally been identified as $3d^{10}4s-3d^{9}4s4p$, $3d^{10}4p-3d^{9}4p^{2}$ and $3d^{10}4s-3d^{10}7p$. This has led to determine 11 levels of the configuration $3d^{9}4s4p$, 10 of $3d^{9}4p^{2}$ and 2 of $3d^{10}7p$, included in the same table.

The spectra of Mo XV:

Mo XV is Ni I-like; the ground configuration consists of all closed subshells up to 3d, hence a $^{1}S_{0}$ as ground level. Most of the excited configurations will arise out of the elevation of a 3d electron to a higher level, resulting in $3d^{9}nl$ for various possible values of n and l. Alexander et al in their aforementioned paper reported the three transitions from the $3p^{9}4p$ configuration (J=1) that can combine with the ground level. Two of them, namely those from $^{3}D_{1}$ and $^{1}P_{1}$ have been confirmed since then by Schwob et al (1977) and Klapisch et al (1978). The latter authors have reported two additional ($\Delta J=2$, Electric Quadrupole) transitions from $3d^{9}4s$ levels. Mansfield et al (1978) also reported these lines from the DITE Tokamak.

In 1980 Burkhalter et al identified resonance transitions from $3d^{9}4p$ and $3d^{9}4f$; Schwitzer et al (1981) also reported them with the addition of those from $3d^{9}5f$. Wyart et al (1981) confirmed the transitions from $3d^{9}4p$, but Burkhalter et al and Mansfield et al both are uncertain about the identification

of the resonance transition $3d^9 4f\ ^3D_1$ ——— Mansfield et al found it lying in the $3p^6 - 3d^5 4p$ band of Mo XIX.

Derived energy levels are given in table 12 and plotted in Fig. 12.

The Sixteenth Spectrum of Molybdenum (Mo XVI)

This is a Co I-like ion with 27 electrons, $3p^6 3d^9$ as ground configuration and $^2D_{5/2}$ as the lowest level. Edlén was the first to identify the resonance transitions $3p^6 3d^9\ ^2D - 3p^5 3d^{10}\ ^2P$ in a vacuum spark spectrum; Alexander et al (1971) measured them. Then Schwob et al (1977) classified three lines as Mo XVI transitions $3d^9 - 3d^8 4p$, 4f without assigning terms and levels.

Mansfield et al in their detailed paper of 1978 identified transitions from $3d^8 4s$, 4p, 4f, of Mo XVI, confirming further Edlén's identifications. It was followed by the paper of Burkhalter et al (1980) in which they established 54 energy levels of Mo XVI belonging to the configurations $3p^6 3d^9$, $3p^5 3d^{10}$, $3d^8 4p$ and $3d^8 4f$. The spectrum for this study was produced in a low inductance vacuum spark and a laser generated plasma. This paper confirms earlier identifications except those concerning $3d^8 4s$, and makes a rich contribution of its own.

The reported and derived energy levels of Mo XVI are given in table 13 and plotted in Fig. 13. The spectrum is studied in the 32-78 Å wavelength region.

The Seventeenth Spectrum of Molybdenum (Mo XVII)

This ion of molybdenum is iso-electronic with neutral

iron atom (Fe I) with 26 electrons. The ground configuration $3d^8$ has practically a 2-electron structure. By internal excitation results the interesting configuration $3p^5 3d^9$ with two holes; transitions between these two configuration have been studied by Bogdanovichene et al (1980) and Reader et al (1981). All the nine levels constituting the five ground terms ^3F, ^3P, ^1D, ^1G, ^1S and the 12 levels of the excited configuration have been established. Three levels of the former and two of the latter are freshly revised by the latter authors; otherwise the two lists agree within their experimental errors.

Prior to these papers, Mansfield et al (1978) were the first to identify transitions in this spectrum involving the ground and the $3d^7 4p$ configurations. The latter one has got a complicated structure because of the three holes and one electron involved. The ground structure having been determined in the above mentioned two papers, we could determine level values of $3d^7 4p$ from this third paper, although it reports a lot of blended groups of lines. Levels $(^2H)\ ^3G_3$, $(^2F)\ ^3D_1$, $(^2P)\ ^3D_3$, $(^2G_{9/2,3/2})4$ and $(^2F_{7/2,3/2})$ are the only ones that could not be resolved because they are supposed to give rise to an unresolved structure extending from 42.08 to 42.14 Å.

Energy levels of Mo XVII are given in table 14 and plotted in Fig. 14.

<u>Mo XVIII-XXV</u>

In the above mentioned apeper of Burkhalter et al (1980)

is also includes four resonance transitions reportedly of Mo XVIII, which is a Mn I-like ion with $3p^6 3d^7$ as ground configuration. A group of unresolved lines is attributed to this spectrum by Schwob et al also. The reported transitions do not lead to any level determination and are listed in Table 20.

Schwob et al in their 1977 papers have also classified some lines of Tokamak radiation as transitions in spectra Mo XIX - XXV. These led as to derive the few levels of Mo XXIV and Mo XXV given in table 19 and transitions are assembled in table 20.

Mo XXX

The thirtieth spectrum of Mo is isoelectronic with Al I. The ion contains 13 electrons and will give rise to a one-electron spectrum dominantly, due to the excitation of the outer most 3p electron from the ground state. A part of the spectrum can, however, have a three-electron structure, arising out of the excitation of one 3s electron.

A number of transitions in this spectrum have been reported by Burkhalter et al (1977) and Mansfield et al (1978). Rejecting the apparently inconsistant identifications, we have derived from them the energy levels reported in table 15 ——— the three $3s3p^2$ levels have not been designated; the derived energy levels are plotted in fig. 17. The spectrum is studied in the 15-17 Å wavelength region.

Mo XXXI

Two papers exist on the experimental observations of this Mg I-like spectrum (ground state $3s^2\ ^1S_0$); the first note of Burkhalter et al (1977) was followed by a rather detailed paper by Mansfield et al (1978). We tried to derive the energy levels from the transitions reportedly identified by these authors and met with some success. Ten configurations could be worked out in part. As the reported spectrum consists of a number of unresolved structures, the term analysis involved certain approximations. Levels of 3p3d could be reached from the ground level via 3s3d or $3p^2$. The two sets of values thus obtained showed gross inconsistencies and this casted heavy shadow of doubt on the reported identifications. We are, therefore, reproducing the reported transitions in table 20, ignoring the level structure.

Mo XXXII

This is Na I-like simple one electron spectrum with $3s\ ^2S_{1/2}$ ground level. Interest in this spectrum was aroused by the observation in Tokamak radiation of two Mo XXXII transitions by Minnov (1976) and three others by Schwob et al (1977). Burkhalter et al (1977) came up with an analysis of this spectrum establishing 17 levels on the basis of 22 transitions observed in a laser produced plasma. Mansfield et al (1978) improved upon their measurements and added some new transitions which yielded two more levels.

We are reporting energy levels derived from the later authors' paper. (Table 16, Fig.15). The studies cover the wavelength region 10 - 177 Å.

Mo XXXIII

The study of this He I-like ion (ground level $2s^2 2p^6\ ^1S_0$) began with Aglitskii et al (1975) who reported six resonance transitions; Burkhalter et al followed them (1977 and 1978) with 10 and 17 resonance lines respectively. Aglitskii has recently (1979) improved measurement of five transitions reported by him earlier. Energy levels in table 17 are derived from the best reported measurements, the spectrum having been situated 3-6 Å.

Mo XXXIV

This Fl I-like ion (ground level $2p^5\ ^2P_{3/2}$) is known through the work of Boiko et al (1978) who identified nine $2p^5$-$2p^4 3d$ transitions using a laser produced plasma, Burkhalter et al in their (1978) paper, quoted many times above, have also spotted out two of these transitions. Levels are given in table 18 and plotted in Fig. 17.

Mo XL, XLI and XLII

Lastly we must mention the paper of Turecheck and Kunze (1975) on the He I- and H I-like spectra of Mo XLI and Mo XLII, and that of Beier et al (1978) on Mo XL, XLI. Supposing the identifications correct, we are reporting from them 9 excited levels (Table 19) of these three spectra, observed between 0.5 and 0.7 Å. The latter paper includes predictions on a number of not yet observed transitions in Mo XL and XLI.

Conclusion

This survey of knowledge of the structure of various molybdenum spectra tells us, among other things, how much room there is for original studies of these spectra. Mo I and Mo II are well known and very little can be added to their understanding. Only

three configurations of the Mo III are known in some detail and a fourth only fragementarily. Mo IV is only barely known. The situation of Mo V is slightly better, but its study can also be thought to be in initial stages. Work is going on Mo VI in our laboratory.

Knowledge of resonance transitions of Mo VII is almost complete, but study of transitions between excited configurations has only been started in our laboratory. Complete knowledge of the structure of these configurations will be obtained only when the present studies are completed.

The structure of ns (n = 5-7) and nd (n = 4-6) configurations of Mo VIII-X is almost well known, though studies of transitions to the ground levels from them. The internally excited $4s4p^k$ (k = 6&5) configurations are also made known likewise. Transitions between excited configurations have to be studied to determine the structure of np, nf etc. configurations of these spectra.

The study of Mo XI and Mo XII has begun; Mo XIV and Mo XVI, XVII are known quite sufficiently, along with Mo XXXII, XXXIII. Sixteen other Mo spectra are known fragmentarily, namely Mo XIII, XV, XVIII-XXV, XXX, XXXI, XXXIV, XL-XLII. The rest of Mo spectra are completely unknown so far.

REFERENCES

Alexander E, Even-Zohar N, Fraenkel B S and Goldsmith S, (1971) J. Opt. Soc. Am. 61, 508.

Aglitskii E V, Boiko V A, Krokhin O.N, Pikuz S A and Faenov A Ya (1975) Sov. J. Quantum Electron 4, 1152.

Aglitskii E V, Golts E. Ya, Levykin Yu A, Livshits A M, Mandelshlam S L, and Safronova A S, (1979) Opt. Spectrosc (USSR) 46, 590.

Boiko V A, Pikuz S A, Safronova A S and Faenov A Ya (1978) J. Phys. B. 11, L 503.

Beier R and Kunze H J (1978) Z. Phys. 285A, 347.

Bogdanovichene M I, Kononov E Ya, Merkelis G V, Ramonas A A and Churilov S S (1980) Opt. Spectrosc.(USSR) 49, 244.

Burkhalter P G, Reader J, and Cowan R D (1977) J. Opt. Soc. Am. 67, 1521.

Burkhalter P G, Dozier C M and Nagel D J (1977) Phys. Rev. 15A, 700.

Burkhalter P G, Schneider R, Dozier C M and Cowan R D, (1978) Phys. Rev. 18A, 718.

Burkhalter P G, Reader J and Cowan R D (1980) J. Opt. Soc. Am. 70, 912.

Chaghtai M S Z, (1969) J. Opt. Soc. Am. 59, 969.

Chaghtai M S Z, (1970) Phys. Scr. 1, 31, and 104.

Chaghtai M S Z, and Zahid Ali (1970) Ind. J. Phys. 44, 330.

Chaghtai M S Z, (1970) Phys. Scr. 1, 109.

Chaghtai M.S Z, Singh S P and Khatoon S (1975), J. Phys. B. 8, 1831.

Chaghtai M S Z, Rahimullah K and Khatoon S (1976) Phys. Scr. 14, 281.

Charles G W, (1950) Phys. Rev. 77, 120.

Curtis L J, Lindgard A, Edlén B. Martison I and Nielsen S E (1977) Phys. Scr. 16, 72.

Edlén B, (1947) Physica 13, 545.

Edlén B (1964) in Handbuch der Physik, Vol 27, (Springer, Berlin), 160.

Edlén B and Chaghtai M S Z (1978) 10th EGAS Conference Munich, July 11-14, page 30.

Ekberg J O, Hansen J E and Reader J (1972) J. Opt. Soc. Am. 62, 1143.

Furth H P, (1975) Nucl. Fusion 15, 487.

Group T F.R, (1974) in Plasma Physics and Controlled nuclear fusion research Proc. 5th Intern. Conf. Tokyo.

Group T F R, (1975) Nucl. Fusion 15, 1053.

Hinnov E, (1976), Phys. Rev. 14A, 1533.

Johnson B M, Jones K W, (1980) Phys. Lett. 78A, 61.

Kiess C C (1958) J. Research Nat. Bur. Std. 60, 375.

Khatoon S (1978) Ph.D. Thesis, Muslim University Aligarh, India.

Khatoon S, Chaghtai M S Z and Rahimullah K (1979) Phys. Scr. 19, 22.

Klapisch M, Schwob J L, Finkenthal M, Fraenkel B S, Egert S, Bar-Shalom A, Breton C, De Michelis C and Mattioli M (1978) Phys. Rev. Lett. 41, 403.

Klapisch M, Mandelbaum P, Schwob J L, Bar-Shalom A and Schweitzer N (1981) Phys. Lett. 84A, 177.

Moore C E, (1958) Atomic Energy Level (A.E.L.) Vol. III.

Mansfield M W D, Peacock N J, Smith CC, Hobby M G and Cowan R D (1978) J. Phys. B 11, 1521.

Ranimullah M, Chaghtai M A Z and Khatoon S (1976) Phys. Scr. 14, 221.

Ranimullah M (1977) Ph.D. Thesis Muslim University Aligarh, India.

Ranimullah M, Chaghtai M A Z and Khatoon S (1978) Phys. Scr. 18, 96.

Rico F R (1954) An. Real Soc. Esp. Fisica Y. Quimica (Madrid) [A] 50, 185.

Rico F R (1965) An. Real Soc. Esp. Fisica Y. Quimica (Madrid) [A] 61, 103.

Reader J, Epstein G and Ekberg J O, (1972) J. Opt. Soc. Am. 62, 273.

Reader J and Acquista N, (1976) J. Opt. Soc. Am. 66, 896.

Reader J and Acquista N (1977) Phys. Rev. Lett 39, 184.

Reader J, Gabriel Lutner and Acquista N (1979) J. Opt. Soc. Am. 69, 144.

Reader J, Acquista N (1981) J. Opt. Soc. Am. 71, 434.

Reader J and Ryabtsev A (1981) J. Opt. Soc. Am. 71, 231.

Singh S P (1977) Ph.D. Thesis, Muslim University Aligarh, India.

Schwob J L, Klapisch M, Schweitzer N and Finkenthal M (1977) Phys. Lett. 62A, 85.

Schweitzer N, Klapisch M, Schwob J L, Finkenthal M, Bar-Shalom A, Mandelbaum P and Fraenkel B S (1981) J. Opt. Soc. Am. 71, 219.

Ture Check J J and Kunze H J (1975) Z. Phys. 273A, 111.

Wyart J F, Reader J and Ryabtsev A (1981) J. Opt. Soc. Am. 71, 692.

Figure Captions

Fig. 1. Energy levels of Mo III reproduced in author's notations. Ref. F.R. Rico (1935) An. Real Soc. Esp. Fisica Y. Quimica (Madrid) [A] 31, 103.

Fig. 2. Observed levels of Mo IV.

Fig. 3. Energy levels of Mo V.

Fig. 4. Observed energy levels of Mo VI.

Fig. 5. Energy levels of Mo VII: Most of the levels are given in pair-coupling notations.

Fig. 6. Observed levels of Mo VIII: Levels of nd and ns configurations bear different notations.

Fig. 7. Observed energy levels of Mo IX: For nd levels, a,b and c refer to parent configurations ^4S, ^2D and ^2P respectively.

Fig. 8. Mo X energy levels: nd levels are represented with their parantages.

Fig. 9. Mo XI: Observed energy levels.

Fig.10. Energy levels of eleven times ionized Molybdenum.

Fig.11. Observed energy levels of Mo XIV.

Fig.12. Energy levels of Mo XIII and Mo XV.

Fig.13. Energy levels of Mo XVI.

Fig.14. Energy levels of Mo XVII.

Fig.15. Energy levels of Mo XXXII.

Fig.16. Energy levels of Mo XXXIII.

Fig.17. Energy levels of Mo XXX and Mo XXXIV.

Table 1: Observed Energy Levels of Mo III.

