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Energy levels and radiative rates for transitions in Ar XIII, Ar XIV and Ar XV*,**

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Abstract. Energies for 524 levels of Ar XIII, 460 levels of Ar XIV and 156 levels of Ar XV have been calculated using the GRASP code of Dyall et al. (1989). Additionally, radiative rates, oscillator strengths, and line strengths are calculated for all electric dipole (E1), magnetic dipole (M1), electric quadrupole (E2), and magnetic quadrupole (M2) transitions among these levels. Comparisons are made with the limited results available in the literature, and the accuracy of the data is assessed. Our energy levels are estimated to be accurate to better than 1%, whereas results for other parameters are probably accurate to better than 20%. Additionally, the level lifetimes derived from our radiative rates are in excellent agreement with measured values.

Key words. atomic data – atomic processes

1. Introduction

Recently a wealth of high resolution spectra in the UV, EUV and X-ray regions have been obtained for solar, stellar and other astrophysical sources by many space missions, such as SOHO, *Chandra* and XMM *Newton*. Many of the observed emission lines are from the spectra of highly ionized argon, and some of these from Ar XIV−XVIII have been specifically listed by Dere et al. (2001). A complete list of lines over a wide range of wavelengths for many ions, including those of argon, are available in the CHIANTI database at http://wwwsolar.nrl.navy.mil/chianti.html. Additionally, to provide experimental support to observational data, many lines of Ar IX−XVI in the 20−50 Å X-ray range have been measured in the electron beam ion trap (EBIT) experiments of the Lawrence Livermore National Laboratory (Lepson et al. 2003).

An analysis of observed spectra provides information on the temperature, density and chemical composition of the plasmas. However, such an analysis requires information for a wide range of atomic parameters, such as energy levels, radiative rates, and excitation rate coefficients. Therefore, with this in view we report in this paper our results of energy levels, radiative rates (A-values), oscillator strengths (f-values) and line strengths (S-values) for transitions in Ar XIII, Ar XIV and Ar XV. Similar results for Ar XVI have already been reported by McKeown et al. (2004), whereas calculations are in progress for some other ions, such as Ar XVII and Ar XVIII.

There is paucity of measurements for the above named atomic parameters, and hence theoretical results are of vital importance. A few calculations have been performed in the past by some authors, but most of these are limited to a few energy levels. Therefore, in this work we attempt to report results for a wider range of energy levels, and hence for a larger number of transitions. Furthermore, most of the available theoretical data are confined to the radiative rates for allowed and inter-combination (E1) transitions alone, whereas we here report similar data for other types of transitions as well, namely electric quadrupole (E2), magnetic dipole (M1) and magnetic quadrupole (M2), because these data are also required in the analysis and modelling of plasmas.

2. Energy levels

For our work we have adopted the fully relativistic GRASP (General purpose Relativistic Atomic Structure Package) code of Dyall et al. (1989), and have included configuration interaction (CI) among a large range of configurations/levels. Additionally, Breit and QED corrections have been included to further improve the accuracy of our results. The specific configurations included, results obtained and the accuracy achieved in comparison to the available theoretical and experimental data, are discussed below for each ion.

* Full Tables 1–3 are only available in electronic form at http://www.edpsciences.org
** Tables 4–9 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/436/1141

2.1. Ar XIII

In our earlier work on this ion (Aggarwal et al. 2001), we reported results for energy levels and radiative rates, but only for transitions among the lowest 46 levels of the (1s^2) 2s^{2}2p^2, 2s2p^3, 2p^4, and 2s^{2}2p3ℓ configurations, and adopted the CIV3 program of Hibbert (1975). The inclusion of relativistic effects was confined to one-body operators (namely, mass correction, Darwin, spin-orbit, spin-other-orbit and spin-spin terms), but extensive CI was included among the internal as well as external (up to 4f) orbitals. Furthermore, A-values were reported only for the E1 transitions. However, the energy levels obtained were assessed to be accurate to within 5%, and the radiative rates for a majority of transitions were accurate to within 20%. It may be noted that the experimentally compiled energies by NIST (`http://physics.nist.gov/PhysRefData`) are available for only a few levels as shown in Table 4 of Aggarwal et al. (2001).

A larger calculation involving 1274 levels of Ar XIII was performed by Nahar (2000), who adopted the R-matrix method of Berrington et al. (1995). Her calculations are primarily in the LS coupling scheme, and results for fine-structure transitions were obtained by the inclusion of one-body relativistic operators (only mass correction, Darwin, and spin-orbit terms) in the Breit-Pauli approximation. This approach yields results for a large number of levels (and correspondingly for a very large number of E1 transitions) with comparatively less effort than required in a standard atomic structure calculation. However the accuracy achieved is often poor, especially for transitions among the degenerate levels of a state, because the relativistic effects are not properly accounted, and two-body operators are completely neglected. An inadequacy of this method has been discussed in detail by Hibbert (2003), and has been demonstrated for results in Fe XIII by Young (2004), in Fe XVII by Nahar et al. (2003), and in Fe XXIV by McKeown et al. (2004). We will further discuss below the accuracy of their energy levels in comparison to other available calculations.

In a more recent work, Liang et al. (2004) have reported energy levels and radiative rates for transitions among the 224 levels of the 2s^{2}2p^2, 2s2p^3, 2p^4, 2s^{2}2p3ℓ, 2s2p^{2}3ℓ, 2s^{2}2p4ℓ, and 2s^{2}2p5ℓ ($\ell \le d$) configurations. They have adopted the *Flexible Atomic Code* (FAC) of Gu (2003), which is a fully relativistic code like GRASP, and is available at `http://kipac-tree.stanford.edu/fac`. In general, the discrepancy between their and Nahar's (2000) energy levels is below 2%, as stated by them. However for some levels, the differences between the two sets of data are 5%, and the results of Nahar from the R-matrix code are invariably *lower*. Particularly noteworthy are the levels of the 2s^{2}2p4p configuration, i.e. levels 165−173 (see Table 1), for which her energy levels are lower by over 2 Ryd – see Table 1 of Liang et al. These differences are certainly very large for an atomic structure calculation. Apart from this the ordering of levels are different in the two calculations. Therefore, our aim is to confirm the accuracy and orderings of the available energy levels, and we do this by performing an independent calculation using GRASP, as stated earlier.

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd). The lowest 192 levels are listed here and a complete table for all levels is available in the electronic version only.

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
1	2s^{2}2p^2	$^3P_0$	0.0000	0.0000	0.0000	0.0000
2	2s^{2}2p^2	$^3P_1$	0.0887	0.0890	0.0875	0.0899
3	2s^{2}2p^2	$^3P_2$	0.1980	0.1983	0.1961	0.2068
4	2s^{2}2p^2	$^1D_2$	0.8029	0.8024	0.7977	0.7946
5	2s^{2}2p^2	$^1S_0$	1.5087	1.4917	1.4816	1.5105
6	2s2p^3	$^5S^o_2$	2.0243	2.0116	2.0032	2.0704
7	2s2p^3	$^3D^o_2$	3.9242	3.9161	3.8885	3.8834
8	2s2p^3	$^3D^o_1$	3.9297	3.9216	3.8939	3.8887
9	2s2p^3	$^3D^o_3$	3.9354	3.9270	3.8996	3.9083
10	2s2p^3	$^3P^o_0$	4.5854	4.5805	4.5483	4.5637
11	2s2p^3	$^3P^o_1$	4.5889	4.5838	4.5514	4.5723
12	2s2p^3	$^3P^o_2$	4.5995	4.5944	4.5616	4.5895
13	2s2p^3	$^1D^o_2$	5.9150	5.9067	5.8515	5.7893
14	2s2p^3	$^3S^o_1$	5.9570	5.9445	5.8807	5.8187
15	2s2p^3	$^1P^o_1$	6.5749	6.5696	6.5090	6.4669
16	2p^4	$^3P_2$	8.9522	8.9460	8.8169	8.7985
17	2p^4	$^3P_1$	9.0927	9.0864	8.9582	8.9389
18	2p^4	$^3P_0$	9.1369	9.1307	9.0002	8.9828
19	2p^4	$^1D_2$	9.6518	9.6544	9.5143	9.4537
20	2p^4	$^1S_0$	10.9660	10.9634	10.8036	10.7246
21	2s^{2}2p3s	$^3P^o_0$	28.7548	28.7381	28.7437	28.3584
22	2s^{2}2p3s	$^3P^o_1$	28.7913	28.7746	28.7813	28.4153
23	2s^{2}2p3s	$^3P^o_2$	28.9627	28.9461	28.9498	28.5705
24	2s^{2}2p3s	$^1P^o_1$	29.1234	29.1057	29.1226	28.6911
25	2s^{2}2p3p	$^1P_1$	29.7500	29.7323	29.7409	29.5711
26	2s^{2}2p3p	$^3D_1$	29.8900	29.8719	29.8811	29.9819
27	2s^{2}2p3p	$^3D_2$	29.9078	29.8888	29.8981	29.7284
28	2s^{2}2p3p	$^3D_3$	30.0509	30.0318	30.0387	29.8672
29	2s^{2}2p3p	$^3P_0$	30.0691	30.0515	30.0827	29.8814
30	2s^{2}2p3p	$^3P_1$	30.1017	30.0836	30.1013	29.7131
31	2s^{2}2p3p	$^3S_1$	30.1944	30.1758	30.1946	29.9091
32	2s^{2}2p3p	$^3P_2$	30.2139	30.1963	30.2252	30.0274
33	2s^{2}2p3p	$^1D_2$	30.5850	30.5661	30.6013	30.3512
34	2s2p^{2}3s	$^5P_1$	30.6301	30.6107	30.6440	30.4338
35	2s2p^{2}3s	$^5P_2$	30.7039	30.6846	30.7144	30.5121
36	2s2p^{2}3s	$^5P_3$	30.7979	30.7785	30.8087	30.6147
37	2s^{2}2p3p	$^1S_0$	30.9431	30.9241	30.9674	30.7140
38	2s^{2}2p3d	$^3F^o_2$	31.0087	30.9989	31.0078	30.8405
39	2s^{2}2p3d	$^3F^o_3$	31.1024	31.0929	31.1069	30.9525
40	2s^{2}2p3d	$^1D^o_2$	31.1455	31.1349	31.1482	30.9875
41	2s^{2}2p3d	$^3F^o_4$	31.2237	31.2142	31.2231	31.0580
42	2s2p^2(^{4}P)3s	$^3P_0$	31.2763	31.2663	31.3165	31.0196
43	2s^{2}2p3d	$^3D^o_1$	31.3040	31.2934	31.3046	31.1575
44	2s2p^2(^{4}P)3s	$^3P_1$	31.3353	31.3254	31.3722	31.0811
45	2s^{2}2p3d	$^3D^o_2$	31.3481	31.3373	31.3518	31.2082
46	2s^{2}2p3d	$^3D^o_3$	31.4236	31.4137	31.4264	31.2391
47	2s2p^2(^{4}P)3s	$^3P_2$	31.4388	31.4286	31.4753	31.1922
48	2s^{2}2p3d	$^3P^o_2$	31.4896	31.4774	31.4890	31.2667
49	2s^{2}2p3d	$^3P^o_1$	31.5096	31.4968	31.5096	31.3042
50	2s^{2}2p3d	$^3P^o_0$	31.5234	31.5101	31.5231	31.3365
51	2s2p^{2}3p	$^5D^o_0$	31.6819	31.6636	31.7020	31.7422
52	2s2p^{2}3p	$^5D^o_1$	31.6986	31.6803	31.7186	31.7346
53	2s2p^{2}3p	$^5D^o_2$	31.7432	31.7248	31.7611	31.8098
54	2s2p^2(^{4}P)3p	$^3S^o_1$	31.7781	31.7600	31.7983	31.7701
55	2s2p^{2}3p	$^5D^o_3$	31.8091	31.7908	31.8249	31.8786
56	2s^{2}2p3d	$^1P^o_1$	31.8275	31.8120	31.8247	31.6435
57	2s^{2}2p3d	$^1F^o_3$	31.8359	31.8261	31.8444	31.6290
⋆ 58	2s2p^{2}3p	$^5P^o_2$	31.8860	31.8664	31.9026	31.9653
⋆ 59	2s2p^{2}3p	$^5P^o_1$	31.8859	31.8670	32.1984	31.9408
60	2s2p^{2}3p	$^5D^o_4$	31.8954	31.8772	31.9115	31.9692
61	2s2p^{2}3p	$^5P^o_3$	31.9500	31.9304	32.3373	32.4047
62	2s2p^2(^{4}P)3p	$^3D^o_1$	32.1635	32.1491	32.4244	32.1702
63	2s2p^2(^{4}P)3p	$^3D^o_2$	32.2178	32.2035	31.9034	32.2342
⋆ 64	2s2p^{2}3p	$^5S^o_2$	32.3092	32.2924	32.2509	32.3483

Table 1. continued.

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
★ 65	$2s2p^2(^4P)3p$	$^3D^o_3$	32.3042	32.2898	32.4829	32.3278
66	$2s2p^23p$	$^3P^o_0$	32.3854	32.3751	31.9651	32.0299
67	$2s2p^23p$	$^3P^o_1$	32.4165	32.4060	32.4556	32.4346
68	$2s2p^2(^4P)3p$	$^3P^o_2$	32.4458	32.4347	32.3610	32.4715
69	$2s2p^23s$	$^3D_1$	32.4927	32.4722	32.4805	32.2589
70	$2s2p^23s$	$^3D_2$	32.4967	32.4762	32.4846	32.2633
71	$2s2p^23s$	$^3D_3$	32.5014	32.4809	32.4893	32.2688
72	$2s2p^23d$	$^5F_1$	32.7661	32.7504	32.7957	32.7358
73	$2s2p^23d$	$^5F_2$	32.7852	32.7695	32.8161	32.7627
74	$2s2p^23d$	$^5F_3$	32.8171	32.8014	32.8489	32.8022
75	$2s2p^23d$	$^5F_4$	32.8662	32.8505	32.8968	32.8533
76	$2s2p^23s$	$^1D_2$	32.8806	32.8649	32.8823	32.6031
77	$2s2p^23d$	$^5F_5$	32.9335	32.9180	32.9626	32.9151
78	$2s2p^23d$	$^5D_0$	32.9757	32.9574	32.9982	32.9479
79	$2s2p^23d$	$^5D_1$	32.9788	32.9606	33.0022	32.9550
80	$2s2p^23d$	$^5D_2$	32.9862	32.9680	33.0113	32.9690
81	$2s2p^23d$	$^5D_3$	33.0023	32.9842	33.0300	32.9905
82	$2s2p^23d$	$^5D_4$	33.0455	33.0276	33.0704	33.0180
83	$2s2p^23d$	$^5P_3$	33.2043	33.1841	33.2270	33.1345
84	$2s2p^2(^4P)3d$	$^3P_2$	33.2245	33.2071	33.2476	33.1421
85	$2s2p^23d$	$^5P_2$	33.2463	33.2264	33.2684	33.2120
86	$2s2p^23d$	$^5P_1$	33.2644	33.2441	33.2874	33.1973
87	$2s2p^2(^4P)3d$	$^3P_1$	33.3031	33.2860	33.3244	33.2565
88	$2s2p^2(^4P)3d$	$^3P_0$	33.3433	33.3262	33.3638	33.2754
89	$2s2p^2(^4P)3d$	$^3F_2$	33.3745	33.3631	33.4029	33.3123
90	$2s2p^23s$	$^3S_1$	33.4343	33.4132	33.4062	33.4983
91	$2s2p^2(^4P)3d$	$^3F_3$	33.4344	33.4231	33.4599	33.3824
92	$2s2p^2(^4P)3d$	$^3F_4$	33.5170	33.5057	33.5426	33.4645
93	$2s2p^23p$	$^3F^o_2$	33.5648	33.5454	33.5564	33.5488
94	$2s2p^23p$	$^3F^o_3$	33.5880	33.5686	33.5796	33.5940
95	$2s2p^23p$	$^3F^o_4$	33.6164	33.5970	33.6075	33.6210
96	$2s2p^2(^2P)3s$	$^3P_0$	33.7242	33.7052	33.7046	33.3804
97	$2s2p^23p$	$^1F^o_3$	33.7320	33.7125	33.7320	33.7302
98	$2s2p^2(^2P)3p$	$^3D^o_1$	33.7419	33.7306	33.7562	33.7459
99	$2s2p^2(^2P)3p$	$^3D^o_2$	33.7551	33.7439	33.7618	33.6108
100	$2s2p^2(^2P)3p$	$^1D^o_2$	33.7638	33.7469	33.7703	33.7637
101	$2s2p^2(^4P)3d$	$^3D_1$	33.7673	33.7649	33.7956	33.2725
102	$2s2p^2(^2P)3p$	$^3D^o_3$	33.7732	33.7617	33.9618	33.7826
103	$2s2p^2(^4P)3d$	$^3D_2$	33.7866	33.7842	33.8155	33.7195
104	$2s2p^2(^4P)3d$	$^3D_3$	33.8108	33.8088	33.8398	33.7477
105	$2s2p^2(^2P)3s$	$^3P_1$	33.8660	33.8458	33.8424	33.6919
106	$2s2p^2(^2P)3p$	$^1P^o_1$	33.9316	33.9168	33.7894	33.8113
107	$2s2p^23p$	$^3P^o_0$	33.9427	33.9342	33.9550	33.9449
108	$2s2p^23p$	$^3P^o_1$	33.9455	33.9352	33.9354	33.9486
109	$2s2p^2(^2P)3p$	$^3P^o_2$	33.9477	33.9393	33.9560	33.9519
★ 110	$2s2p^23s$	$^1S_0$	33.9562	33.9379	33.9336	33.6681
★ 111	$2s2p^2(^2P)3s$	$^3P_2$	33.9560	33.9356	33.9316	33.5913
112	$2s2p^23s$	$^1P_1$	34.0514	34.0316	34.0333	33.6962
113	$2s2p^23p$	$^3P^o_0$	34.5329	34.5147	34.5126	34.4948
114	$2s2p^23p$	$^3P^o_1$	34.6119	34.5944	34.5978	34.6180
115	$2s2p^2(^2D)3p$	$^3P^o_2$	34.6641	34.6471	34.6502	34.6850
116	$2s2p^23d$	$^3G_3$	34.6728	34.6530	34.6657	34.7041
117	$2s2p^23d$	$^3G_4$	34.6795	34.6597	34.6730	34.7081
118	$2s2p^23d$	$^3G_5$	34.6875	34.6678	34.6804	34.7264
★ 119	$2s2p^2(^2D)3p$	$^1P^o_1$	34.7142	34.6957	34.7015	34.6566
★ 120	$2s2p^23p$	$^1S^o_0$	34.7049	34.6883	34.6792	34.6947
121	$2s2p^2(^2P)3d$	$^3F_2$	34.7621	34.7537	34.7678	34.7524
122	$2s2p^2(^2P)3d$	$^3F_3$	34.7691	34.7606	34.7755	34.7557
123	$2s2p^2(^2P)3d$	$^3F_4$	34.7706	34.7619	34.7766	34.7656
124	$2s2p^2(^2P)3d$	$^3D_1$	34.8354	34.8151	34.8276	34.8524
125	$2s2p^2(^2P)3d$	$^3D_2$	34.8402	34.8201	34.8327	34.8593
126	$2s2p^2(^2P)3d$	$^3D_3$	34.8463	34.8265	34.8387	34.8712
127	$2s2p^2(^2P)3d$	$^1F_3$	34.9048	34.8883	34.9000	34.8957
128	$2s2p^2(^2D)3p$	$^3D^o_1$	34.9168	34.8990	34.8974	34.8264
129	$2s2p^2(^2D)3p$	$^3D^o_2$	34.9315	34.9138	34.9101	34.8060
130	$2s2p^2(^2D)3p$	$^3D^o_3$	34.9987	34.9808	34.9757	34.8477

Table 1. continued.

