IMPORTANCE OF ATOMIC AND MOLECULAR RESEARCH FOR ASTRONOMICAL INTERPRETATION

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1. INTRODUCTION

Our understanding of astronomical objects is dependent, primarily, on the analysis of the electromagnetic radiation received from them. Study of this radiation provides us with the information about the physical conditions such as temperature, density, and chemical composition prevailing in astronomical sources. Physical conditions in stellar sources are usually far from the thermodynamic equilibrium. Therefore, for quantitative analysis of astronomical spectra it is essential to consider explicitly the individual atomic and molecular processes entering into the analysis.

The present day astronomical observations span almost the entire electromagnetic spectrum.Till the advent of space probes, astronomers had to content themselves with ground based observations made mainly within the optical and radio windows of the electromagnetic spectrum. The use of rockets and satellites in astronomical research opened up new spectral regions for spectroscopic observations. With the launch of Copernicus satellite in 1972, observations of ultraviolet spectra of bright stars at high spectral resolution became possible. Later in 1978, the launch of the International Ultraviolet Explorer (IUE) extended these studies to considerably fainter objects. For the x-ray studies, Einstein satellite was launched in 1978 for studying a limited number of bright x-ray sources. Later in 1983, EXOST (European x-ray observatory satellite) was launched for a more extensive study within the x-ray band.

For observations at longer wavelenngths, IRAS (Infrared astronomical satellite) was put into orbit in 1983. This is the first space mission intended for a deep survey of the sky at longer wavelengths. Observations at infrared wavelengths may yield new and valuable information about practically all kinds of astronomical objects. For instance, number of molecules radiate at infrared wavelengths. Longward at 1 μm, there are a number of transitions from atoms and ions, some arising from highly ionized elements as forbidden lines.

The most advanced project, to date, is the space telescope (ST). It is a 2.4 m telescope for studies at ultraviolet and optical wavelengths. It would have the capability, in principle, to gain spectral information of very faint objects, as faint as Jupiter at a distance of 10 light years.

Table 1 from Gahm1) summarises the various space missions with their spectral characteristics. Table 2 from Gahm1) gives the important transitions of cosmically abundant elements in the wavelength range 100-1200 Å. This spectral range, which has been poorly explored uptil now, is of great importance astrophysically, since a number of strong transitions arise from ions forming at temperatures of 10^4 to 10^6K. This range is covered in the project Soho (Solar high resolution observatory).

Let us examine the need for atomic data in a few specific astronomical objects.

2. ATOMIC DATA

The most important cosmic source, nearer home, is our Sun. The solar atmosphere has been divided, for practical purposes into temperature shown in Fig.1. The lowest temperature layer called the photosphere comprises mainly neutral and singly ionized species spectra in the visible and infrared are the basic data for photospheric studies. To improve upon existing photospheric models we need to have accurate, at least to the order of 5 to 10%, oscillator strengths and transition probabilities for once ionized elements of iron group, and in particular FeII. Emission lines, in the range of 10 to 13 m, of abundant neutrals MgI, AlI and SiI have been seen but data for these lines are lacking. In an excellent article Grevesse2) has listed many specific needs for accurate atomic data for improving our understanding of solar photosphere. Blackwell et al3,4) have measured oscillator strengths for some transitions of TiI and CrI.

