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Investigation of the hyperfine structure of Pr I and Pr II lines based on highly resolved Fourier transform spectra

B Gamper¹, Z Uddin^{1,2}, M Jahangir², O Allard¹, H Knöckel³, E Tiemann³ and L Windholz¹

¹Institut für Experimentalphysik, Technische Universität Graz, Petersgasse 16, 8010 Graz

² Department of Physics, University of Karachi, University Road, Karachi 75270

³Institut für Quantenoptik, Leibnitz Universität Hannover, Welfengarten 1, 30167 Hannover

E-mail: windholz@tugraz.at

Abstract. We report the recording of new highly resolved Fourier transform spectra of the neutral praseodymium atom. With the help of the new spectra we found about 9000 new lines, from which - in the region 3260 to 9880 Å - 1194 could be classified as transitions between energy levels of the Pr atom and 19 as transitions of the Pr ion. 23 new atomic energy levels of odd parity and one of even parity were discovered during this first examination. The spectra might be very helpful for further laser spectroscopic investigations of the hyperfine structure of Pr I and Pr II transitions.

1. Introduction

Praseodymium is a metal and belongs to the group of lanthanides. The ^{141}Pr atom has a non zero nuclear spin $I = 5/2$ due to the odd number of protons ($Z=59$). Like other lanthanides also Pr has a very rich and complex optical spectrum; it has a few ten thousands lines from which a big part is not classified. The praseodymium nucleus is almost spherically symmetric, thus it has a very small electric quadrupole moment and the hyperfine constants B are very small. The first studies of the hyperfine (hf) structure of spectral lines of Pr were done by King in 1928 [1]. The next extensive continuation of this work was done by Ginibre in 1988; she presented many new energy levels [2], [3] and [4] and listed approximately 17000 spectral lines. Nevertheless, her list is far from being complete. The Poznań group around Dembczyński performed theoretical interpretation of the hyperfine structure of Pr and could solve some of the configuration mixing problems [5]. Furmann, also part of the group in Poznań, investigated the hf structure of Pr via the method of laser-induced fluorescence (LIF) spectroscopy since 2005 [6] and [7] and he could enlarge the level list of Pr I and Pr II. Studies of the hf structure of neutral praseodymium have been performed by the group of Guthöhrlein in Hamburg [8] and by our group since 2004 [9, 10]. Even though the enormous work of Ginibre was based on an evaluation of Fourier transform (FT) spectra, the primary spectral data are not available to us. Nevertheless, the line list of Ginibre, containing approximately 17000 lines, was the basis of all laser spectroscopic work until 2007. In these laser spectroscopic experiments, lines which are given by Ginibre but could not be classified by her were excited by laser light, setting the laser wavelength close to the listed wavelength of the center of gravity (cg), and searching for LIF signals.

However, if someone wants to perform LIF spectroscopy more efficiently, a precise setting of the excitation laser frequency is desired. Thus, we decided to take new FT spectra, having a high resolution in order to resolve at least the widely splitted hf patterns. The goal of our investigation is to classify as many lines as possible and to find up to now unknown energy levels in order to increase the knowledge of the stationary states of the electron shells as a basis for a better theoretical description of these states.

2. Experimental details

FT spectroscopy has a lot of advantages over other spectroscopic techniques: one can record many thousands lines by one scan under Doppler-limited conditions. With a FT spectrometer it is possible to measure very weak signals and to cover a large wave number range per scan. It has high resolution, large dynamic range of the intensity and a relatively low scan time.

The FT spectra were recorded at the Institute of Quantum Optics at the Leibniz University in Hannover with a continuously scanning high resolution FT-IR spectrometer (IFS 120 HR, Bruker Corp.). An example of a sequence of hf structure patterns recorded is shown in figure 1. As a light source we used a home made hollow

cathode lamp which was the same as we use in Graz for performing laser-induced fluorescence spectroscopy. In the hollow cathode lamp (detailed scheme of the apparatus see [11]) a cloud of free praseodymium atoms is produced by cathode sputtering. The copper cathode is lined with praseodymium and has a typical inner diameter of 3 mm and a length of 19 mm. The anodes on both sides of the cathode consist of aluminum and are spaced with a ceramic insulator. The discharge was operated with a current of about 65 mA (dc) using argon as carrier gas at a pressure of about 0.6 mbar. The lamp was cooled by liquid nitrogen to reduce the Doppler width for better hf resolution. The advantage of a hollow cathode lamp is that it produces praseodymium atoms not only in the ground state but also in higher excited states. The emission spectrum of the Pr-Ar plasma under the applied conditions contains mainly Pr I lines, but also Pr II and Ar I and Ar II lines.

The light emitted by the discharge was collected and focused with a set of lenses on the entrance aperture of the FT spectrometer in order to get a Fourier transformed emission spectrum over the very large region from 2380 to 12500 Å. As beam splitters we employed the commercial ones provided by the manufacturer: for the near infrared region between 12500 Å and 10000 Å CaF₂ coated with silicon, for the visible range from 10000 Å to 4000 Å quartz with dielectric coating and for the UV quartz with Al coating. The resolution of the spectra is given by the convolution of the instrumental profile and the width of the spectral lines. The entrance aperture was varied from 0.5 to 1.3 mm diameter. To optimize the signal-to-noise ratio (SNR) the spectra were recorded in parts limiting the recorded ranges by optical dielectric low pass and high pass filters. For the near infrared range a silicon photodiode was used as a detector, while for the visible and UV ranges we employed a photomultiplier. Multiple scans were averaged at a typical resolution of 0.03 cm⁻¹ for an improved SNR.

The original data files of the FT spectrometer contained intensity versus wave number. The specification of the instrument is given to be better than 5.10⁻⁸ relative and 5.10⁻⁷ absolute. This is 0.025 cm⁻¹ at 50000 cm⁻¹ or 0.001 Å at 2000 Å; 0.0125 cm⁻¹ at 25000 cm⁻¹ or 0.002 Å at 4000 Å; 0.005 cm⁻¹ at 10000 cm⁻¹ or 0.005 Å at 10000 Å. Spectra from different regions from IR to UV were combined to form one spectrum. Their correct overlapping was checked by comparing the hf structures of the recorded spectral lines. Then the spectrum was converted to intensity versus air wavelength using the dispersion formula given by Peck and Reader [12]. This spectrum can be handled in graphic form by the existing classification program [13].

3. Results and discussion

The amount of spectral lines in Pr is enormous. An example of the FT spectrum in the visible region is given in Figure 1, which shows only a very narrow part of 2.5 Å of the whole FT spectrum. In this region there are noticeable at least 12 spectral lines with partly resolved hf structure, which are marked by brackets. Meaning of the designations: a: line already classified in ref. [4]; b: mentioned in ref. [4], but not

classified; c: investigated by laser excitation and classified in ref. [9]; d: new lines, discovered with help of this spectrum. Around 5675.75 Å a typical blend situation can be found: Two of the lines appear to be overlapping. Sometimes even more than two lines with practically the same cg wavelength can be found. This is due to the very big number of electronic energy levels of the Pr atom: Transition frequencies between certain different pairs of levels are nearly or exactly degenerate. For such blend situations the assignment of the correct level pair (this assignment we call "classification") is not possible using only the wave number difference of the levels in comparison with the cg wave number from the FT hf pattern. In addition, the shape of the hf pattern has to be considered. For a huge number of lines the classification is possible since the hf pattern predicted from already known hf constants of the involved levels coincides with the hf pattern observed in the FT spectrum. Of course, this procedure provides that the hf constants of the combining levels are already known from earlier measurements.

In other cases hf constants can be determined using the FT pattern, if the transition is known but the hf constants not. The correctness of the hf constants can be proven by comparing the hf patterns of other lines combining with the level under investigation in the FT spectrum. For this purpose it is necessary to extend the FT spectrum over a range as wide as possible.

If the situation in the observed spectrum is very complex, so that the observed spectral structures can not be clearly distinguished, laser spectroscopic experiments are necessary to divide the excited levels by their characteristic fluorescence lines. In this case the FT spectrum can be used conveniently to set the desired laser excitation wavelength.

All components of the hf patterns of the spectral lines appearing in Figure 1 are also possible excitation wavelengths for laser-induced fluorescence (LIF) spectroscopy. The excitation wavelengths can be determined from FT spectra with an uncertainty of few 0.001 Å.

Originally, our database contained approximately 17000 lines of Pr I and Pr II. Up to now we could enlarge this list to about 26000 lines. Many of the 26000 lines are not yet classified, meaning that not every line listed in Ginibres tables [4] or discovered in the present FT spectrum is related to a transition between two already known energy levels. It should be emphasized that our additions to the line list of Ginibre (ref. [4]) are not done automatically by a computer program, but by comparing structures in the graphically depicted FT spectrum with predicted (and graphically represented) hf patterns belonging to transitions which fit in their wave number to the considered part of the FT spectrum. This comparison is possible since in the FT spectrum the relative intensities of the components of an hf pattern fit quite good to the theoretical intensity ratios.

In table 1 all new spectral lines of the praseodymium atom (Pr I) which clearly could be assigned to a transition between two energy levels, are given. This table, containing more than 1200 lines, is available in its full length only in electronic form. In table 2 the Pr I lines of table 1 with an SNR larger than 50, are listed again. Table

3 gives all the newly classified ionic lines (Pr II), respectively. The classification was performed using the cg wave numbers and the shape of the hf patterns, resolved well enough to identify the combining levels without any doubts.

All three tables have the same structure: Column 1 contains the cg wavelength in air in Å. Information about the SNR is given in column 2 (per definition, noise is treated to have $\text{SNR} = 1$. The SNR is a guide to the relative intensities of the lines, since the intensities depend strongly on the type of light source and the conditions under which a discharge is operated). If there is written "nl" in front of the SNR it means that this line is a new one, not known before these investigations. All the other lines are mentioned in the list of Ginibre [4] but they are not classified, either because the energy levels involved in the transition were found after she did her work or because the hf patterns were not sufficiently resolved in her spectra. In columns 3 and 5 the J-values of the involved levels are listed. The corresponding energies in cm^{-1} are given in columns 4 and 6. The energy levels are listed according to their parities, in the column 4 the even ones and in the column 6 the odd ones. If a new level is involved, it is marked with an upper index 'a'.

The cg wavelength for each line given in the tables is obtained by overlapping two graphs: the hf structure obtained from the FT spectrum and a synthetical hf pattern, calculated from the known hf constants of the combining levels. The intensities are normalized for this comparison, and the Gaussian width of the synthetical spectrum has to be chosen close to the width obtained in the FT spectrum. Of course this width is wavelength-dependent. One graph can be shifted against the other in steps of 0.001 Å. The correct position gives then the cg wavelength. Since human brain is quite sensitive to a mismatch of two graphs, it is really possible to notice a mismatch of 0.001 Å over the whole wavelength range (3260 to 9880 Å). Thus, the given wavelengths are good to 0.001 Å for a wide range of SNR. For lines with $\text{SNR} < 10$ the uncertainty is estimated to be 0.002 Å. The absolute wavelength accuracy could be checked in the range 5145 to 3729 Å against a list of Ar-lines used in FT spectrometry for wavelength calibration (see ref. [14]). Agreement was better than 0.001 Å. In the UV and IR region Ar-lines of the present spectrum were compared with Ar-lines of earlier used FT spectra of Ta and Ar, taken at Imperial College London and Kitt Peak National Observatory ([15]). Again the agreement was better than 0.003 Å. Thus the absolute accuracy of the given wavelengths in our tables is better than 0.003 Å.

Pr I energy levels given in Tables 1, 2 (and their hf constants, used for determination of the cg wavelengths) are taken either from the tables of Ginibre [4] or from measurements performed by the group in Hamburg [8] (private communication). The wave numbers have been fine adapted by means of the present FT spectrum. Under assumption that the energy of the lowest even state, 4432.24 cm^{-1} , as given in ref. [16], is correct, we have first energy corrected high lying odd levels, combining with this lower level. Then we have used transitions from these levels to the second lower even energy state to correct its wave number. From this level we were going up to other odd levels and so on. The same procedure was done beginning with the odd ground state level.

The differences of the here given level energies fit to the wave numbers, calculated from the given wavelengths, better than 0.01 cm^{-1} . Energy values given in Table 3 are from Ginibre [3].

For some well resolved lines, which could not be classified as transitions between known levels, it was possible to determine the hf constants and to identify one of the involved levels by its hf constants. Then a new level could be introduced combining the wave number of the identified level and the wave number of the transition. The proof that such a level exists is done by calculating all possible decay wavelengths and looking into the corresponding regions of the FT spectrum for the predicted pattern. If observed structures fit with the expected pattern and the expected cg wavelength, the level is assumed to be really existing. This method of finding new levels is especially important for spectral regions where laser excitation is difficult, e.g. in the IR or UV.

In this way, we could find several new energy levels. The hf constants were determined by fitting the hf pattern of the line under investigation, using the program "Fitter" ([17]). These levels are marked in table 1 and table 2 with subscript "a". The results are shown in table 4. Column 1 of this table gives the energies in cm^{-1} of the newly discovered levels; the accuracy depends mainly on the SNR of the investigated hf patterns. Their J-values are listed in column 2; in the next column the hyperfine constants A (in MHz) are given. Due to the limited resolution of the FT spectrum the value of B was assumed to be zero. The 5th column tells us which lines (wavelengths in air in Å) can be explained with the new levels. The corresponding transitions can be found in table 1.