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
131	$2s2p^23d$	$^1G_4$	35.0017	34.9813	34.9907	35.0237
132	$2s2p^2(^2P)3d$	$^3P_0$	35.0564	35.0414	35.0503	35.0608
133	$2s2p^2(^2P)3d$	$^3P_1$	35.0602	35.0454	35.0542	35.0599
134	$2s2p^2(^2P)3d$	$^3P_2$	35.0650	35.0505	35.0592	35.0772
135	$2s2p^23p$	$^3P^o_0$	35.0775	35.0630	35.0626	34.9600
136	$2s2p^23p$	$^3P^o_1$	35.0875	35.0728	35.0727	34.9408
137	$2s2p^2(^2S)3p$	$^3P^o_2$	35.1164	35.1013	35.1006	34.9412
138	$2s2p^23d$	$^3S_1$	35.1498	35.1309	35.1368	35.1709
139	$2s2p^2(^2P)3d$	$^1D_2$	35.1992	35.1855	35.1914	35.1798
140	$2s2p^2(^2P)3p$	$^3S^o_1$	35.2741	35.2612	35.2769	34.9512
141	$2s2p^2(^2P)3d$	$^1P_1$	35.2833	35.2728	35.2779	35.2475
142	$2s2p^2(^2D)3p$	$^1D^o_2$	35.3864	35.3797	35.3946	35.2850
143	$2s2p^23d$	$^1S_0$	35.4884	35.4836	35.4827	35.4639
144	$2s2p^2(^2S)3p$	$^1P^o_1$	35.6500	35.6544	35.6713	35.5198
145	$2s2p^2(^2D)3d$	$^3D_1$	35.7314	35.7146	35.7094	35.7647
146	$2s2p^2(^2D)3d$	$^3D_2$	35.7457	35.7290	35.7249	35.7844
147	$2s2p^2(^2D)3d$	$^3D_3$	35.7557	35.7390	35.7364	35.8265
148	$2s2p^2(^2D)3d$	$^3F_2$	35.8793	35.8602	35.8548	35.8199
149	$2s2p^2(^2D)3d$	$^3F_3$	35.9927	35.9738	35.9688	35.8722
150	$2s2p^2(^2D)3d$	$^3F_4$	36.0408	36.0216	36.0155	35.9426
151	$2s2p^2(^2D)3d$	$^1D_2$	36.0671	36.0480	36.0416	36.0841
152	$2s2p^2(^2D)3d$	$^1P_1$	36.0960	36.0811	36.0745	36.0657
153	$2s2p^2(^2S)3d$	$^3D_2$	36.1949	36.1755	36.1671	36.0826
★ 154	$2s2p^2(^2S)3d$	$^3D_1$	36.2014	36.1826	36.1749	36.1041
★ 155	$2s2p^2(^2S)3d$	$^3D_3$	36.2011	36.1810	36.1731	36.0765
156	$2s2p^2(^2D)3d$	$^3P_2$	36.3239	36.3076	36.2996	36.2067
157	$2s2p^2(^2D)3d$	$^3P_1$	36.3542	36.3384	36.3307	36.2498
158	$2s2p^2(^2D)3d$	$^3P_0$	36.3585	36.3430	36.3362	36.2726
159	$2s2p^2(^2D)3d$	$^1F_3$	36.4606	36.4546	36.4446	36.3549
160	$2s2p^2(^2S)3d$	$^1D_2$	36.7722	36.7705	36.7538	36.6195
161	$2s^22p4s$	$^3P^o_0$	38.8515	38.8560	38.8699	37.8140
162	$2s^22p4s$	$^3P^o_1$	38.8686	38.8722	38.8862	37.8276
163	$2s^22p4s$	$^3P^o_2$	39.0615	39.0663	39.0783	38.0205
164	$2s^22p4s$	$^1P^o_1$	39.1083	39.1101	39.1224	38.0368
165	$2s^22p4p$	$^3D_1$	39.2641	39.2613	39.2768	37.1417
166	$2s^22p4p$	$^3P_1$	39.3380	39.3370	39.3528	37.2116
167	$2s^22p4p$	$^3D_2$	39.3430	39.3381	39.3536	37.2193
168	$2s^22p4p$	$^3P_0$	39.4065	39.4103	39.4285	37.2710
169	$2s^22p4p$	$^1P_1$	39.4995	39.4989	39.5128	37.3647
170	$2s^22p4p$	$^3D_3$	39.5046	39.4999	39.5132	37.4192
171	$2s^22p4p$	$^3S_1$	39.5564	39.5554	39.5704	37.4039
172	$2s^22p4p$	$^3P_2$	39.5626	39.5650	39.5808	37.4218
173	$2s^22p4p$	$^1D_2$	39.6610	39.6519	39.6685	37.5057
174	$2s^22p4d$	$^3F^o_2$	39.7155	39.7000	39.7146	39.4895
175	$2s^22p4d$	$^3F^o_3$	39.7772	39.7612	39.7745	39.5645
176	$2s^22p4d$	$^3D^o_2$	39.7875	39.7731	39.7848	39.5812
177	$2s^22p4p$	$^1S_0$	39.7926	39.7796	39.7963	37.6009
178	$2s^22p4d$	$^3D^o_1$	39.8319	39.8177	39.8270	39.6311
179	$2s^22p4d$	$^3F^o_4$	39.9287	39.9127	39.9258	39.6996
180	$2s^22p4d$	$^1D^o_2$	39.9473	39.9332	39.9443	39.7327
181	$2s^22p4d$	$^3D^o_3$	39.9874	39.9733	39.9824	39.7602
★ 182	$2s^22p4f$	$^3G_3$	40.0186	39.9980	40.0130	39.8309
★ 183	$2s^22p4f$	$^3G_4$	40.0250	40.0049	40.0204	39.8375
★ 184	$2s^22p4d$	$^3P^o_2$	40.0154	40.0007	40.0094	39.7750
★ 185	$2s^22p4f$	$^3F_3$	40.0321	40.0123	40.0276	39.8445
★ 186	$2s^22p4d$	$^3P^o_1$	40.0230	40.0078	40.0167	39.7821
★ 187	$2s^22p4f$	$^3F_2$	40.0336	40.0139	40.0293	39.8460
★ 188	$2s^22p4d$	$^3P^o_0$	40.0282	40.0126	40.0217	39.7913
★ 189	$2s^22p4d$	$^1P^o_1$	40.1326	40.1177	40.1217	39.8955
★ 190	$2s^22p4d$	$^1F^o_3$	40.1322	40.1150	40.1185	39.8962
191	$2s^22p4f$	$^1F_3$	40.2200	40.2000	40.2132	40.0288
192	$2s^22p4f$	$^3F_4$	40.2226	40.2027	40.2159	40.0316

GRASP1: Present 524 level calculations from the GRASP code.
GRASP2: Present 224 level calculations from the GRASP code.
FAC: Calculations of Liang et al. (2004) from the FAC code.
BPRM : Calculations of Nahar (2000) from the BPRM code.
★: Level has changed order with the inclusion of Breit and QED effects.

In our calculations, we too have included 224 levels of the above stated configurations, and the results obtained are listed in Table 1 along with those of Liang et al. (2004) and Nahar (2000). It is satisfying to note that the discrepancies between our present calculations from GRASP and those of Liang et al. from FAC are below 1.7% for *all* levels, and in fact almost match for a majority of these. Particularly noteworthy in Table 1 is the $2s^22p^2$ $^3P_2$ level (3), for which Nahar's energy is higher by 5% than the experimental (0.1991 Ryd) or any of the other theoretical values. Furthermore, the orderings of the levels is also nearly the same in both sets of calculations, although there are some minor differences, such as for levels 43, 68 and 106. This clearly confirms that energy levels from the semi-relativistic calculations of Nahar with the *R*-matrix code are not as accurate as obtained from the standard atomic structure codes, such as GRASP and FAC. This conclusion is in agreement with those mentioned above for energy levels in Fe XIII, Fe XVII and Fe XXIV.

In order to further assess the accuracy of our energy levels, we have performed several test calculations with increasing number of configurations, such as ($2s^22p$) 6s, 7s, 8s; and ($2s2p^2$) 4ℓ and 5ℓ. This is mainly because many of the energy levels of the $2s2p^24\ell$ configurations lie below those of the $2s^22p5\ell$ configurations (see Table 1) and extend up to an energy of ~45 Ryd. Similarly, many of the levels of the $2s2p^25\ell$ configurations lie just above those of the $2s^22p5d$ $^1P^0_1$ level (356) – the highest level considered by Liang et al. (2004). Therefore, performing a larger calculation than that of Liang et al. has become necessary, which will also help in spectral modelling apart from improving upon the accuracy of the results.

Our final results, obtained for 524 levels belonging to the 26 configurations of Ar XIII [namely, $2s^22p^2$, $2s2p^3$, $2p^4$, $2s^22p3\ell$, $2s2p^23\ell$, $2s^22p4\ell$, $2s^22p$ 5ℓ ($\ell \leq d$), $2s^22p$ 6s, $2s^22p7s$, $2s^22p8s$, $2s2p^24\ell$, and $2s2p^2$ 5ℓ ($\ell \leq d$)], are also listed in Table 1. Before we discuss these results further, we will like to mention here that the inclusion of other higher levels from configurations such as $2s^23\ell^2$, $2s^23\ell3\ell'$ or (2s2p) $3\ell3\ell'$ is of no obvious advantage, as energies of these levels lie well *above* those of the 524 levels mentioned above. However, the two sets of energy levels (from our 224 and 524 level calculations) agree very closely, and we do not observe any noticeable differences. To conclude, we may state with confidence that the energy levels listed in Table 1 from our GRASP or earlier calculations of Liang et al. (2004) from FAC are accurate to about 1%, whereas those of Nahar (2000) differ by up to 2 Ryd (5%) for some levels. Furthermore, the level orderings from the GRASP and FAC codes are nearly the same but differ in many instances with those obtained from the *R*-matrix code.

2.2. Ar XIV

For this ion experimental energy levels on the NIST website are confined to only 16 levels among the $2s^22p$, $2s2p^2$ and $2p^3$ configurations. However, CHIANTI database includes a few more experimental energy levels along with the theoretical energies for the lowest 125 levels of the $2s^22p$, $2s2p^2$, $2p^3$, $2s^23\ell$, $2s2p3\ell$ and $2p^23\ell$ configurations. These theoretical energies are based on the calculations of Zhang et al. (1994) for the $n = 2$ levels, and their unpublished results for the $n = 3$ levels, which have been obtained from the Dirac-Fock-Slater (DFS) code of Sampson et al. (1989). In Table 2 we compare these available energies with our present calculations for 460 levels among 39 configurations, namely $2s^22p$, $2s2p^2$, $2p^3$, $2s^23\ell$, $2s2p3\ell$, $2p^23\ell$, $2s^24\ell$, $2p^24\ell$, $2s2p4\ell$, $2s^25\ell$ ($\ell \leq f$), $2p^25\ell$ ($\ell \leq f$), $2s2p5\ell$ ($\ell \leq f$), $2s^26s$, $2s^27s$ and $2s^28s$. Although all the additional 335 levels included in the present calculations lie *above* the lowest 125 (included in the CHIANTI database), they lie just above those, as can be seen in Table 2. Therefore, a larger calculation has become necessary, especially when some of the observed emission lines belong to the 4ℓ levels – see Table 6 of Lepson et al. (2003).

The agreement between the experimental and theoretical energy levels is generally good, except for two levels, namely $2s2p(^3P)3p$ $^2P_{1/2}$ and $^2P_{3/2}$, i.e. levels 28 and 29, for which the discrepancy is up to 4%. However, experimental values for these (and a few more) levels are not available from the present version of the NIST website, and were stored in the CHIANTI database from the earlier versions, which cannot be independently verified. Nevertheless, the absence of these levels in the current version indicates the unreliability of these energy levels. Moreover, if these two levels are exchanged with the higher $2s2p(^1P)3p$ $^2P_{1/2}$ and $^2P_{3/2}$, i.e. levels 58 and 61, then the agreements with theory are better and within 2%. Finally, the two sets of theoretical energy levels agree very well in both magnitude and orderings, although there are some minor discrepancies of orderings for a few levels, such as 29/30, 40/41 and 48/49. However, energy differences between these levels are very small, and different energy orderings occur due to different amount of CI included. It will also be appropriate here to state that sometimes the levels of the same j value and parity, but from different configurations (or LS states), are highly mixed and it becomes difficult to identify/designate each level on the basis of the strength of the eigenvectors alone. In such cases the identification/designation is performed on the basis of several test calculations with differing amount of CI, and/or on the basis of the strength of the second most contributing eigenvector. Therefore, although all efforts have been made to properly identify/designate the levels of Ar XIV, yet scope of (re)adjustment remains for a few levels.

2.3. Ar XV

For this ion earlier theoretical energies are available up to the $n = 3$ levels, which are stored in the CHIANTI database, and are based on the calculations of Sampson et al. (1984) and Zhang & Sampson (1992), who have adopted their DFS code. Similarly, experimental energies have been listed by NIST for 11 levels of the ($1s^2$) $2s^2$, 2s2p and $2p^2$ configurations, and by Khardi et al. (1994) for some of the $n = 3$ and $n = 4$ levels. In this work we have extended the range of energy levels to 156, which belong to 28 configurations of Ar XV, namely ($1s^2$) $2s^2$, 2s2p, $2p^2$, $2s3\ell$, $2p3\ell$, $2s4\ell$, $2p4\ell$, $2s5\ell$ ($\ell \leq f$), $2p5\ell$ ($\ell \leq f$), 2s6s, 2s7s and 2s8s.

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd). The lowest 125 levels are listed here and a complete table for all levels is available in the electronic version only.

Index	Configuration	Level	Expt.	DFS	GRASP
1	$2s^22p$	$^2P^0_{1/2}$	0.0000	0.0000	0.0000
2	$2s^22p$	$^2P^0_{3/2}$	0.2064	0.2087	0.2055
3	$2s2p^2$	$^4P_{1/2}$	2.0895	2.0833	2.0602
4	$2s2p^2$	$^4P_{3/2}$	2.1678	2.1629	2.1379
5	$2s2p^2$	$^4P_{5/2}$	2.2725	2.2756	2.2422
6	$2s2p^2$	$^2D_{3/2}$	3.7373	3.7720	3.7798
7	$2s2p^2$	$^2D_{5/2}$	3.7461	3.7833	3.7879
8	$2s2p^2$	$^2S_{1/2}$	4.6877	4.7362	4.7584
9	$2s2p^2$	$^2P_{1/2}$	4.9674	5.0176	5.0489
10	$2s2p^2$	$^2P_{3/2}$	5.0544	5.1100	5.1382
11	$2p^3$	$^4S^0_{3/2}$	6.5419	6.5707	6.5551
12	$2p^3$	$^2D^0_{3/2}$	7.3896	7.4380	7.4625
13	$2p^3$	$^2D^0_{5/2}$	7.4068	7.4639	7.4785
14	$2p^3$	$^2P^0_{1/2}$	8.2795	8.3449	8.3882
15	$2p^3$	$^2P^0_{3/2}$	8.3190	8.3882	8.4259
16	$2s^23s$	$^2S_{1/2}$	31.5663	31.0283	31.0761
17	$2s^23p$	$^2P^0_{1/2}$	32.5787	32.0636	32.1137
18	$2s^23p$	$^2P^0_{3/2}$	32.6325	32.1216	32.1704
19	$2s^23d$	$^2D_{3/2}$	33.1729	33.0871	33.1377
20	$2s^23d$	$^2D_{5/2}$	33.1883	33.1036	33.1534
21	$2s2p3s$	$^4P^0_{1/2}$		33.1482	33.2260
22	$2s2p3s$	$^4P^0_{3/2}$		33.2125	33.2905
23	$2s2p3s$	$^4P^0_{5/2}$		33.3422	33.4203
24	$2s2p(^3P)3s$	$^2P^0_{1/2}$		33.6704	33.7704
25	$2s2p(^3P)3s$	$^2P^0_{3/2}$		33.8119	33.9114
26	$2s2p3p$	$^4D_{1/2}$		34.0720	34.1368
27	$2s2p3p$	$^4D_{3/2}$		34.1288	34.1935
28	$2s2p(^3P)3p$	$^2P_{1/2}$	35.8310	34.2244	34.2670
29	$2s2p(^3P)3p$	$^2P_{3/2}$	35.8483	34.4182	34.2885
30	$2s2p3p$	$^4D_{5/2}$		34.2265	34.2915
31	$2s2p3p$	$^4D_{7/2}$		34.3429	34.4066
32	$2s2p3p$	$^4S_{3/2}$			34.4901
33	$2s2p3p$	$^4P_{1/2}$		34.4926	34.6001
34	$2s2p3p$	$^4P_{3/2}$		34.5697	34.6734
35	$2s2p3p$	$^4P_{5/2}$		34.6153	34.7226
36	$2s2p(^3P)3p$	$^2D_{3/2}$		34.6657	34.7586
37	$2s2p(^3P)3p$	$^2D_{5/2}$		34.7949	34.8907
38	$2s2p3d$	$^4F^0_{3/2}$		34.9660	35.0216
39	$2s2p3d$	$^4F^0_{5/2}$		35.0052	35.0603
40	$2s2p3d$	$^4F^0_{7/2}$		35.0659	35.1203
41	$2s2p(^3P)3p$	$^2S_{1/2}$		35.0626	35.1594
42	$2s2p3d$	$^4F^0_{9/2}$		35.1615	35.2137
43	$2s2p3d$	$^4D^0_{5/2}$		35.2414	35.3228
44	$2s2p3d$	$^4D^0_{3/2}$		35.2490	35.3304
45	$2s2p3d$	$^4D^0_{1/2}$		35.2515	35.3326
46	$2s2p(^3P)3d$	$^2D^0_{3/2}$	35.4483	35.3099	35.4021
⋆ 47	$2s2p(^1P)3s$	$^2P^0_{1/2}$		35.3549	35.4359
48	$2s2p(^3P)3d$	$^2D^0_{5/2}$	35.4665	35.3430	35.4313
⋆ 49	$2s2p3d$	$^4D^0_{7/2}$		35.3508	35.4307
50	$2s2p(^1P)3s$	$^2P^0_{3/2}$		35.3631	35.4455
51	$2s2p3d$	$^4P^0_{5/2}$		35.4267	35.5079
52	$2s2p3d$	$^4P^0_{3/2}$		35.4433	35.5225
53	$2s2p3d$	$^4P^0_{1/2}$		35.4578	35.5368
54	$2s2p(^3P)3d$	$^2F^0_{5/2}$	35.9039	35.8203	35.8924
55	$2s2p(^3P)3d$	$^2F^0_{7/2}$	36.0224	35.9482	36.0206
56	$2s2p(^3P)3d$	$^2P^0_{3/2}$		35.9376	36.0427
57	$2s2p(^3P)3d$	$^2P^0_{1/2}$		36.0096	36.1169
58	$2s2p(^1P)3p$	$^2P_{1/2}$		36.3480	36.4411
59	$2s2p(^1P)3p$	$^2D_{3/2}$		36.3688	36.4583
60	$2s2p(^1P)3p$	$^2D_{5/2}$		36.4040	36.4877
61	$2s2p(^1P)3p$	$^2P_{3/2}$		36.4089	36.4997
62	$2s2p(^1P)3p$	$^2S_{1/2}$		36.6613	36.7418
63	$2p^23s$	$^4P_{1/2}$		36.8416	36.9460
64	$2p^23s$	$^4P_{3/2}$		36.9173	37.0225
65	$2p^23s$	$^4P_{5/2}$		37.0231	37.1288
66	$2s2p(^1P)3d$	$^2F^0_{7/2}$	37.2253	37.2830	37.3338
67	$2s2p(^1P)3d$	$^2F^0_{5/2}$	37.2253	37.2885	37.3411
68	$2s2p(^1P)3d$	$^2D^0_{3/2}$	38.2887	37.3694	37.4536
69	$2s2p(^1P)3d$	$^2D^0_{5/2}$	38.2887	37.3910	37.4763
70	$2p^23s$	$^2P_{1/2}$		37.4098	37.5292
71	$2s2p(^1P)3d$	$^2P^0_{1/2}$		37.5545	37.6364
72	$2p^23s$	$^2P_{3/2}$		37.5195	37.6372
73	$2s2p(^1P)3d$	$^2P^0_{3/2}$		37.5739	37.6586
74	$2p^23p$	$^2S^0_{1/2}$		37.6136	37.6969
75	$2p^23p$	$^4D^0_{1/2}$		37.6922	37.7775
76	$2p^23p$	$^4D^0_{3/2}$		37.7328	37.8183
77	$2p^23p$	$^4D^0_{5/2}$		37.8109	37.8961
78	$2p^23s$	$^2D_{5/2}$		37.8135	37.9098
79	$2p^23s$	$^2D_{3/2}$		37.8267	37.9252
80	$2p^23p$	$^4P^0_{1/2}$		37.8977	37.9839
81	$2p^23p$	$^4P^0_{3/2}$		37.9029	37.9903
82	$2p^23p$	$^4D^0_{7/2}$		37.9116	37.9964
83	$2p^23p$	$^4P^0_{5/2}$		37.9620	38.0481
84	$2p^2(^3P)3p$	$^2D^0_{3/2}$		38.0282	38.1159
85	$2p^2(^3P)3p$	$^2D^0_{5/2}$		38.1751	38.2631
86	$2p^2(^3P)3p$	$^2P^0_{3/2}$		38.3271	38.4071
87	$2p^23p$	$^4S^0_{3/2}$		38.2874	38.4344
88	$2p^2(^3P)3p$	$^2P^0_{1/2}$		38.3524	38.4437
89	$2p^23d$	$^4F_{3/2}$		38.4993	38.5675
90	$2p^23d$	$^4F_{5/2}$		38.5402	38.6081
91	$2p^23d$	$^4F_{7/2}$		38.6011	38.6686
92	$2p^23p$	$^2F^0_{5/2}$		38.6743	38.7472
93	$2p^23d$	$^4F_{9/2}$		38.6806	38.7474
⋆ 94	$2p^23d$	$^4D_{3/2}$		38.7955	38.7878
⋆ 95	$2p^23p$	$^2F^0_{7/2}$		38.7137	38.7860
96	$2p^23d$	$^4D_{1/2}$		38.7271	38.8025
97	$2p^23d$	$^4D_{5/2}$		38.7576	38.8298
98	$2p^23d$	$^4D_{7/2}$		38.7985	38.8681
99	$2p^2(^3P)3d$	$^2P_{3/2}$		38.7050	38.8772
100	$2p^2(^3P)3d$	$^2F_{5/2}$		38.8567	38.9235
101	$2p^2(^3P)3d$	$^2P_{1/2}$		38.8930	38.9860
102	$2p^2(^1D)3p$	$^2D^0_{3/2}$		38.9504	39.0691
⋆ 103	$2p^2(^1D)3p$	$^2D^0_{5/2}$		38.9551	39.0760
⋆ 104	$2p^2(^3P)3d$	$^2F_{7/2}$		39.0059	39.0710
105	$2p^23d$	$^4P_{5/2}$		39.0043	39.1089
106	$2p^23d$	$^4P_{3/2}$		39.0473	39.1535
107	$2p^23d$	$^4P_{1/2}$		39.0673	39.1733
108	$2p^23s$	$^2S_{1/2}$		39.1630	39.2393
109	$2p^2(^1D)3p$	$^2P^0_{1/2}$		39.1721	39.2804
110	$2p^2(^1D)3p$	$^2P^0_{3/2}$		39.2687	39.3833
111	$2p^23d$	$^2G_{7/2}$		39.4796	39.5341
112	$2p^23d$	$^2G_{9/2}$		39.4993	39.5529
113	$2p^2(^3P)3d$	$^2D_{5/2}$		39.4742	39.5672
114	$2p^2(^3P)3d$	$^2D_{3/2}$		39.4799	39.5765
115	$2p^2(^1D)3d$	$^2D_{3/2}$		39.6841	39.7694
116	$2p^2(^1D)3d$	$^2D_{5/2}$		39.7265	39.8118
117	$2p^2(^1D)3d$	$^2F_{7/2}$		39.8074	39.8860
118	$2p^2(^1D)3d$	$^2F_{5/2}$		39.8670	39.9502
119	$2p^2(^1D)3d$	$^2P_{1/2}$		39.9243	40.0515
120	$2p^2(^1D)3d$	$^2P_{3/2}$		39.9802	40.1128
121	$2p^23d$	$^2S_{1/2}$		40.0992	40.1744
122	$2p^2(^1S)3p$	$^2P^0_{1/2}$		40.1966	40.2629
123	$2p^2(^1S)3p$	$^2P^0_{3/2}$		40.2210	40.2853
124	$2p^2(^1S)3d$	$^2D_{5/2}$		41.0628	41.0960
125	$2p^2(^1S)3d$	$^2D_{3/2}$		41.0880	41.1225

Expt.: Edlen (1983) for $n = 2$ levels and CHIANTI database (`http://wwwsolar.nrl.navy.mil/chianti.html`) for $n = 3$ levels.