In the higher temperature layers, chromosphere-transition zone and

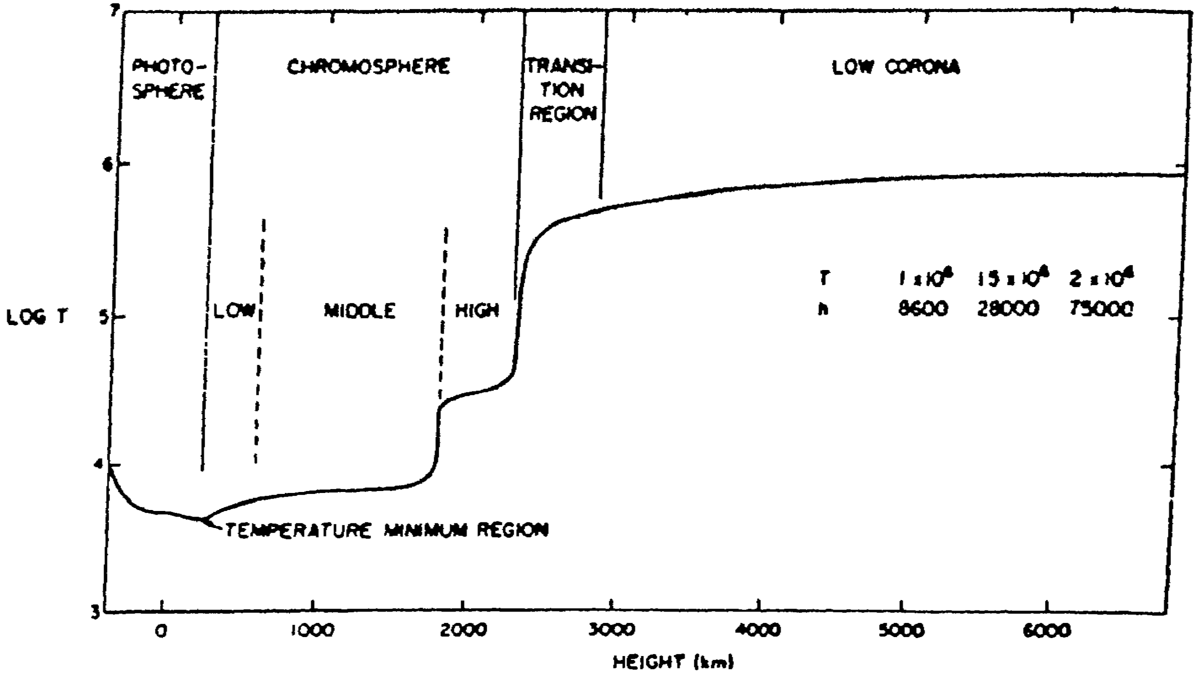

Fig. 1: An illustrative temperature model for the chromosphere, transition region and inner corona.

Courtsey: R. Grant Athay, The Solar Chromosphere and Corona: Quiet Sun. Astrophysics and Space Science Library Vol. 53, Reidel Publications, 1976.

Table 1: Characteristics of the spectrometers on the space missions*

Project	Wavelength or energy region	Spectral Resolution
IUE	1150-3200 Å	300.10^4
Exosat	0.03-2 keV	$\Delta\lambda = 1$ Å ($\lambda < 40$ Å)
		$\Delta\lambda = 2$-4 Å (250 430 Å)
		$\Delta\lambda = 1$-2 Å ($40 < \lambda < 250$ Å)
ST	1050-3200 Å	2×10^4
	1100-3200 Å	1.2×10^5
	1140-10100 Å	10^3, 10^2
FUSE	100-912 Å	10^3, 10^4
	912-1200 Å	3×10^4
SOHO	90-1300 Å	$\Delta\lambda = 0.1, 0.01$ Å
XMM	0.1-10 keV	10, 10^2, 10^3
IRAS	7-23 μm	14-35
ISO	2-70 μm	10^3-10^5
FIRST	100-200 μm	10^4
	300-650 μm	10^6

* Courtsey G. Gahm[1] (1984)

corona, temperatures range from 5×10^4 to 2×10^6 K. In these layers an element exhibits itself in several ionization stages emitting spectral lines characteristic of each ionic stage. Here, we have spectral lines ranging from near ultraviolet to hard x-rays. In a few cases, the ionic species emit forbidden lines which lie in visible and near infrared regions. Very recently Noyes et al5) (see Table 3) have published an extensive list of spectral lines, $\lambda\lambda$ 303-1134 Å, emitted by sunspot plumes. In a subsequent paper Doyle et al6) carried out a diagnostic study of the spectrum. It was observed that reliable excitation rates and collision strengths for stronger transitions are still needed. In particular, contