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ENERGIES OF THE ELECTRONIC CONFIGURATIONS OF THE SINGLY, DOUBLY, AND TRIPLY IONIZED LANTHANIDES AND ACTINIDES

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ABSTRACT

Methods are described for estimating energies of the electronic configurations of the gaseous ions of the lanthanides and actinides. Energies are tabulated for the lowest spectroscopic level of the configurations involving 4f, 5d, 6p, and 6s electrons for the lanthanide ions and 5f, 6d, 7p, and 7s electrons for the actinide ions. Some additional values are listed to be added to the previous tabulation for neutral atoms.

I have previously described[1] a method of calculating energies of some spectroscopic levels of neutral lanthanide and actinide atoms from the thermodynamic data of the metals. These calculations were extended to provide a tabulation of the energies of the lowest spectroscopic levels of many of the electronic configurations of the neutral atoms[1]. The availability of these values now makes it possible to carry out similar calculations for the ions of these elements.

Several authors[2-7] have made estimates of energy differences of electronic configurations such as $f^qd - f^{q+1}$, $f^qds - f^{q+1}s$, or $f^qds^2 - f^{q+1}s^2$, where q is the number of f electrons remaining in the core after promotion of one electron to a d orbital. These methods were based on the ideas of Racah[8] and Jørgensen[9]. The energy required to promote an electron from a 4f to 5d or from a 5f to 6d orbital varies rapidly in a somewhat irregular manner as nuclear charge is increased, but a large portion of the variation and most of the irregularity can be attributed to the pairing energy within the f core. For example, Nugent and Vander Sluis[2] were even able to make the assumption that the energy of a given f^q core as obtained from the data for the trivalent ions could be used unchanged in calculating energies of the neutral atoms. Upon subtracting the electron-spin-pairing energy from the f^qds^2-$f^{q+1}s^2$ energy differences for the neutral atoms, they obtained an almost linear curve from which they could make estimates of unknown values. Their method requires the assumption that interactions of the outer electrons with the f-electron core vary smoothly from element to element. Their results indicate that their assumption is a reasonable one for most f-electron cores, but it will be shown in this paper that, compared to partially filled cores, the f^0 and f^{14} cores interact sufficiently differently with certain groups of outer electrons to cause discontinuities at the ends of the Nugent-Vander Sluis plot.

In this discussion, it will be useful to introduce the symbol n for the total number of valence electrons for a given element. The valence electrons include 4f, 5d 6p, and 6s electrons for the lanthanides and 5f, 6d, 7p, and 7s electrons for the actinides. n is fixed by the number of valence electrons for the neutral atom. For example, for Nd, n = 5 and the configurations $f^{n-3}ds^2$(I), $f^{n-3}ds$(II), $f^{n-3}d$(III), and f^{n-3}(IV) of Nd all contain the same f^2 core. Fig. 1 presents plots of the energy required to promote an electron from an f orbital to a d orbital for different groups of configurations. In all instances, energy differences between configurations are given by the energy difference between the lowest levels of each configuration. Experimental values are shown as circles. The three curves grouped together at the top of the figure correspond to promotion from configurations with f^{n-4} cores to configurations with f^{n-3} cores. The middle group of three curves deals with f^{n-3} cores promoted to f^{n-2} cores and the bottom curve corresponds to f^{n-2} to f^{n-1} promotions. The abscissa, ranging from 0 to 13, is q, the number of f electrons remaining after promotion of an electron from f to d. For q=2, for example, the promotion energies given are for the following energy differences, starting at the top of Fig. 1: f^2d-f^3(Nd IV), f^2ds-f^3s(Nd III), $f^2ds^2-f^3s^2$(Nd II), f^2d-f^3(Pr III), f^2ds-f^3s(Pr II), $f^2ds^2-f^3s^2$(Pr I), and f^2d-f^3(Ce II).

For each promotion of an electron from an f to d orbital, the f core changes from f^3 to f^2 and the contributions due to change in the core should be closely the same. The fact that all of these curves closely parallel one-another confirms the approximate constancy of the core energy. However, if one is interested in accuracies of 1000 cm^{-1} or better, one must recognize that the core energy is not quite constant.

There are several ways of exploiting the concept of an approximately constant pairing energy for a given f^q core. For example, we could consider the plots of the f^qd-f^{q+1} promotion energy for singly, doubly, and triply charged ions versus q, the highest curve of each of the three groups of Fig. 1. The differences between any pairs of these curves would be expected to give straight lines. This is the basis of the Nugent-Vander Sluis calculations and one can draw a line to represent these differences between q=1 and q=12 that is useful for making predictions, but there is a clear break in the slope between q=0 and 1. The differences are large ranging from 57.9×10^3 cm^{-1} for the difference in f to d promotion energies of Ce III and Pr IV to 65.3×10^3 cm^{-1} for the Tm III and Yb IV difference. Although such plots can be useful, Racah[8] has proposed a method based on the same principles which can yield more accurate predictions. Any of the methods that rely on differences of the types discussed above require a sufficiently complete set of data for at least one stage of ionization. With the availability of complete data for the neutral atoms[1], his method can now be used to estimate values for the ions. It will be shown that his method can be generalized to be applied to many more types of electronic configurations than has been done in the past.

The Racah method can be illustrated by comparing the f to d promotion energies for f^2d-f^3(Pr III), f^2ds-f^3s(Pr II), and $f^2ds^2-f^3s^2$(Pr I), the values given at q = 2 for the middle group of curves of Fig. 1. These satisfy the general requirement that f cores be the same. In addition, they belong to the same $f^{n-3}-f^{n-2}$ groups and thus are for the same element. As can be seen from Fig. 1, the promotion energies are closely the same when these conditions are met. Racah suggested that the differences of promotion energies would be constant at about 5000 cm^{-1}. The top curve of Fig. 2 shows, on an expanded scale, the differences $(f^{n-4}d-f^{n-3})$IV$-(f^{n-4}ds-f^{n-3}s)$III between the two top curves of Fig. 1. The next curves are $(f^{n-3}d-f^{n-2})$III $-$ $(f^{n-3}ds-f^{n-2}s)$II and $(f^{n-3}ds-f^{n-2}s)$II$-$ $(f^{n-3}ds^2-f^{n-2}s^2)$I from the second group of curves of Fig. 1. The differences are in the vicinity of the 5000 cm^{-1} suggested by Racah, but an accuracy of 1000 cm^{-1} or better in predictions requires recognition of the possibility of differences ranging as high as 8000 cm^{-1} and variations up to 2000 cm^{-1} for a given set of differences. As each experimental point of Fig. 1 requires knowledge of the energies of two levels, each experimental points of Fig. 2 corresponds to experimental knowledge of energies of four levels. Where experimental points are not indicated, as many as two or three of the energy levels may be known and limits can be placed on the range of positions of the curves. Only a few of the points are uncertain by more than 1000 cm^{-1}. Similar small differences and smooth variations are found for the other Racah curves.

The three groups of curves of Fig. 1 correspond to three groups of Racah relationships. For the top group, as an example, the $f^{n-4}d-f^{n-3}$(IV) promotion energy of the triply charged ion is compared with values of the f to d promotion energies for successively lower charged ions with the same f cores. In the examples of Fig. 1, an s electron is added to both configurations for each reduction of charge. Although not shown in Fig. 1, a fourth curve lies just below the three curves shown corresponding to adding an additional d electron to obtain the promotion energy $f^{n-4}d^2s^2-f^{n-3}ds^2$. In the previous paper[1] on the neutral atoms, this relationship was used to estimate the energies of the tetravalent (four non-f electrons) configurations such as the estimate of 51 $\times 10^3$ cm^{-1} for the fd^2s^2 $^4H^o_{7/2}$ level of Pr I. Only a few were listed for the lanthanides as most were far above the ionization limit. However, for the actinides, values were given for the tetravalent configurations through americium. A parallel group of curves can be generated starting again with the $f^{n-4}d-f^{n-3}$ promotion energy of the triply charged ion and adding an additional d electron to both configurations for each reduction of charge. Altogether, the $f^{n-4}-f^{n-3}$ Racah relations yield a group of seven closely spaced curves of which only three are shown in Fig. 1. For the $f^{n-3}-f^{n-2}$ Racah group, five curves were used. For the $f^{n-2}-f^{n-1}$ group, the Racah relationship was used to generate a curve for the $f^{n-2}ds-f^{n-1}s$ promotion energy from the $f^{n-2}d-f^{n-1}$ curve shown in Fig. 1. This is useful for the prediction of the energies of some univalent configurations of the neutral lanthanides.

The Racah method provides the energy of at least one level of each f core for each stage of ionization. Then consideration of the variation of promotion energies of the d, p, and s electrons relative to one another can provide the energies of the remaining configurations. The comparision of these promotion energies at different stages of ionization can often provide very accurate estimations. For example, the d to p promotion energies for $f^{n-3}ps^2$-$f^{n-3}ds^2$(I) and for $f^{n-2}p$-$f^{n-2}d$(II) are almost identical if compared for cores with equal number of f electrons. The effect of increasing the nuclear charge by one is almost exactly shielded by the addition of two s electrons; the greatest difference is only 900 cm^{-1}. The variety of estimation procedures is illustrated below.

Details of Method of Calculation

The method of estimating energies of each configuration will be illustrated for the singly ionized lanthanides. The lowest levels of the $f^q s$ and $f^q d$ configurations are experimentally established except for the $f^q d$ configurations of Tb and Ho. The comparison of the energy to promote an electron from a d orbital to an s orbital for the singly, doubly, triply ionized lanthanides as indicated in Fig. 3 provides estimated values for Tb and Ho with an uncertainty of less than 1000 cm^{-1}. In Fig. 3, values are given for the $f^q d$ to $f^q s$, $f^q ds$ to $f^q s^2$, and $f^q d^2$ to $f^q ds$ promotional energies versus, q the number of f electrons. This comparison cancels out any contributions of the Jorgensen pairing energy due to the f core. Altogether nine curves involving either one or two non-f electrons were used together with additional curves for configurations with more than two non-f electrons. The others curves are not shown in Fig. 3 for clarity as they fall too close to the curves presented. All of the curves show a characteristic rise between q=0 and 1 and then a slow drop until the sharp break between q=9 and 10 followed by a slow drop and then a sharp drop between q=13 and 14. The experimental point of -18.254×10^3 cm^{-1} for Yb II $f^{13}ds-f^{13}d^2$(q=13 point of third curve from bottom) has been omitted and replaced by a dotted section of the curve to avoid the confusion of intersection with the curve below. This is the only experimental point that was out of line. The uniformally low values for q=0 and q=14 indicates that d electrons are stabilized more than s electrons by interaction with the unfilled f core.

With the s and d levels fixed, the next step is to use the Racah relations which provide the $f^{n-2}s-f^{n-3}ds$ and $f^{n-2}d-f^{n-3}d^2$ energy differences for the singly charged ion from the established values for the $f^{n-2}s^2-f^{n-3}ds^2$ and $f^{n-2}ds-f^{n-3}d^2s$ differences for the neutral atoms. The procedure should be clear from the discussion above in relation to Figs. 1 and 2. In this manner, the energies of the ds levels were estimated for Pr, Pm, Sm, Eu, Tb, Ho, and Er with uncertainties of less than 1000 cm^{-1} except for the Pm value which is uncertain by 2000 cm^{-1}. The energies of the d^2 levels were estimated for Pr, Pm, Sm, Eu, Tb, Dy, Ho, and Er in the same manner with the additional check by use of Fig. 3 to relate the d^2 and ds values. Again, except for Pm, the uncertainties are less than 1000 cm^{-1}.

The f^{n-1} configurations for the singly charged ion are established from the $f^{n-2}d-f^{n-1}$ values given in the lowest curve of Fig. 1. This curve was fixed by comparison with the curves of the $f^{n-3}-f^{n-2}$ and $f^{n-4}-f^{n-3}$ groups given above in Fig. 1. The estimated values for Pr, Nd, Pm, Eu, and Gd are uncertain by about 2000 cm^{-1} and the values for Tb, Dy, Ho, Er, and Tm are uncertain by about 3000 cm^{-1}.