DFS: Zhang et al. (1984) for $n = 2$ and CHIANTI database for $n = 3$ levels.

⋆: Level has changed order with the inclusion of Breit and QED effects.

Table 3. Target levels of Ar XV and their threshold energies (in Ryd). The lowest 46 levels are listed here and a complete table for all levels is available in the electronic version only.

Index	Configuration	Level	Expt.	GRASP	DFS
1	$2s^2$	$^1S_0$	0.0000	0.0000	0.0000
2	2s2p	$^3P_0{}^0$	2.0838	2.0889	2.0934
3	2s2p	$^3P_1{}^0$	2.1493	2.1542	2.1592
4	2s2p	$^3P_2{}^0$	2.3026	2.3066	2.3122
5	2s2p	$^1P_1{}^0$	4.1209	4.1970	4.2503
6	$2p^2$	$^3P_0$	5.5128	5.5470	5.5423
7	$2p^2$	$^3P_1$	5.6054	5.6381	5.6334
8	$2p^2$	$^3P_2$	5.7253	5.7588	5.7554
9	$2p^2$	$^1D_2$	6.2843	6.3563	6.3850
10	$2p^2$	$^1S_0$	7.6602	7.7921	7.8043
11	2s3s	$^3S_1$	35.8584	35.8607	35.5752
12	2s3s	$^1S_0$	36.2684	36.2603	36.0612
13	2s3p	$^1P_1{}^0$	36.8389	36.8287	36.7092
14	2s3p	$^3P_0{}^0$		36.8476	36.7092
15	2s3p	$^3P_1{}^0$		36.8856	36.7740
16	2s3p	$^3P_2{}^0$	36.9109	36.9087	36.8064
17	2s3d	$^3D_1$		37.4271	37.4868
18	2s3d	$^3D_2$		37.4349	37.4868
19	2s3d	$^3D_3$	37.4531	37.4478	37.5192
20	2s3d	$^1D_2$	37.8176	37.8436	37.9728
21	2p3s	$^3P_0{}^0$		38.4926	38.4912
22	2p3s	$^3P_1{}^0$		38.5474	38.5560
23	2p3s	$^3P_2{}^0$		38.7179	38.7828
24	2p3s	$^1P_1{}^0$		39.0693	39.1716
25	2p3p	$^1P_1$		39.1293	39.4632
26	2p3p	$^3D_1$		39.2911	39.2364
27	2p3p	$^3D_2$		39.3045	39.4632
28	2p3p	$^3D_3$	39.4269	39.4621	39.6900
29	2p3p	$^3S_1$	39.5444	39.5632	39.7872
30	2p3p	$^3P_0$		39.5855	39.7872
31	2p3p	$^3P_1$		39.6904	39.9168
32	2p3d	$^3F_2{}^0$		39.7167	39.9816
33	2p3p	$^3P_2$	39.7358	39.7397	39.9816
34	2p3d	$^3F_3{}^0$		39.8219	40.1112
35	2p3d	$^1D_2{}^0$	39.8634	39.8848	40.2084
36	2p3d	$^3F_4{}^0$	39.9108	39.9541	40.3056
37	2p3p	$^1D_2$	39.9955	40.0208	40.3380
38	2p3d	$^3D_1{}^0$		40.0968	40.4676
39	2p3d	$^3D_2{}^0$		40.1423	40.5324
40	2p3d	$^3D_3{}^0$	40.2097	40.2209	40.6620
41	2p3d	$^3P_2{}^0$	40.3053	40.3162	40.7592
42	2p3d	$^3P_1{}^0$		40.3410	40.7592
43	2p3d	$^3P_0{}^0$		40.3586	40.7916
44	2p3p	$^1S_0$		40.5143	40.9212
45	2p3d	$^1F_3{}^0$	40.6607	40.7047	41.3100
46	2p3d	$^1P_1{}^0$	40.7282	40.7611	41.3100

Expt.: NIST (`http://physics.nist/gov/PhysRefData`) for $n = 2$ and Khardi et al. (1994) for $n = 3$ and 4 levels.
DFS: Zhang & Sampson (1992) for $n = 2$ and Sampson et al. (1984) for $n = 3$ levels.
⋆: Level has changed order with the inclusion of Breit and QED effects.

In Table 3 we list our energy levels and those from the experimental and theoretical compilations. Our present theoretical and earlier experimental energies agree closely, in magnitude as well as orderings, for a majority of levels. The only exceptions for a slight difference of orderings are the levels 51/52, 91/92 and 96/97. All of these pairs differ in energy by less than 0.05 Ryd. Considering that Khardi et al. (1994) have referred to their energy levels as "tentative", the agreement between the theoretical and experimental energy levels is highly satisfactory. On the other hand, some of the energy levels from the DFS code are indistinguishable, and examples of these are the levels 29/30, 32/33, 41/42 and 45/46. In general, the DFS energies are slightly higher than our theoretical or earlier experimental results, except for the levels 11−16. Nevertheless, the discrepancy between the two sets of theoretical results is below 1.5%. Due to the inclusion of limited CI only within the $n = 3$ configurations in the DFS calculations, this small discrepancy with our results is not unexpected. Finally, on the basis of the comparisons shown in Table 3, we may state with confidence that our energy levels for Ar XV are accurate to better than 1%.

3. Radiative rates

The absorption oscillator strength (f_{ij}) and radiative rate A_{ji} (in s^{-1}) for a transition $i \rightarrow j$ are related by the following expression:

$$f_{ij} = \frac{mc}{8\pi^2 e^2} {\lambda_{ji}}^2 \frac{\omega_j}{\omega_i} A_{ji} = 1.49 \times 10^{-16} \lambda^2_{ji} (\omega_j/\omega_i) A_{ji} \quad (1)$$

where m and e are the electron mass and charge, respectively, c is the velocity of light, λ_{ji} is the transition energy/wavelength in Å, and ω_i and ω_j are the statistical weights of the lower i and upper j levels, respectively. Similarly, the oscillator strength f_{ij} (dimensionless) and the line strength S (in atomic unit, 1 au = 6.460×10^{-36} cm^2 esu^2) are related by the following standard equations.

For the electric dipole (E1) transitions:

$$A_{ji} = \frac{2.0261 \times 10^{18}}{\omega_j \lambda^3_{ji}} S^{E1} \quad \text{and} \quad f_{ij} = \frac{303.75}{\lambda_{ji} \omega_i} S^{E1}, \quad (2)$$

for the magnetic dipole (M1) transitions:

$$A_{ji} = \frac{2.6974 \times 10^{13}}{\omega_j \lambda^3_{ji}} S^{M1} \quad \text{and} \quad f_{ij} = \frac{4.044 \times 10^{-3}}{\lambda_{ji} \omega_i} S^{M1}, \quad (3)$$

for the electric quadrupole (E2) transitions:

$$A_{ji} = \frac{1.1199 \times 10^{18}}{\omega_j \lambda^5_{ji}} S^{E2} \quad \text{and} \quad f_{ij} = \frac{167.89}{\lambda^3_{ji} \omega_i} S^{E2}, \quad (4)$$

and for the magnetic quadrupole (M2) transitions:

$$A_{ji} = \frac{1.4910 \times 10^{13}}{\omega_j \lambda^5_{ji}} S^{M2} \quad \text{and} \quad f_{ij} = \frac{2.236 \times 10^{-3}}{\lambda^3_{ji} \omega_i} S^{M2}. \quad (5)$$

We present and discuss below our results of radiative rates for each of the argon ions.

3.1. Ar XIII

As stated earlier, our previous results of radiative rates (Aggarwal et al. 2001) were confined to a limited set of transitions within the 46 levels of the $2s^22p^2$, $2s2p^3$, $2p^4$ and $2s^22p3\ell$ configurations. Furthermore, these data are only for the E1 transitions, whereas corresponding results for E2, M1 and M2 transitions may also be required in a modelling calculation. Similarly, the results of Nahar (2000) are restricted to the E1 transitions alone. Although for many transitions the agreement between her results and those of Liang et al. (2004) is satisfactory (see Fig. 2 of Liang et al.), especially for strong transitions, the accuracy of her results is not very high, as already discussed in Sect. 2.1. Since the recent results of Liang et al. are comparatively more accurate, we focus attention on comparing our data with theirs alone. However, we would like to mention here that although they have computed radiative rates for all types of transitions, their results are incomplete. For example, data for the 1−15 and 1−43 E1, 1−19 and 1−33 E2, and 3−16 and 3−19 M1 transitions are missing, and no results are available for transitions with initial levels of 16 and higher.

In Table 4 we present transition energies (ΔE_{ij} in Å), radiative rates (A_{ji} in s^{-1}), oscillator strengths (f_{ij}, dimensionless), and line strengths (S in au), in length form only, for all 40 214 electric dipole (E1) and 51 753 electric quadrupole (E2) transitions among the 524 levels of Ar XIII. The indices used to represent the lower and upper levels of a transition have already been defined in Table 1. Similar results for 40 032 magnetic dipole (M1) and 51 911 magnetic quadrupole (M2) transitions are listed in Table 5. These results not only cover a wider range of transitions among larger number of levels, but are also for *all* possible transitions among the above four types.

In Table 10a we compare our A-values for a limited set of transitions (i.e. from ground level to higher excited levels up to 56) with those of Liang et al. (2004) and our earlier work (Aggarwal et al. 2001). For strong transitions, our results obtained from the 224 and 524 level calculations are comparable (within ∼10%), which confirms the convergence of wavefunctions. Similarly, the present results agree within ∼20% with those of Liang et al. and the agreement with our earlier calculations for 46 levels (Aggarwal et al.) is also satisfactory. However the effect of inclusion of larger CI is clearly visible for transitions, such as 1−15, 1−49 and 1−56, for which the differences are up to a factor of three, although these three transitions are weak and have very small f-values. For weaker transitions, differences in calculations with different amount of CI are often very large, because of additions or cancellations of matrix elements from different configurations. For the same reason, differences between our present calculations and those of Liang et al. for some transitions are several orders of magnitude, and examples of these are: 2−66, 3−62, 4−115, 6−121, 8−157, and 9−159. However, the most probable reason for such large differences for a few select transitions is the problem of identification/designation of a level. In a large calculation involving many levels, such as for Ar XIII, identifying each level on the basis of the strength of an eigenvector of a configuration is not always easy, and sometimes complicated and ambiguous. We have taken care to identify these levels, but scope remains for the interchange of some of the levels. However, such large discrepancies as noted above are not observed between our 224 and 524 level calculations, and differences remain within two orders of magnitude for some very weak transitions, due to the reasons explained above.

Table 10. Comparison of radiative rates (A_{ji} in s^{-1}) for electric dipole (E1) transitions. ($a \pm b \equiv a \times 10^{\pm b}$).

(a) Ar XIII

i	j	CIV46	FAC224	GRASP224	GRASP524
1	8	2.949+09	3.075+09	3.123+09	3.160+09
1	11	2.927+09	2.986+09	3.009+09	2.983+09
1	14	5.891+09	6.343+09	6.564+09	6.615+09
1	15	2.010+06	0.000+00	4.312+06	6.013+06
1	22	1.307+11	1.412+11	1.430+11	1.435+11
1	24	3.565+09	5.244+09	6.174+09	6.261+09
1	43	3.132+12	3.112+12	3.178+12	3.182+12
1	49	5.000+10	6.181+10	7.062+10	7.654+10
1	56	9.283+09	3.196+10	2.616+10	2.736+10

CIV46 : 46 level calculations of Aggarwal et al. (2001) from the CIV3 code.
FAC224: Calculations of Liang et al. (2004) from the FAC code.
GRASP224: Present 224 level calculations from the GRASP code.
GRASP524: Present 524 level calculations from the GRASP code.

As stated in Sect. 1, wavelengths for some transitions of Ar XIII have been measured by Lepson et al. (2003) using an EBIT. In Table 11a we compare our theoretical results with their measurements. Also included in this table are the theoretical wavelengths from the HULLAC code (Hebrew University and Lawrence Livermore Atomic Code, Bar-Shalom et al. 2001), which have been reported by Lepson et al. Although experimental wavelengths are not available for all the transitions listed in Table 11a, and many of these lines are blended (see the last column of Table 5 of Lepson et al.), the agreement among the three sets of data is excellent for all transitions, and hence provides further support for the accuracy of our calculations.

Finally, we briefly comment on the lifetime τ which is defined as follows:

$$\tau_j = \frac{1}{\sum_i A_{ji}} \quad (6)$$

for a level j. Since this is a measurable parameter, it provides a check on the accuracy of calculations. However, to the best our knowledge τ has not been measured for any of the levels of Ar XIII, and hence no comparisons can be made. Nevertheless, we will compare such measurements for levels of other two ions for which data are available.

3.2. Ar XIV

In Table 6 we present transition energies (ΔE_{ij} in Å), radiative rates (A_{ji} in s^{-1}), oscillator strengths (f_{ij}, dimensionless), and line strengths (S in au), in length form only, for all 32 608 electric dipole (E1) and 42 427 electric quadrupole (E2) transitions among the 460 levels of Ar XIV. The indices used to represent the lower and upper levels of a transition have already

Table 10. continued.

(b) Ar XIV

i	*j*	GRASP460	DFS125	*i*	*j*	GRASP460	DFS125
1	3	2.613+06	2.910e+06	1	62	7.806+10	4.503e+10
1	4	6.145+04	6.640e+04	1	63	6.917+09	6.994e+09
1	6	3.526+09	3.350e+09	1	64	7.648+07	1.079e+08
1	8	1.374+10	1.350e+10	1	70	9.727+10	1.387e+11
1	9	8.411+09	7.490e+09	1	72	3.519+10	5.060e+10
1	10	4.152+09	3.980e+09	1	79	7.732+09	1.324e+10
1	16	1.676+11	1.558e+11	1	89	1.160+09	1.661e+09
1	19	2.861+12	2.674e+12	1	94	4.159+09	3.490e+09
1	26	3.098+11	2.570e+11	1	96	2.013+09	3.340e+09
1	27	8.260+10	6.968e+10	1	99	3.139+09	6.499e+09
1	28	7.683+11	6.755e+11	1	101	1.779+10	2.338e+10
1	29	2.810+11	5.527e+10	1	106	1.855+06	9.163e+05
1	32	4.784+10		1	107	1.670+08	1.182e+08
1	33	9.558+09	1.100e+10	1	108	6.266+09	8.885e+09
1	34	1.599+10	1.442e+10	1	114	5.851+10	9.470e+10
1	36	1.175+12	1.120e+12	1	115	2.362+10	3.236e+10
1	41	4.537+11	4.699e+11	1	119	3.151+10	4.226e+10
1	58	2.445+11	2.852e+11	1	120	4.544+09	5.629e+09
1	59	3.338+09	2.254e+08	1	121	6.964+09	1.281e+10
1	61	1.397+11	1.496e+11	1	125	6.061+09	7.954e+09

GRASP460: Present 460 level calculations from the GRASP code.
DFS125: CHIANTI data for 125 level calculations from the DFS code.

(c) Ar XV

i	*j*	GRASP156	DFS46	*i*	*j*	GRASP156	DFS46
1	3	2.660+06	2.689+06	4	7	2.827+09	2.886+09
1	5	9.888+09	9.623+09	4	8	5.507+09	5.638+09
1	13	1.544+12	1.112+12	4	9	2.932+08	2.612+08
1	15	7.245+11	1.039+12	4	11	4.489+11	3.940+11
1	24	1.090+11	1.767+11	4	17	1.212+11	1.240+11
1	38	5.312+09	8.375+09	4	18	1.087+12	1.105+12
1	42	6.358+08	7.354+08	4	19	4.334+12	4.389+12
1	46	1.184+11	1.486+11	4	20	3.203+08	4.961+08
2	7	2.755+09	2.821+09	4	25	2.577+07	1.614+10
2	11	8.916+10	8.169+10	4	26	2.102+10	1.857+08
2	17	2.459+12	2.557+12	4	27	8.600+10	7.529+10
2	25	1.189+11	3.927+11	4	28	7.053+11	7.188+11
2	26	3.915+11	1.321+11	4	29	1.128+11	4.540+10
2	29	2.337+11	2.392+11	4	31	9.753+11	1.012+12
2	31	1.202+11	1.111+11	4	33	9.369+11	1.008+12
3	6	7.202+09	7.358+09	4	37	3.025+10	3.843+10
3	7	1.945+09	1.987+09	5	6	2.924+06	3.673+06
3	8	2.173+09	2.230+09	5	7	3.418+05	3.872+05
3	9	1.944+07	1.502+07	5	8	1.543+07	1.663+07
3	10	1.698+07	1.651+07	5	9	1.758+09	1.541+09
3	11	2.681+11	2.417+11	5	10	1.548+10	1.702+10
3	12	2.406+08	6.788+08	5	11	6.118+08	6.216+08
3	17	1.832+12	1.894+12	5	12	2.762+11	2.482+11
3	18	3.291+12	3.379+12	5	17	3.596+09	5.240+09
3	20	2.351+09	3.539+09	5	18	2.531+09	3.783+09
3	25	2.349+11	3.325+09	5	20	2.991+12	2.745+12
3	26	1.455+10	2.403+11	5	25	6.349+11	4.452+11
3	27	5.991+11	6.092+11	5	26	5.232+11	4.237+11
3	29	6.155+11	6.128+11	5	27	1.153+10	1.565+10
3	30	1.163+12	1.242+12	5	29	1.293+11	1.404+11
3	31	5.788+10	4.566+10	5	30	1.103+10	1.525+10
3	33	1.798+11	1.961+11	5	31	6.987+08	1.924+07
3	37	1.431+10	1.207+10	5	33	7.354+10	8.500+10
3	44	1.040+10	1.108+10	5	37	1.637+12	1.789+12

GRASP156: Present 156 level calculations from the GRASP code.
DFS46: CHIANTI data for 46 level calculations from the DFS code.

been defined in Table 2. Similar results for 32 368 magnetic dipole (M1) and 42 591 magnetic quadrupole (M2) transitions are listed in Table 7.

The only data available to compare with our results are those in the CHIANTI database, as described in Sect. 2.2. These are for the (limited) E1 transitions alone (among 125 levels) and have been obtained from the DFS code. In Table 10b we compare those results with our A-values for transitions from the ground state to higher excited levels up to 125. For strong transitions, as expected, the agreement between the two sets of results is within ~20%. However, for weak transitions ($f \leq \sim 0.001$) the differences can be up to an order of magnitude, as can be seen for the 1−29 and 1−59 transitions. This is a direct consequence of the inclusion of larger CI in our calculations, which mainly affects the weaker transitions, as explained in Sect. 3.1.