As an example we discuss the line with the cg wavelength 9319.006 Å . The relative intensities and distribution of the components (Figure 2) suggest a transition with $\Delta J = -1$ with almost equal values of the hyperfine constants A of both levels. The small sharp peak at the high frequency side of this hf structure pattern is generated under this hypothesis by the coincidence of the five off diagonal ($\Delta F = 0$) hyperfine components within the Doppler width. We fitted the structure assuming $J = 17/2$ and $J' = 15/2$ (the prime marks the upper level of the transition), and got $A = 970 \text{ MHz}$ and $A' = 961 \text{ MHz}$. Then we looked in our level data base for a level with J and A as determined in the fitting process. We found an even level with the energy $11714.367 \text{ cm}^{-1}$, with $A = 970.2(3) \text{ MHz}$, $B = -16(4) \text{ MHz}$ and $J = 17/2$. Assuming that this level is the lower level involved in this transition, we fitted the structure again with fixed hyperfine constants of the lower level and added the cg wave number of the investigated line to the wave number of the lower level. Finally we determined the new level to have $22442.185(5) \text{ cm}^{-1}$, $J = 15/2$, $A' = 959(9) \text{ MHz}$ with odd parity. Fig. 3 shows the hf structure calculated with J, A and J', A' in comparison with the pattern in the FT spectrum. The new level explains 5 other lines in the IR region and 3 lines in the visible region (see Table 4).

We have to emphasize that such a fit is only possible if some of the small components (or a convolution of them) are clearly resolved in the FT spectra. Otherwise, the splitting of the diagonal components is more sensitive to the difference ($A - A'$) than to the

absolute values of A , A' , and one cannot identify one of the involved levels by its A -value.

Altogether 24 new levels could be found by the analysis of FT patterns (mainly located in the IR region); each level explains other previously unclassified lines.

Table 1: Spectral lines of Pr I which clearly could be assigned to a transition between two energy levels

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
3264.301	nl 15	9/2	30625.599	9/2	0
3308.390	nl 4	11/2	30217.535	9/2	0
3363.938	nl 53	11/2	29718.524	9/2	0
3437.597	nl 36	13/2	30458.359	11/2	1376.605
3482.081	nl 7	11/2	30086.879	11/2	1376.605
3500.325	nl 20	11/2	28560.604	9/2	0
3518.513	nl 16	7/2	28412.960	9/2	0
3551.415	nl 9	11/2	28149.750	9/2	0
3617.638	nl 13	11/2	27634.464	9/2	0
3650.240	nl 7	11/2	28764.269	11/2	1376.605
3654.616	nl 44	9/2	4432.240	11/2	31787.102
3670.398	nl 7	9/2	8029.290	11/2	35266.525
3676.089	nl 6	11/2	27195.110	9/2	0
3681.669	nl 26	11/2	27153.870	9/2	0
3693.608	nl 15	11/2	27066.095	9/2	0
3728.799	nl 5	9/2	9105.035	11/2	35915.701
3732.473	nl 48	11/2	26784.270	9/2	0
3734.024	nl 24	11/2	28149.750	11/2	1376.605
3738.704	nl 7	11/2	6313.239	13/2	33052.863
3744.240	nl 8	15/2	9745.420	17/2	36445.505
3751.945	nl 4	9/2	4432.240	11/2	31077.525
3764.900	nl 8	9/2	4432.240	9/2	30985.825
3782.853	nl 8	9/2	4432.240	11/2	30859.807
3785.058	nl 16	11/2	4866.530	13/2	31278.701
3789.689	nl 17	7/2	6535.587	9/2	32915.484
3789.738	nl 10	13/2	6603.606	15/2	32983.162
3792.514	14	11/2	4866.530	13/2	31226.830
3792.953	nl 10	11/2	26357.240	9/2	0
3796.162	nl 8	11/2	4866.530	13/2	31201.444
3822.768	nl 13	9/2	30583.869	11/2	4432.240
3832.285	nl 14	11/2	4866.530	13/2	30953.221
3836.285	nl 12	15/2	28906.235	13/2	2846.744
3844.099	nl 11	11/2	6313.239	13/2	32319.759
3845.830	nl 9	15/2	8363.910	17/2	34358.775
3850.364	nl 23	9/2	5822.905	11/2	31787.102
3895.616	nl 20	9/2	4432.240	11/2	30094.849
3920.839	nl 5	9/2	4432.240	9/2	29929.763
3955.220	nl 12	11/2	4866.530	13/2	30142.420
3966.271	nl 19	9/2	25205.463	9/2	0

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
3977.315	nl 12	11/2	25135.518	9/2	0
3983.367	17	11/2	4866.530	9/2	29963.821
3983.837	nl 14	9/2	4432.240	11/2	29526.571
3994.341	nl 20	11/2	4866.530	13/2	29894.870
4010.870	nl 6	9/2	4432.240	11/2	29357.439
4018.223	nl 5	11/2	4866.530	13/2	29746.124
4064.250	nl 9	13/2	6603.606	13/2	31201.444
4067.606	nl 6	11/2	4866.530	13/2	29444.080
4082.316	nl 11	11/2	4866.530	9/2	29355.515
4095.244	nl 8	9/2	4432.240	7/2	28843.919
4099.596	nl 5	11/2	6892.950	13/2	31278.760
4116.357	nl 19	15/2	27133.216	13/2	2846.744
4140.536	nl 8	13/2	6603.630	11/2	30748.179
4146.146	nl 8	9/2	24111.970	9/2	0
4158.484	nl 9	9/2	5822.905	9/2	29863.351
4181.612	nl 11	9/2	4432.240	7/2	28339.724
4205.089	nl 6	9/2	5822.905	11/2	29596.942
4214.208	nl 29	11/2	6313.239	9/2	30035.807
4216.768	nl 53	11/2	4866.530	13/2	28574.696
4219.806	nl 10	9/2	4432.240	7/2	28123.338
4223.198	nl 16	9/2	4432.240	7/2	28104.309
4232.307	nl 10	11/2	4866.530	13/2	28487.651
4234.681	nl 5	13/2	6603.606	11/2	30211.500
4236.994	nl 20	9/2	4432.240	7/2	28027.233
4242.580	6	11/2	4866.530	11/2	28430.480
4242.853	nl 6	11/2	6892.950	13/2	30455.358
4247.880	nl 4	9/2	5822.890	11/2	29357.427
4252.039	nl 8	9/2	4432.240	7/2	27943.748
4252.622	nl 15	11/2	4866.530	13/2	28374.815
4253.281	nl 13	11/2	6313.239	9/2	29817.885
4257.426	nl 6	9/2	4432.240	9/2	27913.992
4265.477	nl 9	11/2	4866.530	13/2	28303.969
4270.230	nl 16	11/2	6892.949	9/2	30304.302
4273.079	nl 9	13/2	6603.606	13/2	29999.348
4277.584	nl 7	9/2	4432.240	7/2	27803.401
4287.225	nl 5	11/2	6892.949	11/2	30211.500
4290.514	nl 14	9/2	24677.280	11/2	1376.605
4307.900	nl 6	9/2	5822.905	11/2	29029.544
4315.405	nl 24	9/2	5822.905	7/2	28989.185
4319.208	nl 7	7/2	7617.455	5/2	30763.338
4325.278	nl 16	5/2	6451.823	3/2	29565.225
4325.719	nl 28	11/2	6313.239	9/2	29424.282
4328.899	nl 30	9/2	4432.240	7/2	27526.308
4331.816	nl 6	11/2	4866.530	9/2	27945.047
4337.942	nl 11	9/2	5822.905	7/2	28868.744
4356.485	nl 6	9/2	4432.240	11/2	27380.075
4358.728	nl 9	9/2	4432.240	9/2	27368.267

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4363.971	nl 15	13/2	7951.338	11/2	30859.807
4364.944	nl 6	9/2	12519.718	9/2	35422.868
4392.068	nl 9	9/2	22761.920	9/2	0
4397.193	nl 29	9/2	24112.000	11/2	1376.605
4403.569	nl 9	9/2	5822.890	7/2	28525.354
4410.844	nl 13	9/2	4432.240	11/2	27097.270
4415.835	nl 5	11/2	9675.040	13/2	32314.433
4417.178	nl 27	13/2	7951.338	11/2	30583.869
4420.916	nl 9	7/2	6535.530	9/2	29149.238
4422.438	nl 11	9/2	8029.290	9/2	30634.880
4424.660	nl 9	9/2	4432.240	9/2	27026.500
4425.857	nl 10	9/2	8029.290	11/2	30617.441
4428.933	nl 6	11/2	4866.530	9/2	27438.992
4431.893	nl 9	11/2	4866.530	13/2	27423.911
4435.831	nl 12	5/2	6451.823	7/2	28989.185
4436.837	nl 6	9/2	4432.240	11/2	26964.492
4437.451	nl 23	11/2	22529.130	9/2	0
4438.021	nl 5	9/2	4432.240	11/2	26958.490
4439.380	nl 4	7/2	7617.440	7/2	30136.763
4439.614	nl 7	9/2	8029.290	7/2	30547.449
4458.426	nl 12	13/2	7630.170	11/2	30053.346
4461.920	nl 12	9/2	4432.240	9/2	26837.828
4462.201	nl 11	11/2	6892.949	9/2	29297.126
4462.594	nl 6	9/2	8029.290	7/2	30431.492
4466.734	nl 9	9/2	5822.905	7/2	28204.346
4468.215	nl 26	15/2	9745.420	13/2	32119.424
4482.960	nl 19	9/2	5822.905	7/2	28123.338
4487.041	nl 13	5/2	6451.823	5/2	28731.850
4487.412	nl 7	9/2	4432.240	11/2	26710.548
4492.176	nl 25	13/2	7951.338	15/2	30206.021
4494.133	nl 10	9/2	9105.035	9/2	31350.008
4497.014	nl 11	11/2	4866.530	11/2	27097.270
4502.013	nl 19	13/2	6603.606	11/2	28809.661
4502.814	10	9/2	4432.240	9/2	26634.346
4508.438	nl 12	11/2	6313.239	13/2	28487.651
4512.158	nl 13	9/2	4432.240	11/2	26588.368
4519.626	nl 112	15/2	8363.916	15/2	30483.514
4522.684	nl 5	9/2	4432.240	11/2	26536.814
4523.816	nl 14	11/2	6313.250	11/2	28412.285
4523.989	nl 19	9/2	5822.890	7/2	27921.182
4531.497	nl 30	11/2	6313.239	13/2	28374.815
4533.924	nl 25	9/2	4432.240	9/2	26482.007
4534.285	nl 15	13/2	7951.338	13/2	29999.348
4534.348	nl 5	9/2	4432.240	11/2	26479.944
4534.881	nl 8	11/2	6892.949	11/2	28938.062
4541.35	nl 5	11/2	11282.870	13/2	33296.230
4546.096	nl 6	11/2	6313.239	13/2	28303.969

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4546.682	nl 12	11/2	4866.530	13/2	26854.427
4546.713	nl 11	5/2	6451.823	3/2	28439.569
4548.226	nl 4	9/2	5822.905	7/2	27803.401
4551.246	nl 9	9/2	4432.240	11/2	26398.087
4552.857	nl 21	9/2	5822.905	11/2	27780.979
4553.500	nl 14	11/2	6714.199	11/2	28669.174
4554.101	nl 8	15/2	26333.170	15/2	4381.121
4556.661	nl 6	9/2	4432.240	7/2	26371.983
4557.606	nl 4	11/2	10904.070	13/2	32839.463
4560.844	nl 5	9/2	5822.910	11/2	27742.524
4560.958	nl 11	9/2	4432.240	9/2	26351.314
4565.063	nl 11	7/2	9704.750	7/2	31604.099
4567.454	nl 4	5/2	6451.823	7/2	28339.724
4571.334	nl 15	13/2	7951.338	15/2	29820.680
4578.717	nl 4	9/2	8029.290	9/2	29863.351
4584.435	9	7/2	7617.455	9/2	29424.282
4586.971	nl 5	13/2	7951.338	13/2	29746.108
4587.194	nl 6	9/2	4432.240	9/2	26225.952
4590.878	nl 18	11/2	6892.949	11/2	28669.174
4598.951	nl 178	11/2	24584.745	13/2	2846.744
4601.217	nl 4	9/2	4432.240	11/2	26159.548
4605.314	nl 15	7/2	9704.750	5/2	31412.750
4614.926	nl 6	13/2	7951.338	11/2	29614.101
4615.381	nl 12	11/2	6714.199	13/2	28374.815
4616.371	nl 7	7/2	6535.587	7/2	28191.557
4617.572	nl 7	13/2	11462.858	15/2	33113.358
4625.019	nl 4	11/2	4866.530	9/2	26482.007
4628.172	nl 9	11/2	6313.239	9/2	27913.990
4628.809	nl 14	13/2	7951.338	15/2	29549.117
4631.028	nl 5	13/2	14328.241	11/2	35915.701
4631.674	nl 14	17/2	10532.001	15/2	32116.407
4632.908	nl 14	15/2	9745.420	15/2	31324.084
4634.700	9	7/2	7617.455	7/2	29187.782
4636.278	10	11/2	6714.199	9/2	28277.184
4639.887	15	11/2	6714.199	9/2	28260.413
4640.071	nl 37	9/2	5822.905	9/2	27368.267
4641.986	8	11/2	6714.199	13/2	28250.672
4642.487	nl 7	9/2	5822.905	7/2	27357.054
4644.745	nl 8	11/2	4866.530	13/2	26390.208
4651.668	20	7/2	6535.587	7/2	28027.233
4653.786	8	11/2	6892.949	13/2	28374.815
4656.848	11	11/2	6313.239	11/2	27780.979
4660.254	8	17/2	10532.001	17/2	31984.040
4662.205	15	9/2	4432.240	9/2	25875.314
4664.728	40	11/2	6714.199	9/2	28145.675
4665.961	nl 17	13/2	7630.170	13/2	29055.975
4670.172	nl 3	13/2	7951.350	13/2	29357.903

