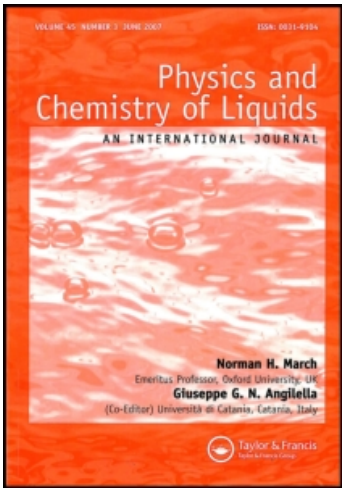

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ABSORPTION SPECTRA OF $Nd(NO_3)_3 6H_2O$ ALCOHOLIC COMPLEXES

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Band intensities and energies of Nd^{3+} ion in methyl, ethyl, isopropyl, butyl and amyl alcohols are studied. The lifetimes (τ_R) for certain fluorescing states of Nd^{3+} ion in all the five alcohols are reported. The second derivative spectra exhibited splittings for certain states of Nd^{3+} in five alcohols.

KEYWORDS: Neodymium complexes, band intensities.

1 INTRODUCTION

Vibrational spectra of polynuclear complexes of lanthanide nitrates have been analysed by Seminara[1]. Interligands charge transfer in lanthanide complexes have been characteristed by Choppin[2]. Bunzli[3] has made a detailed study on the solvation of Nd^{3+} in various organic solvents. Magnetic properties of rare earth complexes have been studied by Urland[4]. Thermodynamic properties of $Nd(NO_3)_3 6H_2O$ in KNO_3 have been investigated by Shevchu[5]. Vicentini and his coworkers have reported the lanthanide adducts spectra with several organic solvents[6-8].

2 EXPERIMENTAL

The neodymium complexes were prepared by putting about 0.1 m% neodymium nitrate into the alcohols of methyl, ethyl, isopropyl, butyl and amyl. These five neodymium complexes have been used for recording the spectra. The UV-VIS spectra have been recorded from 920-320 nm on the UV-VIS spectrophotometer. In the same wavelength range, the second derivative spectra have also been recorded to obtain further clearer information about the energy-level stucture. The measurement of refractive indices of these complexes have been made on a standard refractometer. By

using a microcomputer (DCM Spectrum 31) theoretical evaluation of spectral characteristic parameters has been carried out.

3 RESULTS AND DISCUSSION

3.1 Band Energies

The spectral appearance of the Nd^{3+} in five different alcohols namely methyl(MA), ethyl(EA), isopropyl(IPA) butyl(BA) and amyl(AA) alcohols have revealed the presence of ten electronic states with $^4I_{9/2}$ as the ground state. They are as follows:

$$\begin{aligned} {}^4I_{9/2} &\rightarrow {}^4F_{3/2}, {}^4F_{5/2}, {}^4F_{7/2} \text{ and } {}^4F_{9/2} \\ &\rightarrow {}^2H_{11/2} \\ &\rightarrow {}^4G_{5/2}, {}^4G_{7/2} \text{ and } {}^4G_{9/2} \\ &\rightarrow {}^2D_{3/2} \\ &\rightarrow {}^4D_{3/2} \end{aligned}$$

The experimental energies of these bands relating to the Nd^{3+} ion in five alcohols are presented in Table 1. The theoretical energies of these ten states have been obtained by using the conventional procedures[9–11] and are listed in Table 1. The rms deviation for the band energies is obtained from the relation.

$$\sigma = \left(\frac{\sum \Delta_i^2}{N}\right)^{1/2}$$

where Δi is the difference in energy between the experimental and theoretical values, N is the number of states obtained in the present work. Table 1 shows that the rms deviation are found to be reasonably smaller and thus there exists a successful correlation between the experimental and calculated energy values. The relevent spectroscopic parameters namely Racah (E^1, E^2, E^3), spin-orbit (ξ_{4f}) configurational interaction (α) which characterise the band energies are evaluated by solving the $4f^3$ energy matrices are given in Table 2. As the rms deviations (Table 1) for the band energies are found to be between ± 17 and ± 51 cm^{-1}, the computed parameters that are given in Table 2 are thus chosen as the best fit from the several trials made on the microcomputer. Table 2 also reveals that the following situation exists with regard to E^1 and E^2 values

$$E^1, E^2\text{: EA} > \text{MA} > \text{IPA} > \text{BA} > \text{AA}$$

On the other hand, the values of E^3, ξ_{4f} and α are found to be at maximum in MA and the minimum in AA.

3.2 Band Intensities

The squared reduced matrix elements required for theoretical evaluation of band intensities have been evaluated for Nd^{3+}: Methyl alcohol and are presented in Table 3. The experimental and calculated band intensities of Nd^3 ion in five alcohols are

Table 1 Measured and calculated energies (in cm^{-1}) of the observed levels for $Nd(NO_3)_3 6H_2O$ in various alcohols.