In Table 11b we compare our theoretical wavelengths with the corresponding experimental and theoretical results of Lepson et al. (2003) for the common transitions of Ar XIV. For this ion, many of these lines are blended, but there is no discrepancy among the three sets of data. This confirms the accuracy of our calculations. Finally, the only measured lifetime available for this ion is for the level $2s^22p\ ^2P^0_{3/2}$. The earlier measurements of Serpa et al. (1998) and Moehs & Church (1998) give values of 8.7 ± 0.5 ms and 9.12 ± 0.15 ms, respectively. However, the later measurement by Träbert et al. (2000) gives a value of 9.70 ± 0.15 ms, which also agrees very well with our result of 9.714 ms. Additional measurements of τ for other levels of Ar XIV will be helpful in further assessing the accuracy of our calculations.

3.3. Ar XV

In Table 8 we present transition energies (ΔE_{ij} in Å), radiative rates (A_{ji} in s^{-1}), oscillator strengths (f_{ij}, dimensionless), and line strengths (S in au), in length form only, for all 3616 electric dipole (E1) and 4439 electric quadrupole (E2) transitions among the 156 levels of Ar XV. The indices used to represent the lower and upper levels of a transition have already been defined in Table 3. Similar results for 3568 magnetic dipole (M1) and 4477 magnetic quadrupole (M2) transitions are listed in Table 9.

The only data available to compare with our results are those in the CHIANTI database, as described in Sect. 2.3. These are for the (limited) E1 transitions alone among 46 levels of the $2s^2$, 2s2p, $2p^2$, $2s3\ell$ and $2p3\ell$ configurations, and have been obtained from the DFS code. In Table 10c we compare those results with our A-values for transitions from the lowest 5 levels to higher excited levels up to 46. For strong transitions, as expected, the agreement between the two sets of results is within ~20%. However, for weak transitions ($f \leq \sim 0.001$) differences up to 50% are quite common – see, for example, 1−24, 3−20, 4−20 and 5−30. Moreover, for a few very weak transitions, such as 5−31 ($f = 6.9 \times 10^{-5}$), differences in the two sets of calculations are up to an order of magnitude. This is because of the inclusion of larger CI in our calculations, which mainly affects the weaker transitions, as explained in Sect. 3.1.

Table 11. Comparison between experimental and theoretical wavelengths (Å) for some transitions.

(a) Ar XIII

i	*j*	Transition	EBIT	HULLAC	GRASP
1	43	$(2s^22p^2_{1/2})_0$ – $(2s^22p_{1/2}3d_{3/2})_1$	29.209	29.357	29.11
1	178	$(2s^22p^2_{1/2})_0$ – $(2s^22p_{1/2}4d_{3/2})_1$		23.036	22.88
2	43	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s^22p_{1/2}3d_{3/2})_1$	29.348	29.436	29.19
2	45	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s^22p_{3/2}3d_{3/2})_2$	29.348	29.399	29.15
2	49	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s^22p_{3/2}3d_{3/2})_1$		29.259	29.00
2	50	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s^22p_{3/2}3d_{3/2})_0$		29.250	28.99
2	53	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s2p^2_{1/2}3p_{3/2})_2$	28.658	28.421	28.79
2	186	$(2s^22p_{1/2}2p_{3/2})_1$ – $(2s^22p_{3/2}4d_{3/2})_1$	22.996	22.975	22.82
3	23	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}3s_{1/2})_2$		31.967	31.68
3	46	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}3d_{5/2})_3$	29.348	29.433	29.08
3	48	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}3d_{5/2})_2$	29.348	29.382	29.12
3	49	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}3d_{3/2})_1$	29.209	29.367	29.10
3	65	$(2s^22p^2_{3/2})_2$ – $(2s2p^2_{3/2}3p_{3/2})_3$	28.658	28.442	28.38
3	70	$(2s^22p^2_{3/2})_2$ – $(2s2p_{1/2}2p_{3/2}3s_{3/2})_2$		28.308	28.21
3	180	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}4d_{3/2})_2$		23.045	22.93
3	190	$(2s^22p^2_{3/2})_2$ – $(2s^22p_{3/2}4d_{5/2})_3$		23.059	22.82
4	40	$(2s^22p_{1/2}2p_{3/2})_2$ – $(2s^22p_{1/2}3d_{5/2})_2$		30.304	30.03
4	57	$(2s^22p_{1/2}2p_{3/2})_2$ – $(2s^22p_{3/2}3d_{3/2})_3$	29.549	29.608	29.36
7	44	$(2s2p_{1/2}2p^2_{3/2})_2$ – $(2s2p_{1/2}2p_{3/2}3s_{1/2})_1$		33.285	33.24
9	32	$(2s2p_{1/2}2p^2_{3/2})_3$ – $(2s^22p_{3/2}3p_{1/2})_2$		34.931	34.68
9	47	$(2s2p_{1/2}2p^2_{3/2})_3$ – $(2s2p^2_{3/2}3s_{1/2})_2$		33.175	33.13
9	92	$(2s2p_{1/2}2p^2_{3/2})_3$ – $(2s2p^2_{3/2}3d_{5/2})_4$		30.785	30.81
9	150	$(2s2p_{1/2}2p^2_{3/2})_3$ – $(2s2p^2_{3/2}3d_{5/2})_4$	28.658	28.432	28.38
13	147	$(2s2p_{1/2}2p^2_{3/2})_2$ – $(2s2p^2_{1/2}3d_{5/2})_3$		30.859	30.54

(b) Ar XIV

i	*j*	Transition	EBIT	HULLAC	GRASP
1	19	$(2s^22p_{1/2})_{1/2}$ – $(2s^23d_{3/2})_{3/2}$	27.469	27.517	27.50
1	37	$(2s^22p_{1/2})_{1/2}$ – $(2s2p_{1/2}3p_{3/2})_{3/2}$	26.273	26.265	26.12
1	129	$(2s^22p_{1/2})_{1/2}$ – $(2s^24d_{3/2})_{3/2}$	21.167	21.218	21.21
2	16	$(2s^22p_{3/2})_{3/2}$ – $(2s^23s_{1/2})_{1/2}$		29.544	29.52
2	19	$(2s^22p_{3/2})_{3/2}$ – $(2s^23d_{3/2})_{3/2}$	27.631	27.688	27.67
2	20	$(2s^22p_{3/2})_{3/2}$ – $(2s^23d_{5/2})_{5/2}$	27.631	27.674	27.66
2	32	$(2s^22p_{3/2})_{3/2}$ – $(2s2p_{1/2}3p_{3/2})_{5/2}$	26.273	26.321	26.58
2	130	$(2s^22p_{3/2})_{3/2}$ – $(2s^24d_{5/2})_{5/2}$	21.280	21.316	21.31
6	17	$(2s2p_{1/2}2p_{3/2})_{3/2}$ – $(2s^23p_{1/2})_{1/2}$	32.014	32.215	32.16
7	18	$(2s2p_{1/2}2p_{3/2})_{5/2}$ – $(2s^23p_{3/2})_{3/2}$	32.014	32.161	32.11
7	25	$(2s2p_{1/2}2p_{3/2})_{5/2}$ – $(2s2p_{3/2}3s_{1/2})_{3/2}$	30.215	30.342	30.25
7	55	$(2s2p_{1/2}2p_{3/2})_{5/2}$ – $(2s2p_{3/2}3d_{3/2})_{7/2}$	28.223	28.332	28.27
8	46	$(2s2p^2_{3/2})_{1/2}$ – $(2s2p_{3/2}3d_{5/2})_{3/2}$		29.214	29.74
10	24	$(2s2p_{1/2}2p_{3/2})_{3/2}$ – $(2s2p_{1/2}3s_{1/2})_{1/2}$	30.344	30.476	31.83
10	54	$(2s2p_{1/2}2p_{3/2})_{3/2}$ – $(2s2p_{1/2}3d_{5/2})_{5/2}$		28.438	29.49
10	56	$(2s2p_{1/2}2p_{3/2})_{3/2}$ – $(2s2p_{1/2}3d_{3/2})_{3/2}$	28.780	28.898	29.63

(c) Ar XV

i	*j*	Transition	EBIT	HULLAC	GRASP
1	13	$(2s^2)_0$ – $(2s3p_{1/2})_1$	24.740	24.739	24.74
1	15	$(2s^2)_0$ – $(2s3p_{3/2})_1$	24.740	24.702	24.71
4	19	$(2s2p_{3/2})_2$ – $(2s3d_{5/2})_3$	25.927	25.921	25.93
5	12	$(2s2p_{3/2})_1$ – $(2s3s_{1/2})_0$	28.340	28.475	28.42
5	20	$(2s2p_{3/2})_1$ – $(2s3d_{5/2})_2$	27.044	27.140	27.08
5	56	$(2s2p_{3/2})_1$ – $(2s4d_{5/2})_2$	20.403	20.467	20.44

EBIT : Measurements of Lepson et al. (2003) from EBIT.
HULLAC: Calculations of Lepson et al. (2003) from the HULLAC code.
GRASP: Present calculations from the GRASP code.

Finally, for transitions involving the levels 25 and 26 (2p3p $^1P_1$ and $^3D_1$), the differences in the two sets of theoretical data appear to be up to three orders of magnitude. This is because these two levels are highly mixed. To be precise, level $^1P_1$ is a mixture of 50% of $^1P_1$ and 47% of $^3D_1$, whereas $^3D_1$ is a mixture of 49% of $^3D_1$ and 41% of $^1P_1$. Therefore, these two levels are clearly identifiable in our calculations based on the strength of their eigenvectors, but their comparable compositions suggest that their orderings are susceptible to change with different combinations of CI. Hence, it is possible that the identification of these two levels has been interchanged in the DFS calculations, as swapping around the results for these two levels removes the large discrepancies observed in Table 10c. However, we would like to emphasize here that our test calculations for the same 46 levels, as adopted in the DFS calculations, provide the *same* orderings with similar compositions, as noted above. Additionally, the *A*-values obtained from these test calculations are comparable to those in Table 10c for the 2–25, 2–26, 3–25, 3–26, 4–26, 5–25 and 5–26 transitions, but is ~30% less for the 4–25 transition. This excellent agreement between the two sets of calculations gives us confidence in our results, and suggests that the levels 25 and 26 have been interchanged in the calculations from the DFS code.

In Table 11c we compare our theoretical and the corresponding experimental and theoretical wavelengths of Lepson et al. (2003) for the common transitions of Ar XV. The first two of these lines are blended, but the agreement is excellent among the three sets of data, and confirms the accuracy of our calculations. Furthermore, lifetime measurements for the 2s2p $^3P^0_2$ level of Ar XV are available in the literature. The earlier measurements of Back et al. (1998) and Moehs & Church (1998) give values of 15.0 ± 0.7 ms and 13.4 ± 0.7 ms, respectively. However, the later measurement by Träbert et al. (2000) gives a value of 15.0 ± 0.8 ms, in agreement with our result of 15.72 ms as well as with that of Back et al. As in case of other ions, additional measurements of τ for other levels of Ar XV will be helpful in further assessing the accuracy of our calculations.

4. Conclusions

In this work, energy levels, radiative rates, oscillator strengths, and line strengths for a large number of transitions in Ar XIII, Ar XIV and Ar XV have been reported. The calculations have been performed using the fully relativistic GRASP code of Dyall et al. (1989), and CI among a large number of levels has been included. Additionally, results are reported for electric and magnetic dipole and quadrupole transitions, which are not so far available in the literature, except for a few E1 transitions. In general, our energy levels agree in magnitude and orderings with the experimental compilations of NIST as well as with other theoretical results. However, differences of up to 2 Ryd are noted for some levels of Ar XIII when compared with the semi-relativistic calculations of Nahar (2000). Nevertheless, our energy levels are assessed to be accurate to better than 1% for a majority of levels in all the three ions. However, the accuracy of other parameters (A, f and S) for a majority of strong transitions is ~20%. Furthermore, theory and experiment are in excellent agreement for lifetimes, but unfortunately these comparisons are restricted to only a level each in Ar XIV and Ar XV, and none in Ar XIII. Therefore, future measurement of lifetimes for additional levels in Ar ions will be helpful in further assessing the accuracy of our results. Nevertheless, the EBIT measurements of wavelengths for 24 transitions of Ar XIII, 16 of Ar XIV and 6 of Ar XV are in excellent agreement with our calculations, and hence provide experimental support to our results.

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Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
1	$2s^22p^2$	$^3P_0$	0.0000	0.0000	0.0000	0.0000
2	$2s^22p^2$	$^3P_1$	0.0887	0.0890	0.0875	0.0899
3	$2s^22p^2$	$^3P_2$	0.1980	0.1983	0.1961	0.2068
4	$2s^22p^2$	$^1D_2$	0.8029	0.8024	0.7977	0.7946
5	$2s^22p^2$	$^1S_0$	1.5087	1.4917	1.4816	1.5105
6	$2s2p^3$	$^5S^o_2$	2.0243	2.0116	2.0032	2.0704
7	$2s2p^3$	$^3D^o_2$	3.9242	3.9161	3.8885	3.8834
8	$2s2p^3$	$^3D^o_1$	3.9297	3.9216	3.8939	3.8887
9	$2s2p^3$	$^3D^o_3$	3.9354	3.9270	3.8996	3.9083
10	$2s2p^3$	$^3P^o_0$	4.5854	4.5805	4.5483	4.5637
11	$2s2p^3$	$^3P^o_1$	4.5889	4.5838	4.5514	4.5723
12	$2s2p^3$	$^3P^o_2$	4.5995	4.5944	4.5616	4.5895
13	$2s2p^3$	$^1D^o_2$	5.9150	5.9067	5.8515	5.7893
14	$2s2p^3$	$^3S^o_1$	5.9570	5.9445	5.8807	5.8187
15	$2s2p^3$	$^1P^o_1$	6.5749	6.5696	6.5090	6.4669
16	$2p^4$	$^3P_2$	8.9522	8.9460	8.8169	8.7985
17	$2p^4$	$^3P_1$	9.0927	9.0864	8.9582	8.9389
18	$2p^4$	$^3P_0$	9.1369	9.1307	9.0002	8.9828
19	$2p^4$	$^1D_2$	9.6518	9.6544	9.5143	9.4537
20	$2p^4$	$^1S_0$	10.9660	10.9634	10.8036	10.7246
21	$2s^22p3s$	$^3P^o_0$	28.7548	28.7381	28.7437	28.3584
22	$2s^22p3s$	$^3P^o_1$	28.7913	28.7746	28.7813	28.4153
23	$2s^22p3s$	$^3P^o_2$	28.9627	28.9461	28.9498	28.5705
24	$2s^22p3s$	$^1P^o_1$	29.1234	29.1057	29.1226	28.6911
25	$2s^22p3p$	$^1P_1$	29.7500	29.7323	29.7409	29.5711
26	$2s^22p3p$	$^3D_1$	29.8900	29.8719	29.8811	29.9819
27	$2s^22p3p$	$^3D_2$	29.9078	29.8888	29.8981	29.7284
28	$2s^22p3p$	$^3D_3$	30.0509	30.0318	30.0387	29.8672
29	$2s^22p3p$	$^3P_0$	30.0691	30.0515	30.0827	29.8814
30	$2s^22p3p$	$^3P_1$	30.1017	30.0836	30.1013	29.7131
31	$2s^22p3p$	$^3S_1$	30.1944	30.1758	30.1946	29.9091
32	$2s^22p3p$	$^3P_2$	30.2139	30.1963	30.2252	30.0274
33	$2s^22p3p$	$^1D_2$	30.5850	30.5661	30.6013	30.3512
34	$2s2p^23s$	$^5P_1$	30.6301	30.6107	30.6440	30.4338
35	$2s2p^23s$	$^5P_2$	30.7039	30.6846	30.7144	30.5121
36	$2s2p^23s$	$^5P_3$	30.7979	30.7785	30.8087	30.6147
37	$2s^22p3p$	$^1S_0$	30.9431	30.9241	30.9674	30.7140
38	$2s^22p3d$	$^3F^o_2$	31.0087	30.9989	31.0078	30.8405
39	$2s^22p3d$	$^3F^o_3$	31.1024	31.0929	31.1069	30.9525
40	$2s^22p3d$	$^1D^o_2$	31.1455	31.1349	31.1482	30.9875
41	$2s^22p3d$	$^3F^o_4$	31.2237	31.2142	31.2231	31.0580
42	$2s2p^2(^4P)3s$	$^3P_0$	31.2763	31.2663	31.3165	31.0196
43	$2s^22p3d$	$^3D^o_1$	31.3040	31.2934	31.3046	31.1575
44	$2s2p^2(^4P)3s$	$^3P_1$	31.3353	31.3254	31.3722	31.0811
45	$2s^22p3d$	$^3D^o_2$	31.3481	31.3373	31.3518	31.2082
46	$2s^22p3d$	$^3D^o_3$	31.4236	31.4137	31.4264	31.2391
47	$2s2p^2(^4P)3s$	$^3P_2$	31.4388	31.4286	31.4753	31.1922
48	$2s^22p3d$	$^3P^o_2$	31.4896	31.4774	31.4890	31.2667
49	$2s^22p3d$	$^3P^o_1$	31.5096	31.4968	31.5096	31.3042
50	$2s^22p3d$	$^3P^o_0$	31.5234	31.5101	31.5231	31.3365
51	$2s2p^23p$	$^5D^o_0$	31.6819	31.6636	31.7020	31.7422
52	$2s2p^23p$	$^5D^o_1$	31.6986	31.6803	31.7186	31.7346
53	$2s2p^23p$	$^5D^o_2$	31.7432	31.7248	31.7611	31.8098
54	$2s2p^2(^4P)3p$	$^3S^o_1$	31.7781	31.7600	31.7983	31.7701
55	$2s2p^23p$	$^5D^o_3$	31.8091	31.7908	31.8249	31.8786
56	$2s^22p3d$	$^1P^o_1$	31.8275	31.8120	31.8247	31.6435
57	$2s^22p3d$	$^1F^o_3$	31.8359	31.8261	31.8444	31.6290
⋆ 58	$2s2p^23p$	$^5P^o_2$	31.8860	31.8664	31.9026	31.9653
⋆ 59	$2s2p^23p$	$^5P^o_1$	31.8859	31.8670	32.1984	31.9408