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4671.245	15	9/2	5822.905	7/2	27224.482
4674.505	15	11/2	6313.239	11/2	27699.892
4675.033	40	11/2	6892.949	9/2	28277.184
4675.100	9	11/2	6714.220	9/2	28098.250
4675.480	10	15/2	8363.916	13/2	29746.108
4677.769	nl 16	7/2	7617.455	7/2	28989.185
4680.464	25	11/2	4866.530	9/2	26225.952
4682.023	20	9/2	4432.240	11/2	25789/252
4682.197	22	5/2	6451.823	7/2	27803.341
4683.201	nl 4	13/2	6603.606	15/2	27950.545
4686.980	nl 6	11/2	4866.530	13/2	26196.260
4687.540	10	13/2	7951.338	15/2	29278.510
4688.519	10	11/2	6714.199	13/2	28036.928
4688.562	25	13/2	7951.338	11/2	29273.796
4689.722	nl 5	15/2	9745.420	15/2	31062.660
4689.831	8	13/2	10470.300	11/2	31787.102
4690.018	10	11/2	6313.239	13/2	27629.152
4690.068	12	9/2	8029.290	7/2	29344.977
4691.779	25	13/2	7630.147	11/2	28938.062
4691.952	nl 9	5/2	6451.823	5/2	27758.950
4692.652	55	11/2	4866.530	9/2	26170.480
4693.661	nl 9	9/2	5822.890	9/2	27122.250
4695.201	nl 6	17/2	9770.330	15/2	31062.660
4697.998	45	11/2	6313.239	9/2	27592.946
4705.959	15	13/2	7951.338	11/2	29195.047
4708.704	nl 8	13/2	7951.338	15/2	29182.662
4711.327	8	9/2	8643.839	9/2	29863.351
4714.477	nl 6	11/2	6892.950	11/2	28098.267
4714.548	nl 8	11/2	6714.199	11/2	27919.207
4715.227	30	9/2	4432.240	9/2	25634.194
4715.421	15	9/2	5822.905	7/2	27023.987
4717.314	nl 3	5/2	11107.690	5/2	32300.347
4718.618	nl 20	11/2	4866.530	11/2	26053.248
4720.774	10	19/2	11151.490	17/2	32328.452
4725.877	nl 8	9/2	9105.035	9/2	30259.211
4726.144	12	13/2	9464.460	11/2	30617.463
4726.244	10	11/2	22529.130	11/2	1376.605
4730.222	10	11/2	8829.078	9/2	29963.821
4738.670	15	11/2	6892.949	11/2	27990.015
4742.700	6	11/2	9483.540	13/2	30562.676
4743.748	20	5/2	6451.830	7/2	27526.308
4745.069	6	7/2	6535.587	9/2	27604.203
4748.794	7	11/2	6892.950	9/2	27945.039
4752.817	15	11/2	8829.078	9/2	29863.351
4753.837	8	11/2	11944.223	13/2	32974.060
4755.808	40	11/2	6892.949	9/2	27913.990
4757.009	15	5/2	6451.823	5/2	27467.559

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4758.583	35	11/2	4866.530	9/2	25875.314
4766.966	nl 20	11/2	9483.540	13/2	30455.358
4767.566	11	11/2	10841.482	11/2	31810.670
4768.116	45	9/2	4432.240	7/2	25399.020
4782.459	7	15/2	8765.556	15/2	29669.456
4783.424	18	13/2	7951.338	13/2	28851.022
4786.181	20	9/2	5822.905	11/2	26710.548
4792.795	10	13/2	7951.338	13/2	28810.160
4792.854	20	7/2	6535.587	9/2	27394.149
4792.909	25	13/2	7951.338	11/2	28809.661
4795.241	50	7/2	30427.864	9/2	9579.832
4795.426	15	9/2	12068.109	9/2	32915.480
4796.845	20	11/2	6313.239	13/2	27154.450
4797.956	20	7/2	32165.955	9/2	11329.710
4798.394	6	17/2	9770.330	17/2	30604.830
4798.809	30	7/2	6535.587	9/2	27368.267
4800.796	7	11/2	9675.040	11/2	30498.989
4801.742	20	5/2	29806.252	3/2	8986.444
4802.040	20	13/2	7630.147	13/2	28448.810
4802.883	55	11/2	6313.239	11/2	27128.251
4810.925	15	5/2	6451.823	5/2	27232.039
4811.731	8	5/2	34013.314	7/2	13236.599
4813.538	12	9/2	5822.905	7/2	26591.841
4813.833	8	11/2	4866.530	9/2	25634.194
4814.255	12	11/2	4866.530	11/2	25632.372
4815.667	35	7/2	7617.455	5/2	28377.208
4819.510	6	17/2	10532.001	15/2	31275.181
4820.562	22	5/2	6451.823	7/2	27190.496
4823.343	6	7/2	9704.750	7/2	30431.510
4823.790	12	11/2	6714.199	9/2	27438.992
4824.328	6	11/2	6714.199	11/2	27436.682
4825.813	70	9/2	4432.240	7/2	25148.347
4826.325	20	9/2	5822.905	11/2	26536.814
4826.944	20	11/2	6892.949	9/2	27604.203
4828.477	12	9/2	10920.380	11/2	31625.080
4831.422	35	15/2	8363.916	13/2	29055.974
4831.495	25	9/2	4432.240	7/2	25123.984
4832.069	nl 6	5/2	6451.720	5/2	27141.016
4833.266	nl 11	11/2	4866.530	9/2	25550.693
4833.361	nl 3	13/2	10266.510	11/2	30950.266
4834.709	20	17/2	25059.089	15/2	4381.121
4842.913	8	7/2	7617.455	9/2	28260.413
4843.129	40	7/2	6535.587	9/2	27177.628
4849.232	10	9/2	8320.255	7/2	28936.317
4852.822	5	7/2	6535.587	7/2	27136.408
4853.899	29	15/2	8363.916	13/2	28960.156
4855.627	6	13/2	9464.460	11/2	30053.346

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4856.907	nl 15	11/2	6714.199	13/2	27297.680
4857.073	6	11/2	8829.078	9/2	29411.858
4857.522	8	13/2	7630.147	13/2	28211.024
4857.826	8	9/2	31029.588	7/2	10449.941
4858.262	14	13/2	6603.606	11/2	27181.349
4861.964	105	11/2	4866.530	11/2	25428.607
4862.294	12	13/2	7630.170	11/2	28190.866
4864.622	nl 11	13/2	6603.606	13/2	27154.447
4865.990	20	13/2	7630.147	13/2	28175.209
4867.384	12	15/2	9745.420	13/2	30289/295
4869.332	70	11/2	6892.949	13/2	27423.911
4871.188	10	5/2	6451.720	5/2	26974.973
4872.929	20	11/2	9483.540	13/2	29999.350
4873.218	20	9/2	5822.905	9/2	26337.496
4877.116	nl 5	9/2	5822.905	7/2	26321.099
4878.194	nl 97	13/2	6603.606	11/2	27097.270
4879.251	35	9/2	4432.240	11/2	24921.466
4882.565	nl 4	11/2	6892.949	9/2	27368.267
4883.659	nl 7	7/2	7617.455	9/2	28088.187
4890.834	4	9/2	11184.410	11/2	31625.080
4890.942	16	11/2	6714.199	13/2	27154.450
4891.324	nl 6	7/2	6535.530	9/2	26974.246
4892.954	20	13/2	6603.606	15/2	27035.451
4897.867	20	11/2	9483.540	13/2	29894.870
4899.456	25	11/2	6892.949	13/2	27297.680
4899.849	nl 10	5/2	29389.577	3/2	8986.444
4903.836	6	7/2	6535.587	5/2	26922.093
4904.463	nl 5	13/2	9464.460	11/2	29848.320
4904.704	10	9/2	8643.839	7/2	29026.738
4911.460	50	13/2	6603.606	11/2	26958.467
4911.998	25	13/2	7951.338	13/2	28303.969
4913.153	25	11/2	29927.716	9/2	9579.832
4913.442	5	13/2	6603.606	15/2	26950.256
4915.407	230	11/2	23185.260	13/2	2846.744
4915.934	18	13/2	7951.338	15/2	28287.674
4916.365	12	11/2	31664.301	9/2	11329.710
4916.999	90	11/2	6313.239	13/2	26645.170
4918.367	12	7/2	7617.455	7/2	27943.748
4921.651	nl 5	17/2	9770.330	17/2	30083.020
4924.895	nl 11	13/2	7951.338	13/2	28250.672
4925.137	10	7/2	10194.740	9/2	30493.058
4925.315	450	15/2	23144.347	13/2	2846.744
4925.565	8	7/2	7617.455	9/2	27913.992
4926.374	6	7/2	6535.587	9/2	26828.828
4926.559	8	9/2	8643.839	7/2	28936.317
4927.059	55	15/2	8765.556	13/2	29055.974
4927.389	5	13/2	7630.147	11/2	27919.207

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4928.454	12	11/2	6892.948	9/2	27177.628
4930.775	15	11/2	6313.239	11/2	26588.368
4931.669	nl 3	17/2	12736.636	15/2	33008.091
4934.091	25	11/2	6892.949	13/2	27154.450
4934.209	nl 25	9/2	5822.905	7/2	26083.919
4935.747	nl 6	9/2	5822.905	7/2	26077.608
4936.822	nl 6	11/2	6714.199	11/2	26964.492
4940.021	20	9/2	4432.240	7/2	24669.420
4941.500	10	9/2	8029.290	9/2	28260.413
4943.344	10	11/2	6313.239	11/2	26536.814
4946.319	5	17/2	10532.001	17/2	30743.399
4948.508	25	9/2	8029.290	11/2	28231.857
4951.158	nl 6	7/2	6535.587	7/2	26727.245
4955.233	12	9/2	8029.290	7/2	28204.346
4958.234	nl 6	7/2	28412.960	9/2	8250.170
4958.376	12	9/2	8029.290	7/2	28191.557
4960.479	nl 4	13/2	6603.606	11/2	26757.324
4960.898	20	9/2	8643.839	9/2	28795.855
4961.027	290	11/2	22998.237	13/2	2846.744
4962.213	23	5/2	29133.138	3/2	8986.444
4962.440	nl 3	15/2	35493.283	13/2	15347.433
4962.959	nl 5	17/2	12736.670	15/2	32880.323
4963.853	25	5/2	6451.823	7/2	26591.841
4964.105	6	13/2	10423.680	13/2	30562.676
4964.181	55	11/2	29718.524	9/2	9579.832
4968.359	30	7/2	6535.530	5/2	26657.370
4971.514	12	11/2	8829.078	11/2	28938.062
4974.297	12	13/2	6603.606	15/2	26701.341
4977.863	nl 7	13/2	6603.606	11/2	26686.944
4980.473	28	17/2	10532.001	17/2	30604.830
4981.232	6	13/2	7630.147	11/2	27699.892
4983.128	8	13/2	9464.450	11/2	29526.570
4983.605	25	13/2	10423.680	15/2	30483.514
4983.729	5	11/2	9483.540	13/2	29543.242
4983.929	nl 6	9/2	8029.280	9/2	28088.171
4984.912	13	11/2	4866.530	11/2	24921.466
4990.882	14	11/2	9268.750	15/2	29299.668
4991.069	6	17/2	9770.330	13/2	29800.480
4992.319	45	9/2	5822.905	7/2	25848.090
4992.551	8	11/2	6313.239	9/2	26337.496
4995.013	8	9/2	8029.290	9/2	28043.749
4995.727	25	7/2	9918.170	9/2	29929.693
4998.646	5	11/2	9483.533	13/2	29483.354
5002.416	nl 6	13/2	6603.606	11/2	26588.368
5005.950	8	7/2	9704.750	7/2	29675.409
5006.330	6	21/2	12665.074	19/2	32634.220
5007.259	10	13/2	9464.460	11/2	29429.898

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5009.393	nl 15	9/2	8320.255	9/2	28277.184
5009.867	6	9/2	11713.249	7/2	31668.036
5011.381	25	7/2	8013.104	5/2	27962.119
5015.918	nl 6	11/2	6714.199	13/2	26645.170
5016.563	nl 9	11/2	8829.078	9/2	28757.493
5017.880	65	13/2	7951.338	15/2	27879.216
5018.268	nl 116	13/2	31918.637	11/2	11997.050
5023.471	nl 5	13/2	7630.147	15/2	27531.150
5023.935	40	17/2	9770.330	15/2	29669.474
5028.016	35	11/2	6313.239	13/2	26196.253
5028.391	nl 10	9/2	8643.830	7/2	28525.354
5029.391	20	15/2	9745.420	17/2	29623.001
5029.705	45	13/2	6603.606	11/2	26479.944
5030.254	nl 12	11/2	6714.199	11/2	26588.368
5031.493	nl 10	5/2	6451.823	7/2	26321.099
5031.559	nl 8	11/2	8829.078	11/2	28698.091
5031.770	85	11/2	9675.040	13/2	29543.242
5032.116	28	7/2	11668.787	7/2	31535.639
5034.639	55	15/2	8765.556	15/2	28622.414
5035.615	10	11/2	10841.482	13/2	30694.484
5036.352	30	7/2	7617.455	5/2	27467.559
5037.113	35	15/2	8363.916	13/2	28211.024
5038.893	22	11/2	8829.078	11/2	28669.174
5039.832	45	7/2	6535.587	7/2	26371.986
5040.430	nl 10	15/2	8363.916	15/2	28197.961
5041.550	60	13/2	7951.338	11/2	27780.979
5042.623	30	9/2	8320.255	9/2	28145.675
5043.337	20	11/2	6714.199	11/2	26536.814
5043.611	50	7/2	7617.455	9/2	27438.992
5046.976	20	11/2	9675.040	13/2	29483.340
5047.431	22	13/2	7630.147	11/2	27436.682
5049.068	nl 6	13/2	14087.563	13/2	33887.677
5050.308	nl 9	15/2	11483.450	13/2	31278.760
5051.337	12	9/2	11184.410	7/2	30975.574
5051.588	nl 20	7/2	8013.104	7/2	27803.341
5052.289	nl 8	13/2	16069.900	13/2	35857.286
5054.501	20	17/2	9770.330	15/2	29549.140
5055.723	60	9/2	8029.290	7/2	27803.341
5056.569	125	11/2	4866.530	9/2	24637.265
5057.665	nl 6	17/2	11714.367	19/2	31480.828
5061.203	30	9/2	11184.410	7/2	30937.040
5061.447	nl 11	9/2	8029.290	11/2	27780.979
5061.743	22	11/2	8829.078	9/2	28579.611
5064.405	nl 12	17/2	9770.330	19/2	29510.473
5064.968	45	15/2	9745.420	13/2	29483.340
5065.286	14	11/2	9483.540	11/2	29220.280
5068.703	nl 12	9/2	8320.255	9/2	28043.749

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5074.000	170	11/2	4866.530	9/2	24569.356
5075.068	nl 5	15/2	9745.420	13/2	29444.080
5075.586	135	11/2	8829.090	13/2	28525.569
5075.865	270	9/2	5822.905	9/2	25518.489
5076.327	20	13/2	13467.459	13/2	33161.246
5077.880	17	11/2	8829.078	11/2	28516.848
5077.984	nl 8	13/2	10423.680	11/2	30110.987
5078.617	nl 11	7/2	14045.708	5/2	33730.711
5078.881	30	11/2	6714.199	11/2	26398.087
5079.266	280	11/2	22529.130	13/2	2846.744
5081.627	15	5/2	30123.185	7/2	10449.941
5081.689	nl 5	15/2	8363.916	13/2	28036.928
5081.931	15	13/2	10470.300	13/2	30142.519
5082.147	nl 3	11/2	9675.040	9/2	29346.312
5082.164	10	13/2	10423.680	11/2	30094.818
5082.312	25	9/2	8029.290	11/2	27699.892
5082.712	12	13/2	12118.054	11/2	31787.102
5082.780	25	7/2	10194.740	9/2	29863.299
5083.105	15	13/2	7630.147	13/2	27297.680
5083.707	nl 9	17/2	12736.636	15/2	32401.839
5084.975	20	9/2	12068.109	11/2	31728.490
5087.299	nl 14	5/2	6451.720	5/2	26103.032
5087.444	nl 16	7/2	9704.750	9/2	29355.545
5088.550	nl 21	13/2	10423.680	11/2	30070.158
5088.715	15	13/2	13467.459	15/2	33113.358
5089.229	35	11/2	6892.949	11/2	26536.814
5091.956	17	9/2	8643.839	9/2	28277.184
5094.097	35	9/2	8029.290	7/2	27654.383
5095.476	40	9/2	5822.890	9/2	25442.742
5096.794	60	13/2	6603.606	11/2	26218.316
5096.989	15	11/2	10841.482	13/2	30455.358
5099.136	60	9/2	5822.905	11/2	25428.607
5100.548	nl 13	7/2	8013.104	7/2	27613.379
5102.010	nl 6	11/2	13250.690	11/2	32845.298
5102.427	nl 16	9/2	9105.035	11/2	28698.091
5103.453	nl 25	11/2	6313.239	13/2	25902.359
5104.006	35	11/2	6892.949	11/2	26479.944
5104.101	35	15/2	8363.916	15/2	27950.545
5105.878	nl 9	13/2	7951.338	15/2	27531.150
5109.078	nl 60	7/2	6535.530	5/2	26103.032
5110.653	nl 14	15/2	11483.450	13/2	31044.990
5110.997	nl 5	7/2	7617.455	9/2	27177.628
5114.261	50	9/2	8643.839	7/2	28191.557
5114.450	20	9/2	8643.839	11/2	28190.835
5115.064	15	9/2	12519.718	9/2	32064.342
5115.512	15	17/2	12736.636	15/2	32279.575
5115.752	nl 14	7/2	6535.587	7/2	26077.608

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5117.291	380	15/2	9745.420	17/2	29281.511
5118.082	40	15/2	9745.420	15/2	29278.510
5119.475	nl 2	3/2	9650.060	3/2	29177.805
5123.819	15	17/2	9770.330	17/2	29281.511
5124.750	10	9/2	5822.905	9/2	25330.615
5125.508	30	7/2	7617.455	9/2	27122.282
5126.511	20	7/2	29246.322	5/2	9745.313
5130.633	nl 11	13/2	7951.338	11/2	27436.682
5130.693	nl 11	15/2	8765.556	13/2	28250.672
5130.965	nl 12	13/2	10266.510	11/2	29750.596
5131.245	nl 11	7/2	9704.750	7/2	29187.753
5131.414	nl 22	11/2	9483.540	9/2	28965.900
5131.780	nl 7	15/2	8363.916	17/2	27844.904
5132.931	25	11/2	9483.540	13/2	28960.155
5133.996	nl 38	13/2	7951.350	13/2	27423.929
5134.331	nl 15	11/2	6313.239	11/2	25789/252
5136.270	55	11/2	30793.720	9/2	11329.710
5136.554	25	11/2	10841.482	9/2	30304.328
5137.191	30	9/2	8643.839	7/2	28104.309
5137.746	nl 4	11/2	6892.949	9/2	26351.314
5138.297	85	11/2	6714.199	9/2	26170.480
5140.456	12	11/2	8829.078	9/2	28277.184
5141.065	35	5/2	6451.823	7/2	25897.628
5145.418	15	11/2	9268.750	11/2	28698.103
5145.583	20	13/2	7951.350	11/2	27380.069
5146.033	35	9/2	4432.240	11/2	23859.280
5148.025	18	7/2	6535.530	5/2	25955.285
5153.249	50	9/2	8643.830	9/2	28043.749
5154.471	45	13/2	7630.170	13/2	27025.398
5155.889	nl 19	7/2	8013.108	7/2	27403.063
5157.619	45	9/2	8643.830	7/2	28027.240
5158.005	28	11/2	8829.090	13/2	28211.019
5159.359	nl 3	13/2	11462.858	11/2	30839.845
5159.437	nl 6	13/2	6603.630	11/2	25980.151
5160.055	nl 7	7/2	12049.463	5/2	31423.759
5160.198	nl 12	9/2	8029.280	7/2	27403.063
5160.433	12	7/2	10194.740	9/2	29567.550
5162.555	nl 11	9/2	8029.280	9/2	27394.123
5162.628	nl 8	7/2	12049.463	9/2	31414.112
5163.382	20	11/2	8829.090	11/2	28190.866
5163.992	nl 4	15/2	11483.450	13/2	30842.933
5164.391	nl 8	11/2	13035.713	11/2	32393.690
5166.709	20	17/2	12736.636	19/2	32085.996
5166.976	25	17/2	11714.367	15/2	31062.650
5167.167	nl 5	13/2	10266.510	11/2	29614.101
5167.496	20	13/2	7951.350	13/2	27297.717
5167.541	50	9/2	8643.830	11/2	27990.060

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5169.444	nl 10	11/2	6714.210	11/2	26053.238
5171.980	nl 17	5/2	11646.260	7/2	30975.574
5172.688	nl 8	13/2	10423.680	11/2	29750.596
5173.086	40	9/2	5822.890	7/2	25148.315
5173.103	nl 47	11/2	6892.950	11/2	26218.327
5173.528	nl 7	5/2	11107.690	7/2	30431.510
5174.777	110	11/2	6313.239	11/2	25632.322
5177.821	15	11/2	29718.524	13/2	10410.760
5178.660	nl 8	7/2	7617.440	5/2	26922.023
5179.969	nl 6	17/2	11714.367	17/2	31014.122
5180.481	25	15/2	9745.420	15/2	29043.204
5183.491	100	9/2	19286.645	9/2	0
5183.719	25	9/2	9105.035	7/2	28390.848
5189/277	nl 19	13/2	10266.510	15/2	29549.140
5185.335	20	11/2	11282.870	13/2	30562.700
5185.439	nl 20	15/2	10466.730	13/2	29746.124
5186.016	22	9/2	8643.830	7/2	27921.182
5186.417	nl 6	13/2	10470.300	13/2	29746.124
5187.176	nl 12	17/2	9770.330	15/2	29043.204
5187.600	nl 11	15/2	8765.570	13/2	28036.928
5188.367	20	17/2	10532.001	15/2	29800.480
5189.033	20	11/2	10904.070	11/2	30170.090
5189.850	30	11/2	9675.040	11/2	28938.062
5190.494	120	13/2	7951.350	15/2	27212.011
5192.500	45	5/2	6451.823	7/2	25705.204
5193.356	47	7/2	13454.250	9/2	32704.290
5196.752	nl 22	11/2	6313.239	9/2	25550.693
5202.937	20	11/2	9483.540	11/2	28698.103
5208.202	nl 10	9/2	12519.718	7/2	31714.917
5208.940	nl 12	9/2	5822.905	9/2	25015.330
5210.956	130	15/2	8765.570	15/2	27950.542
5212.059	nl 5	13/2	6603.606	11/2	25789/252
5213.404	100	11/2	9675.040	13/2	28851.059
5216.523	nl 6	7/2	8013.108	9/2	27177.628
5219.312	16	15/2	9745.420	15/2	28899.719
5220.665	nl 14	11/2	10904.070	11/2	30053.361
5223.241	nl 12	13/2	10423.680	15/2	29563.560
5223.986	75	9/2	8643.830	11/2	27780.979
5225.915	nl 13	9/2	13822.500	7/2	32952.378
5226.088	34	11/2	6313.239	9/2	25442.695
5227.178	nl 12	13/2	10423.680	15/2	29549.140
5227.804	nl 33	7/2	8013.140	7/2	27136.408
5231.691	115	15/2	8765.570	15/2	27874.491
5232.600	22	15/2	9745.420	13/2	28851.059
5233.350	nl 7	13/2	10423.680	11/2	29526.571
5233.563	nl 8	9/2	10356.710	11/2	29458.910
5235.476	nl 7	17/2	12736.636	15/2	31831.809

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5236.068	25	9/2	8029.280	9/2	27122.282
5236.853	25	11/2	8829.090	11/2	27919.207
5237.650	nl 11	11/2	6892.949	11/2	25980.167
5240.541	35	9/2	5822.905	7/2	24899.636
5244.116	nl 9	9/2	9105.017	11/2	28168.719
5247.222	10	13/2	9464.450	11/2	28516.842
5252.448	90	5/2	6451.823	7/2	25485.269
5254.881	12	15/2	12250.534	15/2	31275.165
5257.536	135	13/2	7630.147	13/2	26645.170
5257.855	nl 18	13/2	7951.350	13/2	26965.207
5259.274	135	7/2	19008.740	9/2	0
5259.889	nl 6	9/2	13974.730	11/2	32981.247
5260.015	nl 8	11/2	11944.223	11/2	30950.266
5260.554	20	11/2	9483.540	13/2	28487.647
5261.896	14	9/2	9105.017	7/2	28104.309
5266.365	nl 12	11/2	12658.416	13/2	31641.506
5267.660	200	17/2	10532.001	19/2	29510.473
5267.971	nl 5	15/2	10466.730	13/2	29444.080
5270.007	20	13/2	10423.680	15/2	29393.693
5272.696	nl 16	9/2	8643.839	9/2	27604.203
5275.824	35	9/2	8643.839	9/2	27592.946
5276.623	12	11/2	30692.414	13/2	11746.340
5280.101	24	15/2	8363.916	13/2	27297.680
5280.717	nl 15	19/2	11151.490	17/2	30083.020
5284.800	nl 9	9/2	8320.255	9/2	27237.190
5285.018	nl 8	13/2	10266.510	15/2	29182.662
5285.628	1650	13/2	20290.580	11/2	1376.605
5286.635	30	13/2	9464.460	13/2	28374.815
5287.547	85	7/2	6535.587	9/2	25442.695
5287.725	nl 22	11/2	9268.741	13/2	28175.209
5289.631	nl 13	11/2	9675.040	13/2	28574.696
5290.536	120	11/2	6313.239	11/2	25209.670
5290.946	52	13/2	6603.606	15/2	25498.559
5291.885	nl 22	11/2	6892.949	11/2	25789/252
5292.283	nl 208	9/2	18890.180	9/2	0
5293.670	17	5/2	16059.899	7/2	34945.103
5299.787	100	7/2	6535.587	7/2	25399.020
5300.035	nl 13	7/2	11274.180	7/2	30136.763
5303.009	nl 10	3/2	11911.437	5/2	30763.338
5303.421	nl 15	11/2	9675.040	13/2	28525.548
5306.517	nl 10	13/2	9464.460	13/2	28303.969
5306.583	35	7/2	9918.170	9/2	28757.493
5306.742	40	9/2	9105.035	7/2	27943.748
5307.207	40	11/2	6714.199	11/2	25551.259
5308.816	160	13/2	6603.606	13/2	25434.959
5309.716	nl 9	11/2	11282.870	11/2	30110.987
5310.678	22	7/2	8013.104	9/2	26837.828

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5310.820	nl 10	7/2	11668.787	9/2	30493.058
5311.268	nl 14	5/2	13127.787	7/2	31950.447
5313.475	nl 28	15/2	10466.730	17/2	29281.511
5315.359	88	13/2	10470.300	15/2	29278.521
5317.648	85	11/2	8829.078	13/2	27629.152
5317.929	30	11/2	27634.464	11/2	8835.380
5318.951	nl 9	9/2	8029.290	11/2	26824.764
5320.349	18	15/2	8363.916	13/2	27154.450
5321.302	nl 9	13/2	13146.599	13/2	31933.765
5327.425	nl 28	15/2	8765.556	15/2	27531.150
5327.702	12	9/2	10920.380	9/2	29684.988
5328.078	nl 70	15/2	23144.347	15/2	4381.100
5329.498	nl 10	9/2	10356.710	7/2	29115.014
5333.235	nl 11	11/2	4866.530	11/2	23611.664
5334.866	45	11/2	6892.949	11/2	25632.372
5337.453	nl 51	9/2	4432.240	7/2	23162.497
5340.178	nl 8	11/2	6714.199	13/2	25434.959
5341.548	60	15/2	10466.730	15/2	29182.662
5341.990	70	11/2	6714.199	11/2	25428.607
5342.064	66	7/2	8013.104	7/2	26727.245
5342.332	20	9/2	8643.839	7/2	27357.054
5342.589	nl 26	13/2	10470.300	15/2	29182.662
5352.117	nl 9	9/2	8643.839	7/2	27322.843
5355.191	nl 4	11/2	6714.199	13/2	25382.476
5357.859	nl 17	15/2	11483.442	13/2	30142.420
5366.731	33	15/2	10466.704	15/2	29094.773
5370.335	145	11/2	6313.239	13/2	24928.881
5376.774	66	9/2	8643.839	9/2	27237.190
5378.800	nl 9	15/2	8363.916	15/2	26950.256
5379.328	nl 6	13/2	10266.516	13/2	28851.022
5381.780	nl 29	11/2	6714.199	9/2	25290.248
5382.696	nl 31	13/2	10470.344	15/2	29043.236
5386.394	nl 19	11/2	9483.533	9/2	28043.749
5389.731	36	9/2	27384.059	11/2	8835.380
5390.511	32	9/2	11713.220	9/2	30259.211
5391.580	58	15/2	9745.391	15/2	28287.674
5394.051	91	9/2	8643.839	9/2	27177.628
5397.91	19	9/2	11549.619	11/2	30070.158
5405.006	46	7/2	6535.587	5/2	25031.771
5415.132	30	11/2	27195.110	13/2	8733.450
5415.839	nl 9	19/2	13626.687	19/2	32085.996
5416.123	nl 4	11/2	10841.417	13/2	29299.668
5419.933	20	9/2	4432.240	9/2	22877.542 ^a
5423.186	30	15/2	8765.556	17/2	27199.779
5423.544	nl 10	15/2	10466.704	15/2	28899.719
5424.089	64	11/2	9268.741	11/2	27699.892
5425.204	nl 18	13/2	10423.669	13/2	28851.022

