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Atomic data for many-multiplet and alkali-doublet analyses of varying α

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ABSTRACT
Atomic data for varying many-multiplet and alkali-doublet analyses of varying-α

Key words: atomic data – line: profiles – methods: laboratory – techniques: spectroscopic – quasars: absorption lines – ultraviolet: general

1 INTRODUCTION

2 INPUT DATA

2.1 Atomic data

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Table 1. Atomic data for transitions usable in many-multiplet or alkali-doublet analyses, i.e. transitions with precise laboratory wavelengths. Information for isotopic and hyperfine components is given in italics. Columns 1 and 2 show the common names used for the transitions. Column 3 shows the mass number for each ionic species. The derivation of the laboratory wavenumbers, ω_0, is summarized by the value of X as follows: 0 – Measured wavelength; 1 – Inferred from component wavelengths; 2 – Inferred from measured composite wavelength and measured component splitting; 3 – Inferred from measured composite wavelength and calculated component splitting. Column 6 gives the reference(s) for the wavenumber measurement and/or calculations (specified below the table). Vacuum laboratory wavelengths, λ_0, are derived from the wavenumbers. Columns 8 and 9 show the lower and upper/excited state electronic configurations. The ID letters in column 10 offer a simple shorthand for labelling transitions used to fit absorption systems. Column 11 shows the ionization potential for the relevant ion, IP^+, and for the ion with a unit lower charge, IP^-. Column 12 shows the oscillator strengths, f, taken from Morton (2003) or the relative strengths of the hyperfine or isotopic components. The latter are taken from Rosman & Taylor (1998). The q coefficients and their uncertainties are from Berengut et al. (2009) except for those of Cr II which are from Berengut (2011, in prep.). Note that uncertainties quoted for the q coefficients are representative only, not statistical. Wavenumbers are on the Whaling et al. (1995) Ar II calibration scale. In particular, the Ni II wavenumbers have been scaled from their original values to account for the calibration difference between the Ar II scales of Norlén (1973) and Whaling et al. (1995). Exceptions to this rule are the Mg I and II wavenumbers which are on a highly accurate absolute scale generated using a frequency-comb calibration system. The Whaling et al. (1995) scale best agrees with this absolute scale.