Configuration	Terms	J	E (cm^{-1})
$4d^4$	a ^5D	0	0.00
		1	243.10
		2	669.60
		3	1225.20
		4	1873.80
	a ^3P	0	11273.30
		1	12509.80
		2	14357.30
	a ^3H	4	12630.31
		5	13201.34
		6	13741.54
	a ^3F	2	13927.76
		3	13947.40
		4	14295.85
	a ^3G	3	15672.25
		4	16143.15
		5	16763.13
	a ^3D	3	19390.90
		2	19783.28
		1	19995.50
	b ^3P	2	30992.50
		1	32292.70
		0	32887.80

Table 1 contd...

	b ^3F	4	31932.50
		3	32142.80
		2	32126.50
$4d^3(^4F)5s$	a ^5F	1	32419.44
		2	32844.04
		3	33453.10
		4	34226.01
		5	35130.10
$4d^3(^4P)5s$	a ^5P	1	42405.50
		2	42665.90
		3	43462.69
$4d^3(^4F)5s$	c ^3F	2	42605.84
		3	43562.61
		4	44656.23
$4d^3(^2G)5s$	b ^3G	3	-
		4	46557.96
		5	46581.03
$4d^3(^2P)5s$	c ^3P	0	-
		1	48753.45
		2	49052.05
$4d^3(^4F)5p$	z $^5G^o$	2	73854.05
		3	74725.54
		4	75817.48
		5	77114.11
		6	78690.21
	z $^3D^o$	1	75973.01
		2	76837.80
		3	78159.42

Table 1 contd.....

	$z\ ^5F^o$	1	77734.96
		2	78058.00
		3	78575.30
		4	79498.00
		5	80344.06
	$z\ ^5D^o$	0	78569.00
		1	78678.30
		2	79014.90
		3	79509.44
		4	80096.48
	$z\ ^3F^o$	2	79469.30
		3	80355.60
		4	81299.90
$4d^3(^4P)5p$	$y\ ^5D^o$	0	81521.93
		1	81601.80
		2	81867.00
		3	82221.00
		4	82772.87
	$z\ ^5P^o$	1	85684.30
		2	86427.80
		3	87392.80
?	$^3F^o$?	4	83148.70
?	^2F ?	4	84545.49
$4d^3(^4F)6s$	$6s\ ^5F$	1	131462.31
		2	131826.00

Table 1 contd.....

	3	132294.79
	4	133056.00
	5	134012.30
6s ^3F	2	134403.00
	3	135375.00
	4	136470.00

a, b, c z and y are the parentages in author's notation

Table 2: Observed Energy Levels of Mo IV.

Configurations	Designation	J	E (cm^{-1})
$4d^3$	$4d^3\ ^4F$	3/2	0.0
		5/2	780.0
		7/2	1759.0
		9/2	2858.6
$4d^2(^3F)5s$	$5s\ ^4F$	3/2	60893.4
		5/2	61624.1
		7/2	62705.3
		9/2	64042.6
$4d^2(^3F)5p$	$5p\ ^4F$	3/2	111756.5
		5/2	112921.0
		7/2	114619.4
		9/2	115956.7
$4d^2(^3F)5p$	$5p\ ^4D$	1/2	115790.4
		3/2	116584.3
		5/2	117602.3
		7/2	118076.5
Mo V($^3F2$)	Limit	-	374180

Table 3: Observed Energy Levels of Mo V

Configurations	Terms	J	E (cm^{-1})
$4d^2$	^3F	2	0.00
		3	1585
		4	3359
	^3P	0	11165
		1	11812
		2	13413
$4d(^2D)5s$	^1D	2	83971
	^3D	1	92381
		2	93113
		3	94837
$4d(^2D)5p$	^1F	3	141150
	^1P	1	147209
	^3D	1	148950
		2	151212
		3	153041
	^3F	2	150346
		3	151196
		4	155033
	^1D	2	151760
	^3P	0	157060
		1	156616
		2	157852
$4d(^2D)5d$	^1D	2	212620

Table 3 contd.....

	^3D	3	213840
		2	214671
		1	214786
	^1P	1	215874
$4d(^2D)4f$	^3F	2	231724
		3	234886
		4	241112
$4d(^2D)5d$	^3F	2	236714
		3	239071
		4	242104
$4d(^2D)4f$	^3G	3	243665
		4	244841
		5	245830
Mo VI ($^2D_{3/2}$)	Limit	-	493360

Table 4: Observed Energy Levels of Mo VI.

Design	J	E (cm^{-1})	E	n-n*	Calculated E (Edlén, 76)
4d ^2D	3/2	0		1.3318	
			2583^T		
	5/2	2583^T		1.3256	2582
5s ^2S	1/2	119725^T		1.9870	119725
5p ^2P	1/2	182404^T		1.7434	182404
			4927^T		
	3/2	187331^T		1.7216	187332
4f ^2F	5/2	267038^C		0.2954	267036
			407^C		
	7/2	267445^C		0.2928	267446
5d ^2D	3/2	282819^T		1.1895	282814
			787^T		
	5/2	283606^T		1.1840	283600
6s ^2S	1/2	313803^T		1.9521	313800
6p ^2P	1/2	340571^R		1.7077	340564
			1992^R		
	3/2	342563^R		1.6866	342556
5f ^2F	5/2	376414		0.2954	
			157		
	7/2	376571		0.2933	
6d ^2D	3/2	386166^R		1.1613	386158
			387^R		
	5/2	386553^R		1.1558	386545

Table 4 contd.....

5g ^2G	7/2,9/2	395172		0.0268	395113
7s ^2S	1/2	400768		1.9373	(400700)±300
7p ^2P	1/2	414850^R		1.6889	414846
			1205^R		
	3/2	416055^R		1.6659	416061
7d ^2D	3/2	439460^R		1.1498	439458
			228^R		
	5/2	439688^R		1.1443	439684
6f ^2F	5/2	441183		0.1059	441179
			111^R		
	7/2	441294		0.1031	441294
6g ^2G	7/2,9/2	443738		0.0386	443710
8p ^2P	1/2	453064		1.7716	
			91		
	3/2	453155		1.7689	
7g ^2G	7/2,9/2	473200^R		0.0459	473198
7h ^2H	9/2,11/2	474062^R		0.0093	474068
8g ^2G	7/2,9/2	492377		0.0511	492379
8h ^2H	9/2,11/2	493024^R		0.0096	493021
8i ^2I	11/2,13/2	493114^R		0.0038	493119

Limit $4p^6\ 4d\ ^2D_{3/2} - 4p^6\ ^1S_0 = 554900 \pm 200\ cm^{-1}$
(evaluated by B. Edlén)

Originally estimated by

T = Trawick
C = Charles
R = Romanov and Striganov; they report splitting of 6g and 7g levels by 2.73 and 3.07 cm^{-1} respectively.

Table 5: Observed Energy Levels of Mo VII

Configurations	Terms	J	E (cm^{-1})
$4p^6$	^1S	0	0.00
$4p^5\ 4d$	^3P	1	305563
	^3D	1	341711
	^1P	1	417538
$4p^5\ 5s$	(3/2, 1/2)	1	481294
	(1/2, 1/2)	1	502930
$4p^5 5d$	^3P	1	658992
	^3D	1	669066
	^1P	1	689779
$4p^5\ 6s$	(3/2, 1/2)	1	710061
	(1/2, 1/2)	1	732563
$4p^5\ 6d$	^3D	1	795520
$4p^5\ 7s$	(3/2, 1/2)	1	816413
	(1/2, 1/2)	1	839342
$4p^5\ 8s$	(3/2, 1/2)	1	874998
	(1/2, 1/2)	1	898093
$4p^5\ 9s$	(3/2, 1/2)	1	910830
$4p^5\ 10s$	(3/2, 1/2)	1	934536
$4s\ 4p^6\ 5p$	^3P	1	780390
	^1P	1	789696

Table 6: Observed Energy Levels of Mo VIII.

Configurations	Terms	J	E (cm^{-1})
$4s^2\ 4p^5$	^2P	3/2	0.0
		1/2	23276
$4s\ 4p^6$	^2S	1/2	233830
$4s^2\ 4p^4\ 4d$	$(^3P)\ ^4D$	5/2	308699
	" ^4D	3/2	309938
	" ^4F	3/2	335663
	" ^4F	5/2	337941
	" ^4P	1/2	336936
	" ^4P	3/2	339525
	" ^4P	5/2	346215
	^2F	5/2	357811
	^2P	3/2	421559
	^2P	1/2	430969
	^2D	5/2	426778
	^2D	3/2	447876
	$(^1D)\ ^2P$	3/2	348832
	" ^2P	1/2	330800
	" ^2D	5/2	353148
	" ^2D	3/2	341362
	" ^2F	5/2	371341
	" ^2S	1/2	411512
	$(^1S)\ ^2D$	5/2	404903
	" ^2D	3/2	394545

Table 6 contd.....

$4s^2\ 4p^4\ 5d$	$(^3P_2)$	^4P	1/2	730472
	"	^4F	5/2	744258
	"	^4F	3/2	741552
	$(^3P_1)$	^4P	5/2	748161
	"	^4P	3/2	745165
	$(^3P_1)$	^2F	5/2	749531
	"	^2P	3/2	750937
	(^3P_o)	^2D	5/2	733372
	"	^2D	3/2	731073
	$(^1D_2)$	^2S	1/2	759112
	"	^2P	3/2	761941
	"	^2P	1/2	770370
	"	^2D	5/2	763015
	"	^2D	3/2	767167
	"	^2F	5/2	764770
	(^1S_o)	^2D	5/2	800351
	"	^2D	3/2	789781
$4s^2\ 4p^4\ 6d$	(^3P_o)	^2D	5/2	890834
	"	^2D	3/2	891999
	$(^3P_1)$	^4P	5/2	907534
	"	^4P	3/2	906608
	$(^3P_1)$	^2F	5/2	909889
	"	^2P	3/2	910220
	$(^1D_2)$	^2S	1/2	920428
	"	^2P	3/2	921068
	"	^2D	5/2	923747

Table 6 contd....

	$(^1D_2)\ ^2P$	1/2	924105		
	" ^2D	3/2	927660		
	$(^1S_0)\ ^2D$	3/2	964373		
$4s^2\ 4p^4\ ns$			5s	6s	7s
	$(^3P_2,1/2)$	5/2	521461	789754	916634
		3/2	527389	791823	919154
	$(^3P_0,1/2)$	1/2	538732	806614	928921
	$(^3P_1,1/2)$	3/2	543336	810363	932812
		1/2	548923	812274	934364
	$(^1D_2,1/2)$	5/2	518812	825687	948129
		3/2	559813	825714	948153
	$(^1S_0,1/2)$	1/2	595829	862803	982044

Table 7: Observed Energy Levels of Mo IX (cm^{-1})

Designation	E (cm^{-1})		
$4s^2\ 4p^4$			
$^3P_2$	0		
$^3P_0$	16589		
$^3P_1$	20576		
$^1D_2$	35674		
$^1S_0$	72885		
$4s\ 4p^5$			
$^3P_2$	233122.9		
$^3P_1$	246113.0		
$^3P_0$	256536.7		
$^1P_1$	295624.1		
$4s^2\ 4p^3\ nd$	4d	5d	6d
b $^3D_1$	347777	797355	987579
b $^3F_2$	350444	800579	990382
b $^3F_3$	353696	-	-
b $^3G_3$	362277	822534	1014603
c $^1D_2$	381528	828728	1016860
c $^3D_1$	380383	825266	1015585
c $^3P_1$	388801	830015	1018148
c $^3D_2$	392634	-	-
c $^3F_3$	395360	-	-
c $^3F_2$	396711	-	-
c $^3D_3$	402590	839507	1024196
c $^3P_2$	405684	839713	1025122

Table 7 contd.....

b $^3S_1$	416746	-	-
b $^3P_2$	419123	840654	1033227
c $^1F_3$	424009	845474	1031317
b $^1P_1$	420947	843565	-
a $^3D_3$	431498	847507	-
b $^3P_1$	433445	848809	1040059
a $^3D_2$	441012	-	-
a $^3D_1$	447509	865366	1056382
b $^1D_2$	456111	869633	1057289
b $^1F_3$	466718	-	-
c $^1P_1$	487905	866605	1065491
$4s^2\ 4p^3\ ns$	5s	6s	7s
a $^5S_2{}^o$	571798	875565	1025704
a $^3S_1{}^o$	582355	880842	1028743
b $^3D_2{}^o$	601679	905858	1055312
b $^3D_1{}^o$	602455	906239	1055089
b $^3D_3{}^o$	609235	912477	1062162
b $^1D_2{}^o$	613394	915504	1064357
c $^3P_0{}^o$	628649	933385	1082463
c $^3P_1{}^o$	630391	934288	1083142
c $^3P_2{}^o$	644120	947617	1097040
c $^1P_1{}^o$	647534	950649	1099412

a represents (^4S)
b represents (^2D)
c represents (^2P)

Table 8. Observed Energy Levels of Mo II.

Configurations	J	E(cm^{-1})		
$4s^2\ 4p^3$				
^4S	3/2	0.00		
^2D	3/2	26886		
^2D	5/2	35522		
^2P	1/2	55313		
^2P	3/2	70544		
$4s\ 4p^4$				
^4P	5/2	224939		
	3/2	239891		
	1/2	244457		
^2D	3/2	276573		
	5/2	281535		
^2S	1/2	314504		
^2P	3/2	318423		
	1/2	341642		
$4s^2\ 4p^2\ nd$		4d	5d	6d
$(^3P)\ ^4D$	3/2	377188	880202	1086993
$(^3P)\ ^4D$	5/2	383475	888324	1102750
$(^3P)\ ^2P$	3/2	404273	-	-
$(^1D)\ ^2G$	7/2	408837	-	-
$(^3P)\ ^4P$	5/2	416034	-	-

Table 8 contd...

$(^3F)\ ^2F$	1/2	419351	893722	1109027
$(^3F)\ ^4F$	3/2	420327	905274	1110307
$(^3F)\ ^4F$	1/2	427439	-	-
$(^3F)\ ^2D$	3/2	429585	907396	-
$(^3F)\ ^2D$	5/2	439691	914656	1125685
$(^1D)\ ^2D$	3/2	445970	-	-
$(^1D)\ ^2D$	5/2	448827	915223	1130675
$(^1D)\ ^2F$	1/2	452929	-	-
$(^1D)\ ^2F$	5/2	458418	916122	1149656
$(^1D)\ ^2P$	3/2	462530	929938	1151585
$(^1D)\ ^2S$	1/2	463584	934036	1159504
$(^1D)\ ^2F$	7/2	468252	934693	-
$(^1S)\ ^2D$	3/2	487294	939586	1166710
$(^1S)\ ^2D$	5/2	489003	963415	1172871
$4s^2\ 4p^2\ ns$		5s	6s	7s
^4P	1/2	638999	989394	1160568
^4P	3/2	654947	998292	1171183
^2P	1/2	660981	1002578	1173765
^4F	5/2	664258	1003528	1176768
^2F	3/2	669948	1008269	1180003
^2D	5/2	692660	1032364	1205972
^2D	3/2	695263	1034200	1206796
^2S	1/2	723115	1065433	1233176

Table 9: Observed Energy Levels of Mo XI.

Configurations	Terms	J	E (cm^{-1})
$4s^2\ 4p^2$	^3P	0	0
	^3P	1	17590
	^3P	2	27136
	^1D	2	54719
	^1S	0	84808
$4s\ 4p^3$	^3S	1	335178
	^1P	1	362196
$4s^2\ 4p\ 4d$	^3F	2	380832
	^3F	3	390018
	^1D	2	415602
	^3P	1	424400
	^3P	2	430145
	^3P	0	435558
	^3D	1	441686
	^3D	3	444196
	^3D	2	445333
	^1F	3	475300
	^1P	1	482661
$4s^2\ 4p\ 5s$	^3P	0	707202
	^3P	1	709077
	^3P	2	735196
	^1P	1	739589

Table 10: Observed Energy Levels of Mo XII

Configurations	Terms	J	E (cm^{-1})
$4s^2\ 4p$	^2P	1/2	0.00
		3/2	28359
$4s^2\ 4d$	^2D	3/2	419709
		5/2	425986
$4s\ 4p^2$	^2S	1/2	306175
	^2P	1/2	325507
		3/2	332029
	^4P	1/2	191028
		3/2	200337
		5/2	214482
$4p^3$	^4S	3/2	495946
	^2D	3/2	527661
		5/2	535296
	^2P	1/2	558108
		3/2	573486
$4s^2\ 5d$	^2D	3/2	814820
		5/2	820489

Table 11. Observed Energy Levels of Mo XIV.