The p levels can be calculated from the s to p promotion energies given in Fig. 4. As noted in the discussion of Fig. 3, there are a number of additional curves for promotion of s to p electrons that are omitted for clarity. The dp-ds(II) and p-s(II) curves are presented in Fig. 4 as an example of how closely the curves can follow one another. Another example is the dp-ds(I) curve which would fall just above the bottom curve of Fig. 4 for the ps-s^2(I) promotion energy. The experimental points for the dp-ds promotion range from 1.2 to 1.5 $\times$ 10^3 cm^{-1} above the ps-s^2 curve. In contrast to Fig. 3, there is no clear evidence for discontinuities at q=0 and 14 and the s and p electrons must interact with the f cores in a similar manner. The entire class of curves for the promotion of an electron from a p to s orbital show a very regular and slow variation with q, and it is quite easy to estimate promotion energies with an uncertainty much below 1000 cm^{-1}.

The dp levels can also be obtained from the ds levels and the s to p promotions energies of Fig. 4. In addition curves similar to those of Figs. 3 and 4 can be prepared for d to p promotion and one can check the energies of the dp levels by starting from the the d^2 levels. These same p-d promotion energy curves can be used to estimate the energies of the ps levels from the ds levels. Then the s to p promotion energies can be used to calculate the energies of the s^2 levels from the ps levels. These values can be checked through curves of the type of Fig. 3 starting with the ds level. The p^2 levels can be obtained from either of the p^2-dp or p^2-ps promotions or by the p^2-ds energy difference. This last difference is an interesting one in that one electron is promoted from a d orbital to a p orbital while one electron is demoted from an s orbital to a p orbital. Such relationships are often useful for predictive purposes.

To estimate values for configurations with three non-f electrons, it is necessary to use the Racah relationships to obtain d^2s-ds, ds^2-s^2 and d^3-d^2 differences as discussed in connection with Figs. 1 and 2. The energy of the dps configuration can be obtained from the ds^2 value by use of s-p promotions curves similar to those in Fig. 4. The energy of the ps^2 configuration was calculated from the estimates of the ps^2-ds^2 promotion which was expected to be very close to the p-d promotion of the doubly charged ions. Most of the ps^2 levels and all of the p^2s, dp^2, and p^3 levels were estimated to be well above the ionization limits and are not given in the tables of energies if they are more than 10 000 cm^{-1} above the ionization limits.

In a similar manner, but in a different order depending upon which data are available, energies can be calculated for the lowest level of each of the electronic configurations of the other stages of ionization and for the various ions of the actinides.

Tabulation of Level Values

Tables I-XXX present for all of the lanthanide and actinides the energy level values of the lowest level of the lowest spectroscopic term of each electronic configuration for singly, doubly, and triply charged ions. The values given are restricted to configurations involving 4f, 5d, 6p and 6s electrons for the lanthanides and 5f, 6d, 7p, and 7s electrons for the actinides.

The energies are given in thousands of wavenumbers. Experimental values are given to 0.001×10^3 cm^{-1}. Estimated values are given in parentheses to the nearest 0.1×10^3 cm^{-1} for accurate estimates and rounded off to the nearest 1×10^3 cm^{-1} for less certain estimates. When the uncertainty of the estimated value is 1×10^3 cm^{-1} or over, some estimate of the uncertainty is given in the tables.

The tables follow the format used for the tabulation of energy level values for the neutral atoms[1]. All levels are given an LS designation. In addition, JJ or JL designations are given for appropriate configurations. For many configurations, Hund's Rule is expected to hold and the J value given corresponds to Hund's Rule. When the levels given in the tables do not correspond to Hund's Rule, the symbol is followed by an asterisk. When an experimental value is designated by an asterisk, the value tabulated is the lowest observed level of the configuration and it is possible that additional observations might find a lower level of the configuration. In general, an attempt was made to estimate the J value of the lowest energy level and experimental data that did not correspond to the lowest energy level were supplemented by estimates of the energy of the lowest level. For each table, the energy values for the singly charged ion(M II) are tabulated first followed by values for the doubly charged ion(M III) and then by values for the triply charged ion(M IV).

Moore's bibliography[10] was used for a review of the literature and those references will not be duplicated here. The numbers in parentheses after each table heading refers to recent references and to those older references from which tabulated values were actually obtained.

The relationships between the energy level values of the neutral atoms and the ions allow the prediction of values for some neutral configurations that have not been observed yet. As mentioned in connection with the discussion of Figs. 1 and 2, it is possible to estimate energies of the $f^{n-1}s$ configurations of the neutral atoms. For those elements where the lowest level of the $f^{n-1}s$ configuration does not lie above 10 000 cm^{-1} over the ionization limit, the values are tabulated in Table XXXI along with values for other levels that were tabulated previously[1] but which were improved by consideration of the complete data for the ions.

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Table I. Lanthanum

Odd Terms			10^3 cm^{-1}	Even Terms		
			La II (11)			
fs	$^3F^o_2$	14.148		d^2	$^3F_2$	0.000
fd	$^1G^{o*a}_4$	16.599		ds	$^3D_1$	1.895
dp	$^1D^{o*}_2$	24.463		s^2	$^1S_0$	7.395
ps	$^3P^o_0$	31.786		fp	$^3G_3$	35.453
				f^2	$^3H_4$	55.107
				p^2	$^3P_0$	60.095
			La III(12)			
f	$^2F^o_{5/2}$	7.195		d	$^2D_{3/2}$	0.000
p	$^2P^o_{1/2}$	42.015		s	$^2S_{1/2}$	13.591

[a]For explanation of the asterisks and parentheses for all tables, see discussion entitled "Tabulation of Level Values"

Table II. Cerium

Odd Terms		10^3 cm^{-1}		Even Terms	
		Ce II (13-15)			
fd^2	$^4H^o_{7/2}$*	0.000	f^2s	$^4H_{7/2}$	3.854
fds	$^2G^o_{9/2}$*	2.382	f^2d	$^4K_{11/2}$	7.092
fs^2	$^2F^o_{5/2}$	9.779	fdp	$^2H_{9/2}$*	24.663
f^2p	$^4I^o_{9/2}$	25.766	fps	$(^4G_{5/2})$	(34.)
f^3	$^4I^o_{9/2}$	38.195	d^2s	$^4F_{5/2}$*	37.849
fp^2	$(^4G^o_{5/2})$a	(61.5)±1	d^3	$(^4F_{3/2})$	(41.)±8
dps	$(^4F^o_{3/2})$	(73.)±3	ds^2	$(^2D_{3/2})$	(49.)±2
ps^2	$(^2P^o_{1/2})$	(92.)±4			
		Ce III (16,17)			
fd	$^1G^o_4$ *	3.277	f^2	$^3H_4$	0.000
fs	$^3F^o_2$	19.236	d^2	$^3F_2$	40.440
dp	$^3F^o_2$	92.635	fp $\frac{5}{2}\,\frac{1}{2}$	$(^3F_3)^*$	48.267
ps	$(^3P^o_0)$	(117.)±5	ds	$^3D_1$	63.335
gf $^2[\frac{9}{2}]$	$(^3H^o_4)^*$	122.906	s^2	$^1S_0$	(86.)±9
			p^2	$^3P_0$	(152.)±9
		Ce IV (18)			
f	$^2F^o_{5/2}$	0.000	d	$^2D_{3/2}$	49.737
p	$^2P^o_{1/2}$	122.585	s	$^2S_{1/2}$	86.602

Table III. Praseodymium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Pr II (19,20)			
f^3s	$^5I^o_4$	0.000	f^2d^2	$(^5L_6)$	(5.5)
f^3d	$^5L^o_6$	3.893	f^2ds	$(^5K_5)$	(8.)±2
f^2dp	$(^5L^o_6)$	(31.)±2	f^2s^2	$(^3H_4)$	(16.)±2
f^2ps	$(^5I^o_4)$	(39.5)±2	f^3p	$^5K_5$	22.675
fd^2s	$(^5H^o_3)$*	(55.)±4	f^4	$(^5I_4)$	(32.)±2
fd^3	$(^5I^o_4)$	(57.)±4	f^2p^2	$(^5I_4)$	(68.)±2
fds^2	$(^3H^o_4)$	(67.)±3	fdps	$(^5I_4)$	(91.)±4
		Pr III (21)			
f^3	$^4H^o_{7/2}$*	0.000	f^2d	$^4H_{9/2}$*	12.847
f^2p 4,$\frac{1}{2}$	$^4I^o_{7/2}$*	58.164	f^2s	$^4H_{7/2}$	28.399
fd^2	$^4H^o_{7/2}$*	60.524	fdp	$(^4I_{9/2})$	(114.)±3
fds	$^4H^o_{7/2}$	84.135	fps	$(^4G_{5/2})$	(140.)±5
fs^2	$(^2F^o_{5/2})$	(108.)±9			
fp^2	$(^4G^o_{5/2})$	(175.)±9			
		Pr IV (22-24)			
fd	$^1G^o_4$ *	61.171	f^2	$^3H_4$	0.000
fs	$^3F^o_2$	100.259	fp $\frac{5}{2}$ $\frac{1}{2}$	$(^3F_3)$*	136.851
			d^2	$^3F_2$	139.712

Table IV. Neodymium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
Nd II (25-28)					
f^3d^2	$^6M^o_{13/2}$	9.229	f^4s	$^6I_{7/2}$	0.000
f^3ds	$^6K^0_{9/2}$ *	11.310	f^4d	$^6L_{11/2}$	4.438
f^3s^2	$(^4I^o_{9/2})$	(17.5)±1	f^3dp	$^6M_{13/2}$	34.782
f^4p	$^6K^o_{9/2}$	23.230	f^3ps	$(^6K_{9/2})$	(42.)±1
f^5	$(^6H^o_{5/2})$	(33.)±3	f^2d^2s	$(^6L_{11/2})$	(67.)±9
f^3p^2	$(^6K^o_{9/2})$	(71.)±4	f^2d^3	$(^6L_{11/2})$	(69.)±9
f^2d^2p	$(^6M^o_{13/2})$	(95.)±9	f^2ds^2	$(^4K_{11/2})$	(78.)±5
Nd III (29)					
f^3d	$(^5L^o_6)$	(16.)±1	f^4	$^5I_4$	0.000
f^3s	$(^5I^o_4)$	(30.5)±2	f^3p	$(^5K_5)$	(61.)±2
f^2dp	$(^5L^o_6)$	(126.)±4	f^2d^2	$(^5L_6)$	(72.)±5
f^2ps	$(^5I^o_4)$	(152.)±9	f^2ds	$(^5K_5)$	(96.)±5
			f^2s^2	$(^3H_4)$	(120.)±7
Nd IV (3,30)					
f^3	$^4I^o_{9/2}$	0.000	f^2d	$^4I_{9/2}$*	(71.5)±1
f^2p	$^4I^o_{9/2}$	(147.)±2	f^2s	$^4H_{7/2}$	(110.)±5
fd^2	$(^4H^o_{7/2})$*	(160.)±5			

Table V. Promethium

Odd Terms		10^3 cm^{-1}	Even Terms		10^3 cm^{-1}
Pm II (31)					
f^5s	$(^7H^o_2)$	0.000	f^4d^2	$(^7M_6)$	(9.5)±3
f^5d	$^7K^o_4$	5.332	f^4ds	$(^7L_5)$	(11.)±2
f^4dp	$(^7M^o_6)$	(35.)±3	f^4s^2	$(^5I_4)$	(17.)±3
f^4ps	$(^7K^o_4)$	(42.)±3	f^5p	$(^7I_3)$	(23.4)
f^3d^2s	$(^7M^o_6)$	(70.)±9	f^6	$(^7F_0)$	(26.)±2
f^3d^3	$(^7M^o_6)$	(72.)±9	f^4p^2	$(^7K_4)$	(71.)±4
f^3ds^2	$(^5L^o_6)$	(82.)±7	f^3d^2p	$(^7N_7)$	(97.)±9
Pm III					
f^5	$(^6H^o_{5/2})$	0.000	f^4d	$(^6L_{11/2})$	(16.)±2
f^4p	$(^6K^o_{9/2})$	(61.)±3	f^4s	$(^6I_{7/2})$	(29.5)±3
f^3d^2	$(^6M^o_{13/2})$	(76.)±6	f^3dp	$(^6M_{13/2})$	(130.)±5
f^3ds	$(^6L^o_{11/2})$	(99.5)±5	f^3ps	$(^6K_{9/2})$	(155.)±9
f^3s^2	$(^4I^o_{9/2})$	(122.)±9			
f^3p^2	$(^6K^o_{9/2})$	(192.)±9			
Pm IV					
f^3d	$(^5L^o_6)$	(75.5)±2	f^4	$(^5I_4)$	0.000
f^3s	$(^5I^o_4)$	(113.)±5	f^3p	$(^5K_5)$	(150.)±3
			f^2d^2	$(^5L_6)$	(172.)±6

