THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 129:367–376, 2000 July

THEORETICAL OSCILLATOR STRENGTHS IN Pr III AND APPLICATION TO SOME CP STARS

P. PALMERI, P. QUINET, AND Y. FRÉMAT
Astrophysique et Spectroscopie, Université de Mons-Hainaut, 15 Rue de la Halle, B-7000 Mons, Belgium; p.palmeri@umh.ac.be
J.-F. WYART
Laboratoire Aimé Cotton, Centre National de Recherches Scientifiques II, Bât. 505, Centre Universitaire, F-91405 Orsay, France; jean-francois.wyart@lac.u-psud.fr
AND
E. BIÉMONT
Astrophysique et Spectroscopie, Université de Mons-Hainaut, 15 Rue de la Halle, B-7000 Mons, Belgium, and Institut d'Astrophysique, Université de Liège, 5, Avenue de Cointe, B-4000 Liège, Belgium; e.biemont@ulg.ac.be
Received 1999 August 23; accepted 1999 November 29

ABSTRACT

A set of transition probabilities is obtained for the first time for many transitions of Pr III of astrophysical interest. A relativistic Hartree-Fock method, combined with a least-squares fitting of the available experimental levels, including a large number of newly determined values, has been used for the calculations in which configuration interaction and core-polarization effects have been introduced. The interest of the new data set is illustrated by considering the chemical composition of the chemically peculiar (CP) stars HD 101065 (Przybylski's star) and HD 141556 (χ Lupi).

Subject headings: atomic data — stars: chemically peculiar — stars: individual (HD 101065, HD 141556)

1. INTRODUCTION

Praseodymium is one of the odd-Z lanthanides ($Z = 59$). It has one stable isotope (^{141}Pr) and 14 short-lived ones. An accurate determination of Pr abundance in different types of stars is important in astrophysics in relation with nucleosynthesis, Pr being generated by both the rapid and slow neutron capture processes (i.e., the *r* and *s* processes). So far, the abundance determination of Pr in chemically peculiar (CP) stars was essentially based on the second spectra emitted by the singly ionized atoms. The CP (Ap and Am) stars, however, are characterized by the relative weakness of the second spectrum of Pr in contrast to some other lanthanides (La II, Ce II, Nd II, ...; Mathys & Cowley 1992). A detailed knowledge of the third spectra of the lanthanides does allow a better understanding of these stars in relation with the fact that these spectra arise from the dominant, doubly ionized species. It has been pointed out (Cowley & Greenberg 1988) that the third spectra of the lanthanides can be identified in the *IUE* spectra of CP stars with the help of statistical techniques, although these contributions are weak and the UV absorption spectra are dominated by the iron-group strong contributions.

An accurate determination of transition probabilities of the lines of astrophysical interest is essential in order to give a strong support or to better assess these identifications. In fact, the presence of Pr III in one Ap star (Hg-Mn χ Lupi star) was mentioned by Bidelman (1966) a long time ago. Later on, doubly ionized praseodymium was identified in three magnetic Ap stars, i.e., HD 25354, HD 51418, and HD 200311 (Aikman, Cowley, & Crosswhite 1979), and this confirmed, in the case of HD 200311, a previous identification due to Adelman (1974) from a study of lines appearing in the blue region. More recently, the identification of Pr III lines in the red spectrum of magnetic Ap stars has been reported by Mathys & Cowley (1992), who emphasized the great strength of Pr III lines in some stars in contrast to the relative weakness of Pr^+ spectrum in upper main-sequence CP stars. Transitions of doubly ionized lanthanides, and particularly of Pr III, have been identified in the spectral range 5445–6587 Å of the extreme peculiar star HD 101065 (Przybylski's star) by Cowley & Mathys (1998).

The Pr III levels compiled by the NIST (Martin et al. 1978) were taken from Sugar's analysis (1963, 1969) with some additions and revisions made by Crosswhite, Crosswhite, & Judd (1968), Sugar (1974), and Wyart, Blaise, & Camus (1974). More than 3300 lines have been classified in the spectral range 821 to 10717 Å. In Sugar's lists (1969, 1974) about 4400 lines have been included above 2107 Å and more than 2900 lines in the range below that wavelength limit. More recently, a new analysis of the Pr III energy level scheme has been realized by Wyart & Palmeri (2000, unpublished) and is described in the next section of the present paper.

There are no published transition probabilities or radiative lifetimes in Pr III. This lack of oscillator strengths prompted us to perform calculations in the framework of the relativistic Hartree-Fock (HFR) approach. In view of the interest in the Pr III spectrum for astrophysics and the possibility of considering a huge number of well-determined energy levels which makes reliable a least-squares fitting procedure, we have decided to undertake the present effort which consists in providing the first detailed set of *f*-values for many lines of Pr III observed or observable in astrophysical spectra.

The present paper summarizes part of an extensive work devoted to a systematic study of the transition probabilities in lanthanide spectra of astrophysical interest. More details and tables with numerical results can be found on the Web site of Mons University where a new database is under construction.[1]

2. NEW ENERGY LEVELS IN Pr III

As recalled and compiled by Martin et al. (1978), the analysis of the Pr III spectrum led Sugar to 234 levels of the odd parity configurations $4f^3$, $4f^26p$, $4f5d^2$, $4f5d6s$, and $4f^25f$ and to 167 levels of even parity configurations $4f^25d$,

[1] At http://www.umh.ac.be/~astro/dream.shtml.