Designation	J	E (cm^{-1})
4s ^2S	1/2	0.00
4p ^2P	1/2	236085
	3/2	267332
4d ^2D	3/2	649976
	5/2	655242
4f ^2F	5/2	1033350
	7/2	1033368
5s ^2S	1/2	1089691
5p ^2P	1/2	1192036
	3/2	1205254
5d ^2D	3/2	1372413
	5/2	1374330
5f ^2F	5/2	1540440
	7/2	1540574
5g ^2G	7/2,9/2	1577546
6s ^2S	1/2	1579705
6p ^2P	1/2	1633615
	3/2	1640046
6f ^2F	5/2	1818244
	7/2	1818317
6g ^2G	7/2,9/2	1841006
7g ^2G	7/2,9/2	2000101

Table 11 contd...

Designation	J	E (cm^{-1})
$3d^9 4s4p$ $(^2D, ^3P)\,^4P$	1/2	1383400
$(^2D, ^3P)\,^2P$	1/2	1898000
$(^2D, ^3P)\,^4D$	1/2	1905750
$(^2D, ^1P)\,^2P$	1/2	1968960
$(^2D, ^3P)\,^4P$	3/2	1861340
$(^2D, ^3P)\,^4F$	3/2	1874940
$(^2D, ^3P)\,^2D$	3/2	1885220
$(^2D, ^3P)\,^2P$	3/2	1895720
$(^2D, ^3P)\,^4D$	3/2	1914770
$(^2D, ^1P)\,^2P$	3/2	1945620
$[(3/2,1/2)_2,3/2]$	3/2	1987500
$3d^9 4p^2$ $(^2D, ^1D)\,^2S$	1/2	2143950
$(^2D, ^3P)\,^2P$	1/2	2190700
$(^2D, ^1D)\,^2P$	3/2	2143940 ?
$(^2D, ^3P)\,^2D$	3/2	2158460
$(^2D, ^3P)\,^4F$	3/2	2171600
$(^2D, ^1D)\,^2D$	3/2	2180320
$(^2D, ^3P)\,^2P$	3/2	2194630

Table 11 contd.....

	$(^2D,^3P)\,^2D$	5/2	2190210
	$(^2D,^1D)\,^2F$	5/2	2208210
	$(^2D,^1S)\,^2D$	5/2	2220830
$3d^{10}7p$	^2P	1/2	1874730
	^2P	3/2	1878710

Table 13. Energy levels of Mo XIII and Mo XV.

Ion	Configuration	Term	E (cm^{-1})
Mo XIII	$3d^{10}4s^2$	$^1S_0$	0.00
	$4s5p$	$^3P_1$	1126510
		$^1P_1$	1139110
	$3d^94s^24p$	$^1P_1$	1848390
		$^3D_1$	1867380
Mo XV	$3d^{10}$	$^1S_0$	0.00
	$3d^94s$	$^3D_2$	1699730
		$^1D_2$	1726520
	$3d^94p$	$^3P_1$	1962480
		$^1P_1$	1982240
		$^3D_1$	2003450
	$3d^94f$	$^3D_1$	2773230
		$^1P_1$	2827420
	$3d^95f$	$(5/2,7/2)_1$	3358640
		$(5/2,5/2)_1$	3394670

Table 18. Energy levels of Lo IVI.

Configuration	Term	J	E (cm^{-1})
$3d^{6}3d^{9}$	^{2}D	5/2	000
	^{2}D	3/2	27000
$3p^{5}3d^{10}$	^{2}P	3/2	1318000
	^{2}P	1/2	1464000
$3d^{8}4s$	$(^{3}F_{4},1/2)$	7/2	1849400
	$(^{3}F_{3},1/2)$	7/2	1870000
	$(^{1}G_{4},1/2)$	7/2	1925300
	$(^{1}G_{4},1/2)$	9/2	1926700
$3d^{8}4p$	$(^{3}F_{4},1/2)$	7/2	2089300
	$(^{3}F_{3},1/2)$	5/2	2112500
	$(^{3}F_{3},1/2)$	7/2	2116300
	$(^{3}F_{2},1/2)$	5/2	2117700
	$(^{3}F_{2},1/2)$	3/2	2119300
	$(^{3}F_{4},3/2)$	7/2	2134500
	$(^{3}F_{3},3/2)$	3/2	-
	$(^{3}F_{4},3/2)$	5/2	2135000
	$(^{3}F_{2},3/2)$	1/2	-

Table 13 contd...

$(^3T_2, 1/2)$	5/2	2147500
$(^3F_2, 1/2)$	3/2	2147500
$(^3F_3, 3/2)$	5/2	2151900
$(^3F_3, 3/2)$	7/2	2156500
$(^3P_1, 1/2)$	1/2	-
$(^3F_2, 3/2)$	7/2	2157600
$(^3F_2, 3/2)$	5/2	2160500
$(^3F_2, 3/2)$	3/2	2164900
$(^1D_2, 1/2)$	5/2	2168000
$(^3P_1, 1/2)$	3/2	2172300
$(^1G_4, 1/2)$	7/2	2173000
$(^3P_0, 1/2)$	1/2	2173400
$(^1D_2, 1/2)$	3/2	2173900
$(^3P_2, 3/2)$	5/2	2180900
$(^1D_2, 3/2)$	1/2	-
$(^3P_2, 3/2)$	7/2	2183400
$(^1D_2, 3/2)$	3/2	2190500
$(^1D_2, 3/2)$	5/2	2195800

Table 13 contd...

	$(^3P_0, 3/2)$	3/2	2199200
	$(^3P_1, 3/2)$	5/2	2204200
	$(^3P_1, 3/2)$	1/2	2206400
	$(^3P_1, 3/2)$	3/2	2208300
	$(^1D_2, 3/2)$	7/2	-
	$(^1G_4, 3/2)$	5/2	2213000
	$(^3P_2, 3/2)$	3/2	-
	$(^3P_2, 3/2)$	1/2	2222500
	$(^1G_4, 3/2)$	7/2	2222600
	$(^1S_0, 1/2)$	1/2	2274000
	$(^1S_0, 3/2)$	3/2	2308500
$3d^84f$	$(^3F_4, 7/2)$	7/2	2941200
	$(^3F_4, 7/2)$	5/2	2941200
	$(^3F_3, 7/2)$	5/2	2968200
	$(^3P_2, 5/2)$	7/2	2976200
	$(^3P_2, 5/2)$	5/2	2980300
	$(^3P_2, 7/2)$	5/2	2984300
	$(^3P_2, 7/2)$	7/2	2996000

Table 13 contd....

$(^3F_0, 7/2)$	7/2	2997700
$(^3F_1, 5/2)$	5/2	3007500
$(^1G_4, 5/2)$	3/2	3029300
$(^1G_4, 5/2)$	5/2	3036800
$(^3F_1, 5/2)$	7/2	3041800
$(^1G_4, 7/2)$	1/2	3045700
$(^1G_4, 7/2)$	3/2	3057400
$(^1D_2, 5/2)$	5/2	3057400
$(^1S_0, 7/2)$	7/2	3115300
$(^1S_0, 5/2)$	5/2	3118700
$(^1S)\ ^2F$	7/2	3122100

Table 14. Energy levels of Mo XVII.

Configuration	Term	J	E (cm^{-1})
$3p^6 3d^8$	^3F	4	0.00
		3	24250
		2	27030
	^3P	2	51000
		0	58350
		1	70310
	^1D	2	77960
	^1G	4	82420
	^1S	0	176700
$3p^5 3d^9$	^3F	4	1262860
	^1D	2	1281600
	^3F	3	1311160
	^3D	2	1342800
	^3P	1	1352050
	^3P	0	1356860
	^3D	3	1370010
	^3D	1	1391470

Table 14 contd....

	^3F	2	1445570
	^3P	2	1471690
	^1F	3	1544660
	^1P	1	1563830
$3d^74p$	$(^4F_{9/2,3/2})$	4	2319110
	$(^4F)\ ^3D$	3	2323420
	$(^4F)\ ^3F$	4	2340820
	$(^2H_{11/2,1/2})$	5	2353490
	$(^2G_{7/2,1/2})$	3	2359660
	$(^2G_{9/2,3/2})$	3	2376650
	$(^2H)\ ^3G$	4	2382180
	$(^4P_{5/2,3/2})$	3	2385500
	$(^4P_{5/2,3/2})$	1	2389420
	$(^2G_{7/2,3/2})$	3	2390550
	$(^2G_{7/2,3/2})$	4	2392340
	$(^2G)\ ^3F$	2	2393350
	$(^4P_{1/2,3/2})$	1	2397320
	$(^2D_{5/2,3/2})$	3	

Table 14 contd...

$(^2_3D)\ ^3F$	4	2404420
$(^2H_{11/2,3/2})$	5	2410710
$(^2H)\ ^1G$	4	2413420
$(^2_3D)\ ^1P$	1	2419370
$(^2P_{1/2,3/2})$	2	2424230
$(^2P_{1/2,3/2})$	1	2427530
$(^2H_{9/2,3/2})$	5	2435920
$(^2F)\ ^3D$	1	2442030
$(^2F_{3/2,5/2})$	3	
$(^2F_{5/2,3/2})$	2	2443340
$(^2D_{3/2,3/2})$	3	2451530
$(^2F)\ ^1F$	3	2471340
$(^2_1D_{5/2,1/2})$	3	2485800
$(^2_1D_{3/2,3/2})$	3	2517880

Table 15. Energy levels of Mo XXX.

Configuration	Terms	E (cm^{-1})
$3s^2 3p$	$^2P_{1/2}$	0.00
	$^2P_{3/2}$	207710
3d	$^2D_{3/2}$	1080700
	$^2D_{5/2}$	1201900
4s	$^2S_{1/2}$	5762000
4d	$^2D_{3/2}$	6399200
	$^2D_{5/2}$	6429300
4f	$^2F_{5/2}$	6647400
	$^2F_{7/2}$	6740300
$3s3p^2$	$(E_1)_{1/2}$	885350
	$(E_2)_{1/2}$	1038800
	$(E_3)_{3/2}$	1154900

Table 16. Energy levels of Mo XXXII.

Designation	J	E (cm^{-1})
$2p^6 3s\ ^2S$	1/2	0.00
$3p\ ^2P$	1/2	566030
	3/2	782410
$3d\ ^2D$	3/2	1525200
	5/2	1570200
$4s\ ^2S$	1/2	6630700
$4p\ ^2P$	1/2	6868100
	3/2	6956000
$4d\ ^2D$	3/2	7230300
	5/2	7250700
$4f\ ^2F$	5/2	7391300
	7/2	7401700
$5p\ ^2P$	3/2	9735200
$5d\ ^2D$	3/2	9869200
	5/2	9878300
$5f\ ^2F$	5/2	9946200
	7/2	9951700

Table 16 contd...

6f ^2F	5/2	11332000
	7/2	11335000

Table 17. Energy Level of Mo XXXIII.

Designation	J	E (cm^{-1})	Remark
$2p^6\ {}^1S$	0	0.000	
$[2p^5(^2P_{3/2}),3s]$	1	19220000	B
$[2p^5(^2P_{1/2}),3s]$	1	20080000	B
$[2p^5(^2P_{3/2}),3d(^2D_{3/2})]$	1	20612000	A
$[2p^5(^2P_{3/2}),3d(^2D_{5/2})]$	1	20814000	A
$[2p^5(^2P_{1/2}),3d(^2D_{3/2})]$	1	21593000	A
$[2s2p^63p(^2P_{1/2})]$	1	22393000	A
$[2s2p^63p(^2P_{3/2})]$	1	22634000	A
$[2p^5(^2P_{3/2}),4s]$	1	25970000	B
$[2p^5(^2P_{3/2}),4d(^2D_{5/2})]$	1	26600000	B
$[2p^5(^2P_{1/2}),4s]$	1	26740000	B
$[2p^5(^2P_{1/2}),4d(^2D_{3/2})]$	1	27470000	B
$[2p^5(^2P_{3/2}),5d(^2D_{5/2})]$	1	29240000	B
$[2p^5(^2P_{1/2}),5d(^2D_{3/2})]$	1	30120000	B
$[2p^5(^2P_{3/2}),6d(^2D_{5/2})]$	1	30670000	B
$[2p^5(^2P_{3/2}),6d(^2D_{3/2})]$	1	31450000	B
$[2p^5(^2P_{3/2}),7d(^2D_{5/2})]$	1		
$[2p^5(^2P_{1/2}),7d(^2D_{3/2})]$	1	32360000	B

A: from Aglitskii et al (1979)

B: from Burkhalter et al (1978)

Table 18. Energy levels of Mo IXXIV.

Configuration	Term	J	E (cm^{-1})
$2p^5$	^2P	3/2	0.00
$3p^4 3d$	$(^3P)\ ^2D$	3/2	21978000
	$(^3P)\ ^2F$	5/2	22046000
	$(^3P)\ ^2D$	5/2	22119000
	$(^1D)\ ^2S$	1/2	22163000
	$(^1D)\ ^2F$	5/2	22193000
	$(^1D)\ ^2P$	3/2	22193000
	$(^1D)\ ^2D$	5/2	22207000
	$(^1D)\ ^2D$	3/2	22321000
	$(^1D)\ ^2P$	1/2	22361000

Table 19. Energy levels of Miscellaneous Mo spectra.

Ion	Configuration	Terms	E (cm^{-1})
Mo XXIV	$3p^6\ 3d$	$^2D_{3/2}$	0.00
	$4f$	$^2F_{5/2}$	4611700
Mo XXV	$3p^6$	$^1S_0$	0.00
	$3p^5\ 4d$	$^3P_1$	5405400
		$^3D_1$	5562000
Mo XL	$1s^2\ 2s$	$^2S_{1/2}$	0.00
	$1s2s(^3S)2p$	$^2P_{3/2}$	145100000
	$1s2s(^1S)2p$	$^2P_{1/2}$	145200000
	$1s2s2p$	$^4P_{5/2}$	145800000
Mo XLI	$1s^2$	$^1S_0$	0.00
	$1s2p$	$^3P_1$	144400000
		$^3P_2$	145400000
		$^1P_1$	145600000
	$2p^2$	$^1S_0$, $^1D_2$	294400000
Mo XLII	$1s$	$^2S_{1/2}$	0.00
	$2p$	$^2P_{3/2}$	149600000
		$^2P_{1/2}$	-
	$3p$	$^2P_{3/2}$	175200000
		$^2P_{1/2}$	-

Table 20. Known Transitions in Higher Ionizations of Mo atoms.

Ion	λ(Å)	Transitions	jj...→jj	J-J	Remark
Mo XIII	131.375	$4s4p\ ^3P - 4s5s\ ^3S$	-	2-1	-
	127.933	$^3P - \ ^3S$	-	1-1	-
	126.675	$^3P - \ ^3S$	-	0-1	-
Mo XVIII	38.7-40.0	$3d^7 - 3d^6 4p$	-	-	s.l.s
	66.544	$3p^6 3d^7\ ^2H - 3p^5 3d^8 (^1G)\ ^2F$	-	9/2-7/2	-
	67.144	$^2H - \ (^3F)\ ^2G$	-	11/2-9/2	-
	67.347	$^2G - \ (^1D)\ ^2F$	-	7/2-5/2	-
	67.358	$^2F - \ (^3P)\ ^2D$	-	7/2-5/2	-
Mo XIX	33.0-36.9	$3p^6 - 3d^5 4p$	-	-	s.l.
Mo XX	25.2-28.6	$3d^5 - 3d^4 4f$	-	-	s.l.
Mo XXI	24.5-25.2	$3d^4 - 3d^3 4f$	-	-	s.l.
Mo XXII	23.5-24.1	$3d^3 - 3d^2 4f$	-	-	s.l.
Mo XXIII	22.4-22.9	$3d^2 - 3d4f$	-	-	s.l.
Mo XXIV	21.354	$3d\ ^2D - 4f\ ^2F$	-	5/2-7/2	-
Mo XXV	11.00 11.03	$3s3p - 3s5d$	1/2 1/2-1/2 3/2	0-1	-
	11.26 11.32	$3s3p - 3s5d$	1/2 3/2-1/2 5/2	2-3	-
			1/2 3/2-1/2 3/2	2-2	-
	11.482	$3s3p - 3s5d$	1/2 3/2-1/2 3/2	1-2	-

Table 20 contd....