Transition from $^4I_{9/2}$	*Methyl alcohol*		*Ethyl alcohol*		*Isopropyl alcohol*		*Butyl alcohol*		*Amyl alcohol*	
	E_{expt}	E_{calc}	E_{expt}	E_{calc}	E_{expt}	E_{calc}	E_{expt}	E_{calc}	E_{expt}	E_{calc}
$^4D_{3/2}$	28977	29037	28894	28960	28810	28872	28894	28880	28563	28647
$^2D_{3/2}$	22020	21987	22045	22013	21972	21930	21900	21900	21828	21807
$^4G_{9/2}$	19955	19854	19797	19764	19757	19831	19680	19678	19641	19615
$^4G_{7/2}$	19393	19380	19375	19309	19337	19241	19225	19239	19189	19187
$^4G_{5/2}$	17539	17520	17508	17466	17417	17417	17417	17426	17387	17285
$^2H_{11/2}$	16229	16255	16177	16219	16073	16137	16125	16116	16125	16129
$^4F_{9/2}$	14966	15060	14944	14997	14877	14951	14899	14923	14910	14910
$^4F_{7/2}$	13723	13706	13676	13651	13639	13623	13648	13616	13676	13638
$^4F_{5/2}$	12671	12659	12623	12623	12623	12617	12639	12628	12671	12692
$^4F_{3/2}$	11652	11657	11611	11635	11598	11621	11611	11637	11638	11631
rms deviation	±50		±42		±51		±17		±45	

Table 2 Values of Racah (E^1, E^2, E_3), spin-orbit (ξ_{4f}), configurational interaction (α), Judd-Ofelt (T_λ), refractive index (n) and intensity (Ω_λ) Parameters for $Nd(NO_3)_36H_2O$ in various alcohols.

Parameter	*Methyl alcohol*	*Ethyl alcohol*	*Isopropyl alcohol*	*Butyl alcohol*	*Amyl alcohol*
E^1	5032.17	5048.63	5013.23	4998.92	4917.04
E^2	27.92	28.08	27.84	27.37	26.30
E^3	502.65	500.88	498.72	498.90	490.84
ξ_{4f}	912.62	900.93	894.70	882.34	888.92
α	5.917	5.134	3.75	2.74	−2.73
$T_2 \times 10^9$	1.440	0.992	1.575	1.353	1.305
$T_4 \times 10^9$	0.816	0.609	0.607	0.593	0.763
$T_6 \times 10^9$	1.680	1.745	1.737	1.544	1.619
n	1.338	1.369	1.380	1.403	1.406
$\Omega_2 \times 10^{20}$	11.122	8.836	1.580	9.998	9.624
$\Omega_4 \times 10^{20}$	6.307	5.425	4.561	4.382	5.632
$\Omega_6 \times 10^{20}$	12.977	15.542	13.045	11.414	11.940

Table 3 Squared reduced matrix elements $(\psi J|U^\lambda|\psi' J')^2$ for the observed levels of $Nd(NO_3)_36H_2O$: *Methyl alcohol.*

Transtion from $^4I_{9/2}$	$\|U^2\|^2$	$\|U^4\|^2$	$\|U_6\|^2$
$^4D_{3/2}$	0	0.19212	0.01633
$^2D_{3/2}$	0	0.01407	0.00002
$^4G_{9/2}$	0.00291	0.04127	0.02308
$^4G_{7/2}$	0.08737	0.23674	0.07886
$^4G_{5/2}$	0.89547	0.41615	0.03459
$^2H_{11/2}$	0.00118	0.00198	0.02008
$^4F_{9/2}$	0.00045	0.00680	0.05793
$^4F_{7/2}$	0.00167	0.03697	0.42825
$^4F_{5/2}$	0.00094	0.23950	0.39484
$^4F_{3/2}$	0	0.22989	0.05223

listed in Table 4. Table 4 reveals that the hypersensitive transition ($^4I_{9/2} \rightarrow {}^4G_{5/2}$) has the maximum intensity which follows the selection rule

$$\Delta J \leq 2, \Delta L \leq 2 \quad \text{and} \quad \Delta S = 0$$

The intensity of this transition is well monitered by T_2 and $\|U^2\|^2$ parameters. The other two parameters namely T_4 and T_6 will be supplemental to T_2 parameter in explaining the variations in the intensity values of the hypersensitive transition. With regard to the intensities of other remaining bands, all the three (T_λ) parameters will influence the changes. The dependance of f_{cal} (hypersensitive transition) on the Judd-Ofelt T_2 parameter is shown below for the complexes under study.

Parameters	MA	EA	IPA	BA	AA
f_{cal} ($\times 10^6$)	29.597	21.057	31.577	26.335	26.821
T_2 ($\times 10^9$)	1.440	0.992	1.675	1.353	1.305

Table 4 Measured and computed spectral intensities ($f \times 10^6$) of the observed levels for $Nd(NO_3)_3 6H_2O$ in various alcohols.