TABLE 1

VALUES OF THE Pr III PARAMETERS (in cm^{-1}) ADOPTED FOR CALCULATIONS

ODD PARITY				EVEN PARITY			
Config.	Parameter	Value	SF[a]	Config.	Parameter	Value	SF[a]
$4f^3$	E_{av}	20877		$4f^25d$.	E_{av}	27781	
	$F^2(4f,4f)$	64635	73		$F^2(4f,4f)$	71353	73
	$F^4(4f,4f)$	45775	84		$F^4(4f,4f)$	51325	84
	$F^6(4f,4f)$	30688	78		$F^6(4f,4f)$	33522	76
	α	6			α	16	
	β	−330			β	−337	
	γ	810			γ	1377	
	ζ_{4f}	662	92		ζ_{4f}	764	94
$4f^26p$	E_{av}	71398			ζ_{5d}	732	92
	$F^2(4f,4f)$	71822	73		$F^1(4f,5d)$[c]	495	
	$F^4(4f,4f)$	52252	85		$F^2(4f,5d)$	19895	74
	$F^6(4f,4f)$	33686	76		$F^3(4f,5d)$[c]	495	
	α	17			$F^4(4f,5d)$	14991	111
	β	−385			$G^1(4f,5d)$	10211	76
	γ	1391			$G^2(4f,5d)$[c]	1750	
	ζ_{4f}	748	91		$G^3(4f,5d)$	10269	96
	ζ_{6p}	2370	124		$G^4(4f,5d)$[c]	1654	
	$F^2(4f,6p)$	6428	79		$G^5(4f,5d)$	7479	93
	$G^2(4f,6p)$	2024	9	$4f^26s$.	E_{av}	39399	
	$G^4(4f,6p)$	1973	106		$F^2(4f,4f)$	71702	73
$4f5d^2$	E_{av}	72164			$F^4(4f,4f)$	52204	84
	$F^2(5d,5d)$	35431	80		$F^6(4f,4f)$	33763	76
	$F^4(5d,5d)$	24869	84		α	16	
	α	70			β	−337	
	β	−1862			γ	1377	
	ζ_{4f}	858	95		ζ_{4f}	747	91
	ζ_{5d}	883	94		$G^3(4f,6s)$	2355	79
	$F^1(4f,5d)$[c]	677		$4f^27s$.	E_{av}	110720	
	$F^2(4f,5d)$	20588	73		$F^2(4f,4f)$	71935	73
	$F^3(4f,5d)$[c]	351			$F^4(4f,4f)$	52383	84
	$F^4(4f,5d)$	15944	114		$F^6(4f,4f)$	33886	76
	$G^1(4f,5d)$	9283	74		α	16	
	$G^2(4f,5d)$[c]	1967			β	−337	
	$G^3(4f,5d)$	10539	101		γ	1377	
	$G^4(4f,5d)$[c]	2091			ζ_{4f}	772	94
	$G^5(4f,5d)$	6825	85		$G^3(4f,7s)$	873	93
$4f5d6s$......	E_{av}	90890		$4f^26d$.	E_{av}	111662	
	ζ_{4f}	849	94		$F^2(4f,4f)$	71874	73
	ζ_{5d}	1018	100		$F^4(4f,4f)$	52335	84
	$F^1(4f,5d)$[c]	677			$F^6(4f,4f)$	33851	76
	$F^2(4f,5d)$	20470	69		α	16	
	$F^3(4f,5d)$[c]	351			β	−337	
	$F^4(4f,5d)$	16737	113		γ	1377	
	$G^1(4f,5d)$	9834	75		ζ_{4f}	764	93
	$G^2(4f,5d)$[c]	1967			ζ_{6d}	190	114
	$G^3(4f,5d)$	12031	109		$F^1(4f,6d)$[c]	495	
	$G^4(4f,5d)$[c]	2091			$F^2(4f,6d)$	4502	83
	$G^5(4f,5d)$	7364	86		$F^3(4f,6d)$[c]	495	
	$G^3(4f,6s)$	2434	85[b]		$F^4(4f,6d)$	3855	162
	$G^2(5d,6s)$	15497	97		$G^1(4f,6d)$	2061	104
$4f^25f$	E_{av}	121590	$G^2(4f,6d)$[c]	1750			
	$F^2(4f,4f)$	71605	73	$G^3(4f,6d)$	1904	108	
	$F^4(4f,4f)$	52318	85	$G^4(4f,6d)$[c]	1654		
	$F^6(4f,4f)$	33795	76	$G^5(4f,6d)$	1287	93	

TABLE 1—*Continued*

Odd Parity				Even Parity			
Config.	Parameter	Value	SF[a]	Config.	Parameter	Value	SF[a]
$4f^25f$	α	21		$4f5d6p$	E_{av}	124450	
	β	−381			ζ_{4f}	907	100[b]
	γ	1377			ζ_{5d}	1041	100[b]
	ζ_{4f}	754	92		ζ_{6p}	2070	100
	ζ_{5f}	25	100[b]		$F^2(4f,5d)$	26609	88
	$F^1(4f,5f)$[c]	−483			$F^4(4f,5d)$	13257	88
	$F^2(4f,5f)$	2441	53	$F^2(4f,6p)$	6807	85	
	$F^3(4f,5f)$[c]	−483			$F^2(5d,6p)$	16902	83
	$F^4(4f,5f)$	1057	55		$G^1(4f,5d)$	10670	80
	$F^5(4f,5f)$[c]	−483			$G^3(4f,5d)$	9021	80
	$F^6(4f,5f)$	381	30		$G^5(4f,5d)$	6985	80
	$G^0(4f,5f)$	901	25		$G^2(4f,6p)$	1594	80
	$G^2(4f,5f)$	651	28		$G^4(4f,6p)$	1453	80
	$G^4(4f,5f)$	495	32		$G^1(5d,6p)$	7332	80
	$G^6(4f,5f)$	304	27		$G^3(5d,6p)$	6085	80
$4f^27p$	E_{av}	122862		$4f^28s$	E_{av}	139319	
	$F^2(4f,4f)$	71605	73		$F^2(4f,4f)$	72000	73
	$F^4(4f,4f)$	52318	85		$F^4(4f,4f)$	52436	84
	$F^6(4f,4f)$	33795	77		$F^6(4f,4f)$	33919	76
	α	21			α	16	
	β	−381			β	−337	
	γ	1377			γ	1377	
	ζ_{4f}	761	92		ζ_{4f}	766	93
	ζ_{7p}	834	110		$G^3(4f,8s)$	402	93
	$F^2(4f,7p)$	3265	110	$4f^27d$	E_{av}	140102	
	$G^2(4f,7p)$	846	112		$F^2(4f,4f)$	71968	73
	$G^4(4f,7p)$	737	106		$F^4(4f,4f)$	52418	84
$4f^26f$	E_{av}	144209			$F^6(4f,4f)$	33906	76
	$F^2(4f,4f)$	71605	73		α	16	
	$F^4(4f,4f)$	52318	85		β	−337	
	$F^6(4f,4f)$	33795	77		γ	1377	
	α	21			ζ_{4f}	765	93
	β	−381			ζ_{7d}	85	115
	γ	1377			$F^1(4f,7d)$[c]	495	
	ζ_{4f}	777	94		$F^2(4f,7d)$	1893	83
	ζ_{5f}	13	100[b]		$F^3(4f,7d)$[c]	495	
	$F^1(4f,5f)$[c]	−483			$F^4(4f,7d)$	1633	162
	$F^2(4f,5f)$	1228	55		$G^1(4f,7d)$	840	104
	$F^3(4f,5f)$[c]	−483			$G^2(4f,7d)$[c]	1750	
	$F^4(4f,5f)$	538	55		$G^3(4f,7d)$	798	108
	$F^5(4f,5f)$[c]	−483			$G^4(4f,7d)$[c]	1654	
	$F^6(4f,5f)$	355	54		$G^5(4f,7d)$	544	78
	$G^0(4f,5f)$	457	26	$4f^25g$	E_{av}	144786	
	$G^2(4f,5f)$	418	35		$F^2(4f,4f)$	72056	73
	$G^4(4f,5f)$	283	35		$F^4(4f,4f)$	51480	84
	$G^6(4f,5f)$	208	35		$F^6(4f,4f)$	33948	76
					α	16	
					β	−337	
					γ	1377	
					ζ_{4f}	766	93
					ζ_{5g}	0	100[b]
					$F^2(4f,5g)$	551	79
					$F^4(4f,5g)$	59	85[b]
					$F^6(4f,5g)$	16	85[b]
					$G^1(4f,5g)$	17	85[b]
					$G^3(4f,5g)$	9	85[b]
					$G^5(4f,5g)$	6	85[b]
					$G^7(4f,5g)$	5	85[b]

TABLE 1—*Continued*

Scaling factors for the R^k integrals, which are not fixed to SF = 0.85:	
$4f^3$–($4f^26p$,$4f5d^2$,$4f5d6s$,$4f^25f$,$4f^27p$,$4f^26f$)	81
$4f^26p$–($4f5d^2$,$4f5d6s$,$4f^25f$,$4f^27p$,$4f^26f$)	66
$4f5d^2$–($4f5d6s$,$4f^25f$,$4f^27p$,$4f^26f$)	50
$4f5d6s$–($4f^25f$,$4f^27p$,$4f^26f$)	55
$4f^25f$–($4f^27p$,$4f^26f$)	35
$4f^27p$–$4f^26f$	35
$4f^25d$–($4f^26s$,$4f^27s$,$4f^26d$,$4f5d6p$,$4f^28s$,$4f^27d$,$4f^25g$)	94
$4f^26s$–($4f^27s$,$4f^26d$,$4f5d6p$,$4f^28s$,$4f^27d$,$4f^25g$)	102
$4f^27s$–($4f^26d$,$4f5d6p$,$4f^28s$,$4f^27d$,$4f^25g$)	102
$4f^26d$–($4f5d6p$,$4f^28s$,$4f^27d$,$4f^25g$)	78
$4f5d6p$–($4f^28s$,$4f^27d$,$4f^25g$)	103
$4f^28s$–($4f^27d$,$4f^25g$)	102
$4f^27d$–$4f^25g$	78

[a] Scaling factor, which corresponds to the ratio fitted/ab initio (expressed in percent).
[b] Fixed value.
[c] Slater parameter F^k or G^k with an "illegal" value of k (see Cowan 1981).