14.743		$3s^2$ -3s4p	1/2	1/2-1/2	3/2	0-1	E.s.
14.832		$3p^2$ -3p4d	1/2	1/2-3/2	5/2	0-1	-
14.922		$3s^2$ -3s4p	1/2	1/2-1/2	1/2	0-1	E.
15.133		3s3p -3s4d	1/2	1/2-1/2	3/2	0-1	-
15.27		3s3p -3s4d	1/2	1/2-1/2	3/2	1-2	-
15.30		3s3p -3s4d	1/2	1/2-1/2	3/2	1-1	-
15.38						-	-
also		$3p^2$ -3p4d	1/2	3/2-3/2	5/2	2-2	-
15.63						2-2	
		3s3p -3s4d	1/2	3/2-1/2	5/2		
15.64						2-3	
15.69						2-3	
		3s3p -3s4d	1/2	3/2-1/2	3/2		
15.70						2-1	
	also	$3p^2$ -3p4d	3/2	3/2-3/2	5/2	2-1 2-2	
15.77		$3p^2$ -3p4d				2-2	
15.84							
16.003		$3p^2$ -3p4d	3/2	3/2-3/2	5/2	0-1	
16.046		3s3p -3s4d	1/2	3/2-1/2	5/2	1-2	
16.08		$3p^2$ -3p4d	3/2	3/2-3/2	3/2	0-1	
16.14							
	also	3s3p -3s4d	1/2	3/2-1/2	3/2	1-2	
16.23		$3p^2$ -3p4d	3/2	3/2-1/2	5/2	2-3	
16.33							
17.330		3s3d -3s4f	1/2	3/2-1/2	7/2	2-3	
17.445		3s3d ^3D -3s4f ^3F		-		1-2	B
17.500		3s3d ^3D -3s4f ^3F		-		2-3	B
17.556		3s3d ^3D -3s4f ^3F		-		3-4	B
17.578		3s3d ^3D -3s4f ^3F		-		3-3	B
17.871		3s3d ^1D -3s4f ^1F		-		2-3	B

Table 20 contd.

94.71	$3p^2$ -3p3d	1/2	1/2-1/2	3/2	0-1	
94.95	3s3p -3s3d	1/2	1/2-1/2	3/2	0-1	
96.52	3s3p -3s3d	1/2	1/2-1/2	3/2	1-2	
96.82	$3p^2$ -3p3d	1/2	3/2-3/2	3/2	2-3	
97.93	$3p^2$ -3p3d	1/2	3/2-3/2	3/2	1-1	
98.20	3s3p -3s3d	1/2	1/2-1/2	3/2	1-1	
100.39	3s3p -$3p^2$	1/2	1/2-3/2	3/2	1-2	
101.63	$3p^2$ -3p3d	1/2	3/2-3/2	3/2	1-2	
101.97	$3p^2$ -3p3d	1/2	3/2-3/2	3/2	2-3	
103.33	$3p^2$ -3p3d	3/2	3/2-3/2	5/2	2-3	
112.609	3s3p ^3P-3s3d ^3D		-		2-3	B
112.65	3s3p -3s3d	1/2	3/2-1/2	5/2	2-3	
113.853	3s3p ^1P-3s3d ^1D		-		1-2	B
113.88	3s3p -3s3d	1/2	3/2-1/2	5/2	1-2	
115.27	3s3p -3s3d	1/2	3/2-1/2	3/2	2-2	
115.53	$3p^2$ -3p3d	3/2	3/2-3/2	5/2	2-2	
115.944	$3s^2$ ^1S-3s3p ^1P		-		0-1	B
115.97	$3s^2$ -3s3p	1/2	1/2-1/2	3/2	0-1	
116.91	$3p^2$ -3p3d	3/2	3/2-3/2	5/2	0-1	
117.66	3s3p -$3p^2$	1/2	1/2-1/2	3/2	0-1	
117.90	$3p^2$ -3p3d	3/2	3/2-3/2	3/2	2-3	
118.48	$3p^2$ -3p3d	1/2	3/2-1/2	5/2	1-2	
118.74	$3p^2$ -3p3d	3/2	3/2-3/2	3/2	2-1	
118.96	$3p^2$ -3p3d	1/2	3/2-1/2	5/2	2-2	
120.86	3s3d -3p3d	1/2	3/2-3/2	3/2	1-1	
121.07	3s3d -3p3d	1/2	3/2-3/2	5/2	2-2	
121.20	$3p^2$ -3p3d	1/2	3/2-1/2	5/2	3-3	
121.70	3s3d -3p3d	1/2	3/2-3/2	3/2	1-0	
122.86	3s3p -$3p^2$	1/2	3/2-3/2	3/2	2-2	

Table 20 contd....

	124.13	$3s3p - 3p^2$	1/2	3/2-3/2	3/2	1-0
	124.43	$3s3d - 3p3d$	1/2	3/2-3/2	3/2	2-3
	124.83	$3s3d - 3p3d$	1/2	5/2-3/2	5/2	3-2
	133.10	$3s3d - 3p3d$	1/2	5/2-3/2	5/2	2-3
	136.06	$3s3d - 3p3d$	1/2	5/2-3/2	5/2	3-4
Mo XXXIV	4.493	$2p^5\ ^2P - 2p^4(^1S)3d\ ^2D$		-		1/2 - 3/2

g.l.: group of lines

S: Schwob et al. (1977)

B: Burkhalter et al (1977,80)

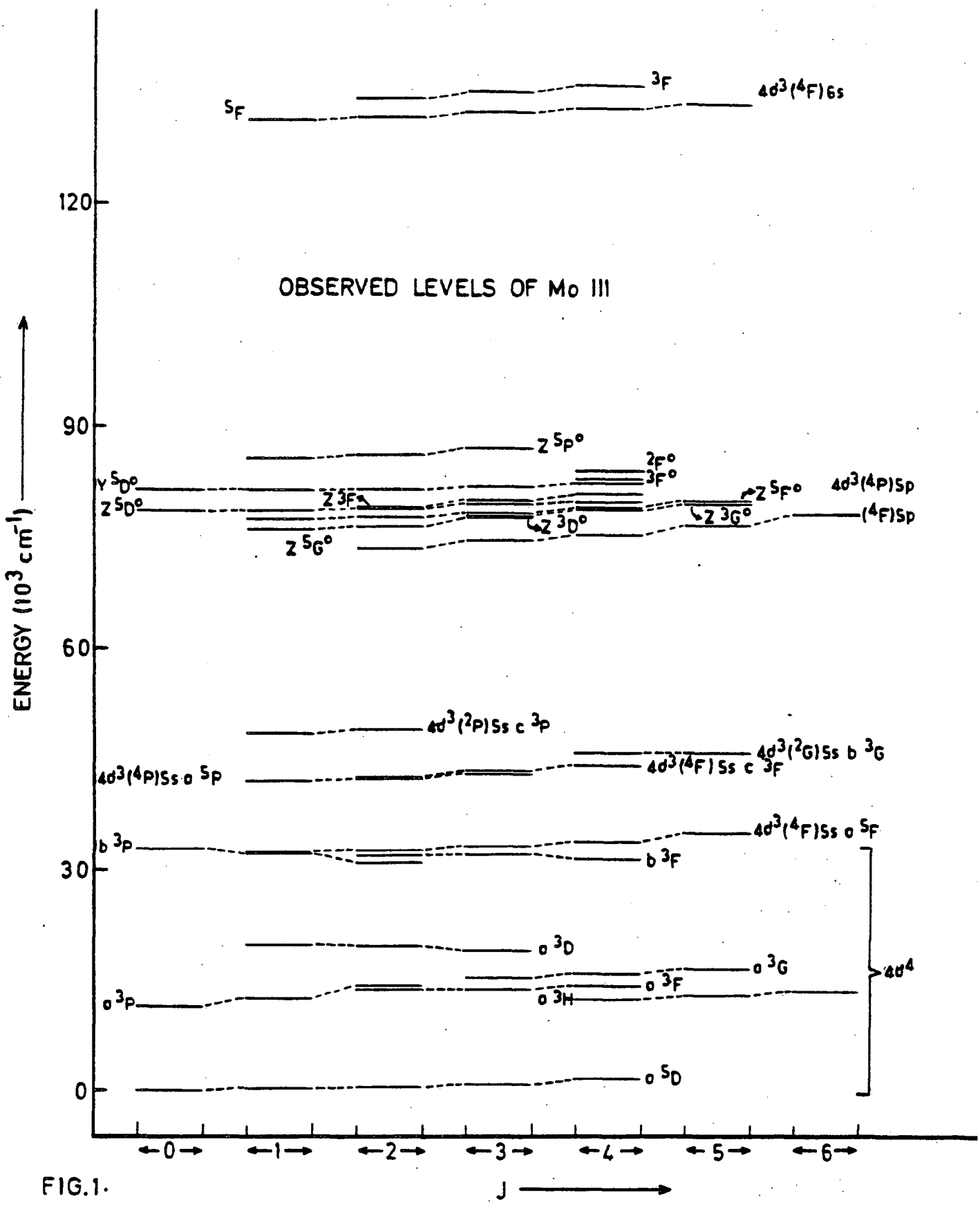

OBSERVED LEVELS OF Mo III
ENERGY (10^3 cm^{-1})
120
90
60
30
0
^5F
^3F
$4d^3(^4F)6s$
$z\,^5P^o$
$^2F^o$
$^3F^o$
$y\,^5D^o$
$z\,^5D^o$
$z\,^3F$
$z\,^5F^o$
$4d^3(^4P)5p$
$z\,^3D^o$
$z\,^3G^o$
$(^4F)5p$
$z\,^5G^o$
$4d^3(^2P)5s\ c\,^3P$
$4d^3(^2G)5s\ b\,^3G$
$4d^3(^4F)5s\ c\,^3F$
$4d^3(^4P)5s\ a\,^5P$
$4d^3(^4F)5s\ a\,^5F$
$b\,^3P$
$b\,^3F$
$a\,^3D$
$a\,^3G$
$a\,^3F$
$a\,^3H$
$a\,^3P$
$a\,^5D$
$4d^4$
0
1
2
3
4
5
6
J

FIG.1.

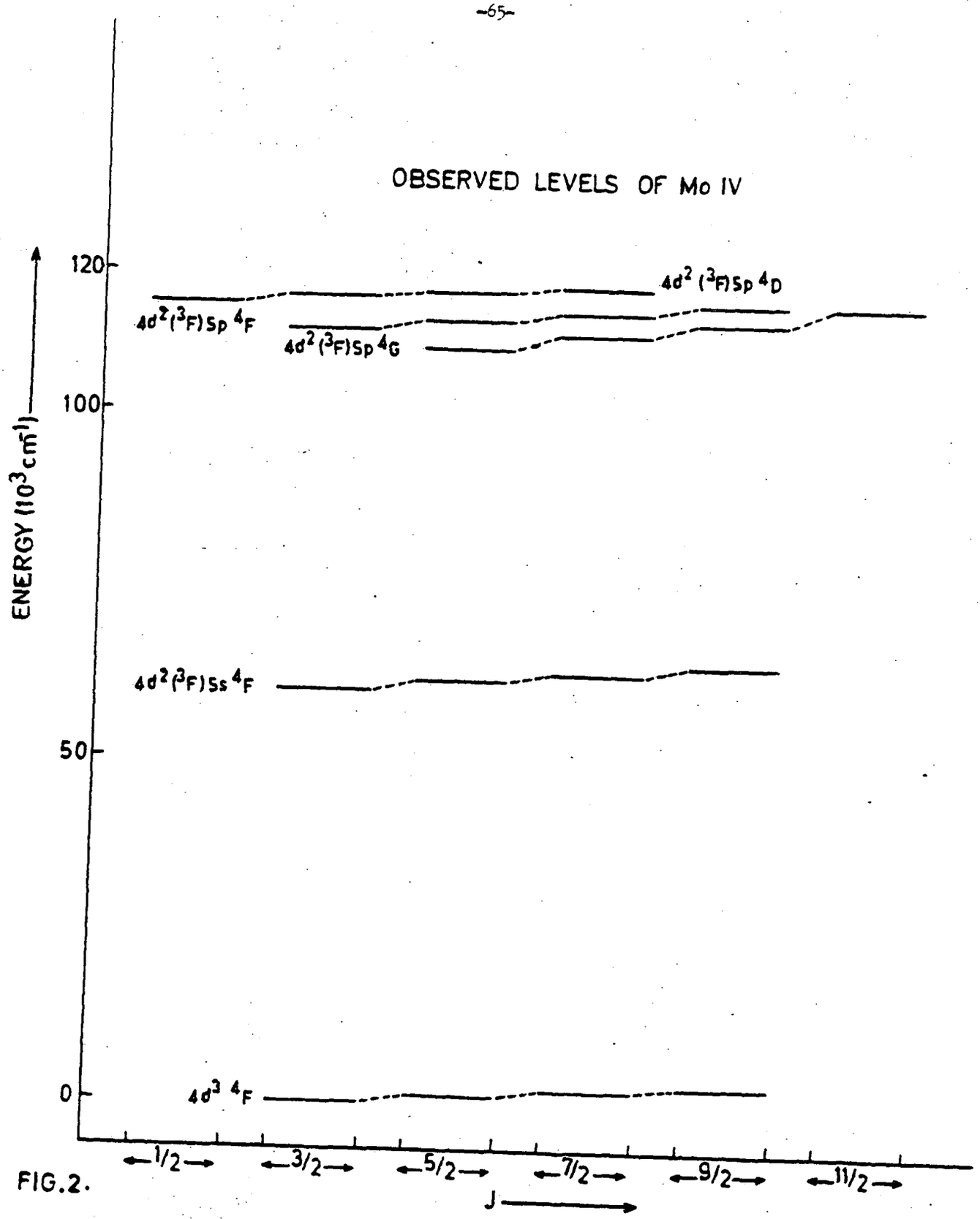

OBSERVED LEVELS OF Mo IV
ENERGY (10^3 cm^{-1})
120
100
50
0
$4d^2(^3F)5p\ ^4D$
$4d^2(^3F)5p\ ^4F$
$4d^2(^3F)5p\ ^4G$
$4d^2(^3F)5s\ ^4F$
$4d^3\ ^4F$
1/2
3/2
5/2
7/2
9/2
11/2
J

FIG.2.