Transition from $^4I_{9/2}$	*Methyl alcohol*		*Ethyl alcohol*		*Isopropyl alcohol*		*Butyl alcohol*		*Amyl alcohol*	
	f_{expt}	f_{calc}	f_{expt}	f_{calc}	f_{expt}	f_{calc}	f_{expt}	f_{calc}	f_{expt}	f_{calc}
$^4D_{3/2}$	7.096	5.341	6.908	4.206	7.344	4.179	6.034	4.021	7.206	4.947
$^2D_{3/2}$	0.318	0.253	0.355	0.190	0.233	0.188	0.289	0.185	0.372	0.235
$^4D_{9/2}$	—	1.530	—	1.352	—	1.383	—	1.261	—	1.428
$^4G_{7/2}$	11.166	8.759	9.404	7.143	9.378	8.260	8.637	7.315	10.839	8.108
$^4G_{5/2}$	29.385	29.597	20.832	21.057	31.479	31.577	26.218	26.335	26.578	26.821
$^2H_{11/2}$	0.105	0.601	0.064	0.605	0.122	0.611	0.113	0.544	0.247	0.753
$^4F_{9/2}$	0.540	1.549	0.574	1.579	0.239	1.569	0.547	1.402	0.877	1.484
$^4F_{7/2}$	10.470	10.332	11.852	10.555	11.062	10.491	9.601	0.360	10.698	9.900
$^4F_{5/2}$	10.793	10.901	9.155	10.555	10.095	10.514	9.356	9.521	9.534	10.434
$^4F_{3/2}$	1.492	3.210	1.662	2.685	1.389	2.671	1.306	2.520	1.613	3.027

From this table it is observed that the hypersensitive level ($^4G_{5/2}$) intensities are found to be reasonably high in isopropyl alcohol (IPA) and much smaller in ethyl alcohol (EA). From Table 2 it is noted that Judd-Ofelt (T_λ) parameters are found to be in the following order for the five Nd^{3+} complexes.

$$T_6 > T_2 > T_4$$

Similar observations have earlier been made for Nd^{3+} in inorganic hosts too[9-10]. Since the change of environments around the rare earth ion influence the variation in band intensities and a little amount of shift in the energy level structure, the values of eigenvectors of the states remain more or less the same. As a result of this there will not be much change in the values of $\|U^\lambda\|^2$ of Nd^{3+} complexes.

In Table 4, there are certain disagreements exist between the measured and theoretical intensities. The reasons, for the above inconsistant correlations are explained as follows. The calculated 'f' is more dependent on Judd-Ofelt (T_λ) and $\|U^\lambda\|^2$ values as explained earlier[9]. As these $\|U_\lambda\|^2$ values are very lightly influenced (in case of certain states) by the environments, there could be a situation for an unsatisfactory agreement between the theory and experimental values. The band intensity of $^4G_{9/2}$ could not be measured experimentally in all the hosts, however the theoretical values are evaluated and presented in Table 3.

3.3 *Radiative Lifetimes* (τ_R)

The lifetimes of the fluorescent states have been determined through the theoretical approach by using the Judd-Ofelt parameters (Table 2). For Nd^{3+}, there are about eight states identified as electronic excited states. Of them, one state is believed to be a radiative transition and the other seven are called non-radiative transitions,[11] they are as follows:

Radiative transition: $^4F_{3/2}$

Non-radiative transitions: $^4F_{5/2}$, $^4F_{9/2}$, $^2H_{11/2}$, $^4G_{5/2}$, $^4G_{7/2}$, $^4G_{9/2}$, $^4D_{3/2}$

For the above eight fluorescing states and their next power lying follow up states, the values of squared reduced matrix elements $\|U^\lambda\|^2$ for Nd^{3+}: methyl alcohol have been computed and listed in Table 5. By using the data given in Tables 2 and 5, the computed numerical values of electric dipole (S_{ed}), magnetic dipoles (S_{md}), transition probability (A) and relaxation rate (A_T) are presented in Table 6. The reciprocal value of A_T gives us the lifetime (τ_R in μs) of the fluorescing state. The theoretically predicted τ_R values for the eight excited states of five Nd^{3+} complexes are summarised in Table 7. From this table, it is noted that the fluorescing state $^2H_{11/2}$ has the maximum and the minimum for $^4D_{3/2}$. The following is the order in which the lifetime values τ_R (in μs) vary from host to host.

$$2H_{11/2} > {}^4F_{3/2} > {}^4F_{9/2} > {}^4F_{5/2} > {}^4G_{9/2} > {}^4G_{7/2} > {}^4G_{5/2} > {}^4D_{3/2}$$

Table 5 Squared reduced matrix elements $(\psi J\|U^{\lambda}\|\psi' J')^2$ for the fluorescent levels ($^4F_{3/2,5/2,9/2}$, $^2H_{11/2}$, $^4G_{5/2,7/2,9/2}$ & $^4D_{3/2}$) and other low-lying levels of $Nd(NO_3)_36H_2O$: *Methyl alcohol.*