$4f^26s$, $4f^27s$, $4f^26d$, and $4f^28s$. Sugar (1969, 1974) had published the whole spectrum, including more than 3200 unclassified lines, and this allowed us to search for new levels with the support of energy and transition probabilities gA predicted by the Cowan (1981) codes. Good wavelength accuracies and a fair correlation between empirical intensities and gA values (although the scale of intensities is not consistent throughout the spectrum) helped us to find 108 new odd levels and 83 even levels, very few levels of the previous analysis being rejected.

For the odd parity, the number of $4f5d6s$ levels increased from 7 to 19, including the lowest one, i.e., $^4H_{7/2}$ located at 84150.60 cm^{-1}. In addition, 42 new levels of $4f^25f$ were determined, and the new configurations $4f^27p$ (starting at 111518.34 cm^{-1}) and $4f^26f$ (starting at 133566.52 cm^{-1}) were located.

For the even parity, the lowest levels of $4f^27s$ at 100214.99 cm^{-1} and $4f^28s$ at 129009.15 cm^{-1} were obtained, as well as 18 levels of the configuration $4f^26d$. In addition, three new configurations, i.e., $4f5d6p$ starting at 113854.23 cm^{-1}, $4f^27d$ starting at 129454.45 cm^{-1}, and $4f^25g$ starting at 134394.16 cm^{-1} were determined. This led to the classification of about 1250 lines.

A parametric study of all 342 known odd levels by means of RCN, RCN2, RCG, and RCE codes (Cowan 1981) ends with an average deviation of 81 cm^{-1}. It should be mentioned that the 20 configuration basis set (for a list, see the § 3) did include 13 experimentally unknown configurations. In the even parity, all 251 levels are described on a 18 configuration basis (eight configurations being partly experimentally known), with an average deviation of 103 cm^{-1}. The detailed results of this analysis will be published elsewhere (J.-F. Wyart & P. Palmeri 2000, in preparation).

3. TRANSITION PROBABILITIES

Pr^{2+} ion is a La-like ion. It is an atomic system with three valence electrons surrounding a Xe-like core. As a consequence, intravalence and core-valence interactions should both be taken into account for calculating the atomic structure. In practice, computer capabilities impose severe limitations on the number of interacting configurations which can be considered simultaneously in the model. Migdalek & Baylis (1978) have suggested an approach (for a review on the subject, see also Hibbert 1989) in which most of the intravalence correlation is represented within a configuration interaction (hereafter abbreviated CI) scheme, while core-valence correlation is described by a core-polarization model potential with a core-penetration corrective term. We have introduced these corrections in the HFR equations (Cowan 1981). For that purpose, we added to the radial equations of the valence orbitals the one-particle potential:

$$V^{\rm Pol}(r) = \frac{-\alpha_d r^2}{2(r^2 + r_c^2)^3}, \quad (1)$$

where α_d is the static dipole polarizability of the ionic core and r_c is the cutoff radius. We corrected the nonequivalent electron part of the exchange potential between valence subshells by the two-particle term:

$$B_{ij}^{\rm Pol} = \frac{-\alpha_d r}{2(r^2 + r_c^2)^{3/2}} \begin{pmatrix} l_i & 1 & l_j \\ 0 & 0 & 0 \end{pmatrix}^2 \times \left[\int_0^\infty \frac{r_2}{(r_2^2 + r_c^2)^{3/2}} P_j(r_2) P_i(r_2) dr_2 + \int_0^{r_c} \frac{r_2}{r_c^3} P_j(r_2) P_i(r_2) dr_2 \right], \quad (2)$$

where P_i and P_j are the radial parts of the atomic orbitals. The second part of equation (2) corresponds to the penetration of the core by the valence orbitals. The interaction between the modified electric fields experienced by the valence electrons is the first part of (2). The dipole-moment operator, $\boldsymbol{d} = -\boldsymbol{r}$, of the valence electron has to be replaced by

$$\boldsymbol{d} = -\boldsymbol{r} + \alpha_d \frac{\boldsymbol{r}}{(r^2 + r_c^2)^{3/2}} + \alpha_d \frac{\boldsymbol{r}}{r_c^3} \, {\rm rect}\,(0, r_c), \quad (3)$$

where

$${\rm rect}\,(0, r_c) = \begin{cases} 1, & 0 \le r \le r_c : \\ 0, & r > r_c . \end{cases}$$

The third part of equation (3) is the penetration correction. The procedure has been described previously (Biémont et al. 1998; Biémont & Quinet 1998; Quinet et al. 1999a, 1999b).

CI was considered among the configurations $4f^3 + 4f^2np$ $(n = 6, 7) + 4fnd^2$ $(n = 5, 6) + 4fns^2$ $(n = 6, 7) + 4f5dns$ $(n = 6, 7) + 4f5dnd$ $(n = 6, 7) + 4f^2nf$ $(n = 5, 6) + 4f6p^2$