Table VI. Samarium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
		Sm II (32, 33)			
f^7	$^8S^o_{7/2}$	18.289	f^6s	$^8F_{1/2}$	0.000
f^5ds	$(^8K^o_{7/2})$	(19.)	f^6d	$^8H_{3/2}$	7.135
f^5d^2	$(^8L^o_{9/2})$	(19.)±1	f^5dp	$(^8L_{9/2})$	(43.)±2
f^6p	$(^8G^o_{1/2})$	(23.4)	f^5ps	$(^8I_{5/2})$	(49.)±1
f^5s^2	$(^6H^o_{5/2})$	(24.)±2	f^4d^2s	$(^8M_{11/2})$	(77.)±9
f^5p^2	$(^8I^o_{5/2})$	(79.)±3	f^4d^3	$(^8M_{11/2})$	(80.)±9
			f^4ds^2	$(^6L_{11/2})$	(89.)±7
		Sm III (34-6)			
f^5d	$^7K^o_4$	24.5	f^6	$^7F_0$	0.000
f^5s	$(^7H^o_2)$	(36.)±2	f^5p	$(^7I_3)$	(67.5)±2
f^4dp	$(^7M^o_6)$	(137.)±6	f^4d^2	$(^7M_6)$	(83.)±5
f^4ps	$(^7K^o_4)$	(161.)±8	f^4ds	$(^7L_5)$	(106.)±5
			f^4s^2	$(^5I_4)$	(128.)±7
		Sm IV (3, 37)			
f^5	$^6H^o_{5/2}$	0.000	f^4d	$(^6L_{11/2})$	(76.)±2
f^4p	$(^6K^o_{9/2})$	(152.)±5	f^4s	$(^6I_{7/2})$	(113.)±6
f^3d^2	$(^6M^o_{13/2})$	(175.)±8			

Table VII. Europium

Eu II (38,39)

Odd Terms		10^3 cm^{-1}	Even Terms		
f^7s	$^9S^o_4$	0.000	f^7p	$^9P_3$	23.774
f^7d	$^9D^o_2$	9.923	f^6ds	$^9H_1$	(28.5)±1
f^6dp	$(^9I^o_2)$	(54.)±2	f^6d^2	$(^9I_2)$	(31.5)±2
f^6ps	$(^9G^o_0)$	(57.)±2	f^6s^2	$(^7F_0)$	(33.)±2
f^5d^2s	$(^9L^o_4)$	(96.)±9	f^8	$(^7F_6)$	(58.)±2
f^5d^3	$(^9L^o_4)$	(100.)±9	f^6p^2	(^9G_o)	(87.)±3
f^5ds^2	$(^7K^o_4)$	(107.)±8			

Eu III (38-40)

f^7	$^8S^o_{7/2}$	0.000	f^6d	$(^8H_{3/2})$	(34.5)±1
f^6p	$(^8G^o_{1/2})$	(78.)±2	f^6s	$(^8F_{1/2})$	(45.)±2
f^5d^2	$(^8L^o_{9/2})$	(102.)±6	f^5dp	$(^8L_{9/2})$	(155.)±9
f^5ds	$(^8K^o_{7/2})$	(125.)±7	f^5ps	$(^8I_{5/2})$	(178.)±9
f^5s^2	$(^6H^o_{5/2})$	(147.)±9			

Eu IV (3,37)

f^5d	$(^7K^o_4)$	(85.5)±1	f^6	$^7F_0$	0.000
f^5s	$(^7H^o_2)$	(120.)±5	f^5p	$(^7I_3)$	(160.)±5
			f^4d^2	$(^7M_6)$	(185.)±8

Table VIII. Gadolinium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		$10^3\ cm^{-1}$
		Gd II (41-44)			
f^7ds	$^{10}D^{o}_{5/2}$	0.000	f^8s	$^{8}F_{13/2}$	7.992
f^7s^2	$^{8}S^{o}_{7/2}$	3.444	f^8d	$^{8}G_{15/2}*$	18.367
f^7d^2	$^{10}F^{o}_{3/2}$	4.027	f^7ps	$^{10}P_{7/2}$	25.669
$f^8p\ 6,\frac{1}{2}$	$^{8}D^{o}_{11/2}*$	32.595	f^7dp	$^{10}F_{3/2}$	25.960
f^7p^2	$(^{10}P^{o}_{7/2})$	$(56.)\pm3$	f^6d^2s	$(^{10}I_{3/2})$	$(77.)\pm9$
f^9	$(^{6}H^{o}_{15/2})$	$(56.)\pm2$	f^6d^3	$(^{10}I_{3/2})$	$(82.)\pm9$
f^6d^2p	$(^{10}K^{o}_{5/2})$	$(104.)\pm9$	f^6ds^2	$(^{8}H_{3/2})$	$(88.)\pm7$
		Gd III (45,46)			
f^7d	$^{9}D^{o}_{2}$	0.000	f^8	$(^{7}F_{6})$	$(1.5)\pm1$
f^7s	$^{9}S^{o}_{4}$	9.195	$f^7p\ \frac{7}{2}\ \frac{1}{2}$	$^{9}P_{3}$	43.020
f^6dp	$(^{9}I^{o}_{2})$	$(130.)\pm7$	f^6d^2	$(^{9}I_{2})$	$(78.)\pm7$
f^6ps	$(^{9}G^{o}_{0})$	$(150.)\pm7$	f^6ds	$(^{9}H_{1})$	$(99.)\pm5$
			f^6s^2	$(^{7}F_{0})$	$(119.)\pm7$
		Gd IV (46,47)			
f^7	$^{8}S^{o}_{7/2}$	0.000	f^6d	$^{8}H_{3/2}$	$(96.)\pm1$
f^6p	$^{8}G^{o}_{1/2}$	$(171.)\pm3$	f^6s	$^{8}F_{1/2}$	$(130.)\pm4$
f^5d^2	$(^{8}L^{o}_{9/2})$	$(205.)\pm9$			

Table IX. Terbium

10^3 cm^{-1}

Tb II (48,49)

Odd Terms			Even Terms		
f^9s	$(^7H^o_8)$	0.000	f^8ds	$(^9G_7)$*	(3.3)
f^9d	$(^7H^o_8)$*	(11.)±1	f^8s^2	$(^7F_6)$	(5.5)±2
f^8ps (6,0)	$(^9F^o_6)$*	(28.)±2	f^8d^2	$(^9H_8)$*	(9.)±3
f^8dp	$(^9H^o_8)$*	(30.)±2	f^9p $(\frac{15}{2},\frac{1}{2})$	$(^7H_7)$*	(24.4)
f^7d^2s	$(^{11}F^o_2)$	(43.)±9	f^{10}	$(^5I_8)$	(40.)±4
f^7d^3	$(^{11}F^o_2)$	(49.)±9	f^8p^2 (6,0)	$(^9F_6)$*	(60.)±5
f^7ds^2	$(^9D^o_2)$	(53.)±7	f^7dps	$(^{11}F_2)$	(75.)±9
			f^7ps^2	$(^9P_3)$	(100.)±9

Tb III

Odd Terms			Even Terms		
f^9	$(^6H^o_{15/2})$	0.000	f^8d	$(^8G_{13/2})$*	(9.5)±1
f^7d^2	$(^{10}F^o_{3/2})$	(50.)±9	f^8s	$(^8F_{13/2})$	(18.)±3
f^8p $(6,\frac{1}{2})$	$(^8F^o_{11/2})$*	(52.)±3	f^7dp	$(^{10}F_{3/2})$	(102.)±9
f^7ds	$(^{10}D^o_{5/2})$	(71.)±5	f^7ps	$(^{10}P_{7/2})$	(120.)±9
f^7s^2	$(^8S^o_{7/2})$	(88.)±9			

Tb IV (3,37)

Odd Terms			Even Terms		
f^7d	$(^9D^o_2)$	(60.)±4	f^8	$^7F_6$	0.000
f^7s	$(^9S^o_4)$	(92.)±9	f^7p	$(^9P_3)$	(135.)±5
			f^6d^2	$(^9I_2)$	(180.)±9

Table X - Dysprosium

Odd Terms		$10^3 cm^{-1}$	Even Terms		
		Dy II (50-52)			
f^9ds	$^8I^o_{17/2}$ *	10.594	$f^{10}s$	$^6I_{17/2}$	0.000
f^9s^2	$^6H^o_{15/2}$	12.336	$f^{10}d$	$^6K_{17/2}$ *	14.846
f^9d^2	$(^8K^o_{19/2})$*	(19.) ±3	f^9ps $\left(\frac{15}{2},0\right)$	$(^8H_{15/2})$*	(36.) ±1
$f^{10}p$ $\left(8,\frac{1}{2}\right)$	$(^6K^o_{15/2})$*	(24.6)	f^9dp	$(^8K_{19/2})$*	(38.) ±2
f^{11}	$(^4I^o_{15/2})$	(44.) ±2	f^8d^2s	$(^{10}G_{15/2})$*	(64.) ±9
f^9p^2 $\left(\frac{15}{2},0\right)$	$(^8H^o_{15/2})$*	(67.) ±3	f^8ds^2	$(^8G_{11/2})$*	(73.) ±7
f^8dps	$(^{10}H^o_{17/2})$*	(96.) ±9	f^8d^3	$(^{10}G_{15/2})$*	(73.) ±9
		Dy III			
f^9d	$(^7H^o_8)$*	(17.5)	f^{10}	$(^5I_8)$	0.000
f^9s	$(^7H^o_8)$	(25.) ±2	f^9p $\left(\frac{15}{2},\frac{1}{2}\right)$	$(^7I_7)$*	(60.) ±2
f^8dp	$(^9H^o_8)$*	(123.) ±9	f^8d^2	$(^9H_8)$*	(71.) ±9
f^8ps (6,0)	$(^9F^o_6)$*	(139.) ±9	f^8ds	$(^9G_7)$*	(91.) ±5
			f^8s^2	$(^7F_6)$	(108.) ±9
			f^8p^2 (6,0)	$(^9F_6)$*	(178.) ±9
		Dy IV (3, 37)			
f^9	$^6H^o_{15/2}$	0.000	f^8d	$(^8G_{15/2})$*	(73.) ±3
f^8p $\left(6,\frac{1}{2}\right)$	$(^8F^o_{11/2})$*	(147.) ±6	f^8s	$(^8F_{13/2})$	(105.) ±9
f^7d^2	$(^{10}F^o_{3/2})$	(156.) ±9			

Table XI - Holmium

Odd Terms			10^3 cm^{-1}	Even Terms			

Ho II (53)

$f^{11}s$		$^5I^o_8$	0.000	$f^{10}s^2$		$(^5I_8)$	(10.) ±2
$f^{11}d$		$(^5K^o_6)$ *	(15.8) ±1	$f^{10}ds$		$(^7K_9)$ *	(11.5)
$f^{10}ps$	(8,0)	$(^7I^o_8)$ *	(34.) ±2	$f^{10}d^2$		$(^7L_{10})$*	(23.) ±1
$f^{10}dp$		$(^7L^o_{10})$ *	(39.) ±1	$f^{11}p$	$(\frac{15}{2},\frac{1}{2})$	$(^5I_7)$ *	(25.)
f^9d^2s		$(^9K^o_{10})$*	(72.) ±9	f^{12}		$(^3H_6)$	(46.) ±4
f^9ds^2		$(^7H^o_8)$ *	(79.) ±7	$f^{10}p^2$	(8,0)	$(^7I_8)$ *	(67.) ±5
f^9d^3		$(^9K^o_{10})$*	(82.) ±7	f^9dps		$(^9K_{10})$*	(103.) ±9

Ho III (54,55)

f^{11}		$^4I^o_{15/2}$	0.000	$f^{10}d$		$^6I_{17/2}$ *	18.1
$f^{10}p$		$^6H^o_{15/2}$ *	57.498	$f^{10}s$		$^6I_{17/2}$ *	21.824
f^9d^2		$(^8K^o_{19/2})$ *	(79.) ±8	f^9dp		$(^8K_{19/2})$*	(130.) ±9
f^9ds		$(^8I^o_{17/2})$ *	(96.) ±5	f^9ps	$(\frac{15}{2},0)$	$(^8H_{15/2})$*	(143.) ±9
f^9s^2		$(^6H^o_{15/2})$	(112.) ±9				
f^9p^2	$(\frac{15}{2},0)$	$(^8H^o_{15/2})$ *	(183.) ±9				

Ho IV (3,37)

f^9d		$(^7H^o_8)$ *	(81.) ±3	f^{10}		$^5I_8$	0.000
f^9s		$(^7H^o_8)$	(112.) ±9	f^9p	$(\frac{15}{2},\frac{1}{2})$	$(^7H_7)$ *	(155.) ±5
				f^8d^2		$(^9H_8)$ *	(178.) ±9

Table XII - Erbium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
Er II (51,56)					
$f^{11}s^2$	$(^4I^o_{15/2})$	(7.0)	$f^{12}s$	$^4H_{13/2}$	0.000
$f^{11}ds$	$(^6K^o_{19/2})$*	(10.5)	$f^{12}d$	$(^4I_{9/2})$ *	16.533
$f^{11}d^2$	$(^6K^o_{13/2})$*	(23.6) ±1	$f^{11}ps$ $(\frac{15}{2},0)$	$(^6I_{15/2})$*	(32.) ±1
$f^{12}p$ $(6,\frac{1}{2})$	$(^4H^o_{11/2})$*	(25.7) ±2	$f^{11}dp$ $(\frac{15}{2},2)$	$(^6K_{11/2})$*	(39.) ±1
f^{13}	$(^2F^o_{7/2})$	(43.) ±3	$f^{10}d^2s$	$(^8L_{21/2})$*	(72.) ±9
$f^{11}p^2$ $(\frac{15}{2},0)$	$(^6I^o_{15/2})$*	(66.) ±2	$f^{10}ds^2$	$(^6I_{17/2})$*	(77.) ±5
$f^{10}dps$	$(^8L^o_{21/2})$*	(101.) ±9	$f^{10}d^3$	$(^8L_{21/2})$*	(83.) ±9
$f^{10}d^2p$	$(^8M^o_{23/2})$*	(101.) ±9			
Er III (34)					
$f^{11}d$ $(\frac{15}{2},\frac{3}{2})$	$(^5L^o_6)$ *	(17.2) ±1	f^{12}	$(^3H_6)$	0.000
$f^{11}s$	$(^5I^o_8)$	(20.) ±3	$f^{11}p$ $(\frac{15}{2},\frac{1}{2})$	$(^5K_7)$ *	(56.) ±2
$f^{10}dp$	$(^7L^o_{10})$*	(129.) ±9	$f^{10}d^2$	$(^7L_{10})$*	(79.) ±5
$f^{10}ps$	$(^7I^o_8)$ *	(140.) ±9	$f^{10}ds$	$(^7K_7)$ *	(95.) ±3
			$f^{10}s^2$	$(^5I_8)$	(107.) ±9
			$f^{10}p^2$ (8,0)	$(^7I_8)$ *	(180.) ±9
Er IV (3,55)					
f^{11}	$^4I^o_{15/2}$	0.000	$f^{10}d$	$^6L_{17/2}$ *	(83.) ±3
$f^{10}p$ $(8,\frac{1}{2})$	$(^6I^o_{15/2})$*	(155.) ±5	$f^{10}s$	$^6I_{17/2}$	(110.) ±9
f^9d^2 $(\frac{15}{2},2)$	$(^8L^o_{11/2})$*	(188.) ±9			

Table XIII - Thulium

Odd Terms			10^3 cm^{-1}	Even Terms			10^3 cm^{-1}
Tm II (54-61)							
$f^{13}s$		$^3F^o_4$	0.000	$f^{12}s^2$		$^3H_6$	12.457
$f^{13}d$	$2\left[\frac{3}{2}\right]$	$^3P^o_2$ *	17.625	$f^{12}ds$	$^3[4]$	$(^5K_5)$*	16.568
$f^{12}ps$	6,0	$(^5I^o_6)$*	38.225	$f^{13}p$	$\frac{7}{2},\frac{1}{2}$	$(^3F_3)$*	25.980
$f^{12}dp$	6,2	$(^5I^o_4)$*	44.838	$f^{12}d^2$	(6,2)	$(^5I_4)$*	30.509
$f^{11}d^2s$		$(^7L^o_{10})$*	(78.) ±9	f^{14}		$^1S_0$	(34.) ±4
$f^{11}ds^2$		$(^5K^o_6)$*	(83.) ±7	$f^{12}p^2$	(6,0)	$(^5I_6)$*	(71.) ±5
$f^{11}d^3$		$(^7L_{10})$*	(90.) ±9	$f^{11}d^2p$		$(^7M_{11})$*	(107.) ±9
Tm III (62)							
f^{13}		$^2F^o_{7/2}$	0.000	$f^{12}d$	$6,\frac{3}{2}$	$(^4I_{9/2})$*	22.897
$f^{12}p$	$6,\frac{1}{2}$	$^4H^o_{11/2}$ *	62.064	$f^{12}s$		$^4H_{13/2}$	25.303
$f^{11}d^2$		$(^6L^o_{19/2})$*	(85.) ±9	$f^{11}dp$		$(^6L_{19/2})$*	(134.) ±9
$f^{11}ds$		$(^6K^o_{17/2})$*	(100.) ±5	$f^{11}ps$	$\left(\frac{15}{2},0\right)$	$(^6I_{15/2})$*	(145.) ±9
$f^{11}s^2$		$(^4I^o_{15/2})$	(110.) ±9				
$f^{11}p^2$	$\left(\frac{15}{2},0\right)$	$(^6I^o_{15/2})$*	(185.) ±9				
Tm IV (3,37)							
$f^{11}d$	$\left(\frac{15}{2},\frac{3}{2}\right)$	$(^5L^o_6)$*	(82.) ±3	f^{12}		$^3H_6$	0.000
$f^{11}s$		$(^5I^o_8)$	(107.) ±5	$f^{11}p$	$\left(\frac{15}{2},\frac{1}{2}\right)$	$(^5K_7)$*	(155.) ±5
				$f^{10}d^2$		$(^7L_{10})$*	(190.) ±9

Table XIV - Ytterbium

Odd Terms			$10^3\ cm^{-1}$	Even Terms			$10^3\ cm^{-1}$
Yb II (63, 64)							
$f^{13}s^2$		$^2F^o_{7/2}$	21.419	$f^{14}s$		$^2S_{1/2}$	0.000
$f^{13}ds$	$^3[\frac{3}{2}]$	$(^4G^o_{5/2})*$	26.759	$f^{14}d$		$^2D_{3/2}$	22.961
$f^{14}p$		$^2P^o_{1/2}$	27.062	$f^{13}ps$	$\frac{7}{2},0$	$(^4F_{7/2})*$	47.912
$f^{13}d^2$	$^3[\frac{5}{2}]$	$(^4G^o_{5/2})*$	45.013	$f^{13}dp$	$\frac{7}{2},2$	$(^4F_{3/2})*$	55.702
$f^{13}p^2$	$(\frac{7}{2},0)$	$(^4F^o_{7/2})*$	(81.) ±5	$f^{12}d^2s$		$(^6K_{9/2})*$	(93.) ±9
				$f^{12}ds^2$	$(6,\frac{3}{2})$	$(^4H_{9/2})*$	(97.) ±4
				$f^{12}d^3$		$(^6K_{9/2})*$	(108.) ±9
Yb III (65-66)							
$f^{13}d$	$\frac{7}{2},\frac{3}{2}$	$^3P^o_2$ *	33.385	f^{14}		$^1S_0$	0.000
$f^{13}s$		$^3F^o_4$	34.656	$f^{13}p$	$\frac{7}{2},\frac{1}{2}$	$(^3D_3)*$	72.140
$f^{12}dp$	(6,2)	$(^5I^o_4)*$	(150.) ±4	$f^{12}d^2$	(6,2)	$(^5I_4)*$	(103.) ±3
$f^{12}ps$	(6,0)	$(^5I^o_6)*$	(160.) ±4	$f^{12}ds$	(6,1)	$(^5I_5)*$	(114.) ±2
				$f^{12}s^2$		$(^3H_6)$	(125.) ±8
				$f^{12}p^2$	(6,0)	$(^5H_6)*$	(200.) ±9
Yb IV (65)							
f^{13}		$^2F^o_{7/2}$	0.000	$f^{12}d$	$(6,\frac{3}{2})$	$(^4H_{9/2})*$	88.195
$f^{12}p$	$(6,\frac{1}{2})$	$(^4H^o_{11/2})*$	(160.)±4	$f^{12}s$		$(^4H_{13/2})$	(114.) ±4
$f^{11}d^2$		$(^6I^o_{19/2})*$	(195.) ±9				

Table XV. Lutecium

Lu II (67, 68)

Odd Terms		10^3 cm^{-1}	Even Terms		10^3 cm^{-1}
$f^{14}ps$	$^3P^o_0$	27.264	$f^{14}s^2$	$^1S_0$	0.000
$f^{14}dp$	$^3F^o_2$	41.225	$f^{14}ds$	$^3D_1$	11.796
$f^{13}ds^2$	$(^3F^o_2)$*	(87.)±4	$f^{14}d^2$	$^3F_2$	29.406
$f^{13}d^2s$	$(^5H^o_6)$*	(88.)±9	$f^{14}p^2$	$(^3P_0)$	(62.)±5
$f^{13}d^3$	$(^5H^o_6)$*	(105.)±9	$f^{13}dps(\frac{7}{2},\frac{3}{2})$	$(^5G_2)$*	(114.)±9
			$f^{13}d^2p$	$(^5I_7)$*	(119.)±9

Lu III (69-72)

Odd Terms		10^3 cm^{-1}	Even Terms		10^3 cm^{-1}
$f^{14}p$	$^2P^o_{1/2}$	38.402	$f^{14}s$	$^2S_{1/2}$	0.000
$f^{13}d^2(3[\frac{5}{2}])$	$(^4G^o_{5/2})$*	(83.)±5	$f^{14}d$	$^2D_{3/2}$	5.708
$f^{13}ds(3[\frac{3}{2}])$	$(^4G^o_{5/2})$*	(92.)±2	$f^{13}dp\ (\frac{7}{2},2)$	$(^4F_{3/2})$*	(129.)±9
$f^{13}s^2$	$(^2F^o_{7/2})$	(101.)±5	$f^{13}ps\ (\frac{7}{2},0)$	$(^4F_{7/2})$*	(137.)±9

Lu IV (72)

Odd Terms		10^3 cm^{-1}	Even Terms		10^3 cm^{-1}
$f^{13}d\ (\frac{7}{2},\frac{3}{2})$	$(^3P^o_2)$*	(100.)±3	f^{14}	$^1S_0$	0.000
$f^{13}s$	$(^3F^o_4)$	(126.)±9	$f^{13}p\ (\frac{7}{2},\frac{1}{2})$	$(^3D_3)$*	(172.)±5
			$f^{12}d^2\ (6,2)$	$(^5I_4)$*	(215.)±9

Table XVI. Actinium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Ac II (11)			
ps	$^3P^o_0$	20.956	s^2	$^1S_0$	0.000
dp	$^3F^o_2$	26.447	ds	$^3D_1$	4.740
fs	$^3F^o_2$	28.201	d^2	$^3F_2$	13.236
fd	$^3H^o_4$	38.907	p^2	$(^3P_0)$	(49.)±3
			fp	$^3F_2$*	54.633
			f^2	$(^3H_4)$	(69.)±5
		Ac III (11)			
f	$^2F^o_{5/2}$	23.455	s	$^2S_{1/2}$	0.000
p	$^2P^o_{1/2}$	29.466	d	$^2D_{3/2}$	0.801

Table XVII. Thorium

Th II (73, 74)

Odd Terms		10^{-3} cm^{-1}	Even Terms		10^{-3} cm^{-1}
fs^2	$^2F^\circ_{5/2}$	4.490	ds^2	$^2D_{3/2}$	0.000
fds	$^4H^\circ_{7/2}$	6.168	d^2s	$^4F_{5/2}$*	1.522
fd^2	$^4H^\circ_{7/2}$*	12.486	d^3	$^4F_{3/2}$	7.001
dps	$(^4F^\circ_{3/2})$	(21.)±3	f^2s	$^4H_{7/2}$	(22.)±1
ps^2	$(^2P^\circ_{1/2})$	(27.)±8	fps	$^4G_{5/2}$	26.489?
d^2p	$^4F^\circ_{3/2}$*	36.39	f^2d	$(^4I_{9/2})$*	(31.)±3
f^2p	$(^4I^\circ_{9/2})$	(48.)±2	fdp	$(^4I_{9/2})$	(31.)±1
fp^2	$(^4G^\circ_{5/2})$	(54.)±4			
f^3	$(^4I^\circ_{9/2})$	(55.)±5			