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5433.716	nl 17	9/2	8320.255	9/2	26718.753
5435.134	55	5/2	9710.615	7/2	28104.309
5437.904	nl 6	15/2	10466.704	13/2	28851.022
5444.773	nl 16	5/2	10828.988	3/2	29190.148
5445.407	89	19/2	11151.448	19/2	29510.445
5446.326	35	13/2	10266.516	15/2	28622.414
5448.433	18	13/2	28032.990	13/2	9684.190
5451.876	nl 23	15/2	11483.442	15/2	29820.657
5453.232	118	11/2	27066.095	13/2	8733.450
5453.533	22	9/2	9105.035	11/2	27436.682
5453.786	19	13/2	10423.669	15/2	28754.461
5453.846	24	7/2	10194.780	7/2	28525.354
5456.397	69	9/2	8029.290	9/2	26351.314
5456.876	56	17/2	12736.636	19/2	31057.048
5458.007	41	5/2	9710.615	7/2	28027.233
5462.883	61	9/2	18300.341	9/2	0
5467.058	nl 7	11/2	4866.530	9/2	23152.820
5467.974	nl 17	13/2	9464.455	15/2	27747.685
5469.027	nl 5	15/2	8765.556	15/2	27045.255
5469.506	189	13/2	19654.728	11/2	1376.605
5471.965	79	15/2	8765.556	15/2	27035.451
5472.499	22	9/2	8320.255	11/2	26588.368
5474.995	nl 9	5/2	8737.448	3/2	26997.230
5498.743	nl 10	9/2	8643.839	11/2	26824.764
5506.379	nl 37	15/2	10466.704	15/2	28622.414
5513.962	nl 13	7/2	8013.104	7/2	26143.830
5514.111	75	9/2	8029.290	11/2	26159.548
5514.574	55	4.5	4432.24	4.5	22560.965 ^a
5514.855	nl 14	11/2	13872.290	9/2	32000.017
5517.615	nl 8	11/2	10841.417	13/2	28960.156
5529.822	37	9/2	30356.670	7/2	12277.947
5530.631	53	15/2	8765.556	15/2	26841.658
5532.249	nl 44	7/2	8013.104	7/2	26083.919
5534.181	55	7/2	8013.104	7/2	26077.608
5536.757	nl 10	11/2	10904.049	13/2	28960.156
5538.374	nl 240	11/2	26784.270	13/2	8733.450
5539.463	18	9/2	11549.619	11/2	29596.942
5542.481	nl 18	13/2	10266.516	13/2	28303.969
5545.227	45	11/2	6892.950	11/2	24921.471
5553.752	nl 30	9/2	8320.255	7/2	26321.099
5556.142	nl 10	7/2	8013.104	9/2	26006.208
5561.672	nl 15	11/2	6714.199	9/2	24689.414
5568.074	nl 8	11/2	6714.199	13/2	24668.738
5569.608	nl 35	7/2	6535.587	9/2	24485.187 ^a
5573.558	nl 20	5/2	6451.823	5/2	24388.702 ^a
5573.898	nl 35	15/2	8765.556	15/2	26701.341
5575.709	nl 28	15/2	9745.391	15/2	27675.355

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5576.243	nl 27	11/2	8829.078	11/2	26757.324
5580.634	46	17/2	14302.923	19/2	32217.025
5590.462	60	11/2	4866.530	11/2	22749.175 ^a
5594.760	82	9/2	4432.240	7/2	22301.160 ^a
5597.433	nl 10	5/2	9710.615	7/2	27570.943
5599.069	nl 14	11/2	6714.199	9/2	24569.356
5599.709	46	7/2	6535.587	5/2	24388.702 ^a
5608.318	nl 14	7/2	28479.761	7/2	10654.110
5609.809	nl 7	15/2	10466.704	15/2	28287.674
5610.062	nl 38	11/2	6714.199	11/2	24534.366
5616.325	27	15/2	12804.483	17/2	30604.778
5617.018	nl 21	15/2	11483.442	17/2	29281.540
5617.656	54	17/2	11714.367	19/2	29510.445
5619.557	nl 16	7/2	11472.423	9/2	29262.534
5621.481	nl 15	15/2	10466.704	13/2	28250.672
5624.964	213	7/2	6535.587	9/2	24308.545
5627.906	nl 9	9/2	8320.255	7/2	26083.919
5628.833	nl 37	13/2	27444.925	13/2	9684.190
5629.411	43	7/2	28412.960	7/2	10654.110
5630.257	nl 18	13/2	6603.606	11/2	24359.861
5631.009	nl 44	9/2	5822.905	9/2	23576.782
5634.928	80	9/2	10356.710	11/2	28098.267
5637.642	nl 20	9/2	8320.255	11/2	26053.248
5638.333	nl 16	19/2	28451.280	17/2	10720.400
5641.382	nl 23	7/2	29830.034	5/2	12108.819
5642.105	nl 23	13/2	7951.338	15/2	25670.302
5643.953	20	7/2	7617.455	9/2	25330.615
5645.438	nl 10	15/2	10466.704	13/2	28175.209
5645.683	64	15/2	22088.820	15/2	4381.100
5648.399	nl 25	15/2	11483.442	15/2	29182.662
5648.941	nl 13	5/2	29806.252	5/2	12108.819
5649.278	56	11/2	9268.741	13/2	26965.207
5655.410	nl 20	11/2	11282.880	13/2	28960.156
5656.529	nl 11	15/2	28342.772	15/2	10668.960
5657.532	39	11/2	10904.049	13/2	28574.696
5659.018	29	9/2	8320.255	7/2	25986.288
5667.381	nl 12	11/2	9268.741	9/2	26908.682
5679.249	49	9/2	8029.290	11/2	25632.372
5680.337	nl 23	15/2	26333.170	13/2	8733.450
5681.381	nl 12	9/2	10920.378	11/2	28516.848
5685.419	nl 7	13/2	10266.516	13/2	27850.489
5688.309	nl 31	11/2	6313.239	9/2	23888.281
5691.836	nl 15	17/2	11714.367	15/2	29278.521
5697.225	nl 18	15/2	14780.939	17/2	32328.494
5697.712	nl 18	11/2	6313.239	11/2	23859.275
5699.955	12	11/2	11944.223	13/2	29483.354
5703.627	37	9/2	8320.255	7/2	25848.090

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5707.982	nl 18	13/2	10266.516	11/2	27780.979
5708.759	17	15/2	16650.620	13/2	34163.027
5709.143	nl 4	11/2	27195.110	13/2	9684.190
5712.192	22	13/2	12041.668	13/2	29543.224
5713.331	nl 9	13/2	13146.599	13/2	30644.667
5717.206	nl 12	7/2	11869.331	9/2	29355.515
5720.451	88	7/2	28412.960	9/2	10936.670
5722.612	nl 17	11/2	27153.870	13/2	9684.190
5723.522	nl 25	11/2	6892.949	11/2	24359.861
5726.350	nl 22	15/2	26191.740 ^a	13/2	8733.453
5726.533	nl 11	7/2	11274.244	5/2	28731.850
5728.378	70	17/2	14028.722	19/2	31480.828
5730.189	nl 5	9/2	10356.752	7/2	27803.341
5731.531	nl 5	11/2	11282.880	13/2	28725.383
5735.781	46	7/2	8013.104	9/2	25442.695
5740.167	nl 26	15/2	11483.442	15/2	28899.719
5745.760	30	9/2	8029.290	11/2	25428.607
5746.622	54	19/2	29309.852	19/2	11913.160
5748.007	75	13/2	6603.606	15/2	23996.130
5752.234	nl 22	11/2	4866.530	11/2	22246.255
5753.327	61	11/2	9268.741	13/2	26645.170
5756.391	nl 81	11/2	8829.078	13/2	26196.253
5765.103	nl 10	11/2	12658.416	13/2	29999.348
5766.634	15	9/2	8643.839	11/2	25980.167
5769.348	nl 13	7/2	28731.220	7/2	11403.067
5775.170	nl 7	15/2	15994.810	17/2	33305.651
5776.612	25	15/2	8363.916	15/2	25670.302
5779.535	nl 13	9/2	10356.752	7/2	27654.383
5781.066	nl 10	9/2	9105.035	11/2	26398.087
5784.299	28	17/2	30848.875	15/2	13565.520
5785.694	20	15/2	27689.990	13/2	10410.760
5787.119	nl 23	17/2	9770.288	15/2	27045.255
5788.347	16	7/2	28412.960	5/2	11141.580
5788.603	nl 8	7/2	30189.694	7/2	12919.185
5790.187	8	11/2	30086.880	9/2	12821.080
5790.406	nl 16	17/2	9770.288	15/2	27035.451
5796.352	nl 6	9/2	10356.752	9/2	27604.203
5798.198	6	15/2	11483.450	13/2	28725.290
5812.204	8	15/2	8765.556	13/2	25965.963
5815.525	25	15/2	29412.690	13/2	12222.100
5817.908	nl 16	15/2	13439.023	15/2	30622.592
5818.866	nl 13	13/2	9464.455	13/2	26645.170
5820.126	nl 9	9/2	12519.718	11/2	29696.709
5823.152	8	7/2	28104.690	9/2	10936.670
5825.121	nl 14	7/2	10194.780	7/2	27357.054
5827.462	nl 30	11/2	6892.949	11/2	24048.320
5837.561	nl 10	9/2	11549.619	9/2	28675.308

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5843.479	53	9/2	8320.255	11/2	25428.607
5846.782	nl 10	13/2	10423.669	11/2	27522.363
5855.199	nl 12	7/2	15634.176	5/2	32708.095
5855.368	nl 19	11/2	19920.355	13/2	2846.744
5864.496	nl 8	13/2	12041.668	13/2	29088.699
5866.071	nl 24	7/2	17042.405	9/2	0
5875.487	28	11/2	10904.049	11/2	27919.207
5879.378	nl 8	7/2	9918.205	5/2	26922.093
5884.989	8	13/2	12041.668	11/2	29029.547
5893.492	234	11/2	6714.199	13/2	23677.365
5896.218	17	9/2	25205.463	9/2	8250.170
5897.409	nl 11	7/2	7617.455	9/2	24569.356
5902.991	40	11/2	16935.880	9/2	0
5904.524	nl 6	17/2	12736.636	17/2	29668.103
5906.326	15	9/2	5822.890	11/2	22749.175 ^a
5906.519	14	13/2	9464.455	13/2	26390.208
5907.249	112	9/2	18300.341	11/2	1376.605
5924.633	25	13/2	10423.669	13/2	27297.680
5929.330	80	11/2	18237.240	11/2	1376.605
5934.451	17	13/2	15772.560	13/2	32618.845
5936.246	nl 58	9/2	8029.290	11/2	24870.318
5938.827	24	11/2	6313.239	13/2	23146.917
5938.228	nl 11	11/2	16835.400	9/2	0
5940.178	34	13/2	29051.942	13/2	12222.100
5940.449	nl 22	13/2	28643.769	15/2	11814.660
5949.765	nl 171	17/2	27523.120	17/2	10720.400
5954.881	36	13/2	10423.669	15/2	27211.960
5957.238	11	13/2	12118.054	15/2	28899.719
5960.933	110	7/2	7617.455	5/2	24388.702 ^a
5970.186	17	15/2	10466.704	15/2	27211.960
5971.086	nl 18	7/2	11869.331	9/2	28612.095
5975.644	16	9/2	27384.059	7/2	10654.110
5977.377	nl 8	11/2	10904.049	13/2	27629.152
5985.748	nl 31	7/2	28104.689	7/2	11403.067
5987.819	nl 94	9/2	8320.255	11/2	25016.201
5993.095	16	7/2	28731.220	9/2	12049.950
5994.418	nl 82	9/2	18054.202	11/2	1376.605
6011.218	35	9/2	8320.255	9/2	24951.215
6014.607	10	13/2	10423.669	15/2	27045.255
6021.988	22	9/2	8320.255	11/2	24921.466
6023.642	68	15/2	27265.622	15/2	10668.960
6030.234	54	15/2	28342.772	17/2	11764.250
6035.413	21	11/2	6313.239	9/2	22877.542 ^a
6047.884	18	7/2	12049.480	9/2	28579.611
6054.231	22	5/2	6451.823	7/2	22964.630 ^a
6061.992	70	9/2	27145.754	7/2	10654.110
6068.436	nl 8	13/2	11562.777	13/2	28036.928