TABLE 2

HFR VALUES OF r_c (in a_0) USED FOR THE DIFFERENT TRANSITION ARRAYS OF Pr III

Matrix Element	r_c	Transition Array
$\langle 6s\|r\|6s \rangle$	3.55	$4f5d6s$–$4f^2 6s$,$4f5d6s$–$4f6snp$,$4f5d6s$–$5d^2 6s$,$4f6s^2$–$4f6snp$, $4f6s^2$–$5d6s^2$,$4f6s7s4$–$4f6snp$,$5d6s6p$–$5d^2 6s$,$5d6s6p$–$5d6s^2$, $6s^2 6p$–$5d6s^2$
$\langle 7s\|r\|7s \rangle$	6.74	$4f5d7s$–$4f^2 7s$
$\langle 5p\|r\|5p \rangle$	1.67	$4f^2 6p$–$4f^2 ns$,$4f^2 6p$–$4f^2 nd$,$4f^3$–$4f^2 nd$,$4f^2 7p$–$4f^2 ns$, $4f^2 7p$–$4f^2 nd$,$4f^2 5f$–$4f^2 nd$,$4f^3$–$4f^2 5g$,$4f^2 5f$–$4f^2 5g$, $4f^2 6f$–$4f^2 nd$,$4f^2 6f$–$4f^2 5g$,
$\langle 6p\|r\|6p \rangle$	4.35	$4f^2 6p$–$4f5d6p$,$5d6s6p$–$4f6s6p$,$5d6s6p$–$5d6p^2$,$5d6s6p$–$6s6p^2$ $5d^2 6p$–$4f5d6p$,$5d^2 6p$–$5d6p^2$,$6s^2 6p$–$6s6p^2$,$4f6p^2$–$4f5d6p$, $4f6p^2$–$4f6s6p$,$4f6p^2$–$5d6p^2$,$4f6p7p$–$4f5d6p$,$4f6p7p$–$4f6s6p$, $6p^3$–$5d6p^2$,$6p^3$–$6s6p^2$
$\langle 7p\|r\|7p \rangle$	7.95	$4f^2 7p$–$4f5d7p$,$4f6p7p$–$4f5d7p$,$4f6p7p$–$4f6s7p$
$\langle 5d\|r\|5d \rangle$	2.37	$4f5d^2$–$4f^2 5d$,$4f5d^2$–$4f5dnp$,$4f5d^2$–$5d^3$,$4f5d^2$–$5d^2 6d$, $4f5d^2$–$4f5d5f$,$4f5d6s$–$4f5dnp$,$4f5d7s$–$4f5dnp$,$4f5d6d$–$4f^2 5d$, $4f5d6d$–$4f5dnp$,$4f5d6d$–$4f5d5f$,$4f5d7d$–$4f^2 5d$ $4f5d7d$–$4f5dnp$,$4f5d7d$–$4f5d5f$,$5d^2 6p$–$5d^3$,$5d^2 6p$–$5d^2 6s$, $5d^2 6p$–$5d^2 6d$
$\langle 6d\|r\|6d \rangle$	5.86	$4f5d6d$–$4f^2 6d$,$4f5d6d$–$5d^2 6d$,$4f6d^2$–$4f^2 6d$
$\langle 7d\|r\|7d \rangle$	10.14	$4f5d7d$–$4f^2 7d$
$\langle 5f\|r\|5f \rangle$	5.95	$4f^2 5f$–$4f5d5f$

$+ 4f6p7p + 5d6s6p + 4f6s7s + 5d^2 6p + 6s^2 6p + 6p^3$ for the odd parity, and $4f^2 nd$ ($n = 5, 6, 7$) $+ 4f^2 ns$ ($n = 6, 7, 8$) $+ 4f5dnp$ ($n = 6, 7$) $+ 4f^2 5g + 4f5d5f + 4f6snp$ ($n = 6, 7$) $+ 5d^3 + 5d^2 6s + 5d^2 6d + 5d6s^2 + 5d6p^2 + 6s6p^2$ for the even parity.

To compute the atomic orbitals (hereafter abbreviated AO) and the radial integrals (E_{av}, ζ, F^k, G^k and R^k), we have chosen the values of α_d tabulated by Fraga et al. (1976) for the Pr^{5+} ion, i.e., $5.40a_0^3$. The cutoff radius, r_c, usually taken as the expectation value of r for the outermost core orbitals has been chosen equal to $1.67a_0$. This value corresponds to the HFR average value $\langle r \rangle$ for the outermost core orbitals ($5p^6$) of the investigated valence configurations. Using a least-squares fitting procedure, the effective interaction parameters (α, β, γ) and the k-forbidden F^k and G^k integrals were adjusted to obtain the best agreement between the calculated eigenvalues and the observed energy levels taken from Martin et al. (1978) and from Wyart & Palmeri (2000, in preparation).

The fitted parameter values are reported in Table 1 for both parties. In the fitting procedure, some R^k Slater integrals were linked together (ratios of their values were held fixed; see last part of Table 1). The adopted values are reported in Table 1. All the other Slater integrals were fixed at 85% of their ab initio values, i.e., calculated without any scaling.

4. RESULTS

To calculate the effect of the polarization on the transition matrices $\langle nl | r^{(1)} | n'1' \rangle$, different ionic cores were considered for the different transition arrays. In equation (3), a value of $8.70a_0^3$ for α_d was chosen for all the transition arrays. It corresponds to a Pr^{+++} core in Fraga et al. (1976) tables. Different cutoff radii (r_c) were used. They are reported in Table 2 for each transition array. They are equal to the mean radius of the outermost AO of the corresponding configuration of Pr III when the active electron of the transition is removed. As an example, if the transition array $4f5d6s$–$4f5d6p$ is considered, the "core" configuration is $4f5d$ and the outermost AO is $5d$.

In Table 3, logarithms of weighted oscillator strengths ($\log gf$) are listed for selected Pr III lines of astrophysical interest. More detailed tables containing f values for a large number of transitions can be found in the DREAM database (see footnote 1).

There are no other experimental or theoretical results available for comparison. The model adopted is similar to the one retained for the isoelectronic ion Ce II. It is therefore reasonably expected that the accuracy of the oscillator strengths will be similar to that obtained in that ion for which a limited number of lifetime measurements are available for comparison (Palmeri et al. 1999). The agreement found in Ce II for most of the lifetimes for which a comparison was possible was within 15%. One can therefore expect an accuracy of a few up to 15% for most of the oscillator strengths obtained in the present work, except maybe for the weaker lines. The uncertainty affecting the transitions involving theoretical levels (i.e., not yet determined experimentally) could eventually be larger, but all these transitions were excluded from our tables. A useful test of the accuracy of the HFR oscillator strengths in the case of the doubly ionized lanthanides has been provided recently by a comparison in the case of La III and Lu III of the calculated radiative lifetimes with measurement performed by laser-induced fluorescence (Biémont et al. 1999). An agreement within a few percent was found also in that paper.

5. ASTROPHYSICAL IMPLICATIONS

Ultraviolet line blanketing plays an important role in the building of stellar atmosphere models. During the past 20 years, a substantial effort has been devoted to the introduction of a large number of transitions in the computations (see for example Kurucz 1979, 1993), most of them