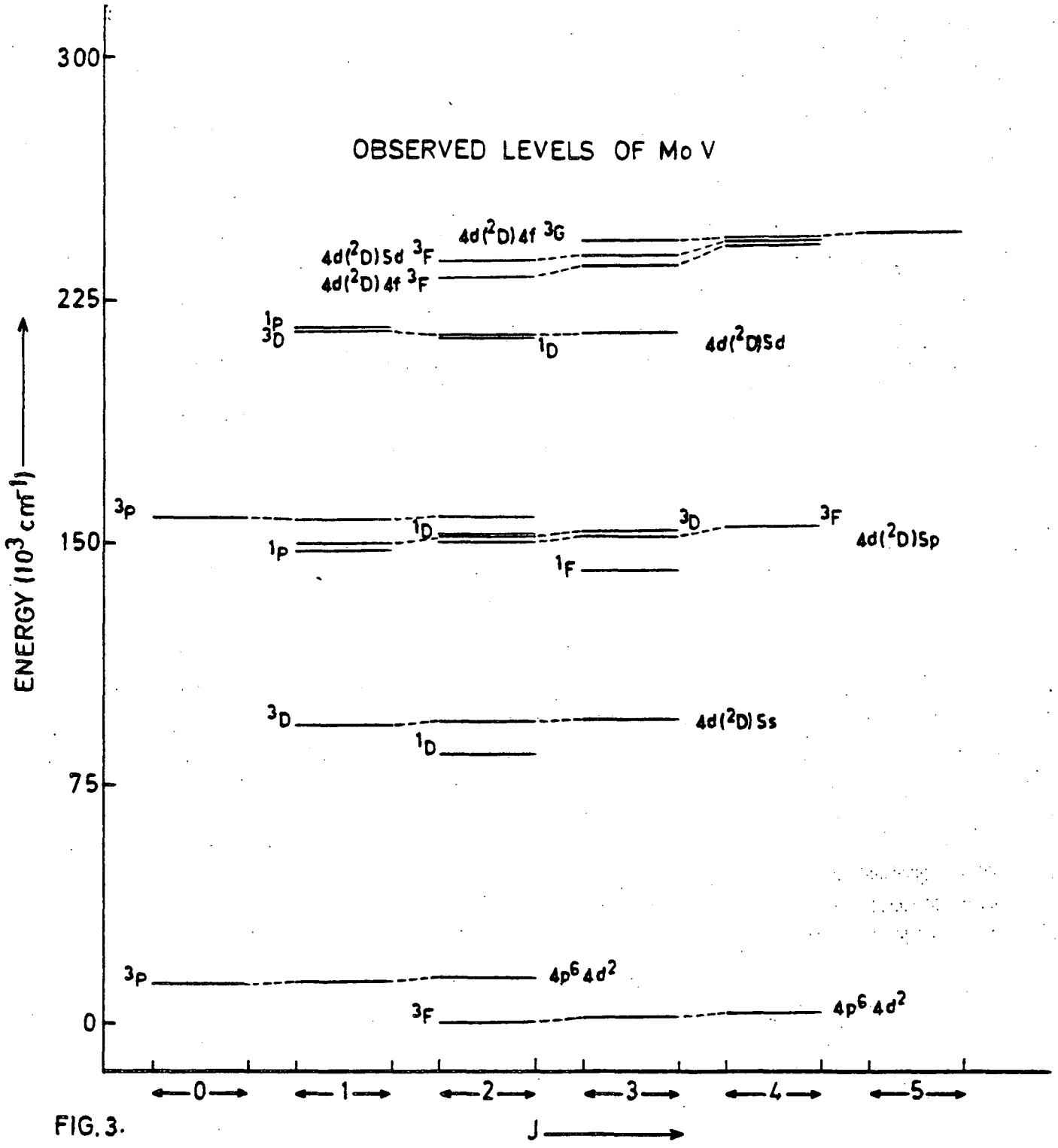
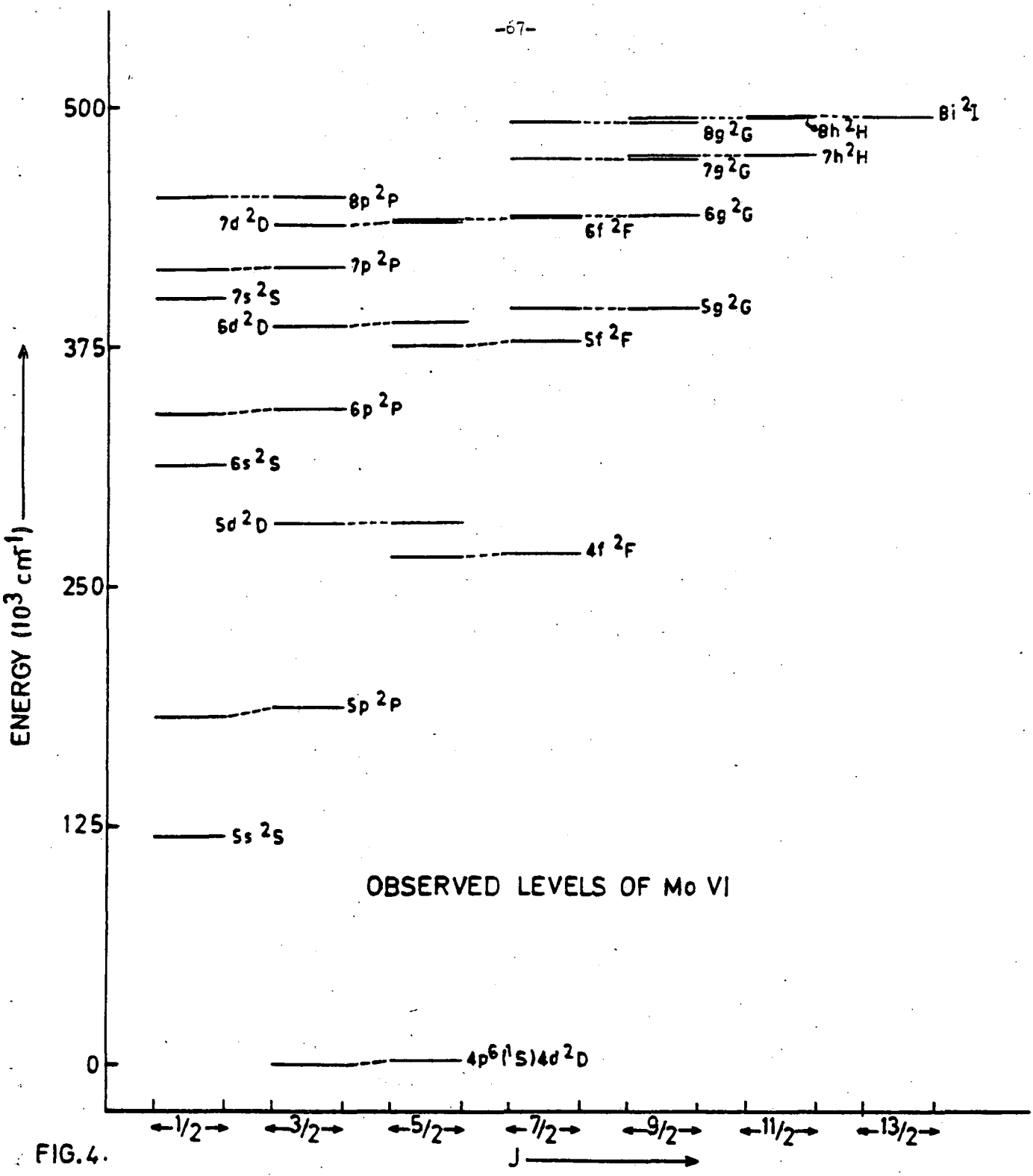

OBSERVED LEVELS OF Mo V
ENERGY (10^3 cm^{-1})
300
225
150
75
0
$4d(^2D)4f\ ^3G$
$4d(^2D)5d\ ^3F$
$4d(^2D)4f\ ^3F$
^1P
^3D
^1D
$4d(^2D)5d$
^3P
^1D
^3D
^3F
^1P
$4d(^2D)5p$
^1F
^3D
$4d(^2D)5s$
^1D
^3P
$4p^6 4d^2$
^3F
$4p^6 4d^2$
0
1
2
3
4
5
J

FIG. 3.



OBSERVED LEVELS OF Mo VI

FIG.4.

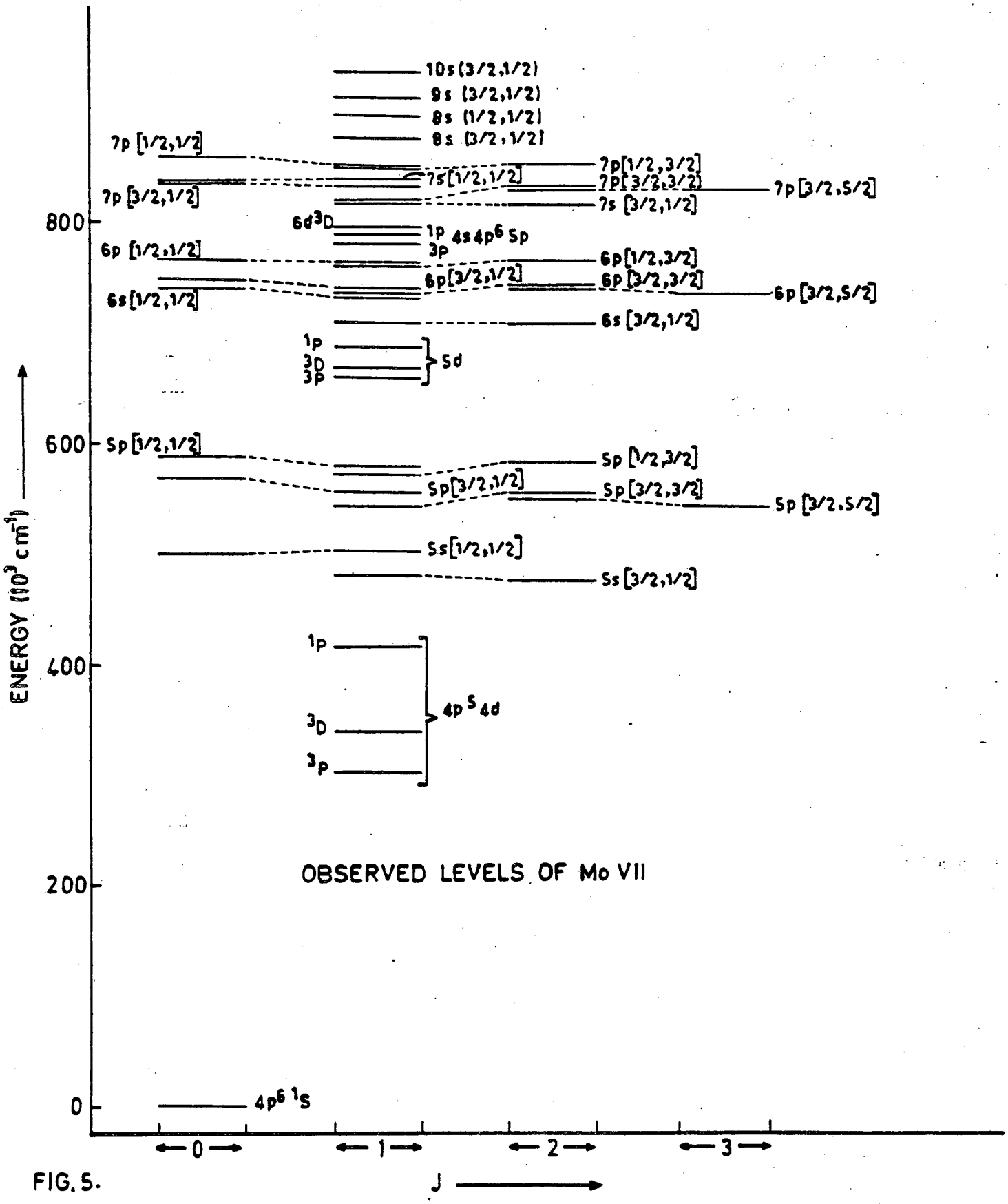

10s (3/2,1/2)
9s (3/2,1/2)
8s (1/2,1/2)
8s (3/2,1/2)
7p [1/2,1/2]
7p [3/2,1/2]
7s[1/2,1/2]
7p[1/2,3/2]
7p[3/2,3/2]
7p [3/2,5/2]
7s [3/2,1/2]
6d 3D
1p
3P
4s4p6 5p
6p [1/2,1/2]
6p[1/2,3/2]
6p[3/2,1/2]
6p [3/2,3/2]
6p [3/2,5/2]
6s[1/2,1/2]
6s [3/2,1/2]
1p
3D
3P
5d
5p [1/2,1/2]
5p [1/2,3/2]
5p[3/2,1/2]
5p [3/2,3/2]
5p [3/2,5/2]
5s[1/2,1/2]
5s [3/2,1/2]
1p
3D
3P
4p5 4d
OBSERVED LEVELS OF Mo VII
4p6 1S
ENERGY (10³ cm⁻¹)
800
600
400
200
0
0
1
2
3
J

FIG. 5.

Levels of nd and ns configurations bear different notations.

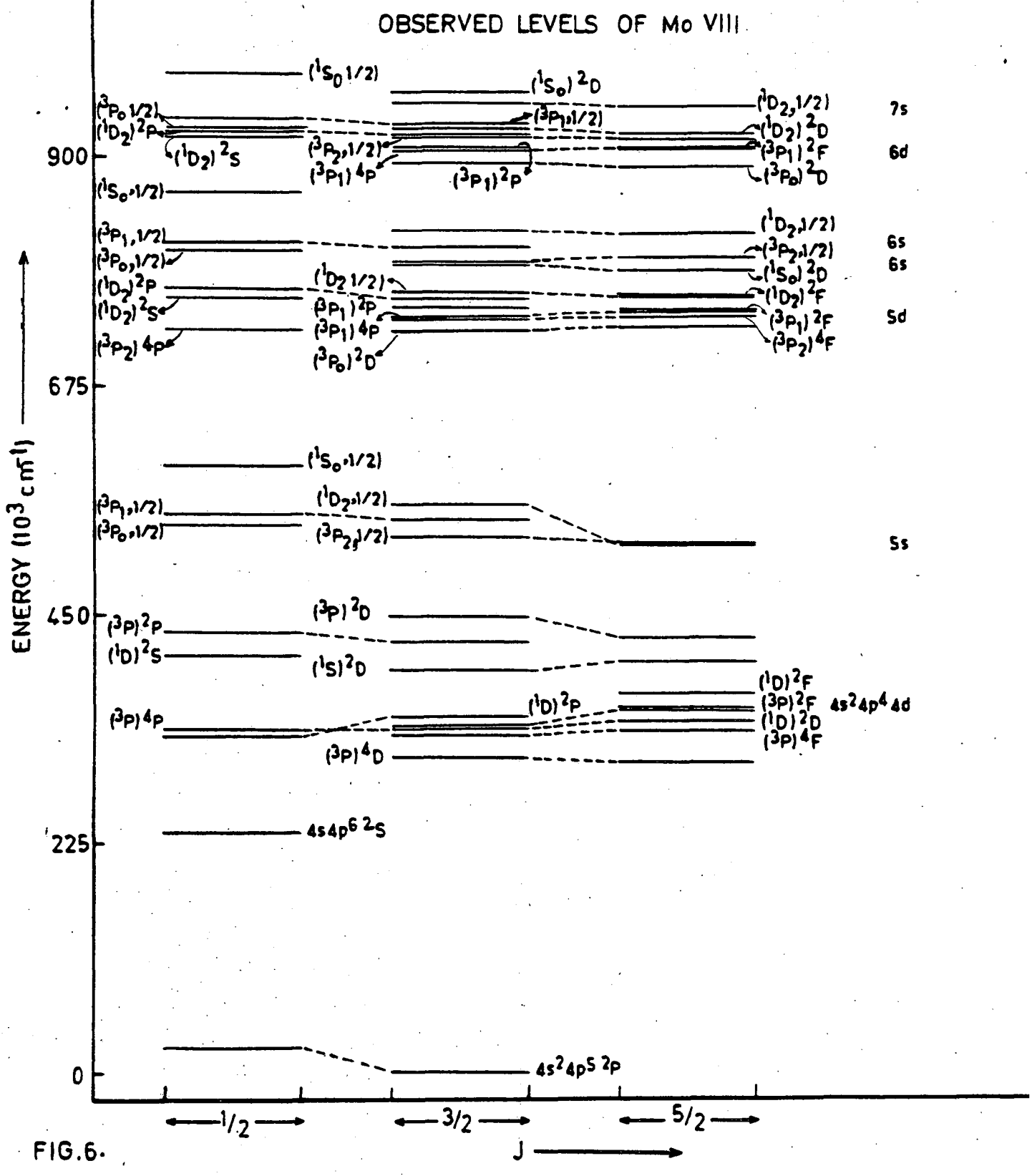


FIG.6.

a,b,c refer to parent configurations ^4S, ^2D and ^2P respectively. They are dropped from ns levels.