Ion	Tran.	A	ω_0 [cm^{-1}]	X	Ref.	λ_0 [Å]	Lower state	Upper state	ID	IP$^-$, IP$^+$ [eV]	f or %	q [cm^{-1}]
Mg I	2026	24.31	49346.772611(36)	1		2026.4749792(15)	$3s^2\ ^1S_0$	$3s4p\ ^1P^o_1$	a_1	—, 7.65	0.113	87(7)
		26	*49346.854173(40)*	*0*	*a*	*2026.4716298(16)*					*11.0*	
		25	*49346.807724(40)*	*0*	*a*	*2026.4735372(16)*					*10.0*	
		24	*49346.756809(35)*	*0*	*a*	*2026.4756281(14)*					*79.0*	
	2852	24.31	35051.28076(19)	1		2852.962797(15)		$3s3p\ ^1P^o_1$	a_2		1.83	90(10)
		26	*35051.32015(25)*	*0*	*b*	*2852.959591(20)*					*11.0*	
		25	*35051.29784(25)*	*0*	*b*	*2852.961407(20)*					*10.0*	
		24	*35051.27311(17)*	*0*	*b*	*2852.963420(14)*					*79.0*	
Mg II	2796	24.31	35760.85417(20)	1		2796.353787(16)	$3s\ ^2S_{1/2}$	$3p\ ^2P_{3/2}$	b_1	7.65, 15.04	0.6155	212(2)
		26	*35760.940387(5)*	*0*	*c*	*2796.3470457(4)*					*11.0*	
		25	*35760.85819(64)*	*3*	*c*	*2796.353473(50)*	$F=2$	$F=1,2,3$			*4.2*	
		25	*35760.91593(64)*	*3*	*c*	*2796.348958(50)*	$F=3$	$F=2,3,4$			*5.8*	
		24	*35760.837397(5)*	*0*	*c*	*2796.3550990(4)*					*79.0*	
	2803	24.31	35669.30439(20)	1		2803.530983(16)		$3p\ ^2P_{1/2}$	b_2		0.3058	121(2)
		26	*35669.390571(5)*	*0*	*c*	*2803.5242094(4)*					*11.0*	
		25	*35669.30690(64)*	*3*	*c*	*2803.530786(50)*	$F=2$	$F=1,2,3$			*4.2*	
		25	*35669.36657(64)*	*3*	*c*	*2803.526096(50)*	$F=3$	$F=2,3,4$			*5.8*	
		24	*35669.287670(5)*	*0*	*c*	*2803.5322972(4)*					*79.0*	
Al II	1670	26.98	59851.976(4)	0	*d*	1670.78861(11)	$3s^2\ ^1S_0$	$3s3p\ ^1P_1$	c_1	5.99, 18.83	1.74	270(30)
Al III	1854	26.98	53916.554(1)	1	*d*	1854.717941(34)	$3s\ ^2S_{1/2}$	$3p\ ^2P_{3/2}$	d_1	18.83, 28.45	0.559	458(6)
		27	*53916.8149(8)*	*0*	*d*	*1854.708966(28)*	$F=2$				*41.7*	
		27	*53916.3574(6)*	*0*	*d*	*1854.724704(21)*	$F=3$				*58.3*	
	1862	26.98	53682.884(2)	1	*d*	1862.791127(69)	$3s\ ^2S_{1/2}$	$3p\ ^2P_{1/2}$	d_2		0.278	224(8)
		27	*53683.1953(15)*	*0*	*d*	*1862.780325(52)*	$F=2$				*41.7*	
		27	*53682.6692(12)*	*0*	*d*	*1862.798581(42)*	$F=3$				*58.3*	
Si II	1526	28.09	65500.4538(7)	0	*d*	1526.706980(16)	$3s^23p\ ^2P^o_{1/2}$	$3s^24s\ ^2S_{1/2}$	e_1	8.15, 16.35	0.133	50(30)
		30	*65500.441994*	*3*	*e*	*1526.7072550*					*3.1*	
		29	*65500.448002*	*3*	*e*	*1526.7071150*					*4.7*	
		28	*65500.454492*	*3*	*e*	*1526.7069637*					*92.2*	
	1808	28.09	55309.3404(4)	0	*d*	1808.012883(13)		$3s3p^2\ ^2D_{3/2}$	e_2		0.00208	520(30)
		30	*55309.435938*	*3*	*f*	*1808.0097601*					*3.1*	
		29	*55309.387116*	*3*	*f*	*1808.0113560*					*4.7*	
		28	*55309.334806*	*3*	*f*	*1808.0130660*					*92.2*	
Si IV	1393	28.09	71748.355(2)	0	*d*	1393.760177(39)	$2p^63s\ ^2S_{1/2}$	$2p^63p\ ^2P_{3/2}$	f_1	33.49, 45.14	0.513	823(40)
		30	*71748.551629*	*3*	*e*	*1393.7563579*					*3.1*	
		29	*71748.451219*	*3*	*e*	*1393.7583084*					*4.7*	
		28	*71748.343484*	*3*	*e*	*1393.7604012*					*92.2*	
	1402	28.09	71287.376(2)	0	*d*	1402.772912(39)		$2p^63p\ ^2P_{1/2}$	f_2		0.254	361(15)
		30	*71287.574290*	*3*	*e*	*1402.7690098*					*3.1*	
		29	*71287.473031*	*3*	*e*	*1402.7710024*					*4.7*	
		28	*71287.364387*	*3*	*e*	*1402.7731402*					*92.2*	
Ti II	1910.6	47.87	52339.240(1)	0	*g*	1910.612382(37)	$3d^24s\ a^4F_{3/2}$	$3d4s4p^4D^o_{1/2}$	g_1	6.82, 13.58	0.104	−1564(150)
	1910.9	47.87	52329.889(1)	0	*g*	1910.953795(37)		$3d4s4p^4F^o_{3/2}$	g_2		0.0980	−1783(300)
	3067	47.87	32602.627(2)	0	*h*	3067.23750(19)		$3d^24p\ z^4D^o_{3/2}$	g_3		0.0489	791(50)
		50	*32602.651577*	*3*	*i*	*3067.2351837*					*5.2*	
		49	*32602.640059*	*3*	*i*	*3067.2362673*					*5.4*	
		48	*32602.628061*	*3*	*i*	*3067.2373961*					*73.7*	
		47	*32602.603236*	*3*	*i*	*3067.2397316*					*7.4*	
		46	*32602.615933*	*3*	*i*	*3067.2385371*					*8.3*	