TABLE 3

CALCULATED log (*gf*) FOR SELECTED LINES OF Pr III OF ASTROPHYSICAL INTEREST

λ(Å)[a]	E_{lower}[b]		J_{lower}	E_{upper}[b]		J_{upper}	log (*gf*)
10716.583......	15705	(*o*)	9/2	25034	(*e*)	9/2	−2.73
10324.591......	16764	(*o*)	9/2	26447	(*e*)	7/2	−2.42
10301.585......	15705	(*o*)	9/2	25410	(*e*)	7/2	−2.37
10238.626......	13888	(*o*)	7/2	23652	(*e*)	7/2	−2.57
10160.334......	10033	(*o*)	9/2	19872	(*e*)	7/2	−2.59
10031.098......	15443	(*o*)	7/2	25410	(*e*)	7/2	−2.68
9991.156	16089	(*o*)	13/2	26095	(*e*)	11/2	−2.65
9334.332	10138	(*o*)	5/2	20848	(*e*)	5/2	−2.48
9265.561	9371	(*o*)	3/2	20160	(*e*)	3/2	−2.37
9222.320	16764	(*o*)	9/2	27604	(*e*)	9/2	−2.42
9131.899	12495	(*o*)	11/2	23442	(*e*)	11/2	−2.16
9099.984	11762	(*o*)	9/2	22748	(*e*)	9/2	−1.98
8854.053	16089	(*o*)	13/2	27380	(*e*)	11/2	−1.53
8771.383	25245	(*o*)	15/2	36642	(*e*)	13/2	−1.86
8691.581	10033	(*o*)	9/2	21535	(*e*)	9/2	−2.07
8602.737	17642	(*o*)	15/2	29263	(*e*)	13/2	−1.45
8567.627	10859	(*o*)	7/2	22528	(*e*)	7/2	−2.29
8244.887	24887	(*o*)	7/2	37012	(*e*)	5/2	−2.35
8132.233	12495	(*o*)	11/2	24788	(*e*)	9/2	−2.33
8119.537	24358	(*o*)	11/2	36671	(*e*)	11/2	−2.17
8102.904	26448	(*o*)	17/2	38786	(*e*)	15/2	−1.24
8001.144	10033	(*o*)	9/2	22528	(*e*)	7/2	−2.73
7972.748	12495	(*o*)	11/2	25034	(*e*)	9/2	−2.43
7914.003	2893	(*o*)	13/2	15526	(*e*)	11/2	−2.86
7897.090	4454	(*o*)	15/2	17113	(*e*)	13/2	−3.05
7888.117	10859	(*o*)	7/2	23533	(*e*)	5/2	−2.76
7866.139	11762	(*o*)	9/2	24471	(*e*)	7/2	−1.99
7814.736	10859	(*o*)	7/2	23652	(*e*)	7/2	−2.75
7781.985	0	(*o*)	9/2	12847	(*e*)	9/2	−2.16
7745.593	9371	(*o*)	3/2	22278	(*e*)	3/2	−2.67
7742.335	10138	(*o*)	5/2	23051	(*e*)	3/2	−2.42
7674.646	11762	(*o*)	9/2	24788	(*e*)	9/2	−2.65
7529.113	26448	(*o*)	17/2	39726	(*e*)	15/2	−1.90
7493.200	20857	(*o*)	3/2	34199	(*e*)	1/2	−2.52
7487.397	0	(*o*)	9/2	13352	(*e*)	11/2	−2.94
7429.053	25245	(*o*)	15/2	38702	(*e*)	13/2	−1.31
7426.475	1398	(*o*)	11/2	14860	(*e*)	11/2	−2.35
7350.607	12495	(*o*)	11/2	26095	(*e*)	11/2	−2.65
7349.749	10859	(*o*)	7/2	24461	(*e*)	5/2	−2.98
7240.208	24887	(*o*)	7/2	38695	(*e*)	5/2	−2.18
7231.625	15443	(*o*)	7/2	29268	(*e*)	5/2	−2.43
7112.528	1398	(*o*)	11/2	15454	(*e*)	13/2	−2.83
7076.618	1398	(*o*)	11/2	15526	(*e*)	11/2	−1.96
7030.388	2893	(*o*)	13/2	17113	(*e*)	13/2	−1.73
6970.965	25392	(*o*)	13/2	39733	(*e*)	11/2	−1.55
6910.144	4454	(*o*)	15/2	18921	(*e*)	15/2	−1.64
6903.522	25245	(*o*)	15/2	39726	(*e*)	15/2	−2.11
6899.059	16764	(*o*)	9/2	31255	(*e*)	7/2	−2.01
6866.801	0	(*o*)	9/2	14559	(*e*)	9/2	−2.18
6857.301	26448	(*o*)	17/2	41027	(*e*)	17/2	−1.91
6827.965	2893	(*o*)	13/2	17535	(*e*)	15/2	−2.76
6706.705	4454	(*o*)	15/2	19360	(*e*)	13/2	−2.55
6578.901	4454	(*o*)	15/2	19650	(*e*)	17/2	−2.67
6501.489	10033	(*o*)	9/2	25410	(*e*)	7/2	−2.79
6500.038	13888	(*o*)	7/2	29268	(*e*)	5/2	−2.04
6444.742	24358	(*o*)	11/2	39870	(*e*)	9/2	−1.76
6429.257	15705	(*o*)	9/2	31255	(*e*)	7/2	−2.14
6310.361	11762	(*o*)	9/2	27604	(*e*)	9/2	−2.50
6195.628	0	(*o*)	9/2	16136	(*e*)	7/2	−1.97
6161.224	12495	(*o*)	11/2	28721	(*e*)	9/2	−2.07
6160.244	1398	(*o*)	11/2	17627	(*e*)	9/2	−1.91
6090.016	2893	(*o*)	13/2	19309	(*e*)	11/2	−1.76
6071.086	2893	(*o*)	13/2	19360	(*e*)	13/2	−3.31
6053.007	0	(*o*)	9/2	16516	(*e*)	7/2	−2.78
5998.944	1398	(*o*)	11/2	18063	(*e*)	9/2	−2.73
5956.052	4454	(*o*)	15/2	21239	(*e*)	13/2	−1.64