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
6069.197	nl 20	7/2	8013.104	9/2	24485.187 ^a
6072.077	39	15/2	27133.216	15/2	10668.960
6074.285	18	17/2	10531.966	17/2	26990.251
6074.993	134	9/2	24706.499	9/2	8250.170
6076.144	nl 12	7/2	28731.220	7/2	12277.947
6083.735	78	11/2	6714.199	13/2	23146.917
6085.810	142	9/2	24677.280	9/2	8250.170
6094.119	31	13/2	25138.184	13/2	8733.450
6100.703	35	7/2	16387.020	9/2	0
6105.825	18	5/2	9710.615	7/2	26083.919
6107.014	90	9/2	25205.463	11/2	8835.380
6118.016	50	11/2	24590.800	9/2	8250.170
6124.960	46	9/2	16322.152	9/2	0
6136.690	24	11/2	9675.044	13/2	25965.963
6138.092	9	15/2	30283.139	13/2	13996.091
6149.670	20	7/2	7617.455	5/2	23874.021
6153.001	nl 15	11/2	6313.239	9/2	22560.965 ^a
6161.073	34	9/2	8643.839	11/2	24870.318
6179.837	28	13/2	10470.344	15/2	26647.525
6191.936	10	13/2	6603.606	11/2	22749.175 ^a
6222.780	9	13/2	10266.516	15/2	26332.055
6223.887	nl 6	9/2	28883.770	9/2	12821.083
6232.579	14	13/2	7630.147	11/2	23670.431
6236.807	102	19/2	29309.852	17/2	13280.440
6238.372	95	7/2	6535.587	9/2	22560.965 ^a
6239.883	nl 8	11/2	9268.741	9/2	25290.248
6242.330	nl 9	9/2	10356.752	7/2	26371.986
6246.546	nl 9	11/2	28054.356	9/2	12049.950
6251.682	10	11/2	30217.484	11/2	14226.248
6270.364	46	15/2	27689.962	13/2	11746.340
6280.999	54	11/2	27662.982	13/2	11746.340
6292.876	22	11/2	28764.269	11/2	12877.670
6297.347	23	15/2	27689.962	15/2	11814.660
6298.408	nl 12	11/2	27195.110	11/2	11322.420
6299.531	28	11/2	4866.530	9/2	20736.338 ^a
6311.952	4	13/2	6603.606	15/2	22442.185 ^a
6312.170	nl 4	11/2	13250.690	13/2	29088.699
6334.990	35	15/2	26191.740 ^a	13/2	10410.760
6337.797	17	7/2	26428.100	7/2	10654.110
6356.666	10	9/2	10356.752	7/2	26083.919
6367.890	10	13/2	10266.510	13/2	25965.900
6372.371	nl 16	5/2	9710.615	7/2	25399.020
6384.451	14	9/2	27936.663	7/2	12277.947
6388.559	35	15/2	27394.976	13/2	11746.340
6389.825	10	11/2	12658.416	13/2	28303.969
6391.011	17	13/2	6603.606	11/2	22246.255
6416.572	15	15/2	27394.976	15/2	11814.660

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
6417.480	nl 15	11/2	11944.223	11/2	27522.363
6425.462	46	13/2	6603.606	15/2	22162.410
6438.160	nl 7	13/2	13659/247	15/2	29182.662
6440.364	53	13/2	13146.599	11/2	28669.174
6440.366	54	15/2	26191.740 ^a	15/2	10668.960
6441.818	56	15/2	27265.622	13/2	11746.340
6442.859	14	13/2	7630.147	13/2	23146.917
6469.039	nl 10	13/2	25138.184	13/2	9684.190
6472.773	34	7/2	26586.550	5/2	11141.581
6479.760	nl 6	11/2	28764.269	13/2	13335.895
6485.370	nl 18	9/2	27145.754	9/2	11730.600
6486.560	650	17/2	25059.089	15/2	9646.850
6516.343	nl 9	9/2	19871.160	9/2	35213.021
6523.982	20	9/2	8029.290	7/2	23353.116 ^a
6539/224	61	19/2	30098.998	19/2	14799.880
6537.471	9	11/2	10904.049	9/2	26196.253
6539.925	22	7/2	26428.100	5/2	11141.581
6559.597	10	13/2	27444.925	11/2	12204.304
6571.034	nl 32	15/2	8363.916	15/2	23578.018 ^a
6576.070	9	11/2	26524.890	11/2	11322.420
6577.508	nl 11	11/2	11282.880	9/2	26482.007
6581.885	7	5/2	9710.615	7/2	24899.636
6583.537	nl 6	11/2	9483.533	13/2	24668.738
6616.025	196	7/2	15110.661	9/2	0
6617.063	nl 4	17/2	12736.636	17/2	27844.904
6617.336	51	15/2	24759/250	15/2	9646.850
6630.181	15	9/2	9105.035	11/2	24183.415 ^a
6632.770	nl 4	15/2	29412.685	17/2	14340.210
6636.333	nl 5	13/2	9464.455	15/2	24528.854
6650.257	nl 3	9/2	8320.255	7/2	23353.116 ^a
6709/237	10	15/2	27133.260	13/2	12222.100
6725.360	85	5/2	6451.823	7/2	21316.810
6749.209	50	15/2	8765.556	15/2	23578.018 ^a
6763.722	5	17/2	14028.722	19/2	28809.400
6765.297	12	15/2	28342.772	15/2	13565.520
6686.434	nl 10	7/2	8013.104	7/2	22964.630 ^a
6703.511	13	9/2	5822.905	9/2	20736.338 ^a
6744.932	nl 14	11/2	6892.949	11/2	21714.802 ^a
6782.978	nl 21	3/2	9650.060	5/2	24388.702 ^a
6788.184	21	13/2	25138.184	13/2	10410.760
6797.865	34	13/2	25138.184	11/2	10431.720
6799.1	37	11/2	25135.518	11/2	10431.720
6808.396	nl 5	7/2	7617.455	7/2	22301.145 ^a
6810.509	10	15/2	9745.420	17/2	24429/240
6810.994	nl 28	5/2	9710.640	5/2	24388.702 ^a
6826.675	nl 110	9/2	8320.255	7/2	22964.630 ^a
6833.879	nl 9	9/2	26032.009	7/2	11403.067

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
6845.305	58	5/2	6451.823	5/2	21056.348 ^a
6847.480	27	13/2	10423.669	15/2	25023.550
6855.001	nl 7	13/2	9464.455	11/2	24048.320
6855.322	18	15/2	17429.980	13/2	2846.744
6885.420	12	17/2	9770.330	19/2	24289.760 ^a
6889.913	24	19/2	29309.852	19/2	14799.880
6893.023	36	7/2	27883.218	9/2	13379.780
6904.230	8	15/2	12250.534	13/2	26730.415
6930.502	nl 8	5/2	8737.448	7/2	23162.497
6931.411	65	11/2	6313.239	9/2	20736.338 ^a
6941.753	45	13/2	17248.381	13/2	2846.744
6942.556	11	13/2	10470.344	11/2	24870.228
6944.485	nl 10	13/2	15772.560	11/2	1376.605
6954.744	nl 14	5/2	6451.823	5/2	20826.530 ^a
6995.508	52	7/2	6535.587	5/2	20826.530 ^a
6998.848	15	15/2	27620.060	13/2	13335.895
7004.687	10	9/2	13432.490	7/2	27704.707
7004.906	nl 17	15/2	17118.558	13/2	2846.744
7008.332	6	11/2	22998.253	13/2	8733.450
7008.775	44	5/2	6451.823	3/2	20715.719
7016.555	14	9/2	9105.035	7/2	23353.116 ^a
7026.094	nl 10	11/2	6714.199	11/2	20942.933 ^a
7037.560	nl 16	7/2	8013.104	9/2	22218.655
7038.110	6	9/2	9105.035	11/2	23309.476
7039.939	23	7/2	6535.587	9/2	20736.338 ^a
7041.108	nl 4	13/2	10470.344	13/2	24668.738
7070.533	30	9/2	14139.300	9/2	0
7076.126	nl 4	11/2	9483.533	11/2	23611.664
7083.429	200	13/2	9464.460	15/2	23578.018 ^a
7091.629	nl 7	5/2	8737.448	7/2	22834.790
7094.691	22	5/2	6451.823	7/2	20542.983
7097.968	26	13/2	7630.147	11/2	21714.802 ^a
7101.187	nl 12	15/2	8363.910	15/2	22442.185 ^a
7115.484	18	11/2	6892.949	11/2	20942.933 ^a
7117.560	24	11/2	16935.880	9/2	30981.669
7128.169	nl 24	13/2	7630.147	15/2	21655.124
7134.864	nl 8	13/2	7630.170	13/2	21641.950
7150.649	16	9/2	8320.255	7/2	22301.160 ^a
7163.745	15	17/2	12736.670	17/2	26692.000 ^a
7183.412	nl 10	9/2	8643.839	9/2	22560.965 ^a
7216.421	nl 4	13/2	27213.988	11/2	13360.529
7221.674	36	11/2	6892.949	9/2	20736.338 ^a
7240.324	nl 6	17/2	9770.330	15/2	23578.018 ^a
7245.184	21	15/2	8363.916	15/2	22162.410
7255.175	380	13/2	15156.070	11/2	1376.605
7265.574	nl 5	13/2	10423.680	11/2	24183.415 ^a
7265.838	7	17/2	18380.340	17/2	32139.568

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
7266.625	17	17/2	10532.001	19/2	24289.760 ^a
7278.726	110	11/2	15111.480	11/2	1376.605
7280.314	35	11/2	8829.078	9/2	22560.965 ^a
7281.341	nl 5	9/2	13974.730	7/2	27704.707
7302.256	nl 5	13/2	7951.350	13/2	21641.950
7309.733	nl 5	15/2	8765.570	15/2	22442.185 ^a
7316.682	13	11/2	14505.090	11/2	28168.714
7319.268	23	7/2	14045.708	7/2	27704.707
7320.071	33	9/2	8643.839	9/2	22301.160 ^a
7320.626	nl 7	7/2	7617.455	9/2	21273.728
7328.016	15	5/2	9710.640	7/2	23353.116 ^a
7335.136	nl 2	13/2	24951.730	11/2	11322.420
7337.282	nl 4	11/2	6714.220	13/2	20339.470
7337.714	12	13/2	13897.891	11/2	27522.363
7346.172	nl 5	11/2	9268.741	9/2	22877.524 ^a
7352.265	nl 5	15/2	11483.442	13/2	25080.951
7354.833	nl 3	13/2	10266.516	11/2	23859.275
7364.208	15	13/2	16422.207	13/2	2846.744
7379.937	nl 5	11/2	551.949	13/2	20439.490
7390.274	nl 2	15/2	12804.483	15/2	26332.055
7393.802	nl 6	9/2	14897.770	11/2	1376.620
7404.778	nl 2	11/2	23185.233	13/2	9684.190
7428.425	nl 3	11/2	13250.690	13/2	26708.776
7436.633	nl 12	13/2	7951.338	11/2	21399/281
7439.04	36	7/2	7617.455	5/2	21056.348 ^a
7440.860	nl 4	13/2	10423.680	11/2	23859.280
7462.398	nl 4	15/2	8765.570	15/2	22162.410
7463.978	nl 9	11/2	9483.533	9/2	22877.524 ^a
7467.496	10	9/2	14764.290	11/2	1376.605
7479.184	nl 3	9/2	10356.752	7/2	23723.515
7483.183	nl 8	7/2	9704.750	7/2	23064.370 ^a
7498.888	nl 7	9/2	12746.082	7/2	26077.608
7509.508	nl 8	13/2	7630.147	11/2	20942.933 ^a
7511.542	nl 15	17/2	11714.367	15/2	25023.550
7523.291	10	9/2	10920.378	9/2	24208.775
7536.197	nl 6	11/2	9483.540	11/2	22749.175 ^a
7539.478	nl 10	7/2	9704.750	7/2	22964.630 ^a
7542.806	12	5/2	9710.640	7/2	22964.630 ^a
7555.046	nl 8	13/2	24554.990	11/2	11322.420
7568.468	nl 15	7/2	7617.455	5/2	20826.530 ^a
7569.105	nl 6	13/2	16250.9	11/2	29458.91
7573.242	nl 3	5/2	8737.448	5/2	21938.328
7599.958	10	13/2	10423.680	15/2	23578.018 ^a
7602.328	nl 2	9/2	8320.255	11/2	21470.498
7603.604	20	15/2	15994.810	13/2	2846.744
7606.547	nl 1	15/2	11483.442	15/2	24626.392
7609.254	nl 17	19/2	11151.490	19/2	24289.760 ^a

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
7620.501	nl 6	7/2	7617.455	9/2	20736.338 ^a
7636.327	40	9/2	14468.310	11/2	1376.605
7651.767	36	19/2	13626.720	17/2	266920 ^a
7661.401	15	15/2	17429.980	15/2	4381.100
7668.138	16	17/2	11714.380	19/2	24751.780 ^a
7684.518	18	11/2	8829.078	9/2	21838.677
7713.015	30	17/2	14028.722	17/2	26990.251
7714.329	15	7/2	9918.170	9/2	22877.524 ^a
7725.252	nl 12	13/2	10266.510	11/2	23207.530
7789/220	nl 6	17/2	12736.636	17/2	25579.110
7790.889	5	13/2	16626.890	11/2	29458.910
7802.166	14	7/2	8013.104	5/2	20826.530 ^a
7804.406	20	9/2	14186.360	11/2	1376.605
7806.808	nl 13	9/2	10356.752	7/2	23162.497
7817.033	nl 3	13/2	13897.891	11/2	26686.944
7842.577	nl 6	13/2	24951.730	11/2	12204.304
7857.475	nl 6	7/2	8013.104	9/2	20736.338 ^a
7866.150	nl 5	13/2	11462.912	15/2	24172.223
7873.840	nl 5	15/2	9745.391	15/2	22442.185 ^a
7884.135	17	15/2	10466.704	13/2	23146.917
7889.311	60	17/2	9770.330	15/2	22442.185 ^a
7910.501	nl 5	13/2	13146.599	11/2	25789/252
7912.997	34	11/2	15111.480	9/2	27745.287
7919.993	10	11/2	15469.560	13/2	2846.744
7929.466	nl 2	11/2	14760.320	9/2	27368.267
7940.172	29	5/2	15113.984	7/2	27704.707
7965.293	nl 9	5/2	6451.823	7/2	19002.837 ^a
7999.185	nl 3	13/2	10470.344	15/2	22968.185
8018.809	17	7/2	6535.587	7/2	19002.837 ^a
8027.119	8	7/2	8013.108	5/2	20467.450 ^a
8062.49	6	15/2	16451.350	13/2	28851.022
8069.405	nl 5	17/2	14302.923	17/2	26692.000 ^a
8086.784	nl 3	11/2	9268.741	9/2	21631.198
8111.028	20	13/2	10423.680	11/2	22749.175 ^a
8139.924	nl 4	17/2	11714.367	15/2	23996.130
8160.791	112	13/2	9464.460	11/2	21714.802 ^a
8170.833	12	5/2	10828.988	7/2	23064.370 ^a
8174.676	11	13/2	11462.912	13/2	23692.444
8210.847	12	13/2	10266.510	15/2	22442.185 ^a
8218.971	5	11/2	9675.044	9/2	21838.677
8222.482	nl 3	11/2	9483.533	13/2	21641.964
8233.786	10	13/2	12041.670	11/2	24183.415 ^a
8238.524	45	11/2	14981.510	13/2	2846.744
8257.844	nl 12	7/2	10194.740	7/2	22301.145 ^a
8276.642	nl 11	7/2	11274.180	7/2	23353.116 ^a
8301.271	12	7/2	8013.104	5/2	20056.146
8320.561	36	17/2	12736.670	19/2	24751.780 ^a