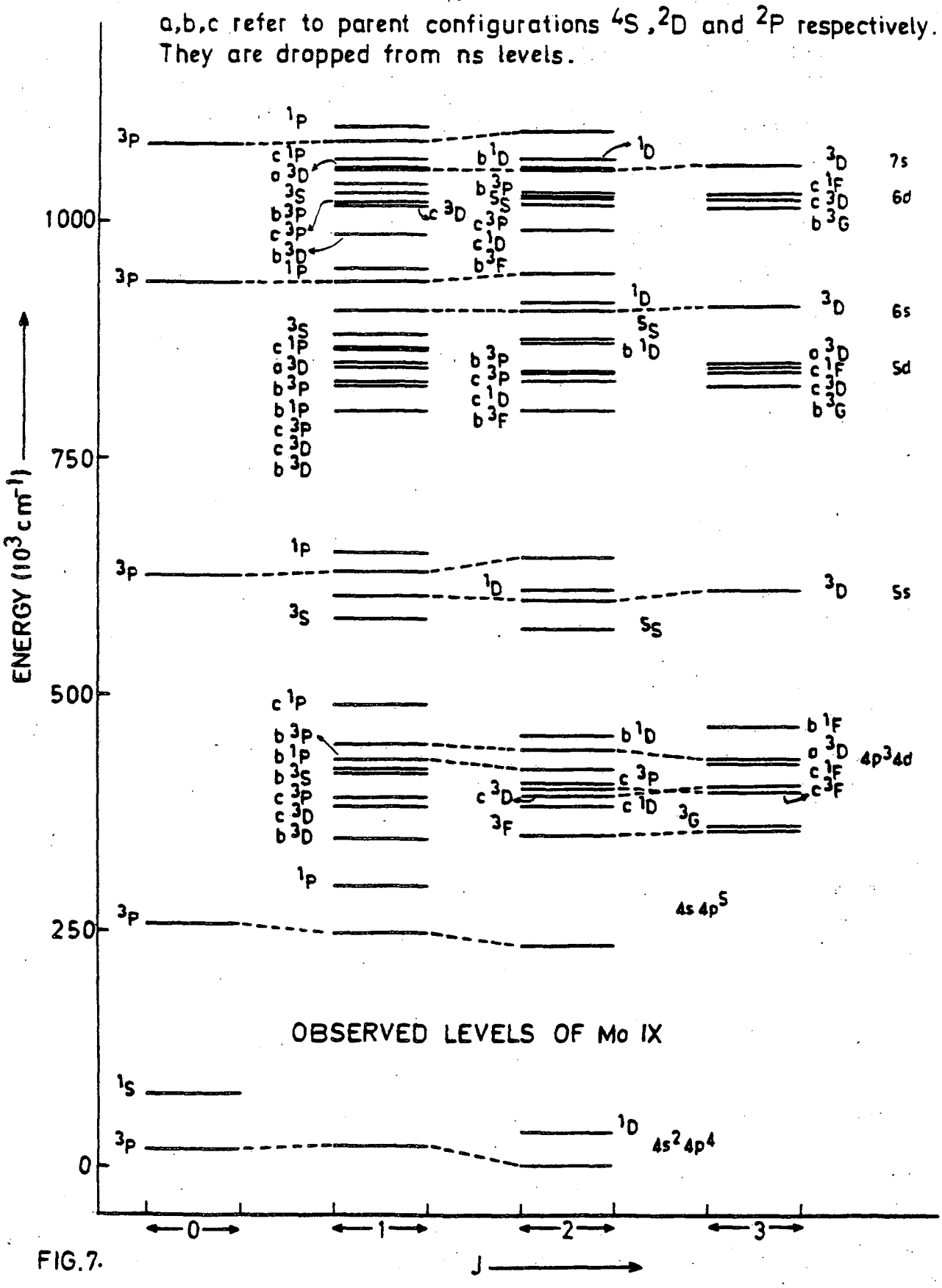


FIG.7.

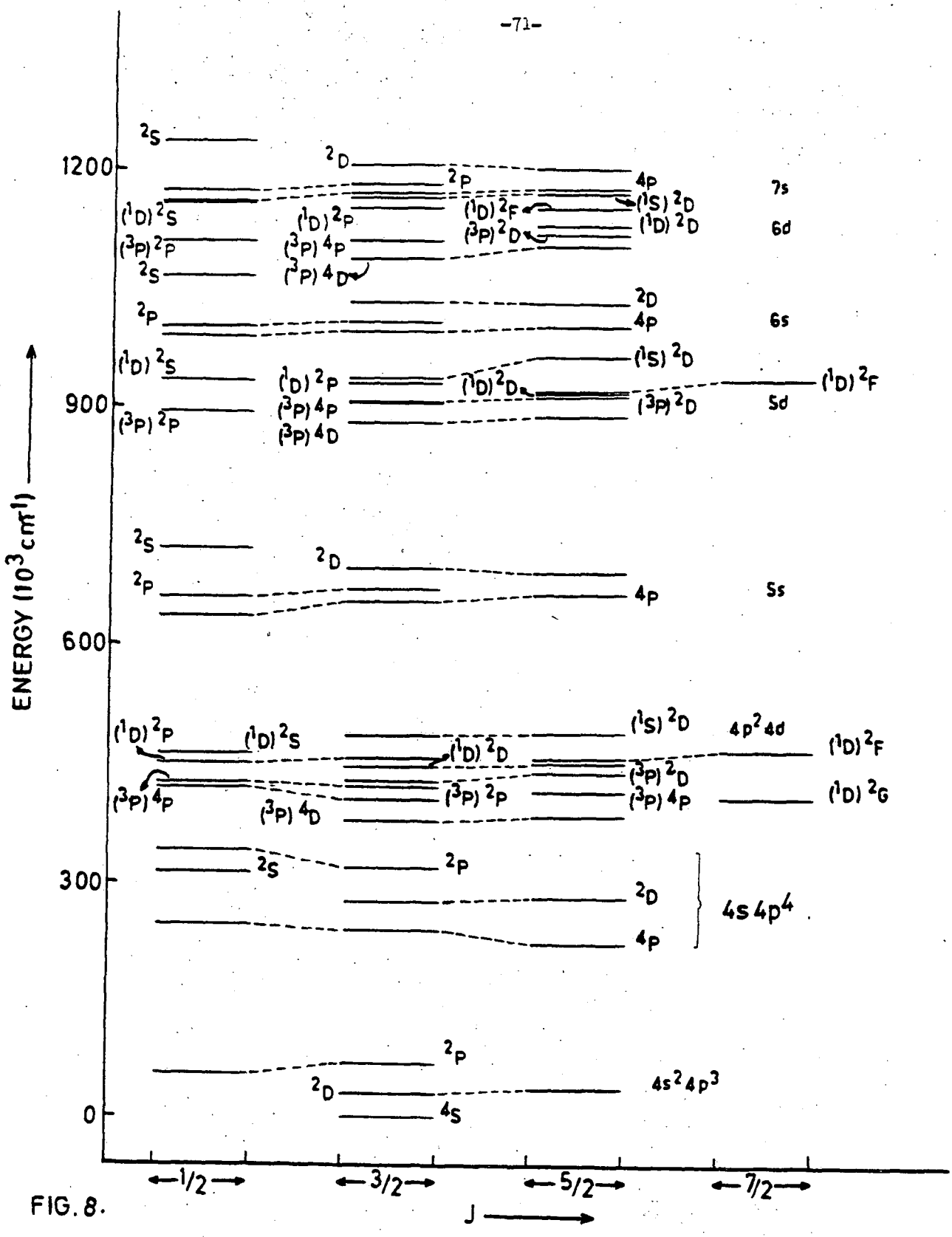

ENERGY (10^3 cm^{-1})
1200
900
600
300
0
^2S
^2D
^2P
^4P
$(^1S)\,^2D$
$(^1D)\,^2S$
$(^1D)\,^2P$
$(^1D)\,^2F$
$(^1D)\,^2D$
$(^3P)\,^2P$
$(^3P)\,^4P$
$(^3P)\,^2D$
$(^3P)\,^4D$
7s
6d
6s
5d
5s
$4p^2 4d$
$(^1D)\,^2G$
$4s\,4p^4$
$4s^2 4p^3$
^4S
1/2
3/2
5/2
7/2
J

FIG. 8.

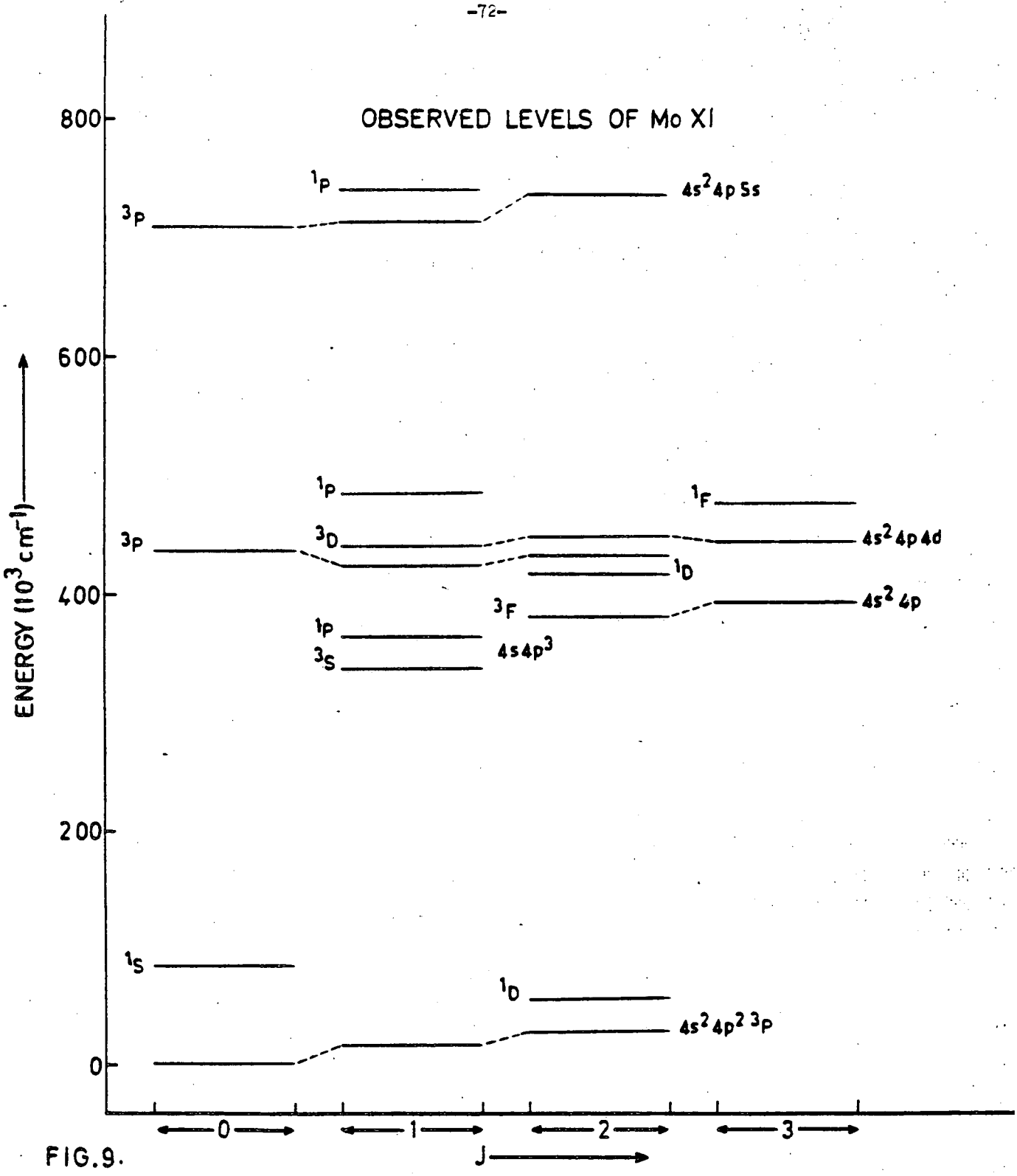

OBSERVED LEVELS OF Mo XI
ENERGY (10^3 cm^{-1})
800
600
400
200
0
^1P
^3P
$4s^2 4p\,5s$
^1P
^3D
^1F
^3P
$4s^2 4p\,4d$
^1D
^3F
$4s^2 4p$
^1P
^3S
$4s4p^3$
^1S
^1D
$4s^2 4p^2\ ^3P$
0
1
2
3
J

FIG.9.

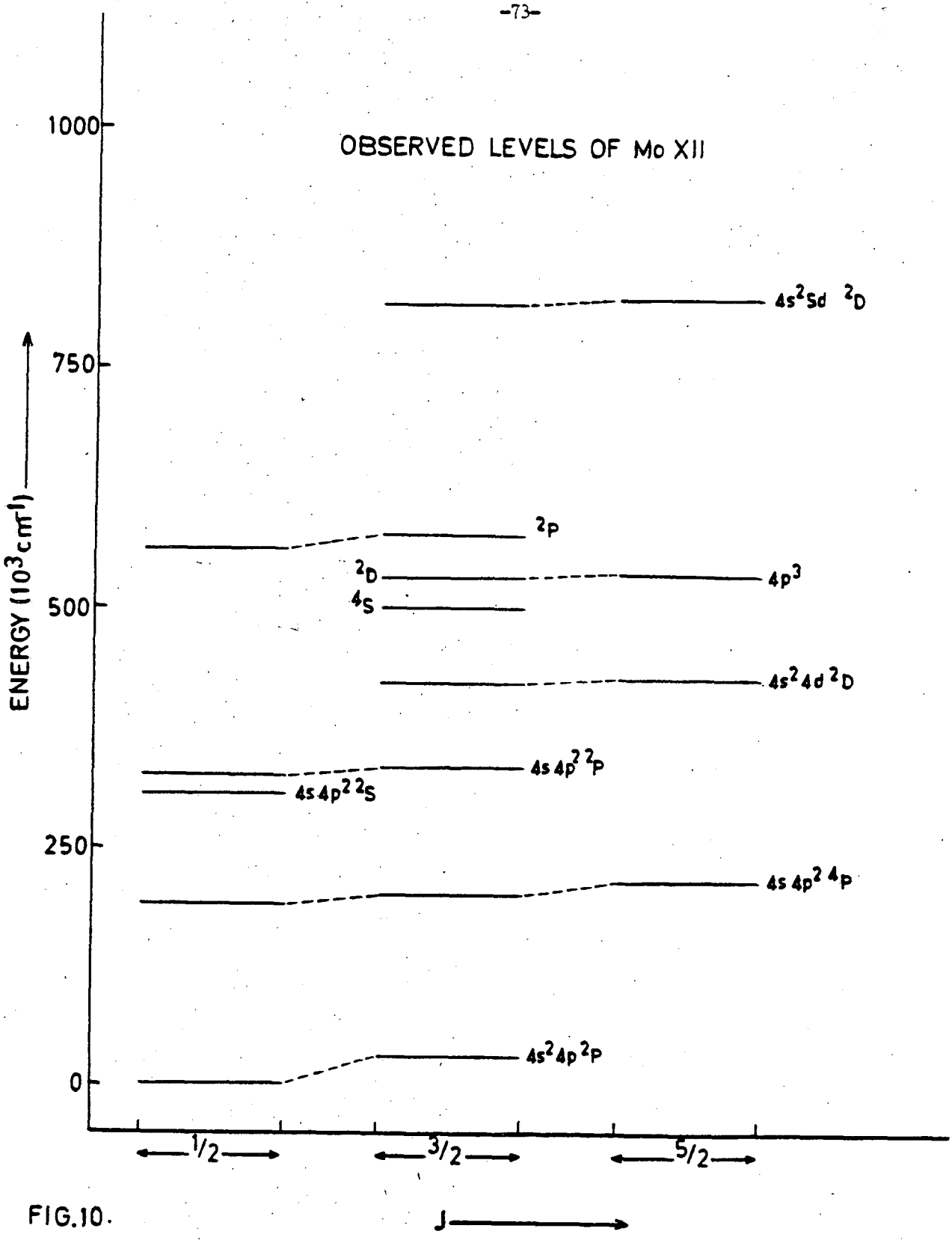

OBSERVED LEVELS OF Mo XII
ENERGY (10^3 cm^{-1})
1000
750
500
250
0
$4s^2 5d\ ^2D$
^2P
^2D
^4S
$4p^3$
$4s^2 4d\ ^2D$
$4s\,4p^2\ ^2P$
$4s\,4p^2\ ^2S$
$4s\,4p^2\ ^4P$
$4s^2 4p\ ^2P$
1/2
3/2
5/2
J

FIG.10.