TABLE 3—*Continued*

λ(Å)[a]	E_{lower}[b]		J_{lower}	E_{upper}[b]		J_{upper}	log (*gf*)
5947.983......	2893	(*o*)	13/2	19701	(*e*)	11/2	−3.33
5844.413......	10033	(*o*)	9/2	27139	(*e*)	7/2	−1.76
5765.266......	12495	(*o*)	11/2	29835	(*e*)	9/2	−2.01
5340.015......	4454	(*o*)	15/2	23175	(*e*)	13/2	−1.57
5299.993......	2893	(*o*)	13/2	21756	(*e*)	11/2	−1.49
5284.697......	1398	(*o*)	11/2	20316	(*e*)	9/2	−1.55
5264.443......	0	(*o*)	9/2	18990	(*e*)	7/2	−1.62
4857.386......	16089	(*o*)	13/2	36671	(*e*)	11/2	−1.72
4775.295......	15705	(*o*)	9/2	36640	(*e*)	7/2	−2.25
4771.827......	14187	(*o*)	5/2	35138	(*e*)	3/2	−2.63
4747.110......	17642	(*o*)	15/2	38702	(*e*)	13/2	−2.32
4728.211......	17642	(*o*)	15/2	38786	(*e*)	15/2	−2.65
4725.553......	16764	(*o*)	9/2	37920	(*e*)	7/2	−2.26
4713.700......	15443	(*o*)	7/2	36652	(*e*)	5/2	−2.30
4625.185......	17410	(*o*)	11/2	39024	(*e*)	9/2	−1.85
4612.022......	14187	(*o*)	5/2	35864	(*e*)	3/2	−2.23
4500.311......	15705	(*o*)	9/2	37920	(*e*)	7/2	−2.59
4000.199......	10033	(*o*)	9/2	35024	(*e*)	7/2	−2.90[c]
3980.514......	38702	(*e*)	13/2	63817	(*o*)	11/2	−1.20
3653.580......	38786	(*e*)	15/2	66148	(*o*)	13/2	−0.85
3440.623......	35801	(*e*)	7/2	64857	(*o*)	9/2	0.09
3436.358......	33466	(*e*)	11/2	62559	(*o*)	11/2	−0.07
3427.018......	30995	(*e*)	9/2	60166	(*o*)	9/2	−0.05
3422.222......	33466	(*e*)	11/2	62679	(*o*)	13/2	0.14
3420.071......	38448	(*e*)	9/2	67679	(*o*)	7/2	−0.02
3415.152......	28885	(*e*)	9/2	58158	(*o*)	7/2	−0.16
3413.210......	28885	(*e*)	9/2	58174	(*o*)	9/2	0.00
3397.456......	30995	(*e*)	9/2	60420	(*o*)	11/2	0.13
3396.625......	30734	(*e*)	11/2	60166	(*o*)	9/2	0.09
3396.069......	28721	(*e*)	9/2	58158	(*o*)	7/2	−0.38
3394.215......	28721	(*e*)	9/2	58174	(*o*)	9/2	−0.28
3391.077......	32760	(*e*)	13/2	62241	(*o*)	11/2	−0.12
3381.842......	33660	(*e*)	5/2	63221	(*o*)	3/2	−0.04
3381.259......	35291	(*e*)	9/2	64857	(*o*)	9/2	−0.01
3380.213......	34825	(*e*)	7/2	64401	(*o*)	5/2	−0.14
3377.141......	45807	(*e*)	5/2	75410	(*o*)	3/2	0.02
3371.924......	38727	(*e*)	7/2	68375	(*o*)	9/2	−0.03
3367.582......	30734	(*e*)	11/2	60420	(*o*)	11/2	0.23
3367.350......	35291	(*e*)	9/2	64980	(*o*)	7/2	0.09
3364.523......	50647	(*e*)	11/2	80361	(*o*)	11/2	0.22
3359.414......	28399	(*e*)	7/2	58158	(*o*)	7/2	0.03
3357.563......	28399	(*e*)	7/2	58174	(*o*)	9/2	0.18
3354.914......	32760	(*e*)	13/2	62559	(*o*)	11/2	0.10
3341.434......	32760	(*e*)	13/2	62679	(*o*)	13/2	0.42
3306.135......	33338	(*e*)	3/2	63576	(*o*)	5/2	−0.10
3080.203......	33466	(*e*)	11/2	65922	(*o*)	11/2	0.38
3066.710......	30995	(*e*)	9/2	63593	(*o*)	9/2	0.11
3058.901......	33466	(*e*)	11/2	66148	(*o*)	13/2	0.41
3050.303......	30995	(*e*)	9/2	63769	(*o*)	7/2	0.07
3045.812......	30995	(*e*)	9/2	63817	(*o*)	11/2	0.13
3042.350......	30734	(*e*)	11/2	63593	(*o*)	9/2	−0.09
3033.309......	28399	(*e*)	7/2	61357	(*o*)	9/2	0.00
3029.376......	35801	(*e*)	7/2	68802	(*o*)	7/2	0.06
3015.134......	30995	(*e*)	9/2	64151	(*o*)	11/2	−0.11
3010.612......	28399	(*e*)	7/2	61606	(*o*)	7/2	0.13
3008.040......	35291	(*e*)	9/2	68526	(*o*)	11/2	0.37
3003.203......	38448	(*e*)	9/2	71736	(*o*)	11/2	0.57
3000.460......	28399	(*e*)	7/2	61718	(*o*)	5/2	0.18
2997.116......	28885	(*e*)	9/2	62241	(*o*)	11/2	0.05
2985.818......	30734	(*e*)	11/2	64215	(*o*)	13/2	0.60
2982.416......	28721	(*e*)	9/2	62241	(*o*)	11/2	−0.06
2981.654......	33338	(*e*)	3/2	66867	(*o*)	3/2	−0.05
2980.537......	32760	(*e*)	13/2	66301	(*o*)	15/2	0.73
2977.062......	33660	(*e*)	5/2	67240	(*o*)	7/2	0.29
2976.860......	33466	(*e*)	11/2	67049	(*o*)	9/2	0.34
2968.833......	28885	(*e*)	9/2	62559	(*o*)	11/2	0.00
2914.489......	30995	(*e*)	9/2	65296	(*o*)	7/2	0.02

TABLE 3—*Continued*

λ(Å)[a]	E_{lower}[b]		J_{lower}	E_{upper}[b]		J_{upper}	log (gf)
2724.030......	25979	(*e*)	15/2	62679	(*o*)	13/2	−0.48
2097.601......	12847	(*e*)	9/2	60520	(*o*)	7/2	−1.13
2097.513......	14860	(*e*)	11/2	62536	(*o*)	9/2	−1.58
2096.496......	14860	(*e*)	11/2	62559	(*o*)	11/2	−0.95
2094.676......	19309	(*e*)	11/2	67049	(*o*)	9/2	−1.72
2094.155......	17113	(*e*)	13/2	64865	(*o*)	11/2	−0.64
2091.411......	18921	(*e*)	15/2	66736	(*o*)	13/2	−0.48
2088.346......	16516	(*e*)	7/2	64401	(*o*)	5/2	−1.15
2083.123......	13352	(*e*)	11/2	61357	(*o*)	9/2	−0.93
2079.441......	19309	(*e*)	11/2	67399	(*o*)	9/2	−2.04
2075.991......	19701	(*e*)	11/2	67871	(*o*)	9/2	−2.95[c]
2075.747......	15046	(*e*)	5/2	63221	(*o*)	3/2	−0.91
2072.534......	18990	(*e*)	7/2	67240	(*o*)	7/2	−1.23
2070.042......	17627	(*e*)	9/2	65935	(*o*)	7/2	−1.22
2065.895......	18990	(*e*)	7/2	67395	(*o*)	5/2	−1.24
2064.736......	17535	(*e*)	15/2	65967	(*o*)	13/2	−1.15
2059.245......	19309	(*e*)	11/2	67871	(*o*)	9/2	−0.67
2054.509......	14559	(*e*)	9/2	63232	(*o*)	7/2	−1.38
2053.531......	15454	(*e*)	13/2	64151	(*o*)	11/2	−0.98
2052.953......	13352	(*e*)	11/2	62063	(*o*)	9/2	−0.86
2050.812......	15454	(*e*)	13/2	64215	(*o*)	13/2	−0.96
2048.865......	18242	(*e*)	11/2	67049	(*o*)	9/2	−0.81
2043.773......	19872	(*e*)	7/2	68802	(*o*)	7/2	−0.90
2042.616......	14860	(*e*)	11/2	63817	(*o*)	11/2	−1.97[c]
2033.950......	19360	(*e*)	13/2	68526	(*o*)	11/2	−0.54
2032.253......	13352	(*e*)	11/2	62559	(*o*)	11/2	−0.96
2032.117......	14559	(*e*)	9/2	63769	(*o*)	7/2	−0.75
2031.865......	12847	(*e*)	9/2	62063	(*o*)	9/2	−1.42
2031.455......	17627	(*e*)	9/2	66853	(*o*)	7/2	−1.73
2027.102......	15526	(*e*)	11/2	64857	(*o*)	9/2	−0.87
2024.540......	12847	(*e*)	9/2	62241	(*o*)	11/2	−1.35
2000.116......	14860	(*e*)	11/2	64857	(*o*)	9/2	−0.72
1998.064......	19360	(*e*)	13/2	69409	(*o*)	11/2	−0.97
1994.692......	18242	(*e*)	11/2	68375	(*o*)	9/2	−0.72
1993.422......	16516	(*e*)	7/2	66681	(*o*)	5/2	−1.20
1989.319......	18063	(*e*)	9/2	68332	(*o*)	7/2	−1.18
1988.139......	14559	(*e*)	9/2	64857	(*o*)	9/2	−1.39
1982.981......	18063	(*e*)	9/2	68492	(*o*)	7/2	−1.14
1927.095......	19701	(*e*)	11/2	71592	(*o*)	9/2	−1.04
1923.365......	23648	(*e*)	13/2	75640	(*o*)	11/2	−1.41
1909.258......	19360	(*e*)	13/2	71736	(*o*)	11/2	−0.88
1816.643......	23648	(*e*)	13/2	78695	(*o*)	11/2	−1.22
1743.377......	32760	(*e*)	13/2	90120	(*o*)	11/2	−0.07
1504.398......	23648	(*e*)	13/2	90120	(*o*)	11/2	−5.02[c]
1484.298......	22748	(*e*)	9/2	90120	(*o*)	11/2	−2.08
1445.517......	24788	(*e*)	9/2	93967	(*o*)	7/2	−2.58[c]
1352.511......	19360	(*e*)	13/2	93297	(*o*)	11/2	−2.51
1286.935......	38786	(*e*)	15/2	116490	(*o*)	17/2	−0.32
1135.004......	30506	(*e*)	11/2	118611	(*o*)	13/2	−0.03
1126.128......	29263	(*e*)	13/2	118063	(*o*)	15/2	−0.41
1108.817......	23648	(*e*)	13/2	113834	(*o*)	15/2	0.36
1104.843......	25979	(*e*)	15/2	116490	(*o*)	17/2	0.58
1103.035......	23175	(*e*)	13/2	113834	(*o*)	15/2	−0.15
1088.659......	29263	(*e*)	13/2	121119	(*o*)	15/2	0.45
1084.417......	41027	(*e*)	17/2	133242	(*o*)	19/2	0.67
1080.459......	35828	(*e*)	9/2	128382	(*o*)	11/2	0.27
1071.422......	19309	(*e*)	11/2	112643	(*o*)	11/2	−0.03
1069.881......	39726	(*e*)	15/2	133194	(*o*)	17/2	0.55
1068.852......	21239	(*e*)	13/2	114797	(*o*)	13/2	0.14
1066.034......	23442	(*e*)	11/2	117248	(*o*)	13/2	0.27
1061.599......	16136	(*e*)	7/2	110334	(*o*)	7/2	−0.03
1059.281......	26095	(*e*)	11/2	120499	(*o*)	13/2	0.07
1057.310......	18063	(*e*)	9/2	112643	(*o*)	11/2	−0.09
1055.143......	21535	(*e*)	9/2	116309	(*o*)	11/2	−0.18
1053.876......	23175	(*e*)	13/2	118063	(*o*)	15/2	0.31
1052.633......	21239	(*e*)	13/2	116239	(*o*)	15/2	0.26
1049.086......	19650	(*e*)	17/2	114971	(*o*)	19/2	0.64