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
8327.581	nl 4	11/2	9268.750	9/2	21273.710
8329.675	5	9/2	14764.290	11/2	26766.200
8333.738	nl 1	9/2	13432.490	11/2	25428.607
8349.501	nl 5	11/2	10904.070	9/2	22877.524 ^a
8376.978	nl 35	15/2	14780.939	13/2	2846.744
8391.486	10	11/2	14760.320	13/2	2846.744
8393.847	10	17/2	10532.001	15/2	22442.185 ^a
8395.932	65	11/2	8829.078	9/2	20736.338 ^a
8415.219	nl 11	9/2	11184.410	7/2	23064.370 ^a
8432.191	nl 2	15/2	15819.324	15/2	27675.355
8453.074	nl 6	11/2	12658.427	9/2	24485.187 ^a
8488.317	nl 3	3/2	14420.003	5/2	26197.8
8526.492	nl 3	9/2	13605.68	9/2	25330.615
8539.710	nl 5	5/2	11646.260	7/2	23353.116 ^a
8549.691	nl13	9/2	11184.410	9/2	22877.542 ^a
8565.573	nl 3	9/2	8643.830	11/2	20315.280
8567.514	20	7/2	11668.787	9/2	0
8571.418	12	15/2	11483.442	13/2	23146.917
8575.204	6	11/2	14505.090	13/2	2846.744
8588.806	nl 3	9/2	11713.220	7/2	23353.116 ^a
8592.744	nl 6	13/2	13146.599	13/2	24781.131
8599/241	nl 3	13/2	9464.460	13/2	21096.530
8614.061	nl 2	9/2	8643.839	11/2	20249.580
8615.883	nl 9	7/2	11274.244	9/2	22877.524 ^a
8624.300	nl 15	7/2	11472.423	7/2	23064.370 ^a
8624.877	nl 2	13/2	24951.730	11/2	13360.529
8644.635	10	15/2	13439.023	13/2	25003.715
8653.316	nl 15	17/2	12736.670	19/2	24289.760 ^a
8682.117	nl 5	9/2	11549.614	7/2	23064.370 ^a
8705.521	nl 11	7/2	11869.331	7/2	23353.116 ^a
8709.564	34	13/2	9464.460	11/2	20942.933 ^a
8717.830	nl 8	11/2	9268.741	9/2	20736.338 ^a
8718.817	nl 5	11/2	11282.870	11/2	22749.175 ^a
8724.067	nl 9	11/2	9483.540	11/2	20942.933 ^a
8764.630	nl 22	3/2	9650.060	5/2	21056.348 ^a
8775.504	10	9/2	13974.730	11/2	25366.965
8801.914	42	9/2	10356.710	11/2	21714.802 ^a
8811.465	27	5/2	9710.640	5/2	21056.348 ^a
8822.442	10	11/2	14178.380	13/2	2846.744
8825.333	10	9/2	11549.614	9/2	22877.524 ^a
8847.259	5	11/2	10904.070	11/2	22203.860
8859.101	13	17/2	15665.829	15/2	4381.120
8881.379	18	13/2	11462.858	13/2	22719.340
8918.421	nl 10	11/2	13376.992	11/2	24586.670
8962.403	20	3/2	11361.817	1/2	22516.490 ^a
8930.529	17	13/2	24554.99	11/2	13360.529
8942.410	16	3/2	11361.817	5/2	22541.342

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
8944.852	10	3/2	9650.060	5/2	20826.530 ^a
8954.679	nl 25	9/2	11713.249	9/2	22877.524 ^a
8965.404	6	9/2	14139.300	9/2	25290.248
8975.694	nl 50	7/2	9918.170	5/2	21056.348 ^a
8986.243	95	19/2	13626.720	19/2	24751.780 ^a
8993.509	67	9/2	19196.472	11/2	8080.440
9015.841	nl 6	7/2	11472.423	9/2	22560.965 ^a
9016.229	nl 6	3/2	12701.269	3/2	23789.203
9019.598	nl 3	5/2	12078.583	7/2	23162.497
9058.096	28	13/2	13146.600	11/2	24183.415 ^a
9062.401	nl 6	7/2	9704.750	9/2	20736.338 ^a
9066.240	nl 50	7/2	11274.180	7/2	22301.145 ^a
9074.106	nl 2	11/2	23067.290	9/2	12049.950
9076.121	nl 11	7/2	12049.480	7/2	23064.370 ^a
9078.497	8	11/2	12658.416	11/2	23670.431
9079.042	nl 7	9/2	11549.614	9/2	22560.965 ^a
9096.905	26	7/2	8013.104	7/2	19002.837 ^a
9110.821	nl 13	7/2	13415.769	5/2	24388.702 ^a
9117.502	7	13/2	14470.060	13/2	25434.959
9132.968	25	9/2	19196.472	9/2	8250.170
9141.072	nl 7	17/2	22700.890	17/2	11764.250
9143.853	nl 10	11/2	11944.223	9/2	22877.524 ^a
9144.025	53	5/2	9710.615	3/2	20643.800
9164.795	nl 13	7/2	9918.170	5/2	20826.530 ^a
9174.839	nl 4	15/2	12250.534	13/2	23146.917
9176.122	27	7/2	13590.350	9/2	24485.187 ^a
9183.414	nl 2	17/2	22700.890	15/2	11814.660
9189.156	6	13/2	11562.790	15/2	22442.185 ^a
9204.247	nl 13	7/2	10194.740	5/2	21056.348 ^a
9208.296	nl 3	9/2	8029.29	9/2	18886.085
9216.883	nl 9	19/2	15845.359	17/2	26692.000 ^a
9230.499	nl 21	13/2	10470.344	11/2	21301.023
9232.162	nl 9	7/2	11572.350	7/2	22301.160 ^a
9241.772	7	3/2	9650.06	5/2	20467.450 ^a
9247.458	15	9/2	28936.494	9/2	18125.523
9248.361	10	17/2	14028.722	15/2	24838.484
9283.717	nl 10	7/2	10194.740	7/2	20963.330
9293.861	50	5/2	9710.640	5/2	20467.450 ^a
9294.657	25	3/2	13033.479	3/2	23789.203
9298.448	25	9/2	11549.614	7/2	22301.160 ^a
9307.186	11	13/2	12118.060	11/2	1376.620
9319.006	50	17/2	11714.367	15/2	22442.185 ^a
9336.680	10	13/2	12041.668	11/2	22749.175 ^a
9337.905	6	5/2	12647.027	7/2	23353.116 ^a
9374.581	10	11/2	15238.140	13/2	25902.360
9385.756	30	1/2	11865.001	1/2	22516.490 ^a
9403.13	nl 5	7/2	10194.740	5/2	20826.530 ^a

nl ... new line, ^a previously unknown energy level

Table 1 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
9425.497	8	11/2	14760.320	11/2	25366.965
9426.870	8	3/2	11911.437	1/2	22516.490 ^a
9428.620	9	9/2	13605.68	9/2	24208.775
9446.839	8	5/2	12481.682	7/2	23064.370 ^a
9471.121	15	7/2	12321.925	9/2	22877.524 ^a
9493.715	nl 18	9/2	11184.410	11/2	21714.802 ^a
9503.761	nl 6	13/2	10423.680	11/2	20942.933 ^a
9511.74	16	9/2	13974.730	9/2	24485.187 ^a
9553.105	nl 10	3/2	12051.530 2	1/2	22516.490 ^a
9560.301	nl 24	9/2	10356.710	9/2	20813.780
9567.360	13	11/2	14760.320	11/2	25209.670
9583.331	66	11/2	11282.870	11/2	21714.802 ^a
9586.286	14	5/2	12647.027	5/2	23075.728
9651.909	15	9/2	12519.718	9/2	22877.524 ^a
9663.357	26	5/2	9710.640	5/2	20056.197
9684.477	6	15/2	20007.142	13/2	9684.19
9699.662	nl 7	11/2	14178.380	9/2	24485.187 ^a
9716.396	nl 3	9/2	11549.614	9/2	21838.683
9716.816	23	9/2	5822.905	7/2	16111.549
9751.899	45	1/2	12264.888	1/2	22516.490 ^a
9768.643	12	9/2	13974.73	9/2	24208.775
9779.645	nl 5	5/2	12078.583	7/2	22301.145 ^a
9792.495	19	5/2	11107.705	7/2	21316.810
9834.801	33	9/2	11549.614	11/2	21714.802 ^a
9945.496	nl 8	3/2	12464.356	1/2	22516.490 ^a
9956.092	15	15/2	16650.620	17/2	26692.000 ^a
9958.534	15	11/2	10904.070	11/2	20942.933 ^a
9864.788	18	5/2	10828.988	7/2	20963.372
9878.011	nl 3	13/2	12041.668	15/2	22162.41

nl ... new line, ^a previously unknown energy level

Table 2: Spectral lines of Pr I with an intensity larger than 50 which clearly could be assigned to a transition between two energy levels

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
3363.938	nl 53	11/2	29718.524	9/2	0
4216.768	nl 53	11/2	4866.530	13/2	28574.696
4519.626	nl 112	15/2	8363.916	15/2	30483.514
4598.951	nl 178	11/2	24584.745	13/2	2846.744
4692.652	55	11/2	4866.530	9/2	26170.480
4795.241	50	7/2	30427.864	9/2	9579.832
4802.883	55	11/2	6313.239	11/2	27128.251
4825.813	70	9/2	4432.240	7/2	25148.347

nl ... new line, ^a previously unknown energy level

Table 2 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
4861.964	105	11/2	4866.530	11/2	25428.607
4869.332	70	11/2	6892.949	13/2	27423.911
4878.194	nl 97	13/2	6603.606	11/2	27097.270
4911.460	50	13/2	6603.606	11/2	26958.467
4915.407	230	11/2	23185.260	13/2	2846.744
4916.999	90	11/2	6313.239	13/2	26645.170
4925.315	450	15/2	23144.347	13/2	2846.744
4927.059	55	15/2	8765.556	13/2	29055.974
4961.027	290	11/2	22998.237	13/2	2846.744
4964.181	55	11/2	29718.524	9/2	9579.832
5017.880	65	13/2	7951.338	15/2	27879/216
5018.268	nl 116	13/2	31918.637	11/2	11997.050
5031.770	85	11/2	9675.040	13/2	29543.242
5034.639	55	15/2	8765.556	15/2	28622.414
5041.550	60	13/2	7951.338	11/2	27780.979
5043.611	50	7/2	7617.455	9/2	27438.992
5055.723	60	9/2	8029.290	7/2	27803.341
5056.569	125	11/2	4866.530	9/2	24637.265
5074.000	170	11/2	4866.530	9/2	24569.356
5075.586	135	11/2	8829.090	13/2	28525.569
5075.865	270	9/2	5822.905	9/2	25518.489
5079.266	280	11/2	22529.130	13/2	2846.744
5096.794	60	13/2	6603.606	11/2	26218.316
5099.136	60	9/2	5822.905	11/2	25428.607
5109.078	nl 60	7/2	6535.530	5/2	26103.032
5114.261	50	9/2	8643.839	7/2	28191.557
5117.291	380	15/2	9745.420	17/2	29281.511
5136.270	55	11/2	30793.720	9/2	11329.710
5138.297	85	11/2	6714.199	9/2	26170.480
5153.249	50	9/2	8643.830	9/2	28043.749
5167.541	50	9/2	8643.830	11/2	27990.060
5174.777	110	11/2	6313.239	11/2	25632.322
5183.491	100	9/2	19286.645	9/2	0
5190.494	120	13/2	7951.350	15/2	27212.011
5210.956	130	15/2	8765.570	15/2	27950.542
5213.404	100	11/2	9675.040	13/2	28851.059
5223.986	75	9/2	8643.830	11/2	27780.979
5231.691	115	15/2	8765.570	15/2	27874.491
5252.448	90	5/2	6451.823	7/2	25485.269
5257.536	135	13/2	7630.147	13/2	26645.170
5259.274	135	7/2	19008.740	9/2	0
5267.660	200	17/2	10532.001	19/2	29510.473
5285.628	1650	13/2	20290.580	11/2	1376.605
5287.547	85	7/2	6535.587	9/2	25442.695
5290.536	120	11/2	6313.239	11/2	25209.670
5290.946	52	13/2	6603.606	15/2	25498.559
5292.283	nl 208	9/2	18890.180	9/2	0