Th III (73, 75, 76)

fd	$\frac{5}{2},\frac{3}{2}$	$^3H^\circ_4$	0.810	d^2		$^3F_2$	0.000
fs	$\frac{5}{2},\frac{1}{2}$	$^3F^\circ_3$*	3.337	ds	$\frac{3}{2},\frac{1}{2}$	$^3D_1$	5.461
dp	$\frac{3}{2},\frac{1}{2}$	$^3F^\circ_2$	37.217	s^2		$^1S_0$	11.898
ps	$\frac{1}{2},\frac{1}{2}$	$^3P^\circ_0$	42.196	f^2		$^3H_4$	15.959
				fp	$\frac{5}{2},\frac{1}{2}$	$^3G_3$	34.372
				p^2		$(^3P_0)$	(80.)±5

Th IV (75, 77)

f	$^2F^\circ_{5/2}$	0.000	d	$^2D_{3/2}$	9.193
p	$^2P^\circ_{1/2}$	60.239	s	$^2S_{1/2}$	23.130

Table XVIII. Protoactinium

Odd Terms — $10^3\ cm^{-1}$ — Even Terms

Pa II (78-80)

Odd Terms			Even Terms		
fds^2	$(^3H^o_4)$	(6.)±3	f^2s^2	$^3H_4$	0.000
fd^2s	$(^5H^o_3)$*	(6.)±4	f^2ds	$^5K_5$	0.823
f^3s	$(^5I^o_4)$	(8.)±1	f^2d^2	$(^5L_6)$	(6.)
fd^3	$(^5I^o_4)$	(11.)±5	d^2s^2	$(^3F_2)$	(25.)±5
f^3d	$(^5L^o_6)$	(16.)±3	fdps	$(^5I_4)$	(28.)±5
f^2ps	$(^5I^o_4)$	22.550?	fps^2	$(^3F_3)$*	(33.)±8
f^2dp	$(^5L^o_6)$	(26.)	f^3p	$(^5K_5)$	(33.)±2
			f^4	$(^5I_4)$	(38.)±6
			fd^2p	$(^5K_5)$	(41.)±4
			f^2p^2	$(^5I_4)$	(50.)±5

Pa III (79)

Odd Terms			Even Terms		
f^3	$(^4I^o_{9/2})$	(4.5)±1	f^2d	$^4I_{11/2}$*	0.000
fd^2	$(^4H^o_{7/2})$*	(10.)±6	f^2s	$(^4H_{7/2})$	(4.)
fds	$(^4H^o_{7/2})$	(17.)±4	d^2s	$(^4F_{5/2})$*	(45.)±10
fs^2	$(^2F^o_{5/2})$	(26.)±6	fdp	$(^4I_{9/2})$	(50.)±6
f^2p	$(^4I^o_{9/2})$	(36.)	fps	$(^4G_{5/2})$	(57.)±6
fp^2	$(^4G^o_{5/2})$	(95.)±8			

Pa IV

Odd Terms			Even Terms		
fd	$(^3H^o_4)$	(20.)±6	f^2	$(^3H_4)$	0.000
fs	$(^3F^o_2)$	(37.)±7	d^2	$(^3F_2)$	(45.)±10
			fp	$(^3G_3)$	(75.)±5

Table XIX. Uranium

Odd Terms		10^3 cm^{-1}	Even Terms		
		U II (81-84)			
f^3s^2	$^4I^o_{9/2}$	0.000	f^4s	$^6I_{7/2}$	4.664
f^3ds	$^6L^o_{11/2}$	0.289	f^4d	$^6L_{11/2}$	12.514
f^3d^2	$^6M^o_{13/2}$	4.585	f^2d^2s	$^6L_{11/2}$	13.783
f^4p	$(^6K^o_{9/2})$	(29.)±2	f^2ds^2	$^4K_{11/2}$	15.680
f^5	$(^6H^o_{5/2})$	(32.)±7	f^2d^3	$(^6L_{11/2})$	(19.)±3
f^2dps	$(^6L^o_{11/2})$	(38.)±5	f^3ps	$^6K_{9/2}$	23.315
f^2ps^2	$(^4I^o_{9/2})$	(44.)±5	f^3dp	$^6M_{13/2}$	26.191
f^3p^2	$(^6K^o_{9/2})$	(50.)±2			
fd^2s^2	$(^4H^o_{7/2})$*	(50.)±10			
f^2d^2p	$(^6M^o_{13/2})$	(51.)±2			
		(85) **U III**			
f^3d	$^5L^o_6$	(0.)±1	f^4	$(^5I_4)$	(1.)±1
f^3s	$(^5I^o_4)$	(4.)±2	f^2d^2	$(^5L_6)$	(20.)±7
f^2dp	$(^5L^o_6)$	(61.)±10	f^2ds	$(^5K_5)$	(27.)±5
f^2ps	$(^5I^o_4)$	(69.)±10	f^3p	$(^5K_5)$	(36.)±6
fds^2	$(^3H^o_4)$	(83.)±10	f^2s^2	$(^3H_4)$	(37.)±6
			d^2s^2	$(^3F_2)$	(70.)±10
			f^2p^2	$(^5I_4)$	(108.)±9
		U IV			
f^3	$(^4I^o_{9/2})$	0.000	f^2d	$(^4K_{11/2})$	(30.)±6
fd^2	$(^4H^o_{7/2})$	(65.)±10	f^2s	$(^4H_{7/2})$	(50.)±7
f^2p	$(^4I^o_{9/2})$	(89.)±9			

Table XX. Neptunium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Np II			
f^5s	$(^7H^o_2)$	(0.)	f^4s^2	$(^5I_4)$	(2.)±3
f^5d	$(^7K^o_4)$	(10.)	f^4ds	$(^7L_5)$	(2.)±2
f^3d^2s	$(^7M^o_6)$	(23.)±5	f^4d^2	$(^7M_6)$	(7.)±3
f^4ps	$(^7K^o_4)$	(25.)±3	f^6	$(^7F_0)$	(22.)±8
f^3ds^2	$(^5L^o_6)$	(26.)±4	f^5p	$(^7I_3)$	(23.)±1
f^4dp	$(^7M^o_6)$	(28.)±4	f^3dps	$(^7M_6)$	(50.)±5
f^3d^3	$(^7M^o_6)$	(29.)±6	f^4p^2	$(^7K_4)$	(53.)±5
			f^3ps^2	$(^5K_5)$	(55.)±10
			f^3d^2p	$(^7N_7)$	(60.)±7
			$f^2d^2s^2$	$(^5L_6)$	(70.)±10
		Np III			
f^5	$(^6H^o_{5/2})$	(0.)	f^4d	$(^6L_{11/2})$	(6.)±3
f^3d^2	$(^6M^o_{13/2})$	(34.)±6	f^4s	$(^6I_{7/2})$	(10.)±4
f^3ds	$(^6L^o_{11/2})$	(41.)±5	f^3dp	$(^6M_{13/2})$	(76.)±6
f^4p	$(^6K^o_{9/2})$	(42.)±7	f^3ps	$(^6K_{9/2})$	(83.)±7
f^3s^2	$(^4I^o_{9/2})$	(50.)±7			
f^3p^2	$(^6K^o_{9/2})$	(123.)±9			
		Np IV			
f^3d	$(^5L^o_6)$	(38.)±7	f^4	$(^5I_4)$	0.000
f^3s	$(^5I^o_4)$	(58.)±10	f^2d^2	$(^5L_6)$	(85.)±10
			f^3p	$(^5K_5)$	(99.)±10

Table XXI. Plutonium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
		Pu II (80, 86 - 90)			
f^5s^2	$^6H^o_{5/2}$	8.199	f^6s	$^8F_{1/2}$	0.000
f^5ds	$^8K^o_{7/2}$	8.710	f^6d	$^8H_{3/2}$	12.008
f^7	$(^8S^o_{7/2})$	(14.)±8	f^5ps	$^8I_{5/2}$	30.956
f^5d^2	$^8L^o_{9/2}$	17.297	f^5dp	$(^8L_{9/2})$	(34.)±5
f^6p	$^8G^o_{1/2}$	22.039	f^4d^2s	$^8M_{11/2}$	37.641
f^5p^2	$(^8I^o_{5/2})$	(60.)±5	f^4ds^2	$^6L_{11/2}$	(41.5)±2
f^4dps	$(^8M^o_{11/2})$	(65.)±7	f^4d^3	$(^8M_{11/2})$	(45.)±5
f^4d^2p	$(^8N^o_{13/2})$	(75.)±5			
$f^3d^2s^2$	$(^6M^o_{13/2})$	(95.)±10			
		Pu III			
f^5d	$(^7K^o_4)$	(13.)±3	f^6	$(^7F_0)$	0.000
f^5s	$(^7H^o_2)$	(17.)±4	f^5p	$(^7I_3)$	(49.)±5
f^4dp	$(^7M^o_6)$	(93.)±7	f^4d^2	$(^7M_6)$	(50.)±6
f^4ps	$(^7K^o_4)$	(98.)±7	f^4ds	$(^7L_5)$	(57.)±5
			f^4s^2	$(^5I_4)$	(65.)±6
			f^4p^2	$(^7K_4)$	(140.)±9
		Pu IV			
f^5	$(^6H^o_{5/2})$	0.000	f^4d	$(^6L_{11/2})$	(47.)±5
f^3d^2	$(^6M^o_{13/2})$	(105.)±10	f^4s	$(^6I_{7/2})$	(65.)±6
f^4p	$(^6K^o_{9/2})$	(106.)±6			

Table XXII. Americium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
		Am II (89, 91)			
f^7s	$^9S^o_4$	0.000	f^6s^2	$(^7F_0)$	(18.5)±1
f^7d	$(^9D^o_2)$	(14.)	f^6ds	$(^9H_1)$	(20.5)±1
f^6ps	$(^9G^o_0)$	(40.5)±1	f^7p	$(^9P_3)$	(24.)±1
f^6dp	$(^9I^o_2)$	(44.)±3	f^6d^2	$(^9I_2)$	(29.)±2
f^5d^2s	$(^9L^o_4)$	(59.)±5	f^8	$(^7F_6)$	(32.)±9
f^5ds^2	$(^7K^o_4)$	(60.)±5	f^6p^2	$(^9G_0)$	(70.)±3
f^5d^3	$(^9L^o_4)$	(62.)±7	f^5dps	$(^9L_4)$	(83.)±6
			f^5d^2p	$(^9M_5)$	(97.)±8
		Am III (92)			
f^7	$(^8S^o_{7/2})$	0.000	f^6d	$(^8H_{3/2})$	(24.)±3
f^6p	$(^8G^o_{1/2})$	(57.)±4	f^6s	$(^8F_{1/2})$	(27.)±4
f^5d^2	$(^8L^o_{9/2})$	(70.)±5	f^5dp	$(^8L_{9/2})$	(113.)±6
f^5ds	$(^8K^o_{7/2})$	(77.)±5	f^5ps	$(^8I_{5/2})$	(117.)±6
f^5s^2	$(^6H^o_{5/2})$	(84.)±6			
f^5p^2	$(^8I^o_{5/2})$	(160.)±7			
		Am IV (93, 94)			
f^5d	$(^7K^o_4)$	(56.)±5	f^6	$^7F_0$	0.000
f^5s	$(^7H^o_2)$	(74.)±6	f^5p	$(^7I_3)$	(114.)±6
			f^4d^2	$(^7M_6)$	(125.)±8

Table XXIII. Curium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		

Cm II (95)

f^7s^2	$^8S^o_{7/2}$	0.000	f^8s	$^8F_{13/2}$	2.094
f^7ds	$^{10}D^o_{5/2}$	4.011	f^8d	$(^8G_{15/2})$*	(18.)±1
f^7d^2	$^{10}F^o_{3/2}$	14.830	f^7ps	$(^{10}P_{7/2})$	(23.)
f^9	$(^6H^o_{15/2})$	(26.)±9	f^7dp	$(^{10}F_{3/2})$	(29.)
$f^8p(6,\frac{1}{2})$	$(^8F^o_{11/2})$*	(26.)±1	f^6ds^2	$(^8H_{3/2})$	(54.)±2
f^7p^2	$(^{10}P^o_{7/2})$	(53.)	f^6d^2s	$(^{10}I_{3/2})$	(54.)±3
f^6dps	$(^{10}I^o_{3/2})$	(77.)±4	f^6d^3	$(^{10}I_{3/2})$	(58.)±5
f^6d^2p	$(^{10}K^o_{5/2})$	(93.)±6			