TABLE 3—*Continued*

λ(Å)[a]	E_{lower}[b]		J_{lower}	E_{upper}[b]		J_{upper}	log (*gf*)
1047.244……	17535	(*e*)	15/2	113024	(*o*)	17/2	0.52
1046.195……	15526	(*e*)	11/2	111110	(*o*)	13/2	0.28
1045.411……	15454	(*e*)	13/2	111110	(*o*)	13/2	−0.31
1044.029……	17113	(*e*)	13/2	112896	(*o*)	15/2	0.32
1043.797……	18921	(*e*)	15/2	114726	(*o*)	17/2	0.43
1042.964……	15454	(*e*)	13/2	111335	(*o*)	15/2	0.38
1041.459……	21756	(*e*)	11/2	117775	(*o*)	13/2	0.36
1038.293……	19360	(*e*)	13/2	115672	(*o*)	15/2	0.34
1038.186……	14559	(*e*)	9/2	110881	(*o*)	11/2	0.08
1030.851……	20316	(*e*)	9/2	117323	(*o*)	11/2	0.02
1029.032……	13352	(*e*)	11/2	110531	(*o*)	13/2	0.43
1026.183……	12847	(*e*)	9/2	110295	(*o*)	11/2	0.15
1021.352……	14860	(*e*)	11/2	112770	(*o*)	13/2	0.20
1012.101……	14860	(*e*)	11/2	113665	(*o*)	11/2	−0.07
1008.612……	12847	(*e*)	9/2	111993	(*o*)	9/2	−0.10

NOTE.—(*o*) = odd parity; (*e*) = even parity.

[a] Wavelengths greater than 2107 Å are from Sugar (1974) and those shorter than 2107 Å are from Sugar (1969). Vacuum wavelength below 2107 Å and air wavelength above 2107 Å. The lines with intensities greater or equal to 200 (Sugar 1974) ($\lambda \geq 4000$ Å), with intensities greater or equal to 100 (Sugar 1974) (2500 Å $\leq \lambda <$ 4000 Å) and with intensities greater or equal to 300 (Sugar 1969, 1974) (1000 Å $\leq \lambda <$ 2500 Å) were selected.

[b] Experimental levels (in cm^{-1}) compiled by Martin et al. (1978).

[c] Cancellation factor < 0.05.

originating from the iron group elements. In most cases, these models give a good agreement between the UV synthetic and observed spectra. However, elements with larger atomic number could also contribute to the line blanketing of CP stars. The best known example is Przybylski's star (HD 101065). Recently, Cowley & Mathys (1998) estimated that the lanthanides are 10,000 times more abundant in HD 101065 than in the Sun. This could explain the large discrepancy observed between the effective temperature derived from photometric measurements (5780 K) and the value determined from the Paschen line profiles (7500 K).

By comparing the central intensities computed for several unblended Pr III lines to the observations made by Cowley & Mathys (1998), we derived, using a sample of eight lines, an average abundance for praseodymium $\sim$ 50000 times larger than the solar value. The synthetic spectra were obtained using Hubeny's computer code (Hubeny 1988) modified in order to introduce the contribution of the lanthanides and, more particularly, of praseodymium. The stellar atmosphere has been taken from Kurucz (1993) and the following fundamental parameters (Cowley & Mathys 1998) were assumed $T_{eff} = 6500$ K, log $g = 3.5$ (cgs), $\xi_{turb} = 2$ km s^{-1}. The results that we obtained for each of these lines are listed in Table 4, where I_λ (col. [2]) is the observed central intensity of the line and log (ϵ/ϵ_0) (col. [3]) is the logarithmic abundance considered relatively to the Sun (ϵ_0). This abundance value is of the same order of magnitude, but somewhat higher, than the value estimated by Cowley & Mathys from Pr II lines (10^4). It is worth noting that abundance values depending upon the ionization stage of the studied spectral lines are often observed in Ap magnetic stars such as HD 101065. In addition, as noted by Cowley & Mathys (1998), there is evidence that the atmosphere of the star is unusual as proven by the simultaneous presence of rather strong lines of the first and third spectra of the rare earth elements. Using the deduced overabundance value, 38

TABLE 4

OBSERVED CENTRAL INTENSITY OF Pr III LINES IN HD 101065 SPECTRUM[a]

λ (Å)[b] (1)	I_λ (2)	log $[\epsilon/\epsilon_0]$ (3)
5765.27……	0.90	4.48
5956.05……	0.57	4.95
5998.94……	0.74	5.18
6053.00……	0.70	4.40
6071.09……	0.90	4.54
6090.02……	0.64	4.54
6160.24……	0.59	4.70
6500.04……	0.86	4.90
		Mean value: 4.71 ± 0.27

[a] According to Cowley & Mathys (1998) and the corresponding derived abundance values of praseodymium.

[b] From Sugar (1969, 1974).