nl ... new line, ^a previously unknown energy level

Table 2 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5299.787	100	7/2	6535.587	7/2	25399.020
5308.816	160	13/2	6603.606	13/2	25434.959
5315.359	88	13/2	10470.300	15/2	29278.521
5317.648	85	11/2	8829.078	13/2	27629.152
5328.078	nl 70	15/2	23144.347	15/2	4381.100
5337.453	nl 51	9/2	4432.240	7/2	23162.497
5341.548	60	15/2	10466.730	15/2	29182.662
5341.990	70	11/2	6714.199	11/2	25428.607
5342.064	66	7/2	8013.104	7/2	26727.245
5370.335	145	11/2	6313.239	13/2	24928.881
5376.774	66	9/2	8643.839	9/2	27237.190
5391.580	58	15/2	9745.391	15/2	28287.674
5394.051	91	9/2	8643.839	9/2	27177.628
5424.089	64	11/2	9268.741	11/2	27699.892
5435.134	55	5/2	9710.615	7/2	28104.309
5445.407	89	19/2	11151.448	19/2	29510.445
5453.232	118	11/2	27066.095	13/2	8733.450
5456.397	69	9/2	8029.290	9/2	26351.314
5456.876	56	17/2	12736.636	19/2	31057.048
5462.883	61	9/2	18300.341	9/2	0
5469.506	189	13/2	19654.728	11/2	1376.605
5471.965	79	15/2	8765.556	15/2	27035.451
5514.111	75	9/2	8029.290	11/2	26159.548
5514.574	55	4.5	4432.24	4.5	22560.965 ^a
5530.631	53	15/2	8765.556	15/2	26841.658
5534.181	55	7/2	8013.104	7/2	26077.608
5538.374	nl 240	11/2	26784.270	13/2	8733.450
5590.462	60	11/2	4866.530	11/2	22749.175 ^a
5594.760	82	9/2	4432.240	7/2	22301.160 ^a
5617.656	54	17/2	11714.367	19/2	29510.445
5624.964	213	7/2	6535.587	9/2	24308.545
5634.928	80	9/2	10356.710	11/2	28098.267
5645.683	64	15/2	22088.820	15/2	4381.100
5649.278	56	11/2	9268.741	13/2	26965.207
5720.451	88	7/2	28412.960	9/2	10936.670
5728.378	70	17/2	14028.722	19/2	31480.828
5746.622	54	19/2	29309.852	19/2	11913.160
5748.007	75	13/2	6603.606	15/2	23996.130
5753.327	61	11/2	9268.741	13/2	26645.170
5756.391	nl 81	11/2	8829.078	13/2	26196.253
5843.479	53	9/2	8320.255	11/2	25428.607
5893.492	234	11/2	6714.199	13/2	23677.365
5907.249	112	9/2	18300.341	11/2	1376.605
5929.330	80	11/2	18237.240	11/2	1376.605
5936.246	nl 58	9/2	8029.290	11/2	24870.318
5949.765	nl 171	17/2	27523.120	17/2	10720.400
5960.933	110	7/2	7617.455	5/2	24388.702 ^a

nl ... new line, ^a previously unknown energy level

Table 2 – Continued

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
5987.819	nl 94	9/2	8320.255	11/2	25016.201
5994.418	nl 82	9/2	18054.202	11/2	1376.605
6023.642	68	15/2	27265.622	15/2	10668.960
6030.234	54	15/2	28342.772	17/2	11764.250
6061.992	70	9/2	27145.754	7/2	10654.110
6074.993	134	9/2	24706.499	9/2	8250.170
6083.735	78	11/2	6714.199	13/2	23146.917
6085.810	142	9/2	24677.280	9/2	8250.170
6107.014	90	9/2	25205.463	11/2	8835.380
6118.016	50	11/2	24590.800	9/2	8250.170
6236.807	102	19/2	29309.852	17/2	13280.440
6238.372	95	7/2	6535.587	9/2	22560.965 ^a
6280.999	54	11/2	27662.982	13/2	11746.340
6440.364	53	13/2	13146.599	11/2	28669.174
6440.366	54	15/2	26191.740 ^a	15/2	10668.960
6441.818	56	15/2	27265.622	13/2	11746.340
6486.560	650	17/2	25059.089	15/2	9646.850
6539/224	61	19/2	30098.998	19/2	14799.880
6616.025	196	7/2	15110.661	9/2	0
6617.336	51	15/2	24759/250	15/2	9646.850
6725.360	85	5/2	6451.823	7/2	21316.810
6749.209	50	15/2	8765.556	15/2	23578.018 ^a
6845.305	58	5/2	6451.823	5/2	21056.348 ^a
6931.411	65	11/2	6313.239	9/2	20736.338 ^a
6995.508	52	7/2	6535.587	5/2	20826.530 ^a
7083.429	200	13/2	9464.460	15/2	23578.018 ^a
7255.175	380	13/2	15156.070	11/2	1376.605
7278.726	110	11/2	15111.480	11/2	1376.605
7889.311	60	17/2	9770.330	15/2	22442.185 ^a
8395.932	65	11/2	8829.078	9/2	20736.338 ^a
8986.243	95	19/2	13626.720	19/2	24751.780 ^a
8993.509	67	9/2	19196.472	11/2	8080.440
9144.025	53	5/2	9710.615	3/2	20643.800
9293.861	50	5/2	9710.640	5/2	20467.450 ^a
9319.006	50	17/2	11714.367	15/2	22442.185 ^a
9583.331	66	11/2	11282.870	11/2	21714.802 ^a

nl ... new line, ^a previously unknown energy level

Table 3. Spectral lines of *Pr* II which clearly could be assigned to a transition between two energy levels

$\lambda/\text{\AA}$	SNR	Even		Odd	
		J-value	Level Energy/ cm^{-1}	J-value	Level Energy/ cm^{-1}
3898.837	nl 11	7	14035.46	8	39676.86
3956.753	nl 49	6	5854.54	6	31120.63
3974.851	nl 9	9	13639.13	9	38790.18
4010.602	nl 14	7	11253.46	7	36180.33
4014.331	nl 3	6	10137.93	7	35041.68
4022.712	nl 10	8	13021.33	8	37873.15
4062.220	nl 6	8	12237.15	8	36847.30
4087.209	nl 5	9	14330.52	9	38790.18
4133.612	nl 11	6	9211.95	7	33397.06
4176.318	nl 7	6	11283.14	5	35220.93
4213.554	nl 8	6	9670.82	7	33397.06
4223.466	nl 6	6	10454.26	5	34124.85
4306.037	nl 9	5	9733.44	6	32950.10
4382.390	nl 6	6	10137.93	6	32950.10
4394.984	nl 6	7	10650.24	7	33397.06
4446.986	nl 5	5	8379.46	6	30860.28
5201.579	nl 15	4	14167.90	5	33387.64
5219.048	38	7	25569.19	7	6413.93
5567.521	nl 2	8	13021.33	7	30977.67

Table 4: New levels found by analysis of hf patterns in the FT spectrum.

energy/ cm^{-1}	J-value	A ¹ /MHz	parity	lines which can be explained (Å)
19002.837(5)	7/2	804(2)	o	9069.905, 8018.809, 7965.293
20467.450(10)	5/2	792(16)	o	9293.861, 9241.771, 8027.119
20736.338(5)	9/2	611 (3)	o	9062.401, 8717.830, 8395.932, 7857.830, 7620.501, 7221.674, 7039.939, 6931.411, 6703.511, 6299.531
20826.530(10)	5/2	822(4)	o	9403.206 9164.799, 8944.852, 7802.166, 7568.468 6995.502, 6954.743
20942.933(5)	11/2	363(3)	o	9958.534, 9503.761, 8724.067, 8709.564, 7509.564, 7115.484, 7026.094
21056.348(5)	5/2	1378(3)	o	9204.274, 8975.694, 8811.465, 8754.630, 7439.040, 6845.305
21714.802(5)	11/2	1100(3)	o	9834.801, 9583.331, 9493.715, 8801.914, 8160.791, 7097.968, 6744.932
22301.145(5)	7/2	746(3)	o	9779.645, 9298.448, 9232.162, 9066.240, 8257.844, 7320.071, 7150.649, 6808.396, 5594.760
22442.185(5)	15/2	959(9)	o	9612.268, 9319.006, 9189.156, 8393.847, 8210.847, 7889.311, 7873.840, 7309.733, 7101.187, 6311.952
22516.49(5)	1/2	-994(5)	o	9945.496, 9751.939, 9553.105, 9426.870, 9385.756, 8926.403
22560.965(5)	9/2	920(5)	o	9079.042, 9015.841, 7280.314, 6283.372, 6153.001, 5514.574
22749.175(5)	11/2	878(9)	o	9336.680, 8718.817, 8111.028, 7536.197, 6191.936, 5590.462
22877.524(5)	9/2	931(5)	o	9651.909, 9471.121, 9143.853, 8954.679, 8825.333, 8615.883, 8549.691, 8349.501, 7714.329, 7463.978, 7346.172, 6117.532, 6035.413, 5419.933
22964.630(5)	7/2	1109(3)	o	7542.806, 7539.478, 6826.625, 6686.434, 6054.231
23064.370(10)	7/2	749(3)	o	9076.121, 8682.117, 8624.300, 8415.219, 7483.183
23353.116(5)	7/2	858(5)	o	9337.905, 8705.521, 8539.710, 8588.806, 8276.642, 7328.016, 7240.324 7016.555 6650.257, 6523.982
23578.018(5)	15/2	535(5)	o	7599.958, 7083.429, 6749.209 ² , 6571.034 ²
24183.415(10)	11/2	969(3)	o	9058.096, 8233.786, 7265.574, 6630.181
24289.760(10)	19/2	990(3)	o	8653,316, 7609.254 ² , 6885.420
24388.702(5)	5/2	1114(3)	o	9110.821, 5810.994, 6782.978, 5960.933, 5599.709, 5573.558
24485.187(5)	9/2	1110(2)	o	9699.662, 9511.740, 9176.122, 8453.074, 6069.197, 5569.608
24751.780(10)	19/2	1012(2)	o	8986.241, 8320.561, 7668.138

¹ The value of the hyperfine constant B could not be determined with significance therefore it is not taken into account in this work. B was set to zero when determining A.² The line was already classified in ref. [4], but this classification is wrong.

Table 4 – Continued

energy/ cm^{-1}	J-value	A^1 /MHz	parity	lines which can be explained ($\text{\AA}$)
26191.740(10)	15/2	478(3)	e	6920.705, 6440.366, 6334.990, 5726.350
26692.000(5)	17/2	837(5)	o	9956.092, 9216.883 ² , 8069.405 ² , 7651.767, 7163,745

¹ The value of the hyperfine constant B could not be determined with significance therefore it is not taken into account in this work. B was set to zero when determining A.

² The line was already classified in reference [4], but this classification is wrong.

4. Conclusion

In this work, we have concentrated on investigations of the hyperfine structure of the Pr atom and ion based on new FT spectra. With the help of these FT spectra we could enlarge the wavelength list of Pr from around 17000 up to 26000 lines. Furthermore we assigned more than 1200 lines to a transition between two known energy levels. By fitting several lines in the IR region we were also able to determine 24 new atomic levels. Even though this number is small compared to the approximately 2000 known energy levels, it shows the potential of FT spectra in classifying lines and finding new energy levels. The new FT spectra of Pr I and Pr II will be very helpful for further laser induced fluorescence spectroscopy experiments because now one can determine exactly possible excitation wavelengths for an investigation of promising structures. The full list of all more than 26000 lines is available on request.

Figure 1. Part of the FT spectrum in the visible region.

a ... line classified by Ginibre (ref. [4])

b ... line given in the tables of Ginibre (ref. [4]), but not classified

c ... line classified before having the FT spectrum by laser spectroscopy (ref. [9])

d ... new line, discovered with help of this spectrum

Around 5675.75 Å a typical blend situation can be noticed: a spectral line with a wide hf splitting (d^1) is overlapped by another line with a small hf splitting (b^1). The most intense component of the widely splitted line was noticed by Ginibre (ref. [4]) and treated to be a spectral line with small hf splitting (b^2).

Figure 2. Appearance of the line 9319.006 Å in the FT spectrum

Figure 3. Best fit of the FT spectrum of the line 9319.006 Å assuming a transition $J = 17/2$ to $J' = 15/2$. The hf constants of the lower level were fixed, the B factor of the upper level was assumed to be zero. The appearance of the line in the FT spectra (solid line) is compared to the fitted line profile (dashed line). All spectral lines appear in the FT spectrum with relative intensity ratios which are very close to the theoretical ones. The upper part of the figure shows the hf level scheme and all transitions.

References

- [1] King A 1928 *Astrophys. J.* **68** 194
- [2] Ginibre A 1989 *Phys. Scripta* **39** 694
- [3] Ginibre A 1989 *Phys. Scripta* **39** 710
- [4] Ginibre A 1988 PhD Thesis Paris
- [5] Ruczkowski J, Stachowska E, Elantkowska M, Guthöhrlein G H and Dembczyński J 2003 *Phys. Scripta* **68** 133
- [6] Furmann B, Stefańska D, Dembczyński J and Stachowska E 2005 *Phys. Scripta* **72** 300
- [7] Furmann B, Stefańska D, Dembczyński J and Stachowska E 2006 *Phys. Scripta* **74** 658
- [8] Guthöhrlein G H, Helmut Schmidt-Universität der Bundeswehr (Holstenhofweg 85, D-22043 Hamburg, Germany), private communication
- [9] Uddin Z PhD Thesis Graz 2006 unpublished
- [10] Gamper B Diploma Thesis Graz 2007 unpublished
- [11] Jaritz N, Jäger H and Windholz L 2002 *Eur. Phys. J. D* **18** 267
- [12] Peck R and Reeder K 1972 *J. Opt. Soc. Am.* **62** 958
- [13] Windholz L and Guthöhrlein G H 2003 *Phys. Scripta* **T105** 55
- [14] Learner R C M and Thorne A P 1988 *J. Opt. Soc. Am. B* **5** 2045
- [15] Messnarz D, Jaritz N, Arcimowicz B, Zilio V O, Engleman, Jr. R, Pickering J C, Jäger H, Guthöhrlein G H and Windholz L 2003 *Phys. Scripta* **68** 170
- [16] Martin W C, Zalubas R, Hagan L. 1978. Atomic Energy Levels - The Rare Earth Elements. Natl. Bur. Stand., NSRDS-NBS 60, p.98, U.S. G.P.O. Washington D.C.
- [17] Program package "Fitter", developed by Guthöhrlein G H, Institute for Experimental Physics, Helmut Schmidt Universität der Bundeswehr Hamburg 1998