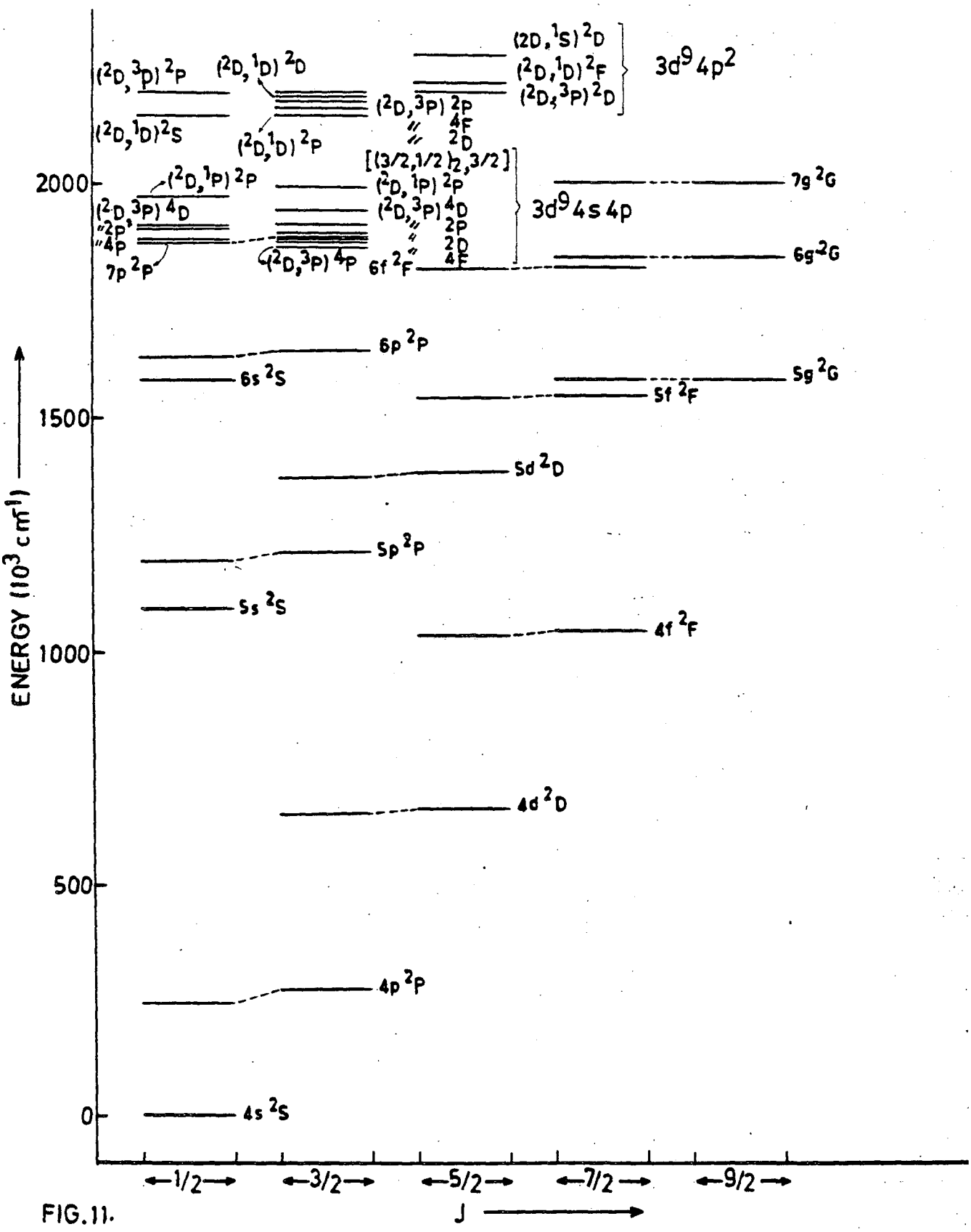

ENERGY (10^3 cm^{-1})
2000
1500
1000
500
0
$(^2D,^3P)\,^2P$
$(^2D,^1D)\,^2D$
$(^2D,^1S)\,^2D$
$(^2D,^1D)\,^2F$
$(^2D,^3P)\,^2D$
$3d^9 4p^2$
$(^2D,^1D)\,^2S$
$(^2D,^1D)\,^2P$
$(^2D,^3P)\,^2P$
^4F
^2D
$[(3/2,1/2)_2,3/2]$
$(^2D,^1P)\,^2P$
$(^2D,^3P)\,^4D$
$(^2D,^3P)\,^4D$
^2P
^2D
^4F
^2P
^4P
$7p\,^2P$
$(^2D,^3P)\,^4P$
$6f\,^2F$
$3d^9 4s 4p$
$7g\,^2G$
$6g\,^2G$
$6p\,^2P$
$6s\,^2S$
$5g\,^2G$
$5f\,^2F$
$5d\,^2D$
$5p\,^2P$
$5s\,^2S$
$4f\,^2F$
$4d\,^2D$
$4p\,^2P$
$4s\,^2S$
1/2
3/2
5/2
7/2
9/2
J

FIG.11.

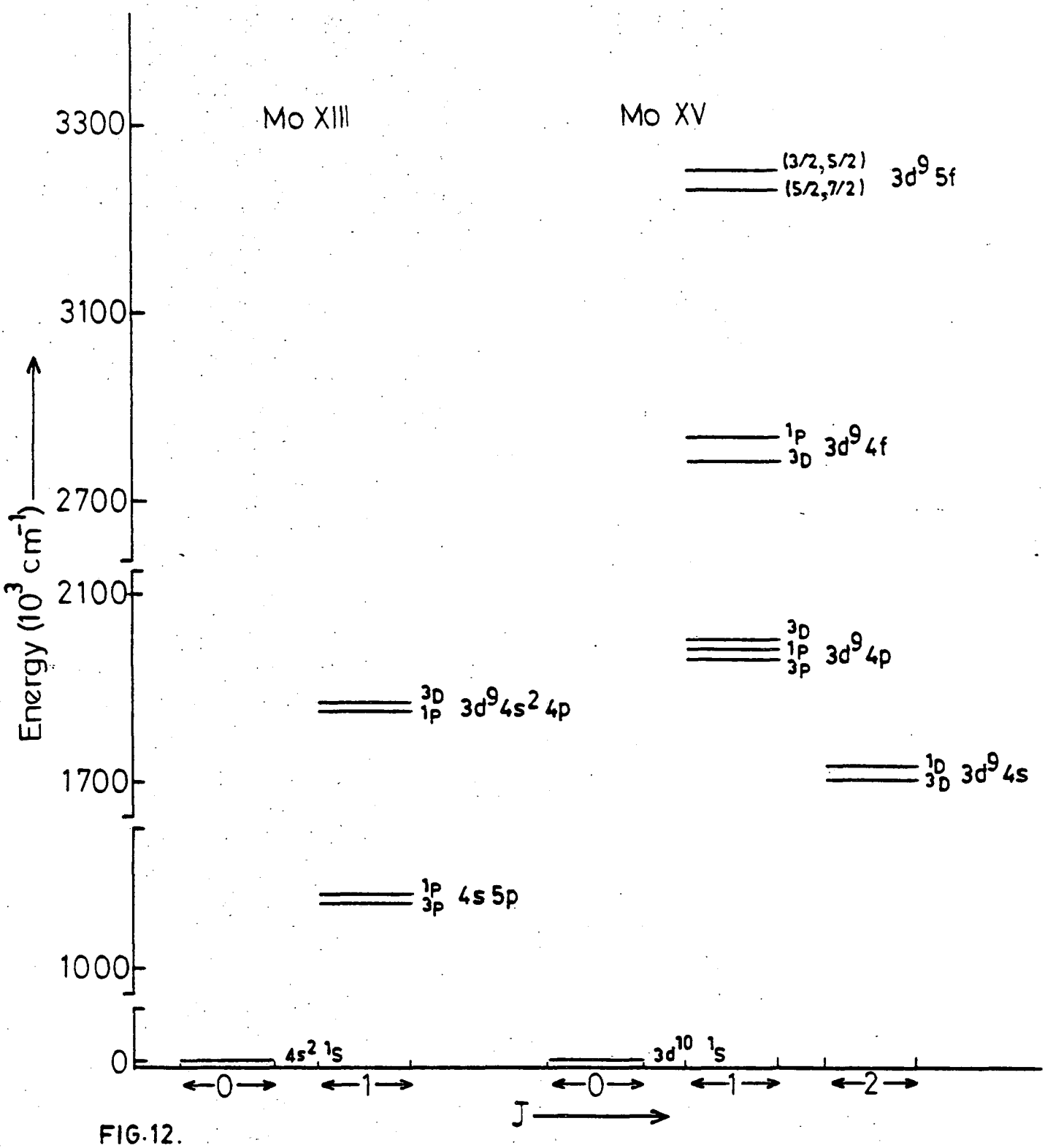

Mo XIII
Mo XV
3300
3100
2700
2100
1700
1000
0
Energy (10^3 cm^{-1})
(3/2, 5/2)
(5/2, 7/2)
$3d^9 5f$
^1P
^3D
$3d^9 4f$
^3D
^1P
^3P
$3d^9 4p$
^3D
^1P
$3d^9 4s^2 4p$
^1D
^3D
$3d^9 4s$
^1P
^3P
$4s 5p$
$4s^2$ ^1S
$3d^{10}$ ^1S
←0→
←1→
←0→
←1→
←2→
J

FIG.12.

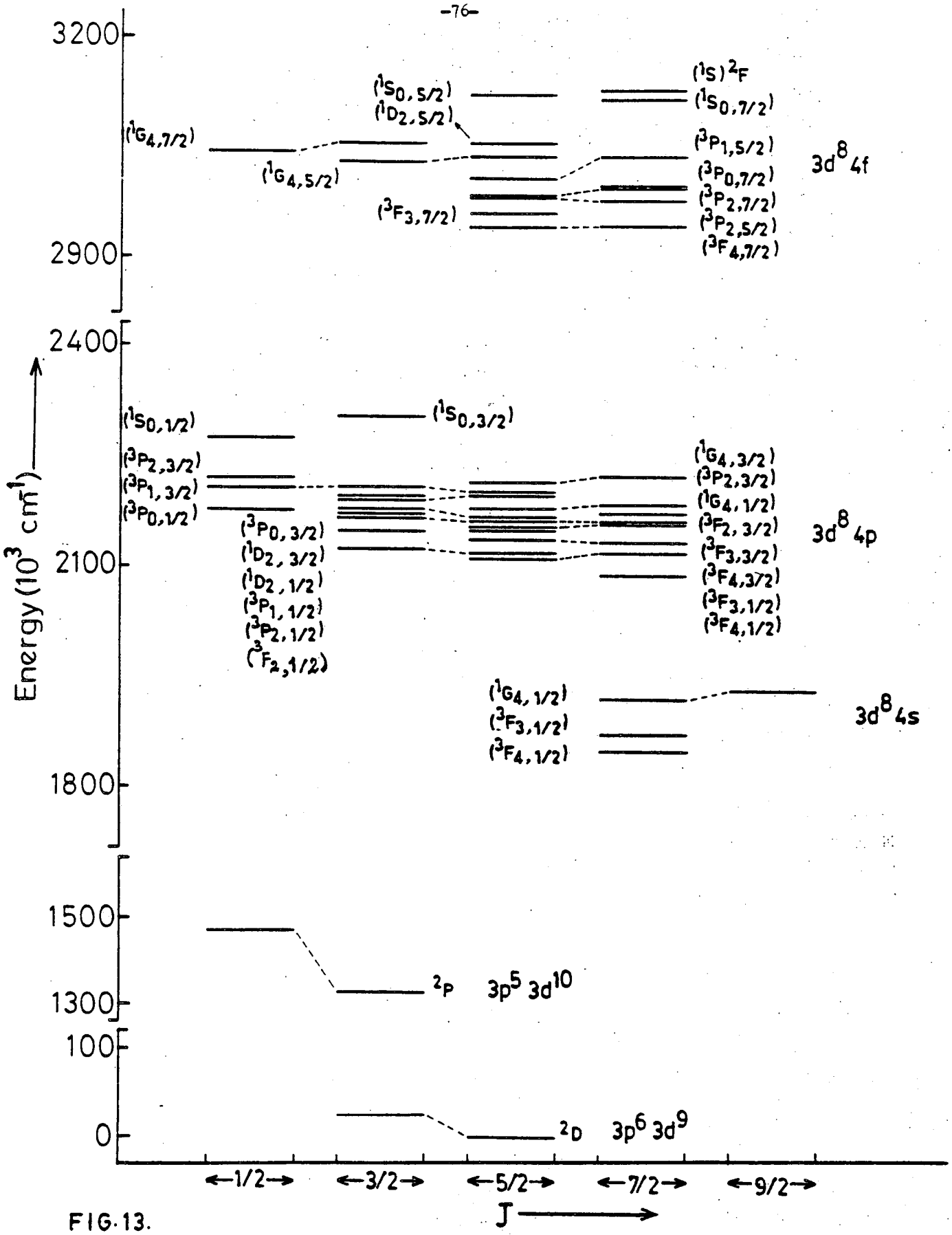

3200
2900
2400
2100
1800
1500
1300
100
0
Energy (10^3 cm^{-1})
(^{1}S)^{2}F
(^{1}S$_{0,5/2}$)
(^{1}D$_{2,5/2}$)
(^{1}S$_{0,7/2}$)
(^{1}G$_{4,7/2}$)
(^{1}G$_{4,5/2}$)
(^{3}P$_{1,5/2}$)
(^{3}P$_{0,7/2}$)
(^{3}P$_{2,7/2}$)
(^{3}F$_{3,7/2}$)
(^{3}P$_{2,5/2}$)
(^{3}F$_{4,7/2}$)
3d^{8}4f
(^{1}S$_{0,1/2}$)
(^{1}S$_{0,3/2}$)
(^{3}P$_{2,3/2}$)
(^{3}P$_{1,3/2}$)
(^{3}P$_{0,1/2}$)
(^{1}G$_{4,3/2}$)
(^{3}P$_{2,3/2}$)
(^{1}G$_{4,1/2}$)
(^{3}F$_{2,3/2}$)
(^{3}P$_{0,3/2}$)
(^{1}D$_{2,3/2}$)
(^{1}D$_{2,1/2}$)
(^{3}P$_{1,1/2}$)
(^{3}P$_{2,1/2}$)
(^{3}F$_{2,1/2}$)
(^{3}F$_{3,3/2}$)
(^{3}F$_{4,3/2}$)
(^{3}F$_{3,1/2}$)
(^{3}F$_{4,1/2}$)
3d^{8}4p
(^{1}G$_{4,1/2}$)
(^{3}F$_{3,1/2}$)
(^{3}F$_{4,1/2}$)
3d^{8}4s
^{2}P
3p^{5}3d^{10}
^{2}D
3p^{6}3d^9
←1/2→
←3/2→
←5/2→
←7/2→
←9/2→
J

FIG.13.