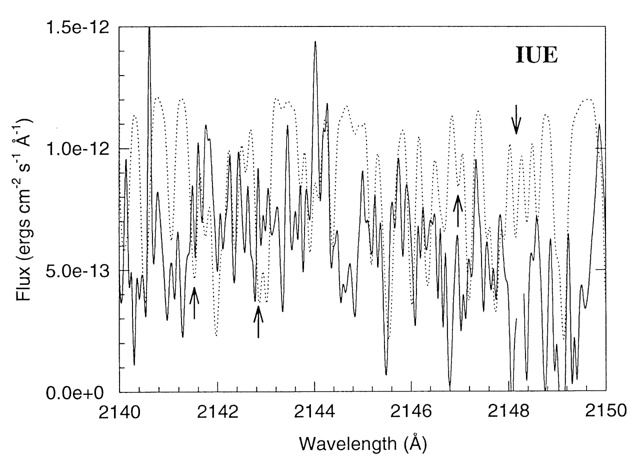

FIG. 1.—Comparison between calculated (*dotted line*) and observed (*solid line*) *IUE* spectra of Przybylski's star. Computations were made using the fundamental parameters derived by Cowley & Mathys (1998). Pr III lines are indicated by arrows.

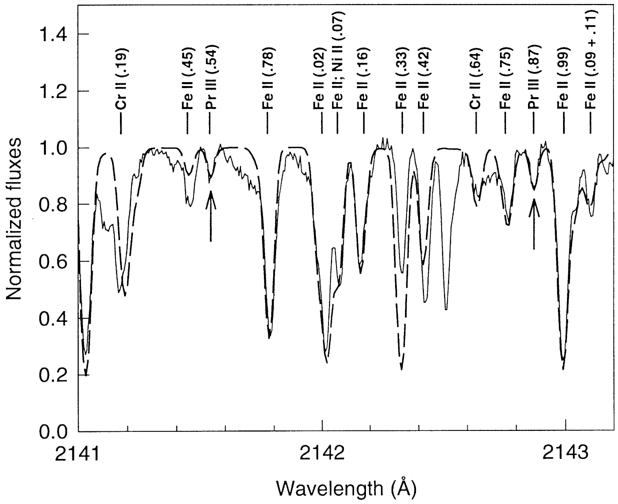

FIG. 2.—Observed (*solid line*) and calculated (*dashed line*) spectra for χ Lupi. Observations are taken from Leckrone et al. (1999). Two Pr III transitions have been identified and are indicated by arrows on the figure.

transitions of Pr III have been calculated between 1100 and 3300 Å to have an equivalent width $W_\lambda > 10$ mÅ indicating that Pr is well represented in the spectrum of HD 101065. We report in Figure 1 a comparison, in the range 2140–2150 Å, between the observed *IUE* spectra and a calculated spectrum obtained using the above described model. Four Pr III lines are indicated on the figure. As shown by this example, most of the Pr III lines are blended at *IUE* spectral resolution. In addition, the disagreement between the synthetic spectrum and the observations can be related to the overabundance of lanthanide elements in the atmosphere of the star and to the lack of accurate atomic data for many transitions of these elements.

χ Lupi is a chemically peculiar star classified as a Hg-Mn star (Smith & Dworetsky 1993) whose magnetic field is well determined (Mathys & Hubrig 1995). The star has been observed with the GHRS spectrograph on board the *Hubble Space Telescope* (Leckrone et al. 1996, 1999) between 1200 and 2700 Å. Using the spectral atlas provided by these authors[2], it has been possible to identify two Pr III transitions in the UV region, at 2141.539 and 2142.870 Å, respectively. A spectrum synthesis has been calculated around these two lines using the following stellar parameters: $T_{\rm eff} = 10{,}750$ K; log $(g) = 4.0$ (cgs); $\xi_{\rm turb} = 1$ km s^{-1}, and $V \sin i = 2$ km s^{-1} (Smith & Dworetsky 1993). The comparison of the calculated spectrum with the observed one is shown in Figure 2. The abundances derived are, respectively, 2.53 and 2.51 (in the usual logarithmic scale). The mean result [log $(\epsilon/\epsilon_0) = 2.52$] is 0.42 dex larger than the result deduced by Leckrone et al. (1999; i.e., 2.1) using Pr II transitions. Similar discrepancies between abundances derived from two different ionization stages have been reported by the same authors for elements like Zr, Pt, Au, and Hg.

E. B., P. Q., and P. P. are, respectively, Research Director and Research Fellows of the Belgian National Fund for Scientific Research (FNRS). Financial support from this organism and also from the Ministère de la Communauté française de Belgique is acknowledged. It is also a pleasure to thank C. R. Cowley (University of Michigan, Ann Arbor) for providing useful information concerning the Przybylski's star.

[2] See http://archive.stsci.edu/hst/chilupi/datalist/html.

REFERENCES

Adelman, S. J. 1974, ApJ, 28, 51
Aikman, G. C. L., Cowley, C. R., & Crosswhite, H. M. 1979, ApJ, 232, 812
Bidelman, W. P. 1966, in IAU Symp. 26, Abundance Determinations in Stellar Spectra, ed. H. Hubenet (New York: Academic), 229
Biémont, E., Dutrieux, J.-F., Martin, I., & Quinet, P. 1998, J. Phys. B, 31, 3321
Biémont, E., & Quinet, P. 1998, Phys. Rev. Lett., 81, 3345
Biémont, E., Li, Z. S., Palmeri, P., & Quinet, P. 1999, J. Phys. B, 32, 1
Cowan, R. D. 1981, The Theory of Atomic Structure and Spectra (Berkeley Univ., CA: California Press)
Cowley, C. R., & Greenberg, M. 1988, MNRAS, 232, 763
Cowley, C. R., & Mathys, G. 1998, A&A, 339, 165
Crosswhite, H., Crosswhite, H. M., & Judd, B. R. 1968, Phys. Rev., 174, 89
Fraga, S., Karwowski, J., & Saxena, K. M. S. 1976, Handbook of Atomic Data (Amsterdam: Elsevier)
Hibbert, A. 1989, Phys. Scripta, 39, 574
Hubeny, I. 1988, Comput. Phys. Commun., 2, 103
Kurucz, R. L. 1979, ApJS, 40, 1
———. 1993, CDROM No. 13, Smithsonian Astrophys. Obs.
Leckrone, D. S., Johansson, S., Wahlgren, G. M., Proffitt, C. R., & Brage, T. 1996, Phys. Scripta, T65, 110
Leckrone, D. S., Proffitt, C. R., Wahlgren, G. M., Johansson, S., & Brage, T. 1999, ApJ, 117, 1454
Martin, W. C., Zalubas, R., & Hagan, L. 1978, Atomic Energy Levels—The Rare-Earth Elements, Nat. Standards Ref. Data Series, NBS 60
Mathys, G., & Cowley, C. R. 1992, A&A, 253, 199
Mathys, G., & Hubrig, S. 1995, A&A, 293, 810
Migdalek, J., & Baylis, W. E. 1978, J. Phys. B, 11, L497
Palmeri, P., Quinet, P., Wyart, J.-F., & Biémont, E. 1999, Phys. Scripta, 61, 323
Quinet, P., Palmeri, P., & Biémont, E. 1999a, J. Quant. Spectrosc. Radiat. Transfer, 62, 625
Quinet, P., Palmeri, P., Biémont, E., McCurdy, M. M., Rieger, G., Pinnington, E. H., Wickliffe, M. E., & Lawler, J. E. 1999b, MNRAS, 307, 934
Smith, K., & Dworetsky, M. 1993, A&A, 274, 335
Sugar, J. 1963, J. Opt. Soc. Am., 53, 831
———. 1969, J. Res. NBS, 73A, 333
———. 1974, J. Res. NBS, 78A, 555
Wyart, J.-F., Blaise, J., & Camus, P. 1974, Phys. Scripta, 9, 325