Table 1 – *continued.* Atomic data for transitions usable in many-multiplet or alkali-doublet analyses.

Ion	Tran.	A	ω_0 [cm^{-1}]	X	Ref.	λ_0 [Å]	Lower state	Upper state	ID	IP$^-$, IP$^+$ [eV]	f or %	q [cm^{-1}]
Ti II	3073	47.87	32532.355(1)	0	*h*	3073.86293(9)		$3d^24p\ z^4D^o_{1/2}$	g_4		0.121	677(50)
		50	*32532.379612*	*3*	*i*	*3073.8606027*					*5.2*	
		49	*32532.368077*	*3*	*i*	*3073.8616926*					*5.4*	
		48	*32532.356062*	*3*	*i*	*3073.8628278*					*73.7*	
		47	*32532.331204*	*3*	*i*	*3073.8651766*					*7.4*	
		46	*32532.343917*	*3*	*i*	*3073.8639753*					*8.3*	
	3230	47.87	30958.586(1)	0	*h*	3230.12169(10)		$3d^24p\ z^4F^o_{5/2}$	g_5		0.0687	673(50)
		50	*30958.610542*	*3*	*i*	*3230.1191252*					*5.2*	
		49	*30958.599041*	*3*	*i*	*3230.1203251*					*5.4*	
		48	*30958.587059*	*3*	*i*	*3230.1215753*					*73.7*	
		47	*30958.562268*	*3*	*i*	*3230.1241619*					*7.4*	
		46	*30958.574948*	*3*	*i*	*3230.1228389*					*8.3*	
	3242	47.87	30836.426(1)	0	*h*	3242.91797(11)		$3d^24p\ z^4F^o_{3/2}$	g_6		0.232	541(50)
		50	*30836.450997*	*3*	*i*	*3242.9153410*					*5.2*	
		49	*30836.439283*	*3*	*i*	*3242.9165729*					*5.4*	
		48	*30836.427080*	*3*	*i*	*3242.9178562*					*73.7*	
		47	*30836.401821*	*3*	*i*	*3242.9205126*					*7.4*	
		46	*30836.414740*	*3*	*i*	*3242.9191540*					*8.3*	
	3384	47.87	29544.454(1)	0	*h*	3384.73001(11)		$3d^24p\ z^4G^o_{5/2}$	g_7		0.358	396(50)
		50	*29544.480532*	*3*	*i*	*3384.7269676*					*5.2*	
		49	*29544.468409*	*3*	*i*	*3384.7283564*					*5.4*	
		48	*29544.455781*	*3*	*i*	*3384.7298032*					*73.7*	
		47	*29544.429586*	*3*	*i*	*3384.7328042*					*7.4*	
		46	*29544.442984*	*3*	*i*	*3384.7312692*					*8.3*	
Cr II	2056	52.00	48632.058(2)	0	*h*	2056.256801(85)	$3d^5\ ^6S_{5/2}$	$3d^44p\ ^6P^o_{7/2}$	h_1	6.77, 16.50	0.103	−1061(70)
		54	*48631.979780*	*3*	*j*	*2056.2601081*					*2.4*	
		53	*48632.019200*	*3*	*j*	*2056.2584414*					*9.5*	
		52	*48632.060079*	*3*	*j*	*2056.2567129*					*83.8*	
		50	*48632.146866*	*3*	*j*	*2056.2530434*					*4.3*	
	2062	52.00	48491.057(2)	0	*h*	2062.235929(85)		$3d^44p\ ^6P^o_{5/2}$	h_2		0.0759	−1280(70)
		54	*48490.980742*	*3*	*j*	*2062.2391725*					*2.4*	
		53	*48491.019238*	*3*	*j*	*2062.2375353*					*9.5*	
		52	*48491.059028*	*3*	*j*	*2062.2358431*					*83.8*	