Transitions	$\|U^2\|^2$	$\|U^4\|^2$	$\|U^6\|^2$	*Transitions*	$\|U^2\|^2$	$\|U^4\|^2$	$\|U^6\|^2$
$^4F_{3/2} \rightarrow {}^4I_{15/2}$	0	0	0.03049	$^4G_{7/2} \rightarrow {}^2H_{9/2}$	0.00956	0.00700	0.04899
$^4I_{13/2}$	0	0	0.20473	$^4F_{3/2}$	0.16289	0.11967	0
$^4I_{11/2}$	0	0.14166	0.41294	$^4I_{15/2}$	0	0.02599	0.01255
$^4I_{9/2}$	0	0.22989	0.05223	$^4I_{13/2}$	0	0.25536	0.08103
				$^4I_{11/3}$	0.86846	0.15737	0.00387
$^4F_{5/2} \rightarrow {}^2H_{9/2}$	0.00696	0.02815	0.00186	$^4I_{9/2}$	0.08737	0.23674	0.07886
$^4F_{3/2}$	0.05127	0.05062	0				
$^4I_{15/2}$	0	0	0.23155	$^4G_{9/2} \rightarrow {}^2K_{13/2}$	0.02137	0.08858	0.14144
$^4I_{13/2}$	0	0.17914	0.40013	$^4G_{7/2}$	0.00005	0.10380	0.05613
$^4I_{11/2}$	0	0.16911	0.03630	$^4G_{5/2}$	0.00021	0.04579	0.23214
$^4I_{9/2}$	0.00094	0.23950	0.39484	$^2G_{7/2}$	0.04231	0.01012	0.08025
				$^2H_{11/2}$	0.01189	0.00854	0.37918
$^4F_{9/2} \rightarrow {}^4F_{7/2}$	0.03397	0.11864	0.02914	$^4F_{9/2}$	0.15820	0.03479	0.21691
$^4S_{3/2}$	0	0.00048	0.00192	$^4F_{7/2}$	0.23731	0.03440	0.14919
$^4F_{5/2}$	0.00540	0.04381	0.07785	$^4S_{3/2}$	0	0.16519	0.00042
$^2H_{9/2}$	0.06497	0.00061	0.13785	$^4F_{5/2}$	0.10458	0.10158	0.00396
$^4F_{3/2}$	0	0.01266	0.10688	$^2H_{9/2}$	0.00067	0.00079	0.15416
$^4I_{15/2}$	0	0.54159	0.46011	$^4F_{3/2}$	0	0.02209	0.04978
$^4I_{13/2}$	0.00935	0.20948	0.52360	$^4I_{15/2}$	0	0.05302	0.26399
$^4I_{11/2}$	0.00055	0.02968	0.38272	$^4I_{13/2}$	0.61658	0.31090	0.04945
$^4I_{9/2}$	0.00045	0.00680	0.05793	$^4I_{11/2}$	0.09851	0.26325	0.01753
				$^4I_{9/2}$	0.00291	0.04127	0.02308
$^2H_{11/2} \rightarrow {}^4F_{9/2}$	0.07066	0.02790	0.06529				
$^4F_{7/2}$	0.00252	0.00006	0.17148	$^4D_{3/2} \rightarrow {}^2P_{3/2}$	0.04796	0	0
$^4S_{3/2}$	0	0.03627	0.00012	$^2D_{5/2}$	0.01531	0.00256	0
$^4F_{5/2}$	0	0.00012	0.02207	$^2P_{1/2}$	0.00038	0	0
$^2H_{9/2}$	0.07266	0.00615	0.09862	$^4G_{11/2}$	0	0.00262	0.20569
$^4F_{3/2}$	0	0.00204	0.00049	$^2D_{3/2}$	0.03459	0	0
$^4I_{15/2}$	0.09709	0.05203	0.00021	$^2K_{15/2}$	0	0	0.00035
$^4I_{13/2}$	0.00280	0.01147	0.00061	$^2G_{9/2}$	0	0.00257	0.05196
$^4I_{11/2}$	0.00427	0.00021	0.00550	$^2P_{3/2}$	0.04796	0	0
$^4I_{9/2}$	0.00118	0.00198	0.02008	$^2D_{5/2}$	0.01531	0.00256	0
				$^2P_{1/2}$	0.00038	0	0
$^4G_{5/2} \rightarrow {}^2G_{7/2}$	0.00688	0.17259	0.00003	$^4G_{11/2}$	0	0.00262	0.20569
$^2H_{11/2}$	0	0.00045	0.01163	$^2D_{3/2}$	0.03459	0	0
$^4F_{9/2}$	0.00009	0.01068	0.07645	$^2K_{15/2}$	0	0	0.00035
$^4F_{7/2}$	0.02191	0.05997	0.17791	$^2G_{9/2}$	0	0.00257	0.05196
$^4S_{3/2}$	0.00467	0.19857	0	$^4G_{9/2}$	0	0.00233	0.07355
$^4F_{5/2}$	0.26596	0.13885	0	$^2K_{13/2}$	0	0	0.00100
$^2H_{9/2}$	0.00422	0.00319	0.03846	$^4G_{7/2}$	0.24665	0.00343	0
$^4F_{3/2}$	0.47207	0.01708	0	$^4G_{5/2}$	0.17008	0.00069	0
$^4I_{15/2}$	0	0	0.00442	$^2G_{7/2}$	0.15151	0.01244	0
$^4I_{13/2}$	0	0.03470	0.04739	$^2H_{11/2}$	0	0.04085	0.01035
$^4I_{11/2}$	0	0.29034	0.09678	$^4D_{3/2} \rightarrow {}^4F_{9/2}$	0	0.17805	0.00248
$^4I_{9/2}$	0.89547	0.41615	0.03349	$^4F_{7/2}$	0.24549	0.06892	0
				$^4S_{3/2}$	0.15642	0	0
$^4G_{7/2} \rightarrow {}^4G_{5/2}$	0.00419	0.38400	0.07589	$^4F_{5/2}$	0.05742	0.19898	0
$^2G_{7/2}$	0.00063	0.01126	0.02235	$^2H_{9/2}$	0	0.02015	0.00605
$^2H_{11/2}$	0	0.02194	0.04375	$^4F_{3/2}$	0.14720	0	0
$^4F_{9/2}$	0.03661	0.08504	0.28835	$^4I_{15/2}$	0	0	0.00821
$^4F_{7/2}$	0.26678	0.10369	0.00033	$^4I_{13/2}$	0	0	0.02695
$^4S_{3/2}$	0.00042	0.16535	0	$^4I_{11/2}$	0	0.27543	0.00689
$^4F_{5/2}$	0.41940	0.00921	0.14311	$^4I_{9/2}$	0	0.19212	0.01633

Table 6 The electric ($S_{ed} \times 10^{22}$), magnetic ($S_{md} \times 10^{22}$) dipole linestrengths, transition probabilities (A in sec^{-1}) and relaxation ratio (A_T in sec^{-1}) for the flourescent levels ($^4F_{3/2,5/2,9/2}$, $^2H_{11/2}$, $^4G_{5/2,7/2,9/2}$ & $^4D_{3/2}$) of $Nd(NO_3)_36H_2O$ in various alcohols.

Transitions *SLJ* *S'L'J'*	*Methyl alcohol*			*Ethyl alcohol*			*Isopropyl alcohol*			*Butyl alcohol*			*Amyl alcohol*		
	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A
	(1)			(2)			(3)			(4)			(5)		
$^4F_{3/2} \rightarrow {}^4I_{15/2}$	39	0	23.90	47	0	31.57	39	0	27.58	34	0	26.82	36	0	27.51
$^4I_{13/2}$	255	0	435.81	318	0	564.78	267	0	488.35	233	0	462.88	244	0	479.89
$^4I_{11/2}$	625	0	2123.10	718	0	2609.30	603	0	2243.90	533	0	2116.50	572	0	2270.90
$^4I_{9/2}$	212	0	1258.80	205	0	1292.80	172	0	1108.40	160	0	1084.70	191	0	1303.70
		A_T	3841		A_T	4498		A_T	3868		A_T	3690		A_T	4082
$^4F_{5/2} \rightarrow {}^2H_{9/2}$	27	0	0	24	0	0	24	0	0	21	0	0	24	0	0
$^4F_{3/2}$	88	33.98	0.41	72	33.89	0.96	87	33.89	0.41	73	34.02	0.36	77	33.36	0.39
$^4I_{15/2}$	300	0	209.14	359	0	272.25	302	0	236.49	264	0	226.15	276	0	234.56
$^4I_{13/2}$	632	0	1033.60	719	0	1261.10	603	0	1087.20	535	0	1034.20	578	0	1116.70
$^4I_{11/2}$	153	0	479.33	148	0	491.02	124	0	421.73	115	0	414.99	138	0	499.76
$^4I_{9/2}$	664	0	3426.90	744	0	4056.90	625	0	5211.20	556	0	3248.90	607	0	3574.30
		A_T	5149		A_T	6081		A_T	6957		A_T	4924		A_T	5425
$^4F_{9/2} \rightarrow {}^4F_{7/2}$	150	28.31	0.50	139	28.31	0.53	134	28.43	0.51	119	28.27	0.46	134	28.71	0.52
$^4S_{3/2}$	2	0	0.01	3	0	0.04	2	0	0.01	2	0	0.01	2	0	0.01
$^4F_{5/2}$	134	0	2.21	149	0	2.54	128	0	2.16	113	0	1.94	122	0	2.16
$^2H_{9/2}$	251	16.23	7.87	271	16.54	7.87	261	16.23	8.34	222	16.16	7.00	227	16.03	7.36
$^4F_{3/2}$	146	0	7.97	172	0	9.66	145	0	8.07	127	0	7.15	134	0	7.83
$^4I_{15/2}$	938	0	943.32	1008	0	1089.92	847	0	936.29	762	0	904.05	854	0	1013.80
$^4I_{13/2}$	822	0	1596.70	935	0	1936.80	790	0	1667.90	698	0	1564.50	752	0	1692.20
$^4I_{11/2}$	516	0.15	1694.00	611	0.12	2125.60	513	0.14	1815.50	450	0.14	1675.60	474	0.14	1778.90
$^4I_{9/2}$	79	0.12	401.54	94	0.09	497.00	79	0.09	425.39	69	0.09	390.40	73	0.09	416.89
		A_T	4655		A_T	5669		A_T	4864		A_T	4551		A_T	4119

$^2H_{11/2} \rightarrow {}^4F_{9/2}$	180	3.34	0.09	175	3.86	0.10	186	3.62	0.07	157	3.72	0.08	161	3.67	0.08
$^4F_{7/2}$	225	0	2.23	268	0	2.90	226	0	2.31	198	0	2.07	207	0	2.18
$^4S_{3/2}$	23	0	2.90	19	0	0.26	16	0	0.20	16	0	0.20	20	0	0.24
$^4F_{5/2}$	28	0	0.92	34	0	1.18	28	0	0.95	25	0	0.86	26	0	0.91
$^2H_{9/2}$	212	15.22	11.50	220	15.15	12.27	222	15.25	11.44	187	15.33	10.52	191	15.42	10.89
$^4F_{3/2}$	2	0	0.14	2	0	0.16	2	0	0.13	2	0	0.12	2	0	0.15
$^4I_{15/2}$	141	0	150.35	114	0	131.88	146	0	170.55	120	0	150.47	123	0	153.98
$^4I_{13/2}$	182	1.06	359.87	18	1.04	38.55	16	1.03	38.15	14	0.98	36.05	16	1.01	39.99
$^4I_{11/2}$	12	0.29	38.76	12	0.29	43.94	12	0.28	44.76	10	0.28	40.01	10	0.28	40.87
$^4I_{9/2}$	28	0	137.98	33	0	170.24	28	0	147.20	24	0	134.64	26	0	142.85
		A_T	704		A_T	401		A_T	415		A_T	375		A_T	392
$^4G_{5/2} \rightarrow {}^2G_{7/2}$	116	8.59	0.08	99	8.67	0.07	534	8.58	0.38	82	8.82	0.05	103	10.27	0.02
$^2H_{11/2}$	15	0	0.30	18	0	0.37	15	0	0.33	13	0	0.32	14	0	0.26
$^4F_{9/2}$	106	0	5.31	124	0	6.73	104	0	5.75	92	0	5.52	97	0	4.86
$^4F_{7/2}$	285	0.21	44.99	319	0.20	53.59	279	0.20	47.26	244	0.18	43.88	260	0.21	41.43
$^4S_{3/2}$	130	0	23.22	111	0	21.03	96	0	18.04	91	0	18.12	116	0	19.65
$^4F_{5/2}$	383	0.02	115.38	310	0.01	98.91	397	0.01	127.58	326	0.01	110.72	334	0.01	103.63
$^2H_{9/2}$	56	0	22.37	65	0	26.65	56	0	23.82	49	0	21.43	51	0	20.70
$^4F_{15/2}$	641	0.02	350.97	426	0.02	244.94	601	0.02	347.56	479	0.01	289.91	463	0.02	263.15
$^4I_{15/2}$	6	0	21.62	6	0	27.83	6	0	23.88	5	0	22.51	6	0	22.58
$^4I_{13/2}$	83	0	526.37	92	0	62.33	77	0	533.48	69	0	508.10	76	0	540.42
$^4I_{11/2}$	309	0	2990.02	308	0	3166.70	258	0	2705.70	237	0	2633.40	279	0	3016.80
$^4I_{9/2}$	1303	0	17696.00	1070	0	15610.00	1361	0	20154.00	1117	0	17407.00	1137	0	17401.00
		A_T	22069		A_T	19880		A_T	23987		A_T	21060		A_T	21434

(*continued*)

Table 6 The electric ($S_{ed} \times 10^{22}$), magnetic ($S_{md} \times 10^{22}$) dipole linestrengths, transition probabilities (A in sec^{-1}) and relaxation ratio (A_T in sec^{-1}) for the flourescent levels ($^4F_{3/2,5/2,9/2}$, $^2H_{11/2}$, $^4G_{5/2,7/2,9/2}$ & $^4D_{3/2}$) of $Nd(NO_3)_36H_2O$ in various alcohols. (*continued*)