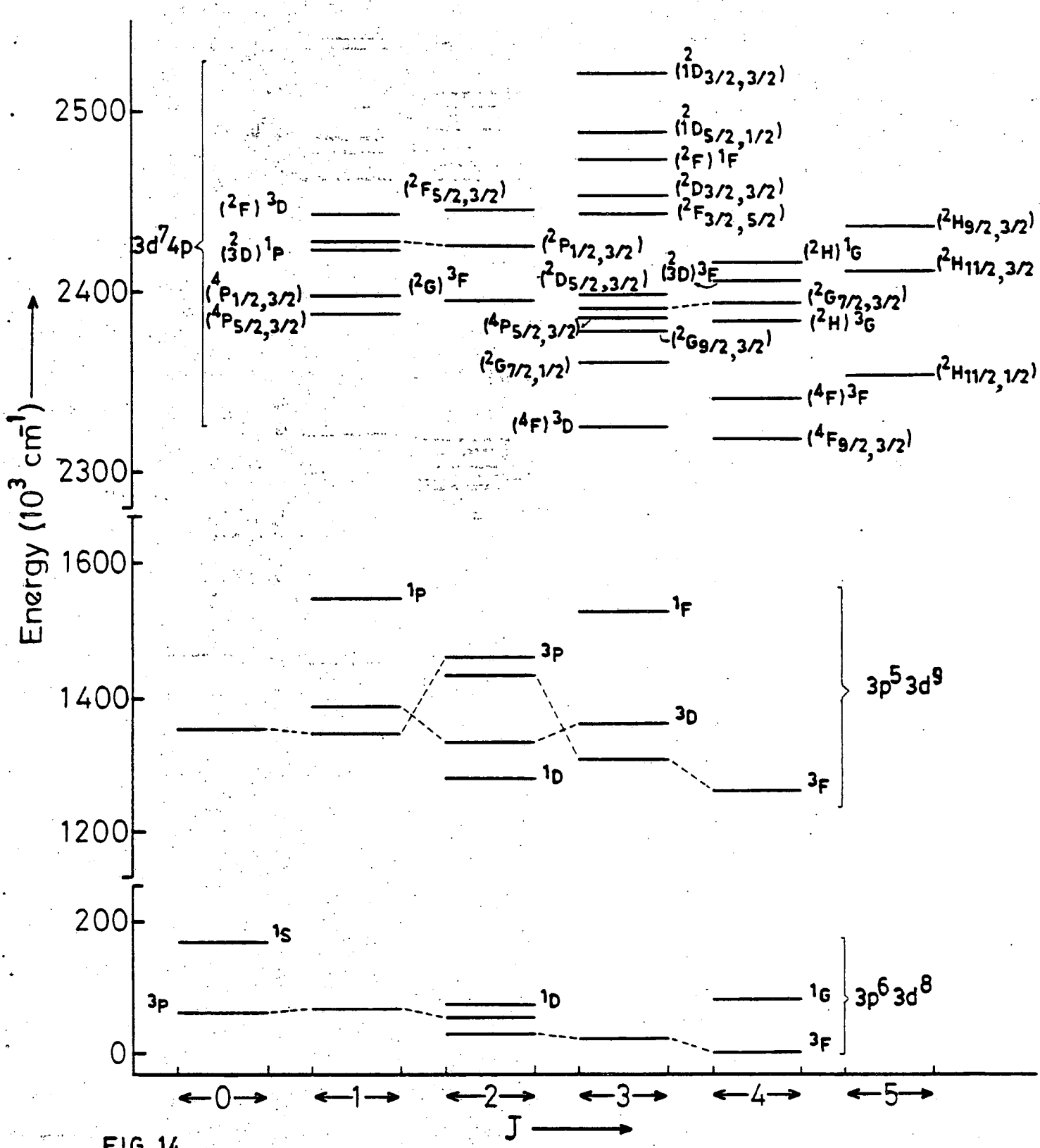

Energy (10^3 cm^{-1})
2500
2400
2300
1600
1400
1200
200
0
$3d^74p$
$(^2F)\,^3D$
$(^2\,^3D)\,^1P$
$(^4P_{1/2,3/2})$
$(^4P_{5/2,3/2})$
$(^2F_{5/2,3/2})$
$(^2G)\,^3F$
$(^2P_{1/2,3/2})$
$(^2D_{5/2,3/2})$
$(^4P_{5/2,3/2})$
$(^2G_{7/2,1/2})$
$(^4F)\,^3D$
$(^2\,^1D_{3/2,3/2})$
$(^2\,^1D_{5/2,1/2})$
$(^2F)\,^1F$
$(^2D_{3/2,3/2})$
$(^2F_{3/2,5/2})$
$(^2\,^3D)\,^3F$
$(^2G_{9/2,3/2})$
$(^2H)\,^1G$
$(^2G_{7/2,3/2})$
$(^2H)\,^3G$
$(^4F)\,^3F$
$(^4F_{9/2,3/2})$
$(^2H_{9/2,3/2})$
$(^2H_{11/2,3/2}$
$(^2H_{11/2,1/2})$
^1P
^3P
^1D
^1F
^3D
^3F
$3p^53d^9$
^1S
^3P
^1D
^1G
^3F
$3p^63d^8$
0
1
2
3
4
5
J

FIG. 14.

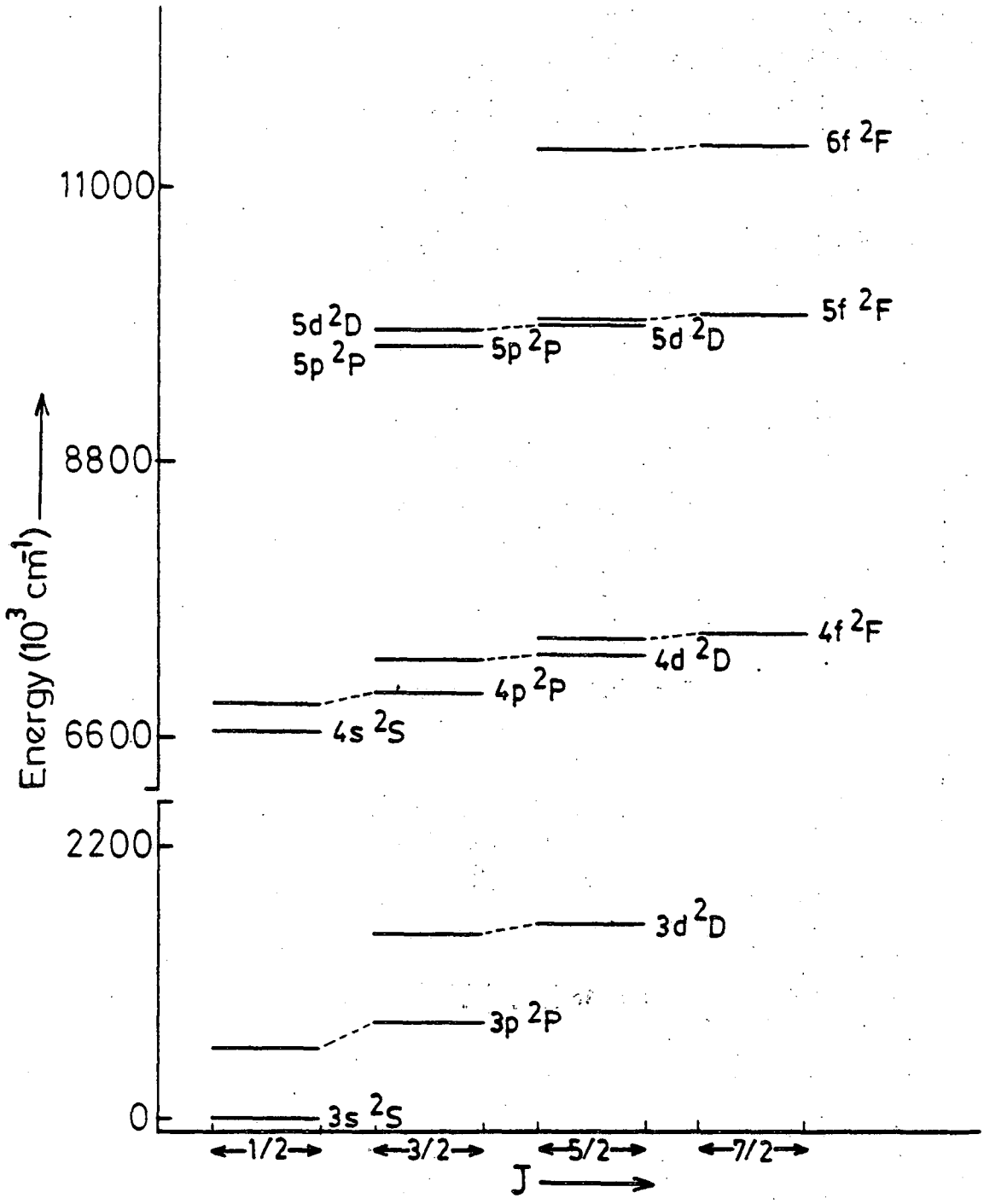

11000
8800
6600
2200
0
Energy (10^3 cm^{-1})
6f ^{2}F
5f ^{2}F
5d ^{2}D
5p ^{2}P
5p ^{2}P
5d ^{2}D
4f ^{2}F
4d ^{2}D
4p ^{2}P
4s ^{2}S
3d ^{2}D
3p ^{2}P
3s ^{2}S
1/2
3/2
5/2
7/2
J

FIG. 15.

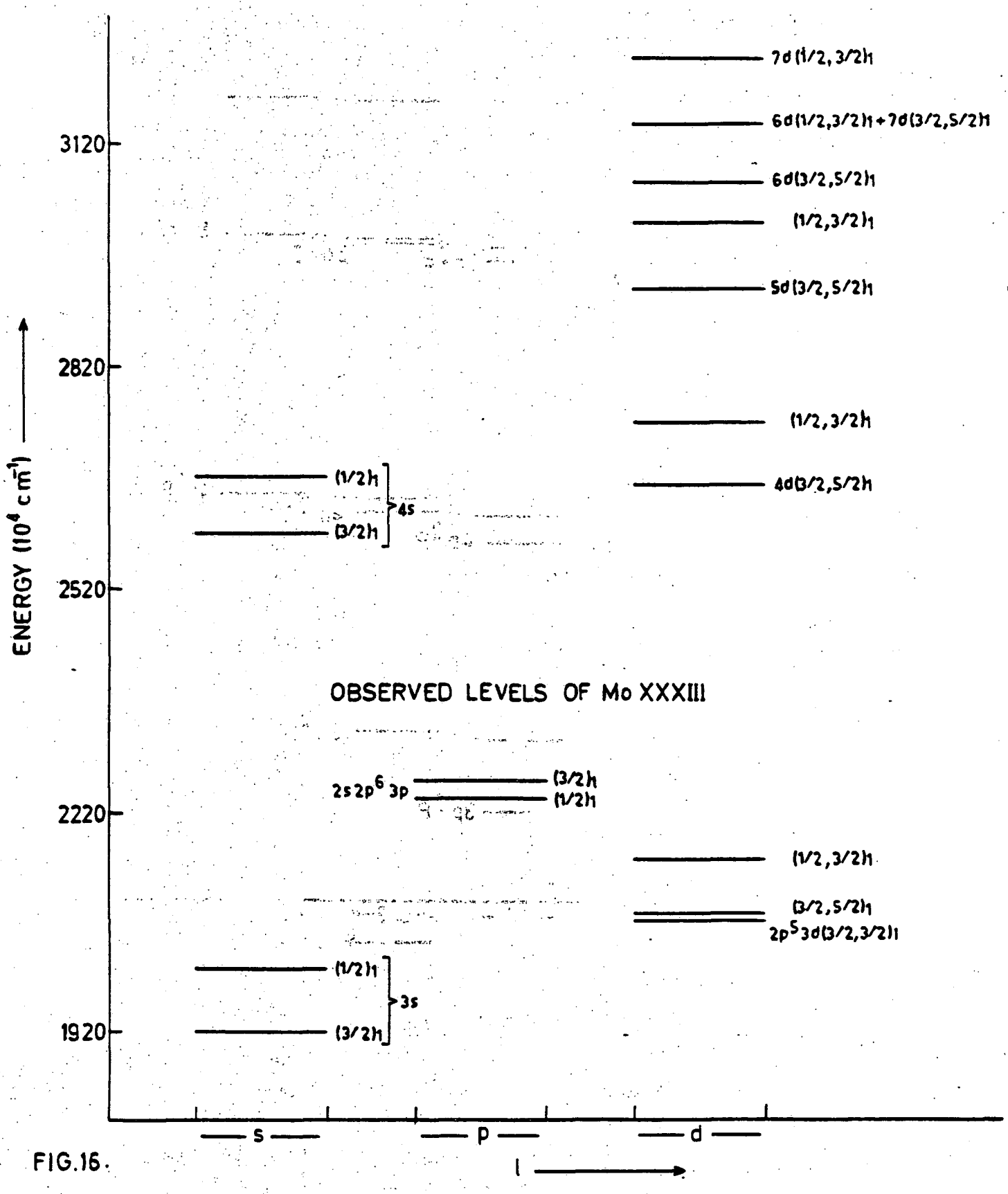

OBSERVED LEVELS OF Mo XXXIII
ENERGY (10^4 cm^{-1})
3120
2820
2520
2220
1920
7d(1/2,3/2)1
6d(1/2,3/2)1+7d(3/2,5/2)1
6d(3/2,5/2)1
(1/2,3/2)1
5d(3/2,5/2)1
(1/2,3/2)1
4d(3/2,5/2)1
(1/2)1
(3/2)1
4s
2s2p^{6}3p
(3/2)1
(1/2)1
(1/2,3/2)1
(3/2,5/2)1
2p^{5}3d(3/2,3/2)1
(1/2)1
(3/2)1
3s
s
p
d
l

FIG.16.

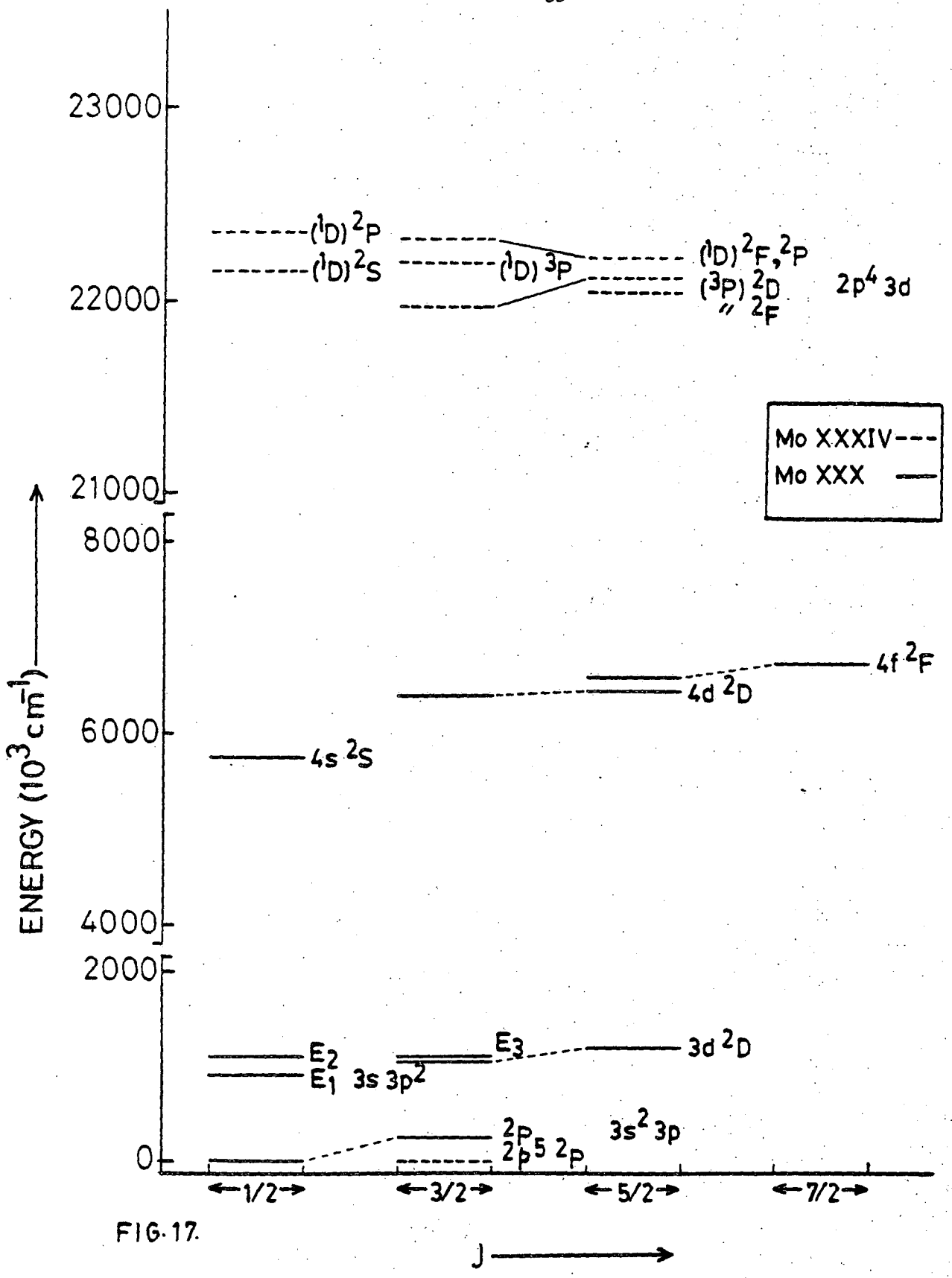

23000
22000
21000
8000
6000
4000
2000
0
ENERGY (10^3 cm^{-1})
(^{1}D) ^{2}P
(^{1}D) ^{2}S
(^{1}D) ^{3}P
(^{1}D) ^{2}F, ^{2}P
(^{3}P) ^{2}D
" ^{2}F
$2p^4 3d$
Mo XXXIV
Mo XXX
4f ^{2}F
4d ^{2}D
4s ^{2}S
E$_2$
E$_1$ 3s 3p^2
E$_3$
3d ^{2}D
^{2}P
^{2}P 5 ^{2}P
3s^2 3p
1/2
3/2
5/2
7/2
J

FIG. 17.