		50	*48491.143461*	*3*	*j*	*2062.2322524*					*4.3*	
	2066	52.00	48398.871(2)	0	*h*	2066.163899(85)		$3d^44p\ ^6P^o_{3/2}$	h_3		0.0512	−1421(70)
		54	*48398.793313*	*3*	*j*	*2066.1672152*					*2.4*	
		53	*48398.832382*	*3*	*j*	*2066.1655474*					*9.5*	
		52	*48398.873065*	*3*	*j*	*2066.1638106*					*83.8*	
		50	*48398.959436*	*3*	*j*	*2066.1601234*					*4.3*	
Mn II	2576	54.94	38806.689(3)	0	*h*	2576.87534(20)	$3d^54s\ a^7S_3$	$3d^54p\ z^7P^o_4$	i_1	7.44, 15.64	0.361	1276(150)
		55	*38806.974333*	*3*	*k*	*2576.8563955*	$F = 0.5, 1.5$	$F = 1.5, 2.5$			*14.3*	
		55	*38806.879265*	*3*	*k*	*2576.8627082*	$F = 2.5$	$F = 1.5, 2.5, 3.5$			*14.3*	
		55	*38806.768508*	*3*	*k*	*2576.8700627*	$F = 3.5$	$F = 2.5, 3.5, 4.5$			*19.0*	
		55	*38806.625155*	*3*	*k*	*2576.8795818*	$F = 4.5$	$F = 3.5, 4.5, 5.5$			*23.8*	
		55	*38806.451511*	*3*	*k*	*2576.8911123*	$F = 5.5$	$F = 4.5, 5.5, 6.5$			*28.6*	
	2594	54.94	38543.121(3)	0	*h*	2594.49669(20)		$3d^54p\ z^7P^o_3$	i_2		0.280	1030(150)
		55	*38543.399993*	*3*	*k*	*2594.4778464*	$F = 0.5, 1.5$	$F = 0.5, 1.5, 2.5$			*14.2*	
		55	*38543.306507*	*3*	*k*	*2594.4841392*	$F = 2.5$	$F = 1.5, 2.5, 3.5$			*14.3*	
		55	*38543.198206*	*3*	*k*	*2594.4914294*	$F = 3.5$	$F = 2.5, 3.5, 4.5$			*19.1*	
		55	*38543.058612*	*3*	*k*	*2594.5008260*	$F = 4.5$	$F = 3.5, 4.5, 5.5$			*23.8*	
		55	*38542.888064*	*3*	*k*	*2594.5123064*	$F = 5.5$	$F = 4.5, 5.5$			*28.6*	
	2606	54.94	38366.230(3)	0	*h*	2606.45886(20)		$3d^54p\ z^7P^o_2$	i_3		0.198	869(150)
		55	*38366.573964*	*3*	*k*	*2606.4354898*	$F = 0.5, 1.5$	$F = 0.5, 1.5, 2.5$			*14.3*	
		55	*38366.459582*	*3*	*k*	*2606.4432603*	$F = 2.5$	$F = 1.5, 2.5, 3.5$			*14.3*	
		55	*38366.325813*	*3*	*k*	*2606.4523480*	$F = 3.5$	$F = 2.5, 3.5, 4.5$			*19.1*	
		55	*38366.153395*	*3*	*k*	*2606.4640614*	$F = 4.5$	$F = 3.5, 4.5$			*23.8*	
		55	*38365.943000*	*3*	*k*	*2606.4783550*	$F = 5.5$	$F = 4.5$			*28.6*	
Fe II	1608	55.85	62171.6245(27)	0	*l*	1608.450813(70)	$3d^64s\ a^6D_{9/2}$	$3d^54s4p\ y^6P^o_{7/2}$	j_1	7.87, 16.18	0.0577	−1030(300)
		58	*62171.668696*	*3*	*m*	*1608.4496700*					*0.3*	
		57	*62171.647992*	*3*	*m*	*1608.4502057*					*2.1*	
		56	*62171.626549*	*3*	*m*	*1608.4507604*					*91.8*	
		54	*62171.581279*	*3*	*m*	*1608.4519316*					*5.8*	