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
60	$2s2p^23p$	$^5D^o_4$	31.8954	31.8772	31.9115	31.9692
61	$2s2p^23p$	$^5P^o_3$	31.9500	31.9304	32.3373	32.4047
62	$2s2p^2(^4P)3p$	$^3D^o_1$	32.1635	32.1491	32.4244	32.1702
63	$2s2p^2(^4P)3p$	$^3D^o_2$	32.2178	32.2035	31.9034	32.2342
⋆ 64	$2s2p^23p$	$^5S^o_2$	32.3092	32.2924	32.2509	32.3483
⋆ 65	$2s2p^2(^4P)3p$	$^3D^o_3$	32.3042	32.2898	32.4829	32.3278
66	$2s2p^23p$	$^3P^o_0$	32.3854	32.3751	31.9651	32.0299
67	$2s2p^23p$	$^3P^o_1$	32.4165	32.4060	32.4556	32.4346
68	$2s2p^2(^4P)3p$	$^3P^o_2$	32.4458	32.4347	32.3610	32.4715
69	$2s2p^23s$	$^3D_1$	32.4927	32.4722	32.4805	32.2589
70	$2s2p^23s$	$^3D_2$	32.4967	32.4762	32.4846	32.2633
71	$2s2p^23s$	$^3D_3$	32.5014	32.4809	32.4893	32.2688
72	$2s2p^23d$	$^5F_1$	32.7661	32.7504	32.7957	32.7358
73	$2s2p^23d$	$^5F_2$	32.7852	32.7695	32.8161	32.7627
74	$2s2p^23d$	$^5F_3$	32.8171	32.8014	32.8489	32.8022
75	$2s2p^23d$	$^5F_4$	32.8662	32.8505	32.8968	32.8533
76	$2s2p^23s$	$^1D_2$	32.8806	32.8649	32.8823	32.6031
77	$2s2p^23d$	$^5F_5$	32.9335	32.9180	32.9626	32.9151
78	$2s2p^23d$	$^5D_0$	32.9757	32.9574	32.9982	32.9479
79	$2s2p^23d$	$^5D_1$	32.9788	32.9606	33.0022	32.9550
80	$2s2p^23d$	$^5D_2$	32.9862	32.9680	33.0113	32.9690
81	$2s2p^23d$	$^5D_3$	33.0023	32.9842	33.0300	32.9905
82	$2s2p^23d$	$^5D_4$	33.0455	33.0276	33.0704	33.0180
83	$2s2p^23d$	$^5P_3$	33.2043	33.1841	33.2270	33.1345
84	$2s2p^2(^4P)3d$	$^3P_2$	33.2245	33.2071	33.2476	33.1421
85	$2s2p^23d$	$^5P_2$	33.2463	33.2264	33.2684	33.2120
86	$2s2p^23d$	$^5P_1$	33.2644	33.2441	33.2874	33.1973
87	$2s2p^2(^4P)3d$	$^3P_1$	33.3031	33.2860	33.3244	33.2565
88	$2s2p^2(^4P)3d$	$^3P_0$	33.3433	33.3262	33.3638	33.2754
89	$2s2p^2(^4P)3d$	$^3F_2$	33.3745	33.3631	33.4029	33.3123
90	$2s2p^23s$	$^3S_1$	33.4343	33.4132	33.4062	33.4983
91	$2s2p^2(^4P)3d$	$^3F_3$	33.4344	33.4231	33.4599	33.3824
92	$2s2p^2(^4P)3d$	$^3F_4$	33.5170	33.5057	33.5426	33.4645
93	$2s2p^23p$	$^3F^o_2$	33.5648	33.5454	33.5564	33.5488
94	$2s2p^23p$	$^3F^o_3$	33.5880	33.5686	33.5796	33.5940
95	$2s2p^23p$	$^3F^o_4$	33.6164	33.5970	33.6075	33.6210
96	$2s2p^2(^2P)3s$	$^3P_0$	33.7242	33.7052	33.7046	33.3804
97	$2s2p^23p$	$^1F^o_3$	33.7320	33.7125	33.7320	33.7302
98	$2s2p^2(^2P)3p$	$^3D^o_1$	33.7419	33.7306	33.7562	33.7459
99	$2s2p^2(^2P)3p$	$^3D^o_2$	33.7551	33.7439	33.7618	33.6108
100	$2s2p^2(^2P)3p$	$^1D^o_2$	33.7638	33.7469	33.7703	33.7637
101	$2s2p^2(^4P)3d$	$^3D_1$	33.7673	33.7649	33.7956	33.2725
102	$2s2p^2(^2P)3p$	$^3D^o_3$	33.7732	33.7617	33.9618	33.7826
103	$2s2p^2(^4P)3d$	$^3D_2$	33.7866	33.7842	33.8155	33.7195
104	$2s2p^2(^4P)3d$	$^3D_3$	33.8108	33.8088	33.8398	33.7477
105	$2s2p^2(^2P)3s$	$^3P_1$	33.8660	33.8458	33.8424	33.6919
106	$2s2p^2(^2P)3p$	$^1P^o_1$	33.9316	33.9168	33.7894	33.8113
107	$2s2p^23p$	$^3P^o_0$	33.9427	33.9342	33.9550	33.9449
108	$2s2p^23p$	$^3P^o_1$	33.9455	33.9352	33.9354	33.9486
109	$2s2p^2(^2P)3p$	$^3P^o_2$	33.9477	33.9393	33.9560	33.9519
⋆ 110	$2s2p^23s$	$^1S_0$	33.9562	33.9379	33.9336	33.6681
⋆ 111	$2s2p^2(^2P)3s$	$^3P_2$	33.9560	33.9356	33.9316	33.5913
112	$2s2p^23s$	$^1P_1$	34.0514	34.0316	34.0333	33.6962
113	$2s2p^23p$	$^3P^o_0$	34.5329	34.5147	34.5126	34.4948
114	$2s2p^23p$	$^3P^o_1$	34.6119	34.5944	34.5978	34.6180
115	$2s2p^2(^2D)3p$	$^3P^o_2$	34.6641	34.6471	34.6502	34.6850
116	$2s2p^23d$	$^3G_3$	34.6728	34.6530	34.6657	34.7041
117	$2s2p^23d$	$^3G_4$	34.6795	34.6597	34.6730	34.7081

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
118	$2s2p^23d$	$^3G_5$	34.6875	34.6678	34.6804	34.7264
⋆ 119	$2s2p^2(^2D)3p$	$^1P^o_1$	34.7142	34.6957	34.7015	34.6566
⋆ 120	$2s2p^23p$	$^1S^o_0$	34.7049	34.6883	34.6792	34.6947
121	$2s2p^2(^2P)3d$	$^3F_2$	34.7621	34.7537	34.7678	34.7524
122	$2s2p^2(^2P)3d$	$^3F_3$	34.7691	34.7606	34.7755	34.7557
123	$2s2p^2(^2P)3d$	$^3F_4$	34.7706	34.7619	34.7766	34.7656
124	$2s2p^2(^2P)3d$	$^3D_1$	34.8354	34.8151	34.8276	34.8524
125	$2s2p^2(^2P)3d$	$^3D_2$	34.8402	34.8201	34.8327	34.8593
126	$2s2p^2(^2P)3d$	$^3D_3$	34.8463	34.8265	34.8387	34.8712
127	$2s2p^2(^2P)3d$	$^1F_3$	34.9048	34.8883	34.9000	34.8957
128	$2s2p^2(^2D)3p$	$^3D^o_1$	34.9168	34.8990	34.8974	34.8264
129	$2s2p^2(^2D)3p$	$^3D^o_2$	34.9315	34.9138	34.9101	34.8060
130	$2s2p^2(^2D)3p$	$^3D^o_3$	34.9987	34.9808	34.9757	34.8477
131	$2s2p^23d$	$^1G_4$	35.0017	34.9813	34.9907	35.0237
132	$2s2p^2(^2P)3d$	$^3P_0$	35.0564	35.0414	35.0503	35.0608
133	$2s2p^2(^2P)3d$	$^3P_1$	35.0602	35.0454	35.0542	35.0599
134	$2s2p^2(^2P)3d$	$^3P_2$	35.0650	35.0505	35.0592	35.0772
135	$2s2p^23p$	$^3P^o_0$	35.0775	35.0630	35.0626	34.9600
136	$2s2p^23p$	$^3P^o_1$	35.0875	35.0728	35.0727	34.9408
137	$2s2p^2(^2S)3p$	$^3P^o_2$	35.1164	35.1013	35.1006	34.9412
138	$2s2p^23d$	$^3S_1$	35.1498	35.1309	35.1368	35.1709
139	$2s2p^2(^2P)3d$	$^1D_2$	35.1992	35.1855	35.1914	35.1798
140	$2s2p^2(^2P)3p$	$^3S^o_1$	35.2741	35.2612	35.2769	34.9512
141	$2s2p^2(^2P)3d$	$^1P_1$	35.2833	35.2728	35.2779	35.2475
142	$2s2p^2(^2D)3p$	$^1D^o_2$	35.3864	35.3797	35.3946	35.2850
143	$2s2p^23d$	$^1S_0$	35.4884	35.4836	35.4827	35.4639
144	$2s2p^2(^2S)3p$	$^1P^o_1$	35.6500	35.6544	35.6713	35.5198
145	$2s2p^2(^2D)3d$	$^3D_1$	35.7314	35.7146	35.7094	35.7647
146	$2s2p^2(^2D)3d$	$^3D_2$	35.7457	35.7290	35.7249	35.7844
147	$2s2p^2(^2D)3d$	$^3D_3$	35.7557	35.7390	35.7364	35.8265
148	$2s2p^2(^2D)3d$	$^3F_2$	35.8793	35.8602	35.8548	35.8199
149	$2s2p^2(^2D)3d$	$^3F_3$	35.9927	35.9738	35.9688	35.8722
150	$2s2p^2(^2D)3d$	$^3F_4$	36.0408	36.0216	36.0155	35.9426
151	$2s2p^2(^2D)3d$	$^1D_2$	36.0671	36.0480	36.0416	36.0841
152	$2s2p^2(^2D)3d$	$^1P_1$	36.0960	36.0811	36.0745	36.0657
153	$2s2p^2(^2S)3d$	$^3D_2$	36.1949	36.1755	36.1671	36.0826
⋆ 154	$2s2p^2(^2S)3d$	$^3D_1$	36.2014	36.1826	36.1749	36.1041
⋆ 155	$2s2p^2(^2S)3d$	$^3D_3$	36.2011	36.1810	36.1731	36.0765
156	$2s2p^2(^2D)3d$	$^3P_2$	36.3239	36.3076	36.2996	36.2067
157	$2s2p^2(^2D)3d$	$^3P_1$	36.3542	36.3384	36.3307	36.2498
158	$2s2p^2(^2D)3d$	$^3P_0$	36.3585	36.3430	36.3362	36.2726
159	$2s2p^2(^2D)3d$	$^1F_3$	36.4606	36.4546	36.4446	36.3549
160	$2s2p^2(^2S)3d$	$^1D_2$	36.7722	36.7705	36.7538	36.6195
161	$2s^22p4s$	$^3P^o_0$	38.8515	38.8560	38.8699	37.8140
162	$2s^22p4s$	$^3P^o_1$	38.8686	38.8722	38.8862	37.8276
163	$2s^22p4s$	$^3P^o_2$	39.0615	39.0663	39.0783	38.0205
164	$2s^22p4s$	$^1P^o_1$	39.1083	39.1101	39.1224	38.0368
165	$2s^22p4p$	$^3D_1$	39.2641	39.2613	39.2768	37.1417
166	$2s^22p4p$	$^3P_1$	39.3380	39.3370	39.3528	37.2116
167	$2s^22p4p$	$^3D_2$	39.3430	39.3381	39.3536	37.2193
168	$2s^22p4p$	$^3P_0$	39.4065	39.4103	39.4285	37.2710
169	$2s^22p4p$	$^1P_1$	39.4995	39.4989	39.5128	37.3647
170	$2s^22p4p$	$^3D_3$	39.5046	39.4999	39.5132	37.4192
171	$2s^22p4p$	$^3S_1$	39.5564	39.5554	39.5704	37.4039
172	$2s^22p4p$	$^3P_2$	39.5626	39.5650	39.5808	37.4218
173	$2s^22p4p$	$^1D_2$	39.6610	39.6519	39.6685	37.5057
174	$2s^22p4d$	$^3F^o_2$	39.7155	39.7000	39.7146	39.4895
175	$2s^22p4d$	$^3F^o_3$	39.7772	39.7612	39.7745	39.5645

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
176	$2s^22p4d$	$^3D^o_2$	39.7875	39.7731	39.7848	39.5812
177	$2s^22p4p$	$^1S_0$	39.7926	39.7796	39.7963	37.6009
178	$2s^22p4d$	$^3D^o_1$	39.8319	39.8177	39.8270	39.6311
179	$2s^22p4d$	$^3F^o_4$	39.9287	39.9127	39.9258	39.6996
180	$2s^22p4d$	$^1D^o_2$	39.9473	39.9332	39.9443	39.7327
181	$2s^22p4d$	$^3D^o_3$	39.9874	39.9733	39.9824	39.7602
⋆ 182	$2s^22p4f$	$^3G_3$	40.0186	39.9980	40.0130	39.8309
⋆ 183	$2s^22p4f$	$^3G_4$	40.0250	40.0049	40.0204	39.8375
⋆ 184	$2s^22p4d$	$^3P^o_2$	40.0154	40.0007	40.0094	39.7750
⋆ 185	$2s^22p4f$	$^3F_3$	40.0321	40.0123	40.0276	39.8445
⋆ 186	$2s^22p4d$	$^3P^o_1$	40.0230	40.0078	40.0167	39.7821
⋆ 187	$2s^22p4f$	$^3F_2$	40.0336	40.0139	40.0293	39.8460
⋆ 188	$2s^22p4d$	$^3P^o_0$	40.0282	40.0126	40.0217	39.7913
⋆ 189	$2s^22p4d$	$^1P^o_1$	40.1326	40.1177	40.1217	39.8955
⋆ 190	$2s^22p4d$	$^1F^o_3$	40.1322	40.1150	40.1185	39.8962
191	$2s^22p4f$	$^1F_3$	40.2200	40.2000	40.2132	40.0288
192	$2s^22p4f$	$^3F_4$	40.2226	40.2027	40.2159	40.0316
193	$2s^22p4f$	$^3G_5$	40.2380			
194	$2s^22p4f$	$^3D_3$	40.2457			
195	$2s^22p4f$	$^1G_4$	40.2462			
196	$2s^22p4f$	$^3D_2$	40.2481			
197	$2s^22p4f$	$^3D_1$	40.2728			
198	$2s^22p4f$	$^1D_2$	40.2815			
199	$2s2p^24s$	$^5P_1$	40.6562			
200	$2s2p^24s$	$^5P_2$	40.7308			
⋆ 201	$2s2p^2(^4P)4s$	$^3P_0$	40.8359			
⋆ 202	$2s2p^24s$	$^5P_3$	40.8281			
203	$2s2p^2(^4P)4s$	$^3P_1$	40.9030			
204	$2s2p^2(^4P)4s$	$^3P_2$	41.0093			
205	$2s2p^24p$	$^5D^o_0$	41.0842			
206	$2s2p^24p$	$^5D^o_1$	41.0918			
207	$2s2p^24p$	$^5D^o_2$	41.1233			
208	$2s2p^2(^4P)4p$	$^3S^o_1$	41.1621			
209	$2s2p^24p$	$^5D^o_3$	41.1852			
210	$2s2p^24p$	$^5P^o_2$	41.2143			
211	$2s2p^24p$	$^5P^o_1$	41.2165			
⋆ 212	$2s2p^2(^4P)4p$	$^3D^o_1$	41.2862			
⋆ 213	$2s2p^24p$	$^5D^o_4$	41.2749			
214	$2s2p^24p$	$^5P^o_3$	41.2897			
215	$2s2p^2(^4P)4p$	$^3D^o_2$	41.3375			
216	$2s2p^24p$	$^5S^o_2$	41.3759			
217	$2s2p^24p$	$^3P^o_0$	41.4047			
218	$2s2p^2(^4P)4p$	$^3D^o_3$	41.4323			
219	$2s2p^24p$	$^3P^o_1$	41.4543			
⋆ 220	$2s2p^24d$	$^5F_1$	41.5004			
⋆ 221	$2s2p^2(^4P)4p$	$^3P^o_2$	41.4896			
222	$2s2p^24d$	$^5F_2$	41.5123			
223	$2s2p^24d$	$^5F_3$	41.5356			
224	$2s2p^24d$	$^5F_4$	41.5893			
225	$2s2p^24d$	$^5D_0$	41.6160			
226	$2s2p^24d$	$^5D_1$	41.6179			
227	$2s2p^24d$	$^5D_2$	41.6217			
228	$2s2p^24d$	$^5D_3$	41.6297			
229	$2s2p^24d$	$^5F_5$	41.6706			
⋆ 230	$2s2p^2(^4P)4d$	$^3P_2$	41.7059			
⋆ 231	$2s2p^24d$	$^5D_4$	41.7006			

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
232	$2s2p^24d$	$^5P_3$	41.7406			
⋆ 233	$2s2p^2(^4P)4d$	$^3F_2$	41.7657			
⋆ 234	$2s2p^24d$	$^5P_2$	41.7646			
235	$2s2p^2(^4P)4d$	$^3P_1$	41.7755			
236	$2s2p^24d$	$^5P_1$	41.7808			
237	$2s2p^24f$	$^5G^o_2$	41.7954			
238	$2s2p^24f$	$^5G^o_3$	41.7984			
239	$2s2p^24f$	$^5D^o_4$	41.8009			
⋆ 240	$2s2p^2(^4P)4f$	$^3G^o_3$	41.8179			
⋆ 241	$2s2p^2(^4P)4d$	$^3F_3$	41.8162			
242	$2s2p^2(^4P)4d$	$^3P_0$	41.8236			
243	$2s2p^24f$	$^5G^o_4$	41.8639			
244	$2s2p^24f$	$^5D^o_3$	41.8653			
245	$2s2p^24f$	$^5D^o_2$	41.8750			
246	$2s2p^2(^4P)4f$	$^3D^o_3$	41.8810			
247	$2s2p^24f$	$^5G^o_5$	41.8822			
248	$2s2p^24f$	$^5F^o_1$	41.8949			
249	$2s2p^2(^4P)4f$	$^3G^o_4$	41.8993			
⋆ 250	$2s2p^2(^4P)4f$	$^3D^o_2$	41.9077			
⋆ 251	$2s2p^2(^4P)4d$	$^3F_4$	41.9053			
252	$2s2p^2(^4P)4d$	$^3D_1$	41.9384			
253	$2s2p^24f$	$^5D^o_0$	41.9608			
254	$2s2p^2(^4P)4d$	$^3D_2$	41.9640			
255	$2s2p^24f$	$^5D^o_1$	41.9662			
256	$2s2p^24f$	$^5G^o_6$	41.9677			
257	$2s2p^2(^4P)4d$	$^3D_3$	41.9804			
258	$2s2p^24f$	$^5F^o_2$	41.9824			
259	$2s2p^2(^4P)4f$	$^3D^o_1$	41.9832			
260	$2s2p^2(^4P)4f$	$^3G^o_5$	41.9847			
261	$2s2p^24f$	$^5F^o_3$	41.9927			
262	$2s2p^24f$	$^5F^o_4$	41.9983			
263	$2s2p^24f$	$^5F^o_5$	42.0026			
264	$2s2p^2(^4P)4f$	$^3F^o_2$	42.0087			
265	$2s2p^2(^4P)4f$	$^3F^o_3$	42.0227			
266	$2s2p^2(^4P)4f$	$^3F^o_4$	42.0263			
267	$2s2p^24s$	$^3D_1$	42.4358			
268	$2s2p^24s$	$^3D_2$	42.4394			
269	$2s2p^24s$	$^3D_3$	42.4447			
270	$2s2p^24s$	$^1D_2$	42.5715			
271	$2s2p^24p$	$^3F^o_2$	42.8735			
272	$2s2p^24p$	$^3F^o_3$	42.8851			
273	$2s2p^24p$	$^3F^o_4$	42.8989			
274	$2s2p^2(^2P)4p$	$^3D^o_1$	42.9177			
275	$2s2p^2(^2P)4p$	$^3D^o_2$	42.9228			
276	$2s2p^2(^2P)4p$	$^3D^o_3$	42.9288			
277	$2s2p^24p$	$^1F^o_3$	42.9365			
278	$2s2p^2(^2P)4p$	$^1D^o_2$	42.9555			
279	$2s2p^24p$	$^3P^o_0$	42.9675			
280	$2s2p^24p$	$^3P^o_1$	42.9706			
281	$2s2p^2(^2P)4p$	$^3P^o_2$	42.9907			
282	$2s2p^2(^2P)4p$	$^1P^o_1$	43.0217			
283	$2s^22p5s$	$^3P^o_0$	43.2642			
284	$2s^22p5s$	$^3P^o_1$	43.2690			
285	$2s2p^24d$	$^3G_3$	43.3015			
286	$2s2p^24d$	$^3G_4$	43.3062			
⋆ 287	$2s2p^2(^2P)4d$	$^3F_2$	43.3144			
⋆ 288	$2s2p^24d$	$^3G_5$	43.3124			
289	$2s2p^2(^2P)4d$	$^3F_3$	43.3180			
290	$2s2p^2(^2P)4d$	$^3F_4$	43.3204			

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
⋆ 291	$2s2p^24s$	$^3S_1$	43.3473			
⋆ 292	$2s2p^2(^2P)4d$	$^3D_1$	43.3425			
293	$2s2p^2(^2P)4d$	$^3D_2$	43.3499			
294	$2s2p^2(^2P)4d$	$^3D_3$	43.3581			
295	$2s2p^24d$	$^3S_1$	43.3992			
296	$2s2p^2(^2P)4d$	$^3P_0$	43.4007			
297	$2s2p^2(^2P)4d$	$^1F_3$	43.4088			
298	$2s2p^24d$	$^1G_4$	43.4161			
299	$2s2p^2(^2P)4d$	$^3P_2$	43.4182			
300	$2s2p^2(^2P)4d$	$^3P_1$	43.4312			
⋆ 301	$2s2p^24s$	$^1S_0$	43.4604			
⋆ 302	$2s^22p5s$	$^3P^o_2$	43.4581			
303	$2s^22p5p$	$^3D_1$	43.4658			
304	$2s^22p5s$	$^1P^o_1$	43.4728			
305	$2s2p^2(^2P)4d$	$^1D_2$	43.4770			
⋆ 306	$2s^22p5p$	$^3D_2$	43.5161			
⋆ 307	$2s2p^2(^2P)4d$	$^1P_1$	43.5122			
⋆ 308	$2s^22p5p$	$^3P_0$	43.5272			
⋆ 309	$2s2p^2(^2P)4f$	$^3G^o_3$	43.5221			
310	$2s2p^2(^2P)4f$	$^3G^o_4$	43.5248			
311	$2s2p^2(^2P)4f$	$^3G^o_5$	43.5286			
312	$2s2p^2(^2P)4f$	$^3F^o_2$	43.5353			
⋆ 313	$2s2p^2(^2P)4f$	$^3F^o_3$	43.5372			
⋆ 314	$2s2p^2(^2P)4f$	$^1G^o_4$	43.5372			
315	$2s2p^2(^2P)4f$	$^3F^o_4$	43.5423			
316	$2s^22p5p$	$^3P_1$	43.5526			
317	$2s2p^2(^2P)4f$	$^1F^o_3$	43.5511			
318	$2s2p^24f$	$^3H^o_4$	43.5775			
319	$2s2p^24f$	$^3H^o_5$	43.5806			
320	$2s2p^2(^2P)4f$	$^3D^o_1$	43.5843			
321	$2s2p^2(^2P)4f$	$^3D^o_2$	43.5847			
⋆ 322	$2s2p^2(^2P)4f$	$^3D^o_3$	43.5857			
⋆ 323	$2s2p^24f$	$^3H^o_6$	43.5855			
324	$2s2p^2(^2P)4f$	$^1D^o_2$	43.5956			
325	$2s2p^24f$	$^1H^o_5$	43.5961			
326	$2s2p^24d$	$^1S_0$	43.6228			
327	$2s2p^24f$	$^3P^o_2$	43.6298			
328	$2s2p^24f$	$^3P^o_1$	43.6308			
329	$2s2p^24f$	$^3P^o_0$	43.6329			
330	$2s2p^24f$	$^1P^o_1$	43.6422			
331	$2s^22p5p$	$^1P_1$	43.6506			
332	$2s^22p5d$	$^3F^o_2$	43.6786			
333	$2s^22p5p$	$^3D_3$	43.6830			
334	$2s^22p5p$	$^3S_1$	43.6913			
335	$2s^22p5p$	$^3P_2$	43.6954			
336	$2s^22p5d$	$^3D^o_2$	43.7111			
337	$2s^22p5d$	$^3F^o_3$	43.7154			
338	$2s^22p5d$	$^3D^o_1$	43.7323			
339	$2s^22p5p$	$^1D_2$	43.7468			
340	$2s2p^2(^2P)4s$	$^3P_0$	43.7791			
341	$2s2p^2(^2P)4s$	$^3P_1$	43.8037			
⋆ 342	$2s2p^24p$	$^3P^o_0$	43.8431			
⋆ 343	$2s^22p5p$	$^1S_0$	43.8359			
344	$2s2p^24p$	$^3P^o_1$	43.8599			
⋆ 345	$2s2p^2(^2D)4p$	$^3P^o_2$	43.8773			
⋆ 346	$2s2p^2(^2P)4s$	$^3P_2$	43.8695			
347	$2s^22p5d$	$^3F^o_4$	43.8905			
⋆ 348	$2s2p^2(^2D)4p$	$^1P^o_1$	43.9043			
⋆ 349	$2s^22p5d$	$^1D^o_2$	43.8984			