Cm III

f^7s	$(^9S^o_4)$	(5.)±5	f^8	$(^7F_6)$	0.
f^7d	$(^9D^o_2)$	(5.)±3	f^7p	$(^9P_3)$	(36.)±5
f^6dp	$(^9I^o_2)$	(103.)±8	f^6d^2	$(^9I_2)$	(63.)±7
f^6ps	$(^9G^o_0)$	(105.)±8	f^6ds	$(^9H_1)$	(67.)±7
			f^6s^2	$(^7F_0)$	(72.)±8
			f^6p^2	$(^9G_0)$	(145.)±9

Cm IV (96)

f^7	$^8S^o_{7/2}$	0.000	f^6d	$(^8H_{3/2})$	(69.)±5
f^6p	$(^8G^o_{1/2})$	(126.)±6	f^6s	$(^8F_{1/2})$	(86.)±6
f^5d^2	$(^8L^o_{9/2})$	(150.)±8			

Table XXIV. Berkelium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Bk II (97,98)			
f^9s	${}^7H^o_8$	0.000	f^8s^2	$({}^7F_6)$	(5.)±3
f^9d	$({}^7H^o_8)$*	(18.)±1	f^8ds	$({}^9G_7)$*	(11.)±2
f^8ps (6,0)	$({}^9F^o_6)$*	(29.)±3	f^{10}	$({}^5I_8)$	(16.)±5
f^8dp	$({}^9H^o_8)$*	(37.)±3	f^8d^2	$({}^9H_8)$*	(22.)±3
f^7ds^2	$({}^9D^o_2)$	(43.)±6	f^9p $\left(\frac{15}{2},\frac{1}{2}\right)$	$({}^7H_7)$*	(25.)±1
f^7d^2s	$({}^{11}F^o_2)$	(55.)±6	f^8p^2 (6,0)	$({}^9G_6)$*	(60.)±4
f^7d^3	$({}^{11}F^o_2)$	(60.)±7	f^7dps	$({}^{11}F_2)$	(66.)±7
			f^7d^2p	$({}^{11}G_1)$	(95.)±8
		Bk III			
f^9	$({}^6H^o_{15/2})$	0.0	f^8s	$({}^8F_{13/2})$	(11.)±6
f^8p $(6,\frac{1}{2})$	$({}^8F^o_{11/2})$*	(44.)±6	f^8d	$({}^8G_{15/2})$*	(14.)±5
f^7d^2	$({}^{10}F^o_{3/2})$	(56.)±7	f^7ps	$({}^{10}P_{7/2})$	(92.)±8
f^7ds	$({}^{10}D^o_{5/2})$	(56.)±7	f^7dp	$({}^{10}F_{3/2})$	(93.)±8
f^7s^2	$({}^8S^o_{7/2})$	(59.)±8			
f^7p^2	$({}^{10}P^o_{7/2})$	(133.)±9			
		Bk IV			
f^7d	$({}^9D^o_2)$	(52.)±5	f^8	${}^7F_6$	0.0
f^7s	$({}^9S^o_4)$	(65.)±6	f^7p	$({}^9P_3)$	(107.)±6
			f^6d^2	$({}^9I_2)$	(140.)±8

Table XXV. Californium

Odd Terms				Even Terms		
			10^3 cm^{-1}			

Cf II (98-100)

f^9s^2	$(^6H^o_{15/2})$	(12.)±4	$f^{10}s$	$^6I_{17/2}$	0.0
f^{11}	$(^4I^o_{15/2})$	(16.)±4	$f^{10}d$	$(^6I_{17/2})$*	(20.)±2
f^9ds	$(^8I^o_{17/2})$*	(20.5)±3	$f^9ps\left(\frac{15}{2},0\right)$	$(^8H_{15/2})$*	(36.)±4
$f^{10}p\left(8,\frac{1}{2}\right)$	$(^6K^o_{15/2})$*	(26.)±1	f^9dp	$(^8K_{19/2})$*	(47.)±4
f^9d^2	$(^8K^o_{19/2})$*	(34.)±4	f^8ds^2	$(^8G_{11/2})$*	(62.)±5
$f^9p^2\left(\frac{15}{2},0\right)$	$(^8H^o_{15/2})$*	(68.)±5	f^8d^2s	$(^{10}G_{15/2})$*	(66.5)±5
f^8dps	$(^{10}H^o_{17/2})$*	(85.)±6	f^8d^3	$(^{10}H_{17/2})$*	(73.)±6

Cf III

f^9s	$(^7H^o_8)$	(19.)±6	f^{10}	$(^5I_8)$	(0.0)
f^9d	$(^7H^o_8)$*	(24.)±5	$f^9p\left(\frac{15}{2},\frac{1}{2}\right)$	$(^7H_7)$*	(52.)±6
f^8ps (6,0)	$(^9F^o_6)$*	(110.)±8	f^8ds	$(^9G_7)$*	(76.)±7
f^8dp	$(^9H^o_8)$*	(113.)±8	f^8s^2	$(^7F_6)$*	(77.)±8
			f^8d^2	$(^9H_8)$*	(78.)±7
			f^8p^2 (6,0)	$(^9G_7)$*	(150.)±9

Cf IV (101)

f^9	$^6H^o_{15/2}$	0.0	f^8d	$(^8G_{15/2})$*	(64.)±5
$f^8p\left(6,\frac{1}{2}\right)$	$(^8F_{11/2})$*	(119.)±6	f^8s	$(^9F_{13/2})$	(77.)±6
f^7d^2	$(^{10}F^o_{3/2})$	(140.)±8			

Table XXVI. Einsteinium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		$10^3\ cm^{-1}$
Es II (98, 102)					
$f^{11}s$	$^5I^o_8$	0.0	$f^{10}s^2$	$(^5I_8)$	(12.)±5
$f^{11}d\left(\frac{15}{2},\frac{3}{2}\right)$	$(^5K^o_6)$*	(22.)±2	f^{12}	$(^3H_6)$	(17.)±4
$f^{10}ps\ (8,0)$	$(^7I^o_8)$*	(36.5)±5	$f^{10}ds$	$(^7K_9)$*	(23.)±2
$f^{10}dp$	$(^7L^o_{10})$*	(50.)±3	$f^{11}p\left(\frac{15}{2},\frac{1}{2}\right)$	$(^5I_7)$*	(27.)±1
f^9ds^2	$(^7H^o_8)$*	(73.)±6	$f^{10}d^2$	$(^7L_{10})$*	(38.)±5
f^9d^2s	$(^9K^o_{10})$*	(80.)±5	$f^{10}p^2\ (8,0)$	$(^7I_8)$*	(69.)±7
f^9d^3	$(^9K^o_{10})$*	(90.)±7	f^9dps	$(^9K_{10})$*	(97.)±8
Es III (103)					
f^{11}	$(^4I^o_{15/2})$	0.0	$f^{10}s$	$(^6I_{17/2})$	(20.)±6
$f^{10}p\ (8,\frac{1}{2})$	$(^6K^o_{15/2})$*	(54.)±6	$f^{10}d$	$(^6H_{15/2})$*	(27.)±5
f^9s^2	$(^6H^o_{15/2})$*	(86.)±8	$f^9ps\left(\frac{15}{2},0\right)$	$(^8I_{15/2})$*	(120.)±8
f^9ds	$(^8I^o_{17/2})$*	(88.)±7	f^9dp	$(^8L_{21/2})$*	(125.)±9
f^9d^2	$(^8L^o_{21/2})$*	(92.)±7			
$f^9p^2\left(\frac{15}{2},0\right)$	$(^8H^o_{15/2})$*	(165.)±10			
Es IV					
f^9d	$(^7H^o_8)$*	(75.)±5	f^{10}	$(^5I_8)$	0.0
f^9s	$(^7H^o_8)$	(86.)±6	$f^9p\left(\frac{15}{2},\frac{1}{2}\right)$	$(^7H_7)$*	(129.)±6
			f^8d^2	$(^9H_8)$*	(155.)±10

Table XXVII. Fermium

Odd Terms		$10^3\ cm^{-1}$	Even Terms		
		Fm II			
$f^{11}s^2$	$(^4I^o_{15/2})$	(9.)±5	$f^{12}s$	$(^4H_{13/2})$	0.0
f^{13}	$(^2F^o_{7/2})$	(14.)±8	$f^{12}d$	$(^4H_{9/2})$*	(24.)±2
$f^{11}ds\left(\frac{15}{2},1\right)$	$(^6K^o_{13/2})$*	(23.)±5	$f^{11}ps\left(\frac{15}{2},0\right)$	$(^6I_{15/2})$*	(34.)±5
$f^{12}p\ (6,\frac{1}{2})$	$(^4H^o_{11/2})$*	(27.)±2	$f^{11}dp\left(\frac{15}{2},2\right)$	$(^6L_{11/2})$*	(50.)±6
$f^{11}d^2\left(\frac{15}{2},2\right)$	$(^6L_{11/2})$*	(40.)±7	$f^{10}ds^2$	$(^6I_{17/2})$*	(78.)±8
$f^{11}p^2\left(\frac{15}{2},0\right)$	$(^6I^o_{15/2})$*	(67.)±7	$f^{10}d^2s$	$(^8L_{21/2})$*	(86.)±8
$f^{10}dps$	$(^8L^o_{21/2})$*	(102.)±9	$f^{10}d^3$	$(^8L_{21/2})$*	(99.)±9
		Fm III			
$f^{11}s$	$(^5I^o_8)$	(17.)±6	f^{12}	$(^3H_6)$	0.0
$f^{11}d\left(\frac{15}{2},\frac{3}{2}\right)$	$(^5K^o_6)$*	(27.)±5	$f^{11}p\left(\frac{15}{2},\frac{1}{2}\right)$	$(^5I_7)$*	(52.)±6
$f^{10}ps\ (8,0)$	$(^7I^o_8)$*	(123.)±8	$f^{10}s^2$	$(^5I_8)$	(89.)±8
$f^{10}dp$	$(^7L^o_{10})$*	(131.)±9	$f^{10}ds$	$(^7K_7)$*	(93.)±7
			$f^{10}d^2$	$(^7L_{10})$*	(98.)±7
			$f^{10}p^2\ (8,0)$	$(^7I_8)$*	(165.)±9
		Fm IV			
f^{11}	$(^4I^o_{15/2})$	0.0	$f^{10}d$	$(^6I_{17/2})$*	(81.)±5
$f^{10}p\ (8,\frac{1}{2})$	$(^6I^o_{15/2})$*	(133.)±6	$f^{10}s$	$(^6I_{17/2})$	(89.)±6
$f^9d^2\left(\frac{15}{2},2\right)$	$(^8K^o_{11/2})$*	(170.)±10			

Table XXVIII. Mendelevium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Md II			
$f^{13}s$	$(^3F^o_4)$	(0.0)	f^{14}	$^1S_0$	(0.0)±5
$f^{13}d\left(\frac{7}{2},\frac{3}{2}\right)$	$(^3P^o_2)$*	(26.)±2	$f^{12}s^2$	$(^3H_6)$	(17.)±5
$f^{12}ps$ (6,0)	$(^5H^o_6)$*	(42.)±5	$f^{13}p\left(\frac{7}{2},\frac{1}{2}\right)$	$(^3D_3)$*	(27.)±2
$f^{12}dp$ (6,2)	$(^5I^o_4)$*	(61.)±6	$f^{12}ds(^3[4])$	$(^5I_5)$*	(33.)±5
$f^{11}ds^2\left(\frac{15}{2},\frac{3}{2}\right)$	$(^5K^o_6)$*	(86.)±7	$f^{12}d^2(6,2)$	$(^5I_4)$*	(52.)±6
$f^{11}d^2s$	$(^7L^o_{10})$*	(98.)±8	$f^{12}p^2(6,0)$	$(^5H_6)$*	(76.)±8
		Md III			
f^{13}	$(^2F^o_{7/2})$	0.0	$f^{12}s$	$(^4H_{13/2})$	(24.)±6
$f^{12}p$ $(6,\frac{1}{2})$	$(^4H^o_{11/2})$*	(60.)±6	$f^{12}d$ $(6,\frac{3}{2})$	$(^4H_{9/2})$*	(37.)±5
$f^{11}s^2$	$(^4I^o_{15/2})$	(93.)±8	$f^{11}ps\left(\frac{15}{2},0\right)$	$(^6I_{15/2})$*	(127.)±8
$f^{11}ds\left(\frac{15}{2},1\right)$	$(^6K^o_{13/2})$*	(100.)±7	$f^{11}dp\left(\frac{15}{2},2\right)$	$(^6K_{11/2})$*	(138.)±9
$f^{11}d^2\left(\frac{15}{2},2\right)$	$(^6K^o_{11/2})$*	(110.)±7			
$f^{11}p^2\left(\frac{15}{2},0\right)$	$(^6I^o_{15/2})$*	(170.)±10			
		Md IV			
$f^{11}d$ $\left(\frac{15}{2},\frac{3}{2}\right)$	$(^5K^o_6)$*	(83.)±5	f^{12}	$(^3H_6)$	0.0
$f^{11}s$	$(^5F^o_8)$	(88.)±6	$f^{11}p\left(\frac{15}{2},\frac{1}{2}\right)$	$(^5I_7)$*	(133.)±6
			$f^{10}d^2$	$(^7L_{10})$*	(175.)±10