Transitions *SLJ* *S'L'J'*	*Methyl alcohol*			*Ethyl alcohol*			*Isopropyl alcohol*			*Butyl alcohol*			*Amyl alcohol*		
	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A	S_{ed}	S_{md}	A
		(1)			(2)			(3)			(4)			(5)	
$^4G_{7/2} \rightarrow {}^4G_{5/2}$	345	38.64	3.44	330	38.59	3.39	279	38.69	2.92	259	38.46	2.78	310	36.98	3.63
$^2G_{7/2}$	36	0.31	0.86	41	0.32	1.00	35	0.32	0.86	31	0.34	0.75	33	0.37	0.70
$^2H_{11/2}$	70	0	6.50	79	0	7.61	67	0	6.63	59	0	6.24	64	0	6.24
$^4F_{9/2}$	468	0.01	74.56	526	0.01	88.67	461	0.01	78.40	403	0.01	72.88	392	0.01	66.07
$^4F_{7/2}$	363	0.79	123.40	292	0.65	104.93	383	0.64	138.04	312	0.63	117.95	315	0.76	113.23
$^4S_{3/2}$	104	0	38.77	90	0	34.94	75	0	29.31	72	0	29.39	93	0	34.89
$^4F_{5/2}$	658	0.34	357.36	598	0.33	341.38	647	0.33	370.63	423	0.33	253.90	579	0.41	334.86
$^2H_{9/2}$	78	0.13	62.69	88	0.13	60.94	79	0.13	55.52	68	0.12	49.55	71	0.10	50.06
$^4F_{3/2}$	257	0	220.97	209	0	185.92	260	0	234.46	216	0	202.29	225	0	205.28
$^4I_{15/2}$	32	0	139.17	33	0	152.97	28	0	130.93	25	0	127.59	29	0	143.68
$^4I_{13/2}$	266	0	1786	264	0	1886.80	222	0	1611.5	204	0	1573.9	240	0	1822.00
$^4I_{11/2}$	1070	0	10532.00	858	0	8945.30	1169	0	12365.00	941	0	10505.00	929	0	10245.00
$^4I_{9/2}$	348	0	4735.20	328	0	4699.40	320	0	4656.10	281	0	4282.50	311	0	4712.90
		A_T	18018		A_T	16513		A_T	19680		A_T	17224		A_T	17732
$^4G_{9/2} \rightarrow {}^2K_{13/2}$	263	0	0.16	286	0	0.16	251	0	0.18	221	0	0.18	239	0	0.42
$^4G_{7/2}$	138	16.32	0.01	143	14.01	0.01	120	13.81	0.01	109	13.88	0.01	125	15.84	0.02
$^4G_{5/2}$	330	0	4.45	385	0	5.29	323	0	4.39	285	0	3.92	303	0	5.02
$^2G_{7/2}$	157	24.36	5.57	167	24.36	6.01	162	24.32	5.87	138	24.49	5.04	142	25.80	4.96
$^2H_{11/2}$	509	0.20	51.32	602	0.20	62.46	512	0.21	54.71	447	0.19	50.37	467	0.08	51.44
$^4F_{9/2}$	479	6.81	80.61	495	6.74	87.55	497	6.77	88.45	421	6.52	79.32	430	5.85	79.18
$^4F_{7/2}$	479	0.45	160.10	460	0.45	161.21	508	0.46	178.52	422	0.47	154.92	425	0.39	153.93
$^4S_{3/2}$	104	0	37.88	90	0	34.06	75	0	28.43	72	0	28.45	93	0	35.10
$^4F_{5/2}$	185	0	96.15	153	0	83.35	183	0	99.40	153	0	87.08	162	0	9.15
$^2H_{9/2}$	201	1.54	127.78	240	1.54	156.98	202	1.54	134.09	176	1.54	120.82	185	1.56	125.81
$^4F_{3/2}$	78	0	12.73	89	0	74.34	75	0	62.50	66	0	57.53	71	0	62.25
$^4I_{15/2}$	376	0	140.22	439	0	1745.10	368	0	1490.50	323	0	1396.20	345	0	1479.00
$^4I_{13/2}$	946	0	5488.10	790	0	4864.60	982	0	6137.20	809	0	5361.10	827	0	5463.70
$^4I_{11/2}$	298	0.64	2516.00	257	0.04	2290.90	266	0.04	2410.90	233	0.04	2226.50	264	0.04	2513.40
$^4I_{9/2}$	59	0.01	684.10	60	0.01	740.08	52	0.01	647.99	47	0.01	611.59	53	0.01	868.37
		A_T	9405		A_T	10312		A_T	11343		A_T	10178		A_T	10943

$^2D_{3/2} \rightarrow$	$^2P_{3/2}$	53	0	3.55	42	0	2.96	60	0	4.41	47	0	3.96	46	0	3.01
	$^2D_{5/2}$	18	0.07	12.85	15	0.06	10.94	20	0.06	15.16	16	0.07	12.45	16	0.10	10.49
	$^2P_{1/2}$	1	0.31	0.57	1	0.31	0.51	1	0.31	0.64	1	0.33	0.62	1	0.37	0.60
	$^4G_{11/2}$	268	0	347.39	321	0	453.01	269	0	387.39	235	0	362.84	247	0	358.65
	$^2D_{3/2}$	38	0.06	67.96	30	0.07	55.96	43	0.06	81.60	34	0.04	67.90	33	0.03	61.36
	$^2K_{15/2}$	1	0	0.88	1	0	2.34	1	0	0.99	1	0	0.93	1	0	0.97
	$^2G_{9/2}$	69	0	132.92	82	0	171.07	68	0	146.38	60	0	135.93	63	0	131.32
	$^4G_{9/2}$	96	0	303.10	115	0	388.85	97	0	332.00	84	0	306.21	89	0	300.17
	$^2K_{13/2}$	1	0	5.11	2	0	6.48	1	0	5.64	1	0	5.22	1	0	5.48
	$^4G_{7/2}$	276	0	1089.70	219	0	834.96	311	0	1202.40	248	0	1005.60	239	0	927.54
	$^4G_{5/2}$	189	0	1079.20	150	0	913.29	214	0	1314.90	170	0	1993.50	164	0	1030.50
	$^2G_{7/2}$	176	0	1180.90	140	0	1001.40	196	0	1417.90	156	0	1176.30	152	0	1074.90
	$^2H_{11/2}$	39	0	359.82	38	0	372.68	32	0	319.75	29	0	311.52	35	0	351.05
	$^4F_{9/2}$	115	0	1242.82	100	0	1153.60	84	0	982.68	80	0	992.71	103	0	1202.40
	$^4F_{7/2}$	316	0	4396.10	254	0	3761.90	340	0	5089.40	275	0	4328.90	275	0	4121.70
	$^4S_{3/2}$	173	0.01	2494.70	138	0.01	2105.90	196	0.01	3021.60	156	0.01	2518.30	150	0.01	2290.20
	$^4F_{5/2}$	189	0.01	3149.60	158	0.01	2806.6	162	0.01	2912.30	144	0.01	2711.50	167	0.01	3009.10
	$^2H_{9/2}$	20	0	372.09	20	0	388.29	17	0	331.38	15	0	318.23	18	0	360.85
	$^4F_{3/2}$	163	0	3300.80	130	0	2779.20	185	0	3896.4	147	0	3323.5	141	0	3085.10
	$^4I_{15/2}$	10	0	483.56	12	0	619.61	10	0	529.08	9	0	491.59	9	0	497.94
	$^4I_{13/2}$	34	0	2076.30	41	0	2652.10	35	0	2261.80	30	0	2092.9	32	0	2129.8
	$^4I_{11/2}$	182	0	13774.00	160	0	12834.00	134	0	10955.00	128	0	11024.00	163	0	13678.00
	$^4I_{9/2}$	142	0	13237.00	129	0	12780.00	108	0	10892.00	102	0	10798.00	127	0	13147.00
			A_T	49110		A_T	46095		A_T	46220		A_T	43083		A_T	47778