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
350	$2s^22p5d$	$^3D^o_3$	43.9130			
351	$2s^22p5d$	$^3P^o_2$	43.9280			
352	$2s^22p5d$	$^3P^o_1$	43.9328			
353	$2s^22p5d$	$^3P^o_0$	43.9348			
354	$2s2p^24s$	$^1P_1$	43.9332			
355	$2s^22p5d$	$^1F^o_3$	43.9817			
356	$2s^22p5d$	$^1P^o_1$	43.9845			
357	$2s2p^24p$	$^1S^o_0$	44.1290			
358	$2s2p^2(^2D)4p$	$^3D^o_1$	44.1820			
359	$2s2p^2(^2D)4p$	$^3D^o_2$	44.2004			
360	$2s2p^24p$	$^3P^o_1$	44.2567			
⋆ 361	$2s2p^2(^2D)4d$	$^3D_1$	44.2796			
⋆ 362	$2s2p^24p$	$^3P^o_0$	44.2737			
⋆ 363	$2s2p^2(^2D)4p$	$^3D^o_3$	44.2731			
364	$2s2p^2(^2D)4d$	$^3D_2$	44.2890			
365	$2s2p^2(^2D)4d$	$^3D_3$	44.2938			
366	$2s2p^2(^2S)4p$	$^3P^o_2$	44.3134			
367	$2s2p^2(^2P)4p$	$^3S^o_1$	44.3401			
368	$2s2p^2(^2D)4d$	$^1D_2$	44.3682			
369	$2s2p^2(^2D)4p$	$^1D^o_2$	44.3827			
370	$2s2p^2(^2S)4p$	$^1P^o_1$	44.4900			
371	$2s2p^2(^2D)4f$	$^3F^o_3$	44.5112			
372	$2s2p^2(^2D)4f$	$^3F^o_4$	44.5113			
373	$2s2p^2(^2D)4f$	$^3F^o_2$	44.5121			
374	$2s2p^2(^2D)4f$	$^1F^o_3$	44.5241			
375	$2s2p^2(^2D)4d$	$^3F_3$	44.6141			
376	$2s2p^2(^2D)4d$	$^3F_2$	44.6144			
377	$2s2p^2(^2D)4d$	$^1P_1$	44.6358			
⋆ 378	$2s2p^2(^2S)4d$	$^3D_2$	44.6822			
⋆ 379	$2s2p^2(^2D)4d$	$^3F_4$	44.6822			
380	$2s2p^2(^2S)4d$	$^3D_1$	44.7257			
381	$2s2p^2(^2S)4d$	$^3D_3$	44.7327			
382	$2s2p^2(^2D)4d$	$^3P_2$	44.7624			
383	$2s2p^2(^2D)4d$	$^3P_1$	44.7788			
384	$2s2p^2(^2D)4d$	$^3P_0$	44.7812			
385	$2s2p^2(^2D)4d$	$^1F_3$	44.8116			
386	$2s2p^2(^2D)4f$	$^3G^o_3$	44.8426			
387	$2s2p^2(^2D)4f$	$^1D^o_2$	44.8438			
388	$2s2p^2(^2D)4f$	$^3G^o_4$	44.8454			
389	$2s2p^2(^2D)4f$	$^3D^o_3$	44.8478			
390	$2s2p^2(^2D)4f$	$^3D^o_1$	44.9262			
391	$2s2p^2(^2D)4f$	$^3D^o_2$	44.9274			
392	$2s2p^2(^2D)4f$	$^3G^o_5$	44.9302			
393	$2s2p^2(^2S)4d$	$^1D_2$	44.9339			
394	$2s2p^2(^2D)4f$	$^1G^o_4$	44.9353			
395	$2s2p^2(^2S)4f$	$^3F^o_2$	44.9655			
396	$2s2p^2(^2S)4f$	$^3F^o_3$	44.9693			
397	$2s2p^2(^2S)4f$	$^3F^o_4$	44.9776			
398	$2s2p^2(^2S)4f$	$^1F^o_3$	44.9892			
399	$2s2p^25s$	$^5P_1$	45.0509			
400	$2s2p^25s$	$^5P_2$	45.1261			
401	$2s2p^2(^4P)5s$	$^3P_0$	45.1325			
402	$2s2p^2(^4P)5s$	$^3P_1$	45.2026			
403	$2s2p^25s$	$^5P_3$	45.2255			
404	$2s2p^25p$	$^5D^o_0$	45.2655			
405	$2s2p^25p$	$^5D^o_1$	45.2687			
406	$2s2p^25p$	$^5D^o_2$	45.2889			
407	$2s2p^2(^4P)5s$	$^3P_2$	45.3091			
408	$2s2p^2(^4P)5p$	$^3S^o_1$	45.3332			
409	$2s2p^25p$	$^5D^o_3$	45.3543			

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
410	$2s2p^25p$	$^5P^o_1$	45.3568			
411	$2s2p^25p$	$^5P^o_2$	45.3680			
412	$2s2p^2(^4P)5p$	$^3D^o_1$	45.3956			
413	$2s2p^2(^4P)5p$	$^3D^o_2$	45.4274			
⋆ 414	$2s2p^25p$	$^3P^o_0$	45.4598			
⋆ 415	$2s2p^25p$	$^5D^o_4$	45.4495			
⋆ 416	$2s2p^25p$	$^5P^o_3$	45.4551			
417	$2s2p^25d$	$^5F_1$	45.4714			
418	$2s2p^25d$	$^5F_2$	45.4778			
⋆ 419	$2s2p^25d$	$^5F_3$	45.4927			
⋆ 420	$2s2p^25p$	$^5S^o_2$	45.4875			
421	$2s2p^25p$	$^3P^o_1$	45.5252			
422	$2s2p^2(^4P)5p$	$^3D^o_3$	45.5266			
423	$2s2p^25d$	$^5F_4$	45.5537			
⋆ 424	$2s2p^25d$	$^5D_0$	45.5630			
⋆ 425	$2s2p^25d$	$^5D_1$	45.5641			
⋆ 426	$2s2p^25d$	$^5D_2$	45.5644			
⋆ 427	$2s2p^2(^4P)5p$	$^3P^o_2$	45.5555			
428	$2s^22p6s$	$^3P^o_0$	45.5743			
429	$2s2p^25d$	$^5P_3$	45.5697			
430	$2s^22p6s$	$^3P^o_1$	45.5795			
431	$2s2p^2(^4P)5d$	$^3P_2$	45.5840			
432	$2s2p^2(^4P)5d$	$^3F_2$	45.6328			
433	$2s2p^25d$	$^5F_5$	45.6443			
⋆ 434	$2s2p^2(^4P)5d$	$^3P_1$	45.6598			
⋆ 435	$2s2p^2(^4P)5d$	$^3F_3$	45.6644			
⋆ 436	$2s2p^25d$	$^5D_4$	45.6564			
437	$2s2p^25d$	$^5D_3$	45.6727			
438	$2s2p^25d$	$^5P_2$	45.6847			
439	$2s2p^25d$	$^5P_1$	45.6926			
440	$2s2p^2(^4P)5d$	$^3P_0$	45.7192			
⋆ 441	$2s2p^2(^4P)5d$	$^3D_1$	45.7601			
⋆ 442	$2s2p^2(^4P)5d$	$^3F_4$	45.7598			
443	$2s^22p6s$	$^3P^o_2$	45.7842			
444	$2s2p^2(^4P)5d$	$^3D_2$	45.7829			
445	$2s^22p6s$	$^1P^o_1$	45.7951			
446	$2s2p^2(^4P)5d$	$^3D_3$	45.7946			
447	$2s2p^25s$	$^3D_1$	46.8135			
448	$2s2p^25s$	$^3D_2$	46.8164			
449	$2s2p^25s$	$^3D_3$	46.8211			
450	$2s2p^25s$	$^1D_2$	46.8807			
451	$2s^22p7s$	$^3P^o_0$	46.9288			
452	$2s^22p7s$	$^3P^o_1$	46.9332			
453	$2s2p^25p$	$^3F^o_2$	47.0324			
454	$2s2p^25p$	$^3F^o_3$	47.0401			
⋆ 455	$2s2p^2(^2P)5p$	$^3D^o_1$	47.0524			
⋆ 456	$2s2p^25p$	$^3F^o_4$	47.0488			
457	$2s2p^2(^2P)5p$	$^3D^o_2$	47.0557			
458	$2s2p^2(^2P)5p$	$^3D^o_3$	47.0606			
459	$2s2p^25p$	$^1F^o_3$	47.0646			
460	$2s2p^2(^2P)5p$	$^3P^o_2$	47.0719			
461	$2s2p^2(^2P)5p$	$^1D^o_2$	47.0847			
462	$2s2p^25p$	$^3P^o_1$	47.0938			
463	$2s2p^25p$	$^3P^o_0$	47.1055			
464	$2s2p^2(^2P)5p$	$^1P^o_1$	47.1117			
465	$2s^22p7s$	$^1P^o_1$	47.1721			
466	$2s^22p7s$	$^3P^o_2$	47.1739			
467	$2s2p^25d$	$^3G_3$	47.2422			
468	$2s2p^25d$	$^3G_4$	47.2461			

Table 1. Target levels of Ar XIII and their threshold energies (in Ryd).

Index	Configuration	Level	GRASP1	GRASP2	FAC	BPRM
469	$2s2p^2(^2P)5d$	$^3F_2$	47.2493			
⋆ 470	$2s2p^2(^2P)5d$	$^3F_3$	47.2522			
⋆ 471	$2s2p^25d$	$^3G_5$	47.2516			
472	$2s2p^2(^2P)5d$	$^3F_4$	47.2553			
473	$2s2p^2(^2P)5d$	$^3D_1$	47.2691			
474	$2s2p^2(^2P)5d$	$^3D_2$	47.2712			
475	$2s2p^2(^2P)5d$	$^3D_3$	47.2741			
476	$2s2p^25d$	$^1G_4$	47.2980			
477	$2s2p^2(^2P)5d$	$^1F_3$	47.3015			
478	$2s2p^2(^2P)5d$	$^3P_0$	47.3041			
479	$2s2p^2(^2P)5d$	$^3P_1$	47.3052			
480	$2s2p^2(^2P)5d$	$^3P_2$	47.3075			
481	$2s2p^25d$	$^3S_1$	47.3180			
482	$2s2p^2(^2P)5d$	$^1D_2$	47.3338			
483	$2s2p^2(^2P)5d$	$^1P_1$	47.3570			
484	$2s2p^25d$	$^1S_0$	47.3799			
485	$2s2p^25s$	$^3S_1$	47.7662			
486	$2s^22p8s$	$^3P^o_0$	47.8148			
487	$2s^22p8s$	$^3P^o_1$	47.8168			
488	$2s2p^25s$	$^1S_0$	47.8201			
489	$2s2p^25p$	$^3P^o_0$	47.9923			
490	$2s2p^25p$	$^3P^o_1$	47.9965			
491	$2s2p^2(^2D)5p$	$^3P^o_2$	48.0032			
492	$2s2p^2(^2D)5p$	$^1P^o_1$	48.0222			
493	$2s^22p8s$	$^3P^o_2$	48.0310			
494	$2s^22p8s$	$^1P^o_1$	48.0329			
495	$2s2p^2(^2P)5s$	$^3P_1$	48.1141			
496	$2s2p^2(^2P)5s$	$^3P_0$	48.1180			
497	$2s2p^2(^2D)5d$	$^3D_1$	48.2031			
498	$2s2p^2(^2D)5d$	$^3D_2$	48.2060			
⋆ 499	$2s2p^2(^2D)5d$	$^3D_3$	48.2121			
⋆ 500	$2s2p^2(^2P)5s$	$^3P_2$	48.2119			
501	$2s2p^25s$	$^1P_1$	48.2245			
502	$2s2p^2(^2D)5d$	$^1D_2$	48.2507			
503	$2s2p^25p$	$^1S^o_0$	48.3140			
504	$2s2p^2(^2D)5p$	$^3D^o_1$	48.3291			
505	$2s2p^2(^2D)5p$	$^3D^o_2$	48.3411			
506	$2s2p^25p$	$^3P^o_1$	48.3675			
507	$2s2p^25p$	$^3P^o_0$	48.4146			
508	$2s2p^2(^2D)5p$	$^3D^o_3$	48.4225			
509	$2s2p^2(^2S)5p$	$^3P^o_2$	48.4409			
510	$2s2p^2(^2P)5p$	$^3S^o_1$	48.4527			
511	$2s2p^2(^2D)5p$	$^1D^o_2$	48.4715			
512	$2s2p^2(^2S)5p$	$^1P^o_1$	48.5256			
513	$2s2p^2(^2D)5d$	$^3F_2$	48.5424			
514	$2s2p^2(^2D)5d$	$^3F_3$	48.5444			
515	$2s2p^2(^2S)5d$	$^3D_1$	48.5515			
516	$2s2p^2(^2D)5d$	$^3P_2$	48.5752			
517	$2s2p^2(^2D)5d$	$^3F_4$	48.6249			
518	$2s2p^2(^2D)5d$	$^1P_1$	48.6415			
519	$2s2p^2(^2S)5d$	$^3D_3$	48.6443			
520	$2s2p^2(^2S)5d$	$^3D_2$	48.6585			
521	$2s2p^2(^2D)5d$	$^3P_1$	48.6689			
522	$2s2p^2(^2D)5d$	$^3P_0$	48.6707			
523	$2s2p^2(^2D)5d$	$^1F_3$	48.6830			
524	$2s2p^2(^2S)5d$	$^1D_2$	48.7388			

GRASP1: Present 524 level calculations from the GRASP code
GRASP2: Present 224 level calculations from the GRASP code
FAC: Calculations of Liang et al. (2004) from the FAC code
BPRM : Calculations of Nahar (2000) from the BPRM code
⋆: Level has changed order with the inclusion of Breit and QED effects

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
1	$2s^22p$	$^2P^o_{1/2}$	0.0000	0.0000	0.0000
2	$2s^22p$	$^2P^o_{3/2}$	0.2064	0.2087	0.2055
3	$2s2p^2$	$^4P_{1/2}$	2.0895	2.0833	2.0602
4	$2s2p^2$	$^4P_{3/2}$	2.1678	2.1629	2.1379
5	$2s2p^2$	$^4P_{5/2}$	2.2725	2.2756	2.2422
6	$2s2p^2$	$^2D_{3/2}$	3.7373	3.7720	3.7798
7	$2s2p^2$	$^2D_{5/2}$	3.7461	3.7833	3.7879
8	$2s2p^2$	$^2S_{1/2}$	4.6877	4.7362	4.7584
9	$2s2p^2$	$^2P_{1/2}$	4.9674	5.0176	5.0489
10	$2s2p^2$	$^2P_{3/2}$	5.0544	5.1100	5.1382
11	$2p^3$	$^4S^o_{3/2}$	6.5419	6.5707	6.5551
12	$2p^3$	$^2D^o_{3/2}$	7.3896	7.4380	7.4625
13	$2p^3$	$^2D^o_{5/2}$	7.4068	7.4639	7.4785
14	$2p^3$	$^2P^o_{1/2}$	8.2795	8.3449	8.3882
15	$2p^3$	$^2P^o_{3/2}$	8.3190	8.3882	8.4259
16	$2s^23s$	$^2S_{1/2}$	31.5663	31.0283	31.0761
17	$2s^23p$	$^2P^o_{1/2}$	32.5787	32.0636	32.1137
18	$2s^23p$	$^2P^o_{3/2}$	32.6325	32.1216	32.1704
19	$2s^23d$	$^2D_{3/2}$	33.1729	33.0871	33.1377
20	$2s^23d$	$^2D_{5/2}$	33.1883	33.1036	33.1534
21	2s2p3s	$^4P^o_{1/2}$		33.1482	33.2260
22	2s2p3s	$^4P^o_{3/2}$		33.2125	33.2905
23	2s2p3s	$^4P^o_{5/2}$		33.3422	33.4203
24	$2s2p(^3P)3s$	$^2P^o_{1/2}$		33.6704	33.7704
25	$2s2p(^3P)3s$	$^2P^o_{3/2}$		33.8119	33.9114
26	2s2p3p	$^4D_{1/2}$		34.0720	34.1368
27	2s2p3p	$^4D_{3/2}$		34.1288	34.1935
28	$2s2p(^3P)3p$	$^2P_{1/2}$	35.8310	34.2244	34.2670
29	$2s2p(^3P)3p$	$^2P_{3/2}$	35.8483	34.4182	34.2885
30	2s2p3p	$^4D_{5/2}$		34.2265	34.2915
31	2s2p3p	$^4D_{7/2}$		34.3429	34.4066
32	2s2p3p	$^4S_{3/2}$			34.4901
33	2s2p3p	$^4P_{1/2}$		34.4926	34.6001
34	2s2p3p	$^4P_{3/2}$		34.5697	34.6734
35	2s2p3p	$^4P_{5/2}$		34.6153	34.7226
36	$2s2p(^3P)3p$	$^2D_{3/2}$		34.6657	34.7586
37	$2s2p(^3P)3p$	$^2D_{5/2}$		34.7949	34.8907
38	2s2p3d	$^4F^o_{3/2}$		34.9660	35.0216
39	2s2p3d	$^4F^o_{5/2}$		35.0052	35.0603
40	2s2p3d	$^4F^o_{7/2}$		35.0659	35.1203
41	$2s2p(^3P)3p$	$^2S_{1/2}$		35.0626	35.1594
42	2s2p3d	$^4F^o_{9/2}$		35.1615	35.2137
43	2s2p3d	$^4D^o_{5/2}$		35.2414	35.3228
44	2s2p3d	$^4D^o_{3/2}$		35.2490	35.3304
45	2s2p3d	$^4D^o_{1/2}$		35.2515	35.3326
46	$2s2p(^3P)3d$	$^2D^o_{3/2}$	35.4483	35.3099	35.4021
47	$2s2p(^1P)3s$	$^2P^o_{1/2}$		35.3549	35.4359
48	$2s2p(^3P)3d$	$^2D^o_{5/2}$	35.4665	35.3430	35.4313
⋆ 49	2s2p3d	$^4D^o_{7/2}$		35.3508	35.4307
50	$2s2p(^1P)3s$	$^2P^o_{3/2}$		35.3631	35.4455
51	2s2p3d	$^4P^o_{5/2}$		35.4267	35.5079
52	2s2p3d	$^4P^o_{3/2}$		35.4433	35.5225
53	2s2p3d	$^4P^o_{1/2}$		35.4578	35.5368
54	$2s2p(^3P)3d$	$^2F^o_{5/2}$	35.9039	35.8203	35.8924