Table XXIX. Nobelium

Odd Terms		10^3 cm^{-1}	Even Terms		10^3 cm^{-1}
		No II			
$f^{13}s^2$	$(^2F^o_{7/2})$	(25.)±6	$f^{14}s$	$^2S_{1/2}$	0.0
$f^{14}p$	$(^2P^o_{1/2})$	(27.)±2	$f^{14}d$	$(^2D_{3/2})$	(30.)±1
$f^{13}ds(^3[\frac{3}{2}])$	$(^4G^o_{5/2})$*	(43.)±5	$f^{13}ps\ (\frac{7}{2},0)$	$(^4F_{7/2})$*	(51.)±6
$f^{13}d^2(^3[\frac{5}{2}])$	$(^4G^o_{5/2})$*	(66.)±7	$f^{13}dp\ (\frac{7}{2},2)$	$(^4F_{3/2})$*	(61.)±7
$f^{13}p^2\ (\frac{7}{2},0)$	$(^4F^o_{7/2})$*	(86.)±8			
		No III			
$f^{13}s$	$(^3F^o_4)$	(31.)±6	f^{14}	$^1S_0$	0.0
$f^{13}d\ (\frac{7}{2},\frac{3}{2})$	$(^3P^o_2)$*	(47.)±5	$f^{13}p\ (\frac{7}{2},\frac{1}{2})$	$(^3D_3)$*	(68.)±6
$f^{12}ps\ (6,0)$	$(^5H^o_6)$*	(145.)±8	$f^{12}s^2$	$(^3H_6)$	(110.)±8
$f^{12}dp\ (6,2)$	$(^5I^o_4)$*	(158.)±9	$f^{12}ds\ (6,1)$	$(^5I_5)$*	(119.)±7
			$f^{12}d^2\ (6,2)$	$(^5I_4)$*	(132.)±7
			$f^{12}p^2\ (6,0)$	$(^5H_6)$*	(190.)±10
		No IV			
f^{13}	$(^2F^o_{7/2})$	0.0	$f^{12}d\ (6,\frac{3}{2})$	$(^4H_{9/2})$*	(95.)±5
$f^{12}p\ (6,\frac{1}{2})$	$(^4H^o_{11/2})$*	(143.)±6	$f^{12}s$	$(^4H_{13/2})$	(97.)±6
$f^{11}d^2\ \frac{15}{2},2$	$(^6K^o_{11/2})$*	(190.)±10			

Table XXX. Lawrencium

Odd Terms		10^3 cm^{-1}	Even Terms		
		Lr II			
$f^{14}ps$	$(^3P^o_0)$	(26.)±2	$f^{14}s^2$	$^1S_0$	0.0
$f^{14}dp$	$(^3F^o_2)$	(52.)±4	$f^{14}ds$	$(^3D_1)$	(23.)±3
$f^{13}ds^2\left(\frac{7}{2},\frac{3}{2}\right)$	$(^3P^o_2)$*	(91.)±9	$f^{14}d^2$	$(^3F_2)$	(49.)±4
$f^{13}d^2s$	$(^5H^o_6)$*	(110.)±9	$f^{14}p^2$	$(^3P_0)$	(62.)±5
		Lr III			
$f^{14}p$	$(^2P^o_{1/2})$	(38.)±2	$f^{14}s$	$^2S_{1/2}$	0.0
$f^{13}s^2$	$(^2F^o_{7/2})$	(86.)±5	$f^{14}d$	$(^2D_{3/2})$	(20.)±2
$f^{13}ds(^3[\frac{3}{2}])$	$(^4G^o_{5/2})$*	(98.)±6	$f^{13}ps\ (\frac{7}{2},0)$	$(^4F_{7/2})$*	(121.)±6
$f^{13}d^2(^3[\frac{5}{2}])$	$(^4G^o_{5/2})$*	(115.)±6	$f^{13}dp\ (\frac{7}{2},2)$	$(^4F_{3/2})$*	(137.)±8
$f^{13}p^2\ (\frac{7}{2},0)$	$(^4F^o_{7/2})$*	(170.)±8			
		Lr IV			
$f^{13}s$	$(^3F^o_4)$	(105.)±7	f^{14}	$^1S_0$	0.0
$f^{13}d\ (\frac{7}{2},\frac{3}{2})$	$(^3P^o_2)$*	(105.)±6	$f^{13}p\ (\frac{7}{2},\frac{1}{2})$	$(^3D_3)$*	(152.)±7
			$f^{12}d^2\ (6,2)$	$(^5I_4)$*	(210.)±10

Table XXXI. Additional Energy Levels of the Neutral Atoms, 10^3 cm^{-1}.

La I	fd^2	$(^4H^o_{7/2})$*	(35.5)±1
	f^2s	$(^4H_{7/2})$	(52.)±10
Ce I	f^2d^2	$(^5L_6)$	(24.8)±1
	f^2dp	$(^5L^o_6)$	(26.6)
	f^3s	$(^5I^o_5)$	(42.)±8
Pr I	f^4s	$(^6I_{7/2})$	(40.)±6
	f^2p^2s	$(^6I_{7/2})$	(42.)±4
Nd I	f^5s	$(^7H^o_2)$	(40.)±5
	f^3p^2s	$(^7K^o_4)$	(46.)±3
Pm I	f^5d^2	$(^8L^o_{9/2})$	(23.)±1
	f^6s	$(^8F_{1/2})$	(34.)±4
	f^4p^2s	$(^8K_{7/2})$	(47.)±3
Sm I	f^6dp	$(^9I^o_2)$	25.809[b]
	f^5d^3	$(^9L^o_4)$	(32.)±2
Eu I	f^6ps^2	$(^8G^o_{1/2})$	(41.)
Gd I	f^8d^2	$(^9H_8)$*	(42.)±2
Tb I	f^8d^3	$(^{10}H_{17/2})$*	(25.)±1
	f^9d^2	$(^8K^o_{19/2})$*	(34.)±3
	$f^{10}s$	$(^6I_{17/2})$	(42.)±9
	$f^7d^2s^2$	$(^{10}F^o_{3/2})$	(45.)±5
Dy I	f^9d^3	$(^9K^o_{10})$*	(35.)±2
	$f^{11}s$	$(^5I^o_8)$	(45.)±9

Ho I	$f^{10}d^3$	$(^8L_{21/2})$*	(39.)±2
	$f^{12}s$	$(^4H_{13/2})$	(47.)±9
Er I	$f^{11}d^2p$	$(^7M_{11})$*	(38.5)±2
	$f^{11}d^3$	$(^7L^o_{10})$*	(39.)±3
	$f^{13}s$	$(^3F^o_4)$	(42.)±9
Tm I	$f^{14}s$	$(^2S_{1/2})$	(33.)±9
	$f^{13}d^2$	$(^4G^o_{5/2})$*	(44.5)±2
	$f^{12}d^2p$	$(^6L^o_{19/2})$*	(46.)±3
	$f^{12}d^3$	$(^6K_{17/2})$*	(48.)±4
Yb I	$f^{13}dps$ $\frac{7}{2},\frac{3}{2}$	$(^5G_2)$*	39.880[c]
	$f^{14}d^2$	$(^3F_2)$	47.584[c]
	$f^{13}d^2p$	$(^5G_2)$*	59.377[c]
Cm I	$f^6d^2s^2$	$(^9I_2)$	(50.)±7

b. ref. 60

c. ref. 104

Fig. 1. Promotion energies for f to d electrons of lanthanides reading down from top:

$$\left.\begin{array}{ll} \mathrm{IV} & f^{n-4}d - f^{n-3} \\ \mathrm{III} & f^{n-4}ds - f^{n-3}s \\ \mathrm{II} & f^{n-4}ds^2 - f^{n-3}s^2 \end{array}\right\} \quad q = n-4$$

$$\left.\begin{array}{ll} \mathrm{III} & f^{n-3}d - f^{n-2} \\ \mathrm{II} & f^{n-3}ds - f^{n-2}s \\ \mathrm{I} & f^{n-3}ds^2 - f^{n-2}s^2 \end{array}\right\} \quad q = n-3$$

$$\mathrm{II} \quad f^{n-2}d - f^{n-1} \qquad q = n-2$$

Fig. 2. Racah plots for lanthanides;reading down from top:

$$(f^{n-4}d - f^{n-3})\mathrm{IV} - (f^{n-4}ds - f^{n-3}s)\mathrm{III},\ q = n-4$$

$$(f^{n-3}d - f^{n-2})\mathrm{III} - (f^{n-3}ds - f^{n-2}s)\mathrm{II},\ q = n-3$$

$$(f^{n-3}ds - f^{n-2}s)\mathrm{II} - (f^{n-3}ds^2 - f^{n-2}s^2)\mathrm{I},\ q = n-3$$

Fig. 3. Promotion energies from 5d to 6s orbitals;reading down from top:

$$f^q s - f^q d \ \mathrm{IV}$$

$$f^q ds - f^q d^2 \ \mathrm{III}$$

$$f^q s - f^q d \ \mathrm{III}$$

$$f^q s^2 - f^q ds \ \mathrm{II}$$

$$f^q ds - f^q d^2 \ \mathrm{II}$$

$$f^q s - f^q d \ \mathrm{II}$$

$$f^q s^2 - f^q ds \ \mathrm{I}$$

Fig. 4. Promotion energies from 6p to 6s orbitals; reading down from top:

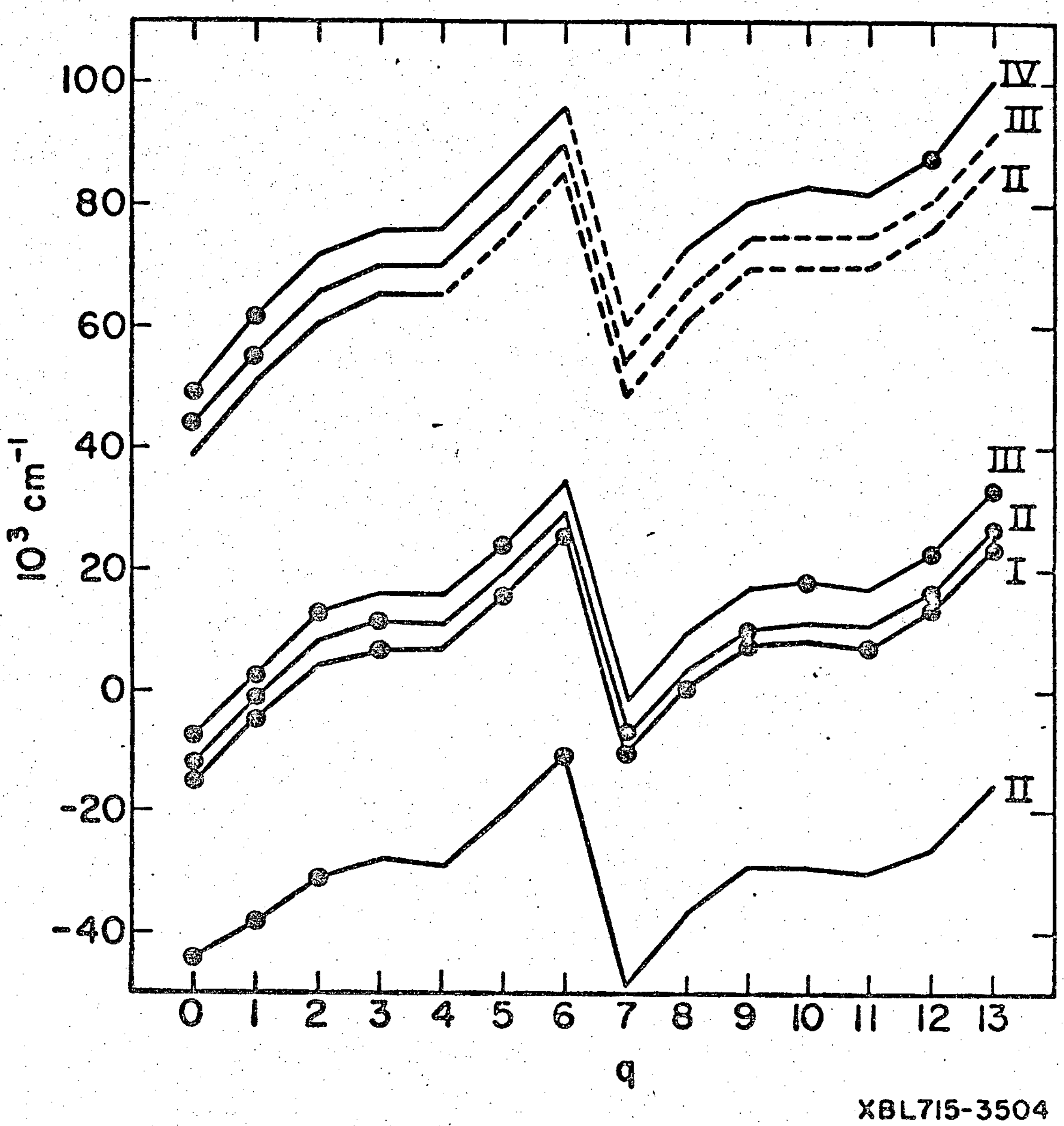
$$f^{n-4}p - f^{n-4}s \text{ IV}$$

$$f^{n-3}p - f^{n-3}s \text{ III}$$

$$f^{n-3}dp - f^{n-3}ds \text{ II}$$

$$f^{n-2}p - f^{n-2}s \text{ II}$$

$$f^{n-2}ps - f^{n-2}s^2 \text{ I}$$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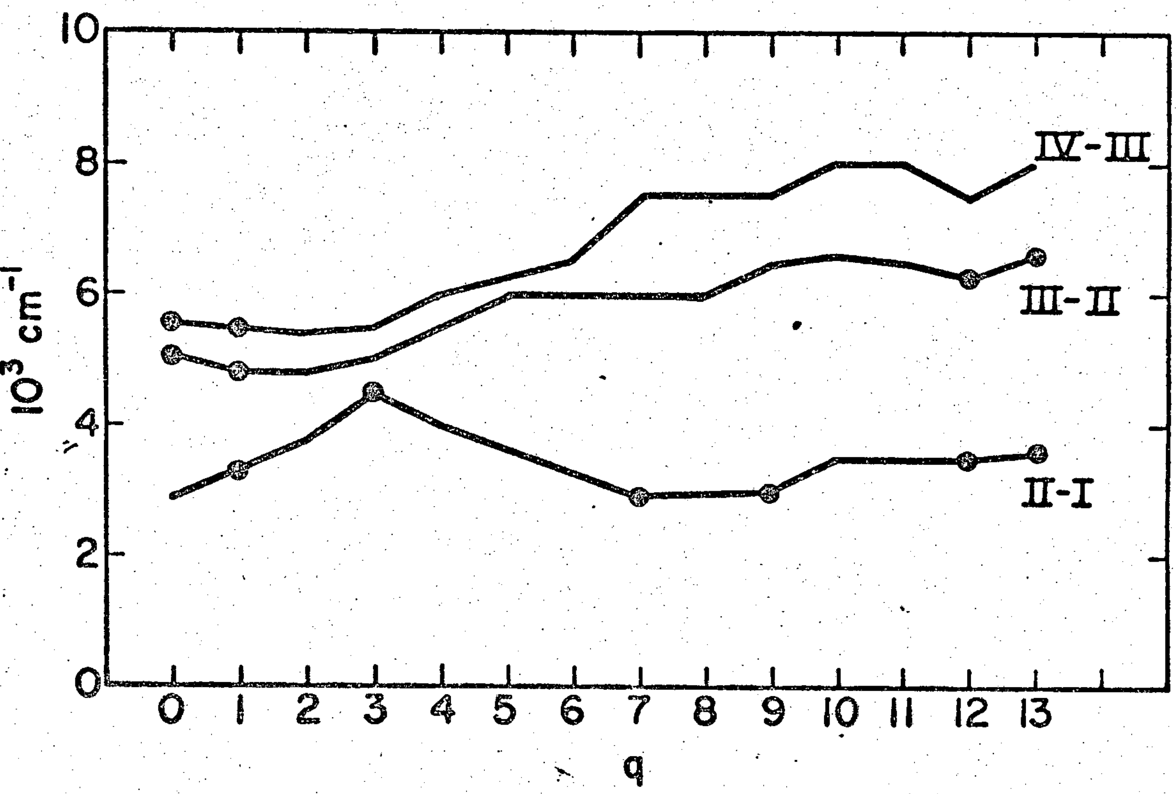
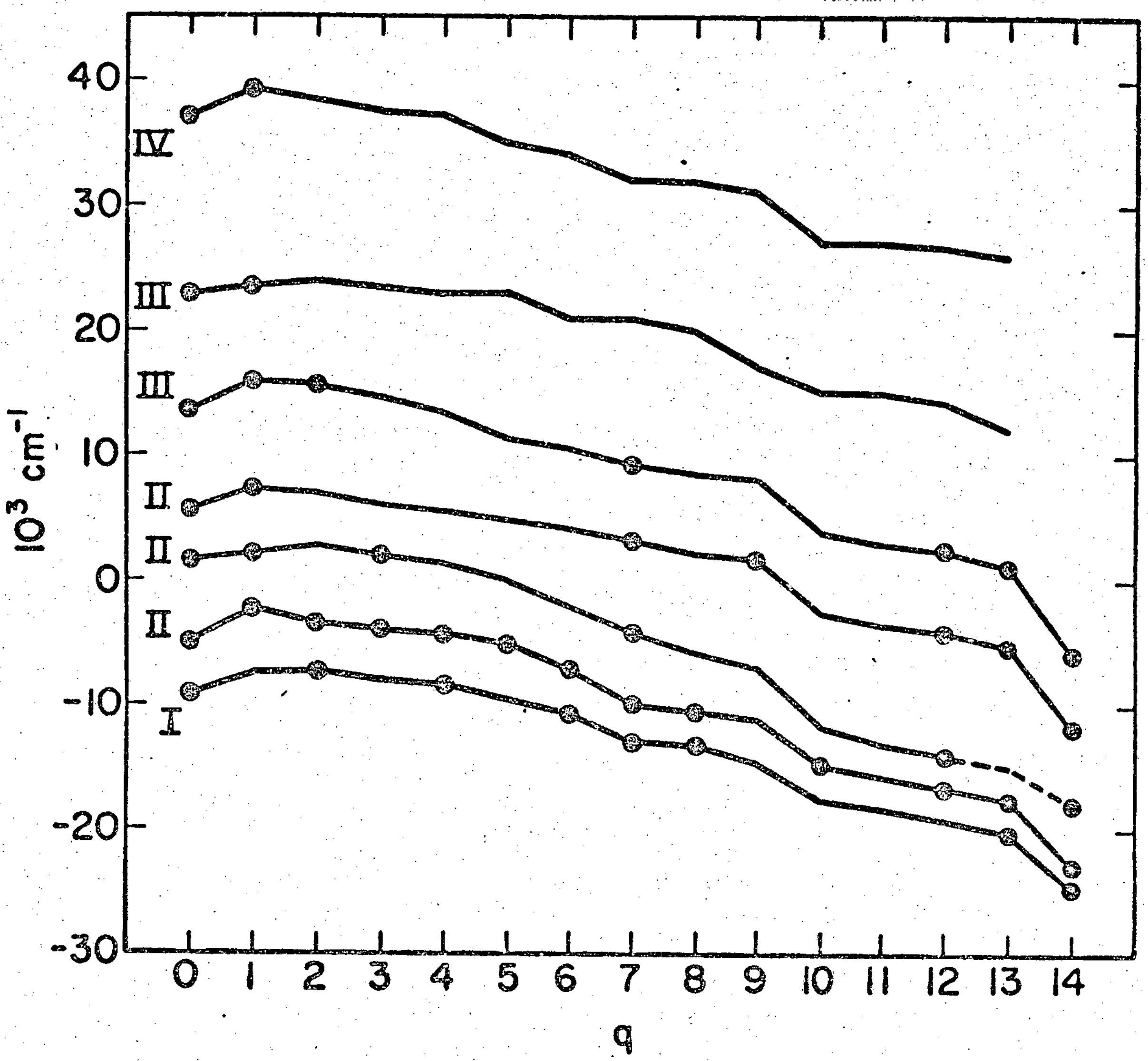
60
40
20
0
-20
-40
10^3 cm^{-1}
0
1
2
3
4
5
6
7
8
9
10
11
12
13
q
IV
III
II
III
II
I
II
XBL715-3504

Figure 1.



XBL715-3507

Figure 2.



XBL715-3505

Figure 3

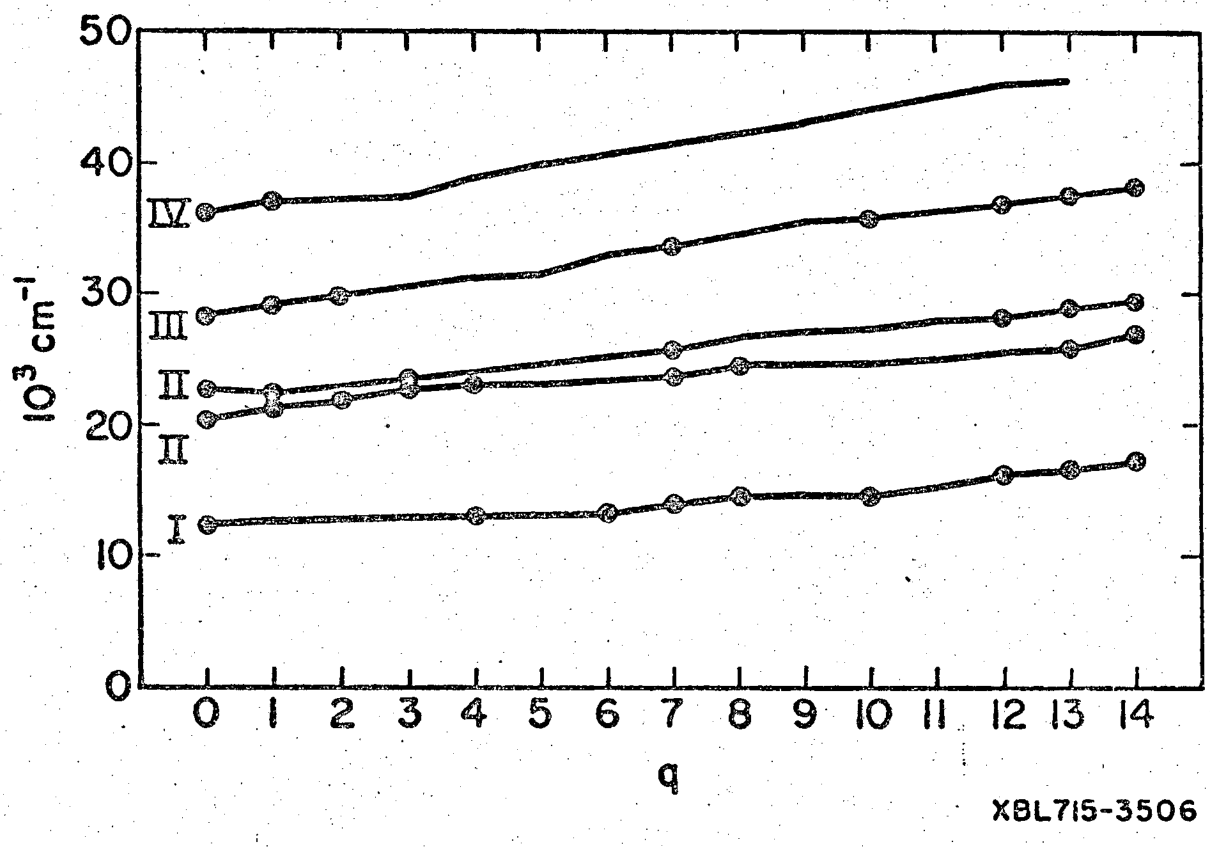

50
40
30
20
10
0
IV
III
II
II
I
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
q
10^3 cm^{-1}
XBL715-3506

Figure. 4.

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