Table 7 The radiative lifetimes (τ_R) *in* μs for the fluorescent level ($^4F_{3/2,5/2,9/2}$, $^2H_{11/2}$, $^4G_{5/2,7/2,9/2}$ & $^4D_{3/2}$) of $Nd(NO_3)_36H_2O$ in various alcohols.

Fluorescent levels	*Methyl alcohol*	*Ethyl alcohol*	*Isopropyl alcohol*	*Butyl alcohol*	*Amyl alcohol*
$^4F_{3/2}$	260.3	222.3	258.5	270.9	244.9
$^4F_{5/2}$	194.1	164.4	143.7	203.1	184.3
$^4F_{9/2}$	214.8	176.4	205.5	219.7	203.2
$^2H_{11/2}$	1418.8	2490.5	2404.8	2666.2	2549.8
$^4G_{5/2}$	45.3	50.3	41.6	47.4	46.6
$^4G_{7/2}$	55.4	60.5	50.8	58.1	56.3
$^4G_{9/2}$	106.3	96.9	88.1	98.2	91.4
$^4D_{3/2}$	20.5	21.6	22.1	23.2	20.9

The following situation has also been noted from Table 7:

$$\tau_R\ (\mu s)\text{: } {}^4F_{3/2}\text{: BA} > \text{MA} > \text{IPA} > \text{AA} > \text{EA}$$
$$^4F_{5/2}\text{: BA} > \text{MA} > \text{AA} > \text{EA} > \text{IPA}$$
$$^4F_{9/2}\text{: BA} > \text{MA} > \text{IPA} > \text{AA} > \text{EA}$$
$$^2H_{11/2}\text{: BA} > \text{AA} > \text{EA} > \text{IPA} > \text{MA}$$
$$^4G_{5/2}\text{: EA} > \text{BA} > \text{AA} > \text{MA} > \text{IPA}$$
$$\tau_R\ (\mu s)\text{: } {}^4G_{7/2}\text{: EA} > \text{BA} > \text{AA} > \text{MA} > \text{IPA}$$
$$^4G_{9/2}\text{: MA} > \text{BA} > \text{EA} > \text{AA} > \text{IPA}$$
$$^4D_{3/2}\text{: BA} > \text{IPA} > \text{EA} > \text{AA} > \text{MA}$$

3.4 Second Derivative Spectra

The following four electronic states which could not be recorded in the normal spectra of Nd^{3+} complexes, are now found to exist in the second derivative spectra. The measured energies of these four new states are presented in Table 7.

$$^4I_{9/2} \rightarrow {}^4S_{3/2},\ {}^2G_{7/2},\ {}^2P_{1/2} \text{ and } {}^4D_{1/2}$$

Thus the second derivative spectra of these Nd^{3+} complexes have revealed altogether fourteen energy states.

Table 8 The measured energies of certain bands revealed by the second derivative spectra, which have not been noticed in the normal spectra of $Nd(NO_3)_36H_2O$ in various alcohols.

Transitions from $^4I_{9/2}$	*Methyl alcohol*	*Ethyl alcohol*	*Isopropyl alcohol*	*Butyl alcohol*	*Amyl alcohol*
$^4S_{3/2}$	13620	13620	13583	13546	13620
$^2G_{7/2}$	21361	21316	21453	21316	21361
$^2P_{1/2}$	23578	23467	23522	23467	23412
$^4D_{1/2}$	29403	29317	29146	29274	29146

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