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
55	2s2p(^{3}P)3d	$^2F^o_{7/2}$	36.0224	35.9482	36.0206
56	2s2p(^{3}P)3d	$^2P^o_{3/2}$		35.9376	36.0427
57	2s2p(^{3}P)3d	$^2P^o_{1/2}$		36.0096	36.1169
58	2s2p(^{1}P)3p	$^2P_{1/2}$		36.3480	36.4411
59	2s2p(^{1}P)3p	$^2D_{3/2}$		36.3688	36.4583
60	2s2p(^{1}P)3p	$^2D_{5/2}$		36.4040	36.4877
61	2s2p(^{1}P)3p	$^2P_{3/2}$		36.4089	36.4997
62	2s2p(^{1}P)3p	$^2S_{1/2}$		36.6613	36.7418
63	2p^{2}3s	$^4P_{1/2}$		36.8416	36.9460
64	2p^{2}3s	$^4P_{3/2}$		36.9173	37.0225
65	2p^{2}3s	$^4P_{5/2}$		37.0231	37.1288
66	2s2p(^{1}P)3d	$^2F^o_{7/2}$	37.2253	37.2830	37.3338
67	2s2p(^{1}P)3d	$^2F^o_{5/2}$	37.2253	37.2885	37.3411
68	2s2p(^{1}P)3d	$^2D^o_{3/2}$	38.2887	37.3694	37.4536
69	2s2p(^{1}P)3d	$^2D^o_{5/2}$	38.2887	37.3910	37.4763
70	2p^{2}3s	$^2P_{1/2}$		37.4098	37.5292
71	2s2p(^{1}P)3d	$^2P^o_{1/2}$		37.5545	37.6364
72	2p^{2}3s	$^2P_{3/2}$		37.5195	37.6372
73	2s2p(^{1}P)3d	$^2P^o_{3/2}$		37.5739	37.6586
74	2p^{2}3p	$^2S^o_{1/2}$		37.6136	37.6969
75	2p^{2}3p	$^4D^o_{1/2}$		37.6922	37.7775
76	2p^{2}3p	$^4D^o_{3/2}$		37.7328	37.8183
77	2p^{2}3p	$^4D^o_{5/2}$		37.8109	37.8961
78	2p^{2}3s	$^2D_{5/2}$		37.8135	37.9098
79	2p^{2}3s	$^2D_{3/2}$		37.8267	37.9252
80	2p^{2}3p	$^4P^o_{1/2}$		37.8977	37.9839
81	2p^{2}3p	$^4P^o_{3/2}$		37.9029	37.9903
82	2p^{2}3p	$^4D^o_{7/2}$		37.9116	37.9964
83	2p^{2}3p	$^4P^o_{5/2}$		37.9620	38.0481
84	2p^2(^{3}P)3p	$^2D^o_{3/2}$		38.0282	38.1159
85	2p^2(^{3}P)3p	$^2D^o_{5/2}$		38.1751	38.2631
86	2p^2(^{3}P)3p	$^2P^o_{3/2}$		38.3271	38.4071
87	2p^{2}3p	$^4S^o_{3/2}$		38.2874	38.4344
88	2p^2(^{3}P)3p	$^2P^o_{1/2}$		38.3524	38.4437
89	2p^{2}3d	$^4F_{3/2}$		38.4993	38.5675
90	2p^{2}3d	$^4F_{5/2}$		38.5402	38.6081
91	2p^{2}3d	$^4F_{7/2}$		38.6011	38.6686
92	2p^{2}3p	$^2F^o_{5/2}$		38.6743	38.7472
93	2p^{2}3d	$^4F_{9/2}$		38.6806	38.7474
⋆ 94	2p^{2}3d	$^4D_{3/2}$		38.7955	38.7878
⋆ 95	2p^{2}3p	$^2F^o_{7/2}$		38.7137	38.7860
96	2p^{2}3d	$^4D_{1/2}$		38.7271	38.8025
97	2p^{2}3d	$^4D_{5/2}$		38.7576	38.8298
98	2p^{2}3d	$^4D_{7/2}$		38.7985	38.8681
99	2p^2(^{3}P)3d	$^2P_{3/2}$		38.7050	38.8772
100	2p^2(^{3}P)3d	$^2F_{5/2}$		38.8567	38.9235
101	2p^2(^{3}P)3d	$^2P_{1/2}$		38.8930	38.9860
102	2p^2(^{1}D)3p	$^2D^o_{3/2}$		38.9504	39.0691
⋆ 103	2p^2(^{1}D)3p	$^2D^o_{5/2}$		38.9551	39.0760
⋆ 104	2p^2(^{3}P)3d	$^2F_{7/2}$		39.0059	39.0710
105	2p^{2}3d	$^4P_{5/2}$		39.0043	39.1089
106	2p^{2}3d	$^4P_{3/2}$		39.0473	39.1535

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
107	$2p^2 3d$	$^4P_{1/2}$		39.0673	39.1733
108	$2p^2 3s$	$^2S_{1/2}$		39.1630	39.2393
109	$2p^2(^1D)3p$	$^2P^o_{1/2}$		39.1721	39.2804
110	$2p^2(^1D)3p$	$^2P^o_{3/2}$		39.2687	39.3833
111	$2p^2 3d$	$^2G_{7/2}$		39.4796	39.5341
112	$2p^2 3d$	$^2G_{9/2}$		39.4993	39.5529
113	$2p^2(^3P)3d$	$^2D_{5/2}$		39.4742	39.5672
114	$2p^2(^3P)3d$	$^2D_{3/2}$		39.4799	39.5765
115	$2p^2(^1D)3d$	$^2D_{3/2}$		39.6841	39.7694
116	$2p^2(^1D)3d$	$^2D_{5/2}$		39.7265	39.8118
117	$2p^2(^1D)3d$	$^2F_{7/2}$		39.8074	39.8860
118	$2p^2(^1D)3d$	$^2F_{5/2}$		39.8670	39.9502
119	$2p^2(^1D)3d$	$^2P_{1/2}$		39.9243	40.0515
120	$2p^2(^1D)3d$	$^2P_{3/2}$		39.9802	40.1128
121	$2p^2 3d$	$^2S_{1/2}$		40.0992	40.1744
122	$2p^2(^1S)3p$	$^2P^o_{1/2}$		40.1966	40.2629
123	$2p^2(^1S)3p$	$^2P^o_{3/2}$		40.2210	40.2853
124	$2p^2(^1S)3d$	$^2D_{5/2}$		41.0628	41.0960
125	$2p^2(^1S)3d$	$^2D_{3/2}$		41.0880	41.1225
126	$2s^2 4s$	$^2S_{1/2}$			42.1824
127	$2s^2 4p$	$^2P^o_{1/2}$			42.6025
128	$2s^2 4p$	$^2P^o_{3/2}$			42.6258
129	$2s^2 4d$	$^2D_{3/2}$			42.9719
130	$2s^2 4d$	$^2D_{5/2}$			42.9783
131	$2s^2 4f$	$^2F^o_{5/2}$			43.1725
132	$2s^2 4f$	$^2F^o_{7/2}$			43.1752
133	2s2p4s	$^4P^o_{1/2}$			44.3159
134	2s2p4s	$^4P^o_{3/2}$			44.3777
⋆ 135	$2s2p(^3P)4s$	$^2P^o_{1/2}$			44.5171
⋆ 136	2s2p4s	$^4P^o_{5/2}$			44.5160
137	$2s2p(^3P)4s$	$^2P^o_{3/2}$			44.6686
138	2s2p4p	$^4D_{1/2}$			44.6978
139	2s2p4p	$^4D_{3/2}$			44.7408
140	$2s2p(^3P)4p$	$^2P_{3/2}$			44.7968
141	2s2p4p	$^4D_{5/2}$			44.8038
142	$2s2p(^3P)4p$	$^2P_{1/2}$			44.8158
143	2s2p4p	$^4P_{1/2}$			44.8683
144	2s2p4p	$^4S_{3/2}$			44.8939
145	2s2p4p	$^4D_{7/2}$			44.9248
146	2s2p4p	$^4P_{3/2}$			44.9822
147	2s2p4p	$^4P_{5/2}$			44.9931
148	$2s2p(^3P)4p$	$^2D_{3/2}$			45.0026
149	2s2p4d	$^4F^o_{3/2}$			45.0389
150	2s2p4d	$^4F^o_{5/2}$			45.0696
151	$2s2p(^3P)4p$	$^2D_{5/2}$			45.0939
152	2s2p4d	$^4F^o_{7/2}$			45.1230
153	2s2p4d	$^4P^o_{5/2}$			45.1525
154	2s2p4d	$^4D^o_{3/2}$			45.1708
155	2s2p4d	$^4D^o_{1/2}$			45.1793
156	$2s2p(^3P)4p$	$^2S_{1/2}$			45.1874
157	$2s2p(^3P)4d$	$^2D^o_{3/2}$			45.2297
158	2s2p4d	$^4F^o_{9/2}$			45.2354
159	$2s2p(^3P)4d$	$^2D^o_{5/2}$			45.2673

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
160	2s2p4f	$^4G_{5/2}$			45.2902
⋆ 161	2s2p4f	$^4G_{7/2}$			45.2953
⋆ 162	2s2p4d	$^4D^o_{7/2}$			45.2936
163	2s2p4d	$^4D^o_{5/2}$			45.3191
164	2s2p4d	$^4P^o_{3/2}$			45.3315
⋆ 165	2s2p4f	$^4F_{3/2}$			45.3422
⋆ 166	2s2p4d	$^4P^o_{1/2}$			45.3386
167	2s2p4f	$^4F_{9/2}$			45.3485
168	2s2p4f	$^4F_{5/2}$			45.3509
169	2s2p(^{3}P)4f	$^2F_{7/2}$			45.3560
170	2s2p(^{3}P)4f	$^2F_{5/2}$			45.3846
171	2s2p(^{3}P)4f	$^2G_{7/2}$			45.3863
172	2s2p(^{3}P)4d	$^2F^o_{5/2}$			45.4170
173	2s2p(^{3}P)4d	$^2P^o_{3/2}$			45.4808
174	2s2p4f	$^4G_{9/2}$			45.4937
175	2s2p4f	$^4F_{7/2}$			45.4994
176	2s2p(^{3}P)4d	$^2F^o_{7/2}$			45.5083
177	2s2p4f	$^4G_{11/2}$			45.5121
178	2s2p4f	$^4D_{5/2}$			45.5151
179	2s2p4f	$^4D_{7/2}$			45.5180
180	2s2p4f	$^4D_{3/2}$			45.5346
181	2s2p(^{3}P)4d	$^2P^o_{1/2}$			45.5358
182	2s2p(^{3}P)4f	$^2G_{9/2}$			45.5417
183	2s2p4f	$^4D_{1/2}$			45.5466
184	2s2p(^{3}P)4f	$^2D_{5/2}$			45.5469
185	2s2p(^{3}P)4f	$^2D_{3/2}$			45.5757
186	2s2p(^{1}P)4s	$^2P^o_{1/2}$			46.4831
187	2s2p(^{1}P)4s	$^2P^o_{3/2}$			46.4872
188	2s2p(^{1}P)4p	$^2S_{1/2}$			46.8751
189	2s2p(^{1}P)4p	$^2D_{3/2}$			46.8887
190	2s2p(^{1}P)4p	$^2D_{5/2}$			46.9018
191	2s2p(^{1}P)4p	$^2P_{1/2}$			46.9116
192	2s2p(^{1}P)4p	$^2P_{3/2}$			46.9272
193	2s^{2}5s	$^2S_{1/2}$			47.2046
194	2s2p(^{1}P)4d	$^2F^o_{7/2}$			47.2340
195	2s^{2}5p	$^2P^o_{1/2}$			47.2382
196	2s2p(^{1}P)4d	$^2F^o_{5/2}$			47.2345
197	2s^{2}5p	$^2P^o_{3/2}$			47.2481
198	2s2p(^{1}P)4d	$^2D^o_{3/2}$			47.2580
199	2s2p(^{1}P)4d	$^2D^o_{5/2}$			47.2666
200	2s2p(^{1}P)4f	$^2F_{5/2}$			47.4060
⋆ 201	2s2p(^{1}P)4d	$^2P^o_{1/2}$			47.4120
⋆ 202	2s2p(^{1}P)4f	$^2F_{7/2}$			47.4090
203	2s2p(^{1}P)4d	$^2P^o_{3/2}$			47.4199
204	2s2p(^{1}P)4f	$^2G_{7/2}$			47.4692
205	2s2p(^{1}P)4f	$^2G_{9/2}$			47.4715
206	2s^{2}5d	$^2D_{3/2}$			47.4824
207	2s^{2}5d	$^2D_{5/2}$			47.4858
208	2s2p(^{1}P)4f	$^2D_{3/2}$			47.5141
209	2s2p(^{1}P)4f	$^2D_{5/2}$			47.5161
210	2s^{2}5f	$^2F^o_{5/2}$			47.5936
211	2s^{2}5f	$^2F^o_{7/2}$			47.5945
212	2p^{2}4s	$^4P_{1/2}$			47.8600

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
213	$2p^24s$	$^4P_{3/2}$			47.9425
214	$2p^24s$	$^2P_{1/2}$			48.0387
215	$2p^24s$	$^4P_{5/2}$			48.0538
216	$2p^24s$	$^2P_{3/2}$			48.1664
217	$2p^24p$	$^4D^o_{1/2}$			48.1977
218	$2p^24p$	$^4D^o_{3/2}$			48.2447
219	$2p^24p$	$^2S^o_{1/2}$			48.2600
220	$2p^24p$	$^4D^o_{5/2}$			48.3174
221	$2p^24p$	$^4P^o_{3/2}$			48.3457
222	$2p^24p$	$^4P^o_{1/2}$			48.3546
⋆ 223	$2p^2(^3P)4p$	$^2D^o_{3/2}$			48.4267
⋆ 224	$2p^24p$	$^4D^o_{7/2}$			48.4203
225	$2p^24p$	$^4P^o_{5/2}$			48.4298
⋆ 226	$2p^24d$	$^4F_{3/2}$			48.5365
⋆ 227	$2p^24p$	$^4S^o_{3/2}$			48.5255
⋆ 228	$2p^24d$	$^4F_{5/2}$			48.5663
⋆ 229	$2p^2(^3P)4p$	$^2D^o_{5/2}$			48.5603
230	$2p^2(^3P)4p$	$^2P^o_{1/2}$			48.5856
231	$2p^2(^3P)4p$	$^2P^o_{3/2}$			48.5950
232	$2p^24d$	$^4F_{7/2}$			48.6298
233	$2p^2(^3P)4d$	$^2P_{3/2}$			48.6491
234	$2p^24d$	$^4D_{1/2}$			48.6562
235	$2p^24d$	$^4D_{5/2}$			48.6782
236	$2p^24s$	$^2D_{3/2}$			48.6982
237	$2p^24s$	$^2D_{5/2}$			48.7015
⋆ 238	$2p^24d$	$^4D_{3/2}$			48.7255
⋆ 239	$2p^24d$	$^4F_{9/2}$			48.7240
⋆ 240	$2p^24f$	$^4G^o_{5/2}$			48.7581
⋆ 241	$2p^24f$	$^4G^o_{7/2}$			48.7655
⋆ 242	$2p^24d$	$^4D_{7/2}$			48.7528
243	$2p^2(^3P)4d$	$^2F_{5/2}$			48.7671
244	$2p^24d$	$^4P_{5/2}$			48.8113
245	$2p^2(^3P)4d$	$^2P_{1/2}$			48.8166
246	$2p^2(^3P)4f$	$^2D^o_{5/2}$			48.8341
⋆ 247	$2p^24f$	$^4D^o_{7/2}$			48.8383
⋆ 248	$2p^24d$	$^4P_{3/2}$			48.8376
⋆ 249	$2p^24f$	$^4G^o_{9/2}$			48.8545
⋆ 250	$2p^24d$	$^4P_{1/2}$			48.8514
251	$2p^2(^3P)4f$	$^2G^o_{7/2}$			48.8633
252	$2p^2(^3P)4f$	$^2D^o_{3/2}$			48.8654
253	$2p^24f$	$^4D^o_{5/2}$			48.8740
254	$2p^2(^3P)4d$	$^2F_{7/2}$			48.9032
255	$2p^24f$	$^4D^o_{1/2}$			48.9549
256	$2p^24f$	$^4G^o_{11/2}$			48.9557
257	$2p^24f$	$^4D^o_{3/2}$			48.9587
258	$2p^2(^3P)4f$	$^2G^o_{9/2}$			48.9702
259	$2p^24f$	$^4F^o_{3/2}$			48.9853

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
260	$2p^2 4f$	$^4F^o_{5/2}$			48.9878
261	$2p^2(^3P)4d$	$^2D_{3/2}$			48.9931
262	$2p^2 4f$	$^4F^o_{7/2}$			48.9962
263	$2p^2 4f$	$^4F^o_{9/2}$			49.0032
264	$2p^2(^3P)4d$	$^2D_{5/2}$			49.0107
265	$2p^2(^3P)4f$	$^2F^o_{5/2}$			49.0148
266	$2p^2(^3P)4f$	$^2F^o_{7/2}$			49.0259
267	$2p^2 4p$	$^2F^o_{5/2}$			49.0711
268	$2p^2 4p$	$^2F^o_{7/2}$			49.0864
269	$2p^2(^1D)4p$	$^2D^o_{5/2}$			49.1230
270	$2p^2(^1D)4p$	$^2D^o_{3/2}$			49.1293
271	$2p^2(^1D)4p$	$^2P^o_{1/2}$			49.1893
⋆ 272	2s2p5s	$^4P^o_{1/2}$			49.2442
⋆ 273	$2p^2(^1D)4p$	$^2P^o_{3/2}$			49.2339
274	2s2p5s	$^4P^o_{3/2}$			49.3058
275	$2s2p(^3P)5s$	$^2P^o_{1/2}$			49.3842
276	$2p^2 4d$	$^2G_{7/2}$			49.3897
277	$2p^2 4d$	$^2G_{9/2}$			49.4038
278	2s2p5p	$^4D_{1/2}$			49.4310
279	2s2p5s	$^4P^o_{5/2}$			49.4450
⋆ 280	2s2p5p	$^4D_{3/2}$			49.4576
⋆ 281	$2p^2(^1D)4d$	$^2F_{7/2}$			49.4438
282	$2p^2(^1D)4d$	$^2F_{5/2}$			49.4517
283	$2p^2(^1D)4d$	$^2D_{3/2}$			49.4613
⋆ 284	$2s2p(^3P)5p$	$^4S_{3/2}$			49.5006
⋆ 285	$2p^2(^1D)4d$	$^2D_{5/2}$			49.4872
286	2s2p5p	$^4D_{5/2}$			49.5154
287	2s2p5p	$^4P_{1/2}$			49.5272
288	$2s2p(^3P)5s$	$^2P^o_{3/2}$			49.5342
289	2s2p5p	$^2P_{1/2}$			49.5430
290	$2p^2(^1D)4d$	$^2P_{1/2}$			49.5432
291	$2p^2(^1D)4f$	$^2G^o_{9/2}$			49.5495
⋆ 292	$2s2p(^3P)5p$	$^2D_{3/2}$			49.5647
⋆ 293	$2p^2(^1D)4f$	$^2G^o_{7/2}$			49.5519
294	$2p^2(^1D)4f$	$^2F^o_{5/2}$			49.5654
295	$2p^2(^1D)4f$	$^2F^o_{7/2}$			49.5684
296	$2p^2 4d$	$^2S_{1/2}$			49.5719
297	$2p^2(^1D)4d$	$^2P_{3/2}$			49.5764
298	2s2p5d	$^4F^o_{3/2}$			49.5956
299	2s2p5d	$^4F^o_{5/2}$			49.6167
300	$2p^2 4f$	$^2H^o_{9/2}$			49.6125
301	$2p^2 4f$	$^2H^o_{11/2}$			49.6143
302	$2p^2(^1D)4f$	$^2D^o_{3/2}$			49.6208
303	$2p^2(^1D)4f$	$^2D^o_{5/2}$			49.6261
304	2s2p5p	$^4D_{7/2}$			49.6476
⋆ 305	2s2p5d	$^4P^o_{5/2}$			49.6701
306	2s2p5d	$^4F^o_{7/2}$			49.6701
⋆ 307	2s2p5p	$^4P_{3/2}$			49.6695
308	2s2p5p	$^4P_{5/2}$			49.6728
⋆ 309	2s2p5d	$^4D^o_{3/2}$			49.6841
⋆ 310	$2p^2 4f$	$^2P^o_{1/2}$			49.6806
⋆ 311	$2s2p(^3P)5p$	$^2P_{3/2}$			49.6843