Table 1 – *continued*. Atomic data for transitions usable in many-multiplet or alkali-doublet analyses.

Ion	Tran.	A	ω_0 [cm^{-1}]	X	Ref.	λ_0 [Å]	Lower state	Upper state	ID	IP$^-$, IP$^+$ [eV]	f or %	q [cm^{-1}]
Fe II	1611	55.85	62065.531(4)	0	n	1611.20027(10)		3d^{6}4p y^{4}F$^{\rm o}_{7/2}$	j_2		0.00138	1560(500)
		58	*62065.502440*	*3*	m	*1611.2010065*					*0.3*	
		57	*62065.515819*	*3*	m	*1611.2006592*					*2.1*	
		56	*62065.529676*	*3*	m	*1611.2002995*					*91.8*	
		54	*62065.558929*	*3*	m	*1611.1995401*					*5.8*	
	2249	55.85	44446.9074(14)	0	n	2249.875320(71)		3d^{6}4p z^{4}D$^{\rm o}_{7/2}$	j_3		0.00182	1604(200)
	2260	55.85	44232.534(6)	0	h	2260.77936(31)		3d^{6}4p z^{4}F$^{\rm o}_{9/2}$	j_4		0.00244	1435(150)
	2344	55.85	42658.243(2)	0	h	2344.21282(11)		3d^{6}4p z^{6}P$^{\rm o}_{7/2}$	j_5		0.114	1540(400)
		58	*42658.217800*	*3*	m	*2344.2142020*					*0.3*	
		57	*42658.229605*	*3*	m	*2344.2135533*					*2.1*	
		56	*42658.241832*	*3*	m	*2344.2128814*					*91.8*	
		54	*42658.267643*	*3*	m	*2344.2114630*					*5.8*	
	2374	55.85	42114.836(2)	0	h	2374.46015(11)		3d^{6}4p z^{6}F$^{\rm o}_{9/2}$	j_6		0.0313	1660(60)
		58	*42114.804727*	*3*	m	*2374.4619178*					*0.3*	
		57	*42114.819377*	*3*	m	*2374.4610918*					*2.1*	
		56	*42114.834550*	*3*	m	*2374.4602364*					*91.8*	
		54	*42114.866583*	*3*	m	*2374.4584303*					*5.8*	
	2382	55.85	41968.065(2)	0	h	2382.76413(11)		3d^{6}4p z^{6}F$^{\rm o}_{11/2}$	j_7		0.320	1550(60)
		58	*41968.040382*	*3*	m	*2382.7655304*					*0.3*	
		57	*41968.051914*	*3*	m	*2382.7648756*					*2.1*	
		56	*41968.063859*	*3*	m	*2382.7641975*					*91.8*	
		54	*41968.089075*	*3*	m	*2382.7627658*					*5.8*	
	2586	55.85	38660.052(2)	0	h	2586.64939(13)		3d^{6}4p z^{6}D$^{\rm o}_{7/2}$	j_8		0.0691	1540(40)
		58	*38660.025896*	*3*	m	*2586.6511386*					*0.3*	
		57	*38660.038124*	*3*	m	*2586.6503204*					*2.1*	
		56	*38660.050790*	*3*	m	*2586.6494730*					*91.8*	
		54	*38660.077528*	*3*	m	*2586.6476840*					*5.8*	
	2600	55.85	38458.991(2)	0	h	2600.17222(14)		3d^{6}4p z^{6}D$^{\rm o}_{9/2}$	j_9		0.239	1410(60)