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
312	$2p^2 4f$	$^2P^o_{3/2}$			49.6815
313	2s2p5d	$^4D^o_{1/2}$			49.6915
314	2s2p5f	$^4G_{5/2}$			49.7102
315	2s2p5f	$^4D_{7/2}$			49.7130
316	$2s2p(^3P)5d$	$^2D^o_{3/2}$			49.7239
317	$2s2p(^3P)5p$	$^2D_{5/2}$			49.7311
318	$2s2p(^3P)5d$	$^2F^o_{5/2}$			49.7448
319	$2s2p(^3P)5p$	$^2S_{1/2}$			49.7559
320	2s2p5f	$^4F_{3/2}$			49.7700
321	2s2p5f	$^4G_{9/2}$			49.7709
322	2s2p5f	$^4F_{5/2}$			49.7752
323	2s2p5f	$^4G_{7/2}$			49.7767
324	$2s2p(^3P)5f$	$^2G_{7/2}$			49.7919
325	$2s2p(^3P)5f$	$^2F_{5/2}$			49.7947
326	2s2p5d	$^4F^o_{9/2}$			49.7974
327	2s2p5d	$^4D^o_{7/2}$			49.8215
328	2s2p5d	$^4D^o_{5/2}$			49.8331
329	2s2p5d	$^4P^o_{3/2}$			49.8405
330	2s2p5d	$^4P^o_{1/2}$			49.8441
331	$2s2p(^3P)5d$	$^2D^o_{5/2}$			49.8703
332	$2s2p(^3P)5d$	$^2P^o_{3/2}$			49.9044
333	$2s2p(^3P)5f$	$^4F_{9/2}$			49.9180
334	2s2p5f	$^4F_{7/2}$			49.9211
335	$2s2p(^3P)5d$	$^2F^o_{7/2}$			49.9240
336	2s2p5f	$^4G_{11/2}$			49.9257
337	2s2p5f	$^4D_{5/2}$			49.9286
338	2s2p5f	$^2F_{7/2}$			49.9367
339	2s2p5f	$^4D_{3/2}$			49.9376
340	$2s2p(^3P)5d$	$^2P^o_{1/2}$			49.9398
341	2s2p5f	$^4D_{1/2}$			49.9440
342	$2s2p(^3P)5f$	$^2G_{9/2}$			49.9466
343	$2s2p(^3P)5f$	$^2D_{5/2}$			49.9503
344	$2s2p(^3P)5f$	$^2D_{3/2}$			49.9652
345	$2s^2 6s$	$^2S_{1/2}$			50.1110
346	$2p^2 4s$	$^2S_{1/2}$			50.1164
347	$2p^2(^1S)4p$	$^2P^o_{1/2}$			50.4864
348	$2p^2(^1S)4p$	$^2P^o_{3/2}$			50.4994
349	$2p^2(^1S)4d$	$^2D_{5/2}$			50.8235
350	$2p^2(^1S)4d$	$^2D_{3/2}$			50.8288
351	$2p^2(^1S)4f$	$^2F^o_{5/2}$			50.9880
352	$2p^2(^1S)4f$	$^2F^o_{7/2}$			50.9897
353	$2s2p(^1P)5s$	$^2P^o_{1/2}$			51.4028
354	$2s2p(^1P)5s$	$^2P^o_{3/2}$			51.4052
355	$2s2p(^1P)5p$	$^2S_{1/2}$			51.5837
356	$2s2p(^1P)5p$	$^2D_{3/2}$			51.5984
357	$2s2p(^1P)5p$	$^2P_{1/2}$			51.6054
358	$2s2p(^1P)5p$	$^2D_{5/2}$			51.6058
359	$2s2p(^1P)5p$	$^2P_{3/2}$			51.6140
360	$2s^2 7s$	$^2S_{1/2}$			51.7387
361	$2s2p(^1P)5d$	$^2F^o_{7/2}$			51.7695
362	$2s2p(^1P)5d$	$^2F^o_{5/2}$			51.7699
363	$2s2p(^1P)5d$	$^2D^o_{3/2}$			51.7705
364	$2s2p(^1P)5d$	$^2D^o_{5/2}$			51.7748
365	$2s2p(^1P)5d$	$^2P^o_{1/2}$			51.8126
366	$2s2p(^1P)5d$	$^2P^o_{3/2}$			51.8157
367	$2s2p(^1P)5f$	$^2F_{5/2}$			51.8433
368	$2s2p(^1P)5f$	$^2F_{7/2}$			51.8448
369	$2s2p(^1P)5f$	$^2G_{7/2}$			51.8722

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
370	2s2p(^{1}P)5f	$^2G_{9/2}$			51.8733
371	2s2p(^{1}P)5f	$^2D_{3/2}$			51.8961
372	2s2p(^{1}P)5f	$^2D_{5/2}$			51.8970
373	2s^{2}8s	$^2S_{1/2}$			52.6642
374	2p^{2}5s	$^4P_{1/2}$			52.7341
375	2p^{2}5s	$^4P_{3/2}$			52.8193
376	2p^{2}5s	$^2P_{1/2}$			52.8610
377	2p^{2}5p	$^4D^o_{1/2}$			52.9080
⋆ 378	2p^{2}5p	$^4D^o_{3/2}$			52.9357
⋆ 379	2p^{2}5s	$^4P_{5/2}$			52.9340
380	2p^{2}5p	$^2S^o_{1/2}$			52.9843
381	2p^{2}5s	$^2P_{3/2}$			52.9885
382	2p^{2}5p	$^4D^o_{5/2}$			53.0118
383	2p^{2}5p	$^4P^o_{3/2}$			53.0256
384	2p^{2}5p	$^4P^o_{1/2}$			53.0441
385	2p^2(^{3}P)5p	$^2D^o_{3/2}$			53.0656
386	2p^{2}5d	$^4F_{3/2}$			53.0783
387	2p^{2}5d	$^4F_{5/2}$			53.0984
388	2p^{2}5p	$^4D^o_{7/2}$			53.1207
389	2p^{2}5p	$^4P^o_{5/2}$			53.1256
⋆ 390	2p^{2}5d	$^4F_{7/2}$			53.1690
⋆ 391	2p^{2}5f	$^4G^o_{5/2}$			53.1756
⋆ 392	2p^{2}5p	$^4S^o_{3/2}$			53.1629
⋆ 393	2p^{2}5d	$^4D_{3/2}$			53.1728
394	2p^{2}5d	$^4D_{1/2}$			53.1781
395	2p^{2}5f	$^4G^o_{7/2}$			53.1821
396	2p^{2}5d	$^4P_{5/2}$			53.1905
397	2p^2(^{3}P)5p	$^2D^o_{5/2}$			53.1953
398	2p^2(^{3}P)5p	$^2P^o_{1/2}$			53.1977
⋆ 399	2p^2(^{3}P)5d	$^2P_{3/2}$			53.2228
⋆ 400	2p^2(^{3}P)5p	$^2P^o_{3/2}$			53.2165
401	2p^2(^{3}P)5d	$^2F_{5/2}$			53.2428
402	2p^2(^{3}P)5f	$^2D^o_{5/2}$			53.2620
403	2p^{2}5f	$^4D^o_{7/2}$			53.2642
404	2p^{2}5f	$^4G^o_{9/2}$			53.2713
⋆ 405	2p^{2}5f	$^4F^o_{3/2}$			53.2776
⋆ 406	2p^2(^{3}P)5f	$^2G^o_{7/2}$			53.2787
⋆ 407	2p^{2}5d	$^4F_{9/2}$			53.2734
⋆ 408	2p^{2}5f	$^4D^o_{5/2}$			53.2859
⋆ 409	2p^{2}5d	$^4D_{7/2}$			53.2858
410	2p^{2}5d	$^4D_{5/2}$			53.3088
411	2p^2(^{3}P)5d	$^2P_{1/2}$			53.3217
412	2p^{2}5d	$^4P_{3/2}$			53.3233
413	2p^{2}5d	$^4P_{1/2}$			53.3314
414	2p^2(^{3}P)5d	$^2F_{7/2}$			53.3720
415	2p^{2}5f	$^4G^o_{11/2}$			53.3817
416	2p^{2}5f	$^4D^o_{1/2}$			53.3837
417	2p^{2}5f	$^4D^o_{3/2}$			53.3858
⋆ 418	2p^2(^{3}P)5d	$^2D_{3/2}$			53.3907
⋆ 419	2p^2(^{3}P)5f	$^2G^o_{9/2}$			53.3901
420	2p^{2}5f	$^4F^o_{5/2}$			53.3959
421	2p^2(^{3}P)5f	$^2D^o_{3/2}$			53.3964
422	2p^{2}5f	$^4F^o_{7/2}$			53.4000
⋆ 423	2p^2(^{3}P)5d	$^2D_{5/2}$			53.4056
⋆ 424	2p^{2}5f	$^4F^o_{9/2}$			53.4054
425	2p^2(^{3}P)5f	$^2F^o_{5/2}$			53.4128
426	2p^2(^{3}P)5f	$^2F^o_{7/2}$			53.4189
427	2p^{2}5s	$^2D_{3/2}$			53.5713

Table 2. Target levels of Ar XIV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	DFS	GRASP
428	$2p^25s$	$^2D_{5/2}$			53.5720
429	$2p^25p$	$^2F^o_{5/2}$			53.7485
430	$2p^25p$	$^2F^o_{7/2}$			53.7567
431	$2p^2(^1D)5p$	$^2D^o_{5/2}$			53.7672
432	$2p^2(^1D)5p$	$^2D^o_{3/2}$			53.7716
433	$2p^2(^1D)5p$	$^2P^o_{1/2}$			53.8112
434	$2p^2(^1D)5p$	$^2P^o_{3/2}$			53.8324
435	$2p^25d$	$^2G_{7/2}$			53.9093
436	$2p^25d$	$^2G_{9/2}$			53.9179
437	$2p^2(^1D)5d$	$^2F_{7/2}$			53.9307
438	$2p^2(^1D)5d$	$^2F_{5/2}$			53.9357
439	$2p^2(^1D)5d$	$^2D_{3/2}$			53.9428
440	$2p^2(^1D)5d$	$^2D_{5/2}$			53.9538
441	$2p^2(^1D)5d$	$^2P_{1/2}$			53.9789
442	$2p^2(^1D)5f$	$^2G^o_{9/2}$			53.9869
443	$2p^2(^1D)5f$	$^2G^o_{7/2}$			53.9887
444	$2p^2(^1D)5f$	$^2F^o_{5/2}$			53.9965
445	$2p^2(^1D)5d$	$^2P_{3/2}$			53.9977
446	$2p^2(^1D)5f$	$^2F^o_{7/2}$			53.9981
447	$2p^25d$	$^2S_{1/2}$			54.0006
448	$2p^25f$	$^2H^o_{9/2}$			54.0162
449	$2p^25f$	$^2H^o_{11/2}$			54.0171
450	$2p^2(^1D)5f$	$^2D^o_{3/2}$			54.0220
451	$2p^2(^1D)5f$	$^2D^o_{5/2}$			54.0255
452	$2p^25f$	$^2P^o_{1/2}$			54.0508
453	$2p^25f$	$^2P^o_{3/2}$			54.0519
454	$2p^25s$	$^2S_{1/2}$			54.9577
455	$2p^2(^1S)5p$	$^2P^o_{1/2}$			55.1525
456	$2p^2(^1S)5p$	$^2P^o_{3/2}$			55.1596
457	$2p^2(^1S)5d$	$^2D_{5/2}$			55.3225
458	$2p^2(^1S)5d$	$^2D_{3/2}$			55.3249
459	$2p^2(^1S)5f$	$^2F^o_{5/2}$			55.3987
460	$2p^2(^1S)5f$	$^2F^o_{7/2}$			55.3995

Expt.: Edlen (1983) for n=2 levels and
CHIANTI database (http://wwwsolar.nrl.navy.mil/CHIANTI.html) for n=3 levels.
DFS: Zhang et al. (1984) for n=2 and CHIANTI database for n=3 levels.
$\star$: Level has changed order with the inclusion of Breit and QED effects

Table 3. Target levels of Ar XV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	GRASP	DFS
1	$2s^2$	$^1S_0$	0.0000	0.0000	0.0000
2	2s2p	$^3P_0{}^o$	2.0838	2.0889	2.0934
3	2s2p	$^3P_1{}^o$	2.1493	2.1542	2.1592
4	2s2p	$^3P_2{}^o$	2.3026	2.3066	2.3122
5	2s2p	$^1P_1{}^o$	4.1209	4.1970	4.2503
6	$2p^2$	$^3P_0$	5.5128	5.5470	5.5423
7	$2p^2$	$^3P_1$	5.6054	5.6381	5.6334
8	$2p^2$	$^3P_2$	5.7253	5.7588	5.7554
9	$2p^2$	$^1D_2$	6.2843	6.3563	6.3850
10	$2p^2$	$^1S_0$	7.6602	7.7921	7.8043
11	2s3s	$^3S_1$	35.8584	35.8607	35.5752
12	2s3s	$^1S_0$	36.2684	36.2603	36.0612
13	2s3p	$^1P_1{}^o$	36.8389	36.8287	36.7092
14	2s3p	$^3P_0{}^o$		36.8476	36.7092
15	2s3p	$^3P_1{}^o$		36.8856	36.7740
16	2s3p	$^3P_2{}^o$	36.9109	36.9087	36.8064
17	2s3d	$^3D_1$		37.4271	37.4868
18	2s3d	$^3D_2$		37.4349	37.4868
19	2s3d	$^3D_3$	37.4531	37.4478	37.5192
20	2s3d	$^1D_2$	37.8176	37.8436	37.9728
21	2p3s	$^3P_0{}^o$		38.4926	38.4912
22	2p3s	$^3P_1{}^o$		38.5474	38.5560
23	2p3s	$^3P_2{}^o$		38.7179	38.7828
24	2p3s	$^1P_1{}^o$		39.0693	39.1716
25	2p3p	$^1P_1$		39.1293	39.4632
26	2p3p	$^3D_1$		39.2911	39.2364
27	2p3p	$^3D_2$		39.3045	39.4632
28	2p3p	$^3D_3$	39.4269	39.4621	39.6900
29	2p3p	$^3S_1$	39.5444	39.5632	39.7872
30	2p3p	$^3P_0$		39.5855	39.7872
31	2p3p	$^3P_1$		39.6904	39.9168
32	2p3d	$^3F_2{}^o$		39.7167	39.9816
33	2p3p	$^3P_2$	39.7358	39.7397	39.9816
34	2p3d	$^3F_3{}^o$		39.8219	40.1112
35	2p3d	$^1D_2{}^o$	39.8634	39.8848	40.2084
36	2p3d	$^3F_4{}^o$	39.9108	39.9541	40.3056
37	2p3p	$^1D_2$	39.9955	40.0208	40.3380
38	2p3d	$^3D_1{}^o$		40.0968	40.4676
39	2p3d	$^3D_2{}^o$		40.1423	40.5324
40	2p3d	$^3D_3{}^o$	40.2097	40.2209	40.6620
41	2p3d	$^3P_2{}^o$	40.3053	40.3162	40.7592
42	2p3d	$^3P_1{}^o$		40.3410	40.7592
43	2p3d	$^3P_0{}^o$		40.3586	40.7916
44	2p3p	$^1S_0$		40.5143	40.9212
45	2p3d	$^1F_3{}^o$	40.6607	40.7047	41.3100
46	2p3d	$^1P_1{}^o$	40.7282	40.7611	41.3100
47	2s4s	$^3S_1$		48.0177	
48	2s4s	$^1S_0$		48.1629	
49	2s4p	$^3P_0{}^o$		48.4025	
50	2s4p	$^3P_1{}^o$		48.4078	
51	2s4p	$^3P_2{}^o$	48.4320	48.4281	
52	2s4p	$^1P_1{}^o$	48.4266	48.4576	

Table 3. Target levels of Ar XV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	GRASP	DFS
53	2s4d	$^3D_1$		48.6413	
54	2s4d	$^3D_2$		48.6441	
55	2s4d	$^3D_3$	48.6617	48.6489	
56	2s4d	$^1D_2$	48.7710	48.7782	
57	2s4f	$^3F_2{}^o$		48.7899	
58	2s4f	$^3F_3{}^o$		48.7911	
59	2s4f	$^3F_4{}^o$	48.8075	48.7932	
60	2s4f	$^1F_3{}^o$	48.8348	48.8252	
61	2p4s	$^3P_0{}^o$		50.4600	
62	2p4s	$^3P_1{}^o$		50.4849	
63	2p4s	$^3P_2{}^o$		50.6883	
64	2p4p	$^3D_1$		50.7375	
65	2p4s	$^1P_1{}^o$		50.7633	
66	2p4p	$^3P_1$		50.8272	
67	2p4p	$^3D_2$		50.8277	
68	2p4p	$^3P_0$		50.9030	
69	2p4d	$^3F_2{}^o$		50.9745	
70	2p4p	$^1P_1$		51.0021	
71	2p4p	$^3D_3$		51.0045	
72	2p4d	$^3F_3{}^o$		51.0464	
73	2p4d	$^3D_2{}^o$	51.0446	51.0630	
74	2p4p	$^3S_1$		51.0692	
75	2p4p	$^3P_2$		51.0704	
76	2p4d	$^3D_1{}^o$		51.1149	
77	2p4f	$^3G_3$		51.1376	
78	2p4f	$^3F_2$		51.1463	
79	2p4f	$^3F_3$		51.1488	
80	2p4f	$^3G_4$		51.1525	
81	2p4p	$^1D_2$		51.1802	
82	2p4d	$^3F_4{}^o$	51.1813	51.2103	
83	2p4d	$^1D_2{}^o$		51.2323	
84	2p4d	$^3D_3{}^o$	51.2770	51.2789	
85	2p4d	$^3P_2{}^o$	51.2998	51.3160	
86	2p4d	$^3P_1{}^o$		51.3260	
87	2p4d	$^3P_0{}^o$		51.3338	
88	2p4p	$^1S_0$		51.3458	
89	2p4f	$^1F_3$	51.1358	51.3493	
90	2p4f	$^3F_4$	51.2679	51.3581	
91	2p4f	$^3D_3$	51.3955	51.3884	
92	2p4f	$^3G_5$	51.3453	51.3892	
93	2p4f	$^3D_2$		51.3945	
94	2p4f	$^1G_4$	51.3909	51.4095	
95	2p4f	$^3D_1$		51.4283	
96	2p4f	$^1D_2$	51.4110	51.4447	
97	2p4d	$^1F_3{}^o$	51.4319	51.4499	
98	2p4d	$^1P_1{}^o$		51.4716	
99	2s5s	$^3S_1$		53.4839	
100	2s5s	$^1S_0$		53.5605	
101	2s5p	$^3P_0{}^o$		53.6710	
102	2s5p	$^3P_1{}^o$		53.6741	
103	2s5p	$^3P_2{}^o$		53.6839	
104	2s5p	$^1P_1{}^o$		53.7088	

Table 3. Target levels of Ar XV and their threshold energies (in Ryd).

Index	Configuration	Level	Expt.	GRASP	DFS
105	2s5d	$^3D_1$		53.7893	
106	2s5d	$^3D_2$		53.7906	
107	2s5d	$^3D_3$		53.7930	
108	2s5d	$^1D_2$		53.8530	
109	2s5f	$^3F_2{}^o$		53.8576	
110	2s5f	$^3F_3{}^o$		53.8582	
111	2s5f	$^3F_4{}^o$		53.8593	
112	2s5f	$^1F_3{}^o$		53.8808	
113	2p5s	$^3P_0{}^o$		55.8720	
114	2p5s	$^3P_1{}^o$		55.8847	
115	2p5p	$^3D_1$		56.0145	
116	2p5p	$^3S_1$		56.0571	
117	2p5p	$^3D_2$		56.0652	
118	2p5p	$^3P_0$		56.0948	
119	2p5s	$^3P_2{}^o$		56.1001	
⋆120	2p5d	$^3F_2{}^o$		56.1341	
⋆121	2p5s	$^1P_1{}^o$		56.1342	
122	2p5d	$^3F_3{}^o$		56.1786	
123	2p5d	$^3D_2{}^o$		56.1801	
124	2p5d	$^3D_1{}^o$		56.2048	
125	2p5f	$^3G_3$		56.2106	
126	2p5f	$^3F_3$		56.2184	
127	2p5f	$^3G_4$		56.2204	
128	2p5f	$^3F_2$		56.2213	
129	2p5p	$^1P_1$		56.2522	
130	2p5p	$^3D_3$		56.2645	
131	2p5p	$^3P_1$		56.2746	
132	2p5p	$^3P_2$		56.2893	
133	2p5p	$^1S_0$		56.3348	
134	2p5p	$^1D_2$		56.3404	
135	2p5d	$^3F_4{}^o$		56.3682	
136	2p5d	$^1D_2{}^o$		56.3741	
137	2p5d	$^3D_3{}^o$		56.3961	
138	2p5d	$^3P_2{}^o$		56.4151	
139	2p5d	$^3P_1{}^o$		56.4201	
140	2s6s	$^3S_1$		56.4301	
141	2p5d	$^3P_0{}^o$		56.4241	
142	2p5f	$^1F_3$		56.4327	
143	2p5f	$^3F_4$		56.4375	
144	2p5f	$^3D_3$		56.4503	
145	2p5f	$^3G_5$		56.4509	
146	2p5f	$^3D_2$		56.4539	
147	2p5f	$^1G_4$		56.4647	
148	2p5f	$^3D_1$		56.4709	
149	2p5d	$^1F_3{}^o$		56.4777	
150	2p5f	$^1D_2$		56.4817	
151	2p5d	$^1P_1{}^o$		56.4891	
152	2s6s	$^1S_0$		56.5392	
153	2s7s	$^3S_1$		58.1432	
154	2s7s	$^1S_0$		58.1709	
155	2s8s	$^3S_1$		59.2645	
156	2s8s	$^1S_0$		59.2821	

Expt.: NIST (`http://www.physics.nist/gov/PhysRefData`) for n=2 and Khardi et al. (1994) for n=3 and 4 levels.
DFS: Zhang & Sampson(1992) for n=2 and Sampson et al. (1984) for n=3 levels.
⋆: Level has changed order with the inclusion of Breit and QED effects