		58	*38458.965068*	*3*	m	*2600.1739730*					*0.3*	
		57	*38458.977216*	*3*	m	*2600.1731517*					*2.1*	
		56	*38458.989798*	*3*	m	*2600.1723011*					*91.8*	
		54	*38459.016359*	*3*	m	*2600.1705053*					*5.8*	
Ni II	1709	58.69	58493.075(4)	0	o	1709.60409(12)	3d^9 ^{2}D$_{5/2}$	3d^{8}4p z^{2}F$^{\rm o}_{5/2}$	k_1	7.64, 18.17	0.0324	−20(250)
	1741	58.69	57420.017(4)	0	o	1741.55295(12)		3d^{8}4p z^{2}D$^{\rm o}_{5/2}$	k_2		0.0427	−1400(250)
	1751	58.69	57080.377(4)	0	o	1751.91555(12)		3d^{8}4p z^{2}F$^{\rm o}_{7/2}$	k_3		0.0277	−700(250)
Zn II	2026	65.41	49355.005(2)	0	h	2026.136964(82)	3d^{10}4s ^{2}S$_{1/2}$	3d^{10}4p ^{2}P$^{\rm o}_{3/2}$	l_1	9.39, 17.96	0.501	2470(25)
		70	*49355.0523(21)*	*2*	p	*2026.135024(87)*					*0.6*	
		68	*49355.0333(20)*	*2*	p	*2026.135802(83)*					*18.8*	
		67	*49355.1578(64)*	*3*	q, r	*2026.13069(26)*	$F = 2$	$F = 1, 2, 3$			*1.7*	
		67	*49354.9288(29)*	*3*	q, r	*2026.14009(12)*	$F = 3$	$F = 2, 3, 4$			*2.4*	
		66	*49355.0110(20)*	*2*	p	*2026.136719(83)*					*27.9*	
		64	*49354.9884(22)*	*2*	p	*2026.137645(90)*					*48.6*	
	2062	65.41	48481.081(2)	0	h	2062.660278(85)		3d^{10}4p ^{2}P$^{\rm o}_{1/2}$	l_2		0.246	1560(25)
		70	*48481.1293(54)*	*3*	e, p	*2062.65822(23)*					*0.6*	
		68	*48481.1099(39)*	*3*	e, p	*2062.65905(17)*					*18.8*	
		67	*48481.2382(95)*	*3*	e, p, q	*2062.65359(40)*	$F = 2$	$F = 2, 3$			*1.7*	
		67	*48481.0040(38)*	*3*	e, p, q	*2062.66355(16)*	$F = 3$	$F = 2, 3$			*2.4*	
		66	*48481.0872(26)*	*3*	e, p	*2062.66001(11)*					*27.9*	
		64	*48481.0639(30)*	*3*	e, p	*2062.66101(13)*					*48.6*	

[a]Hannemann et al. (2006); [b]Salumbides et al. (2006); [c]Batteiger et al. (2009); [d]Griesmann & Kling (2000); [e]Berengut et al. (2003); [f]1.4 × (Mass shift); [g]Ruffoni & Pickering (2010); [h]Aldenius et al. (2006); [i]Berengut et al. (2008); [j]Berengut J. (2012, in prep.); [k]Blackwell-Whitehead et al. (2005); [l]Nave & Sansonetti (2011); [m]Porsev et al. (2009); [n]S. Johansson (priv. comm.); [o]Pickering et al. (2000); [p]Matsubara et al. (2003a); [q]Dixit et al. (2008); [r]Matsubara et al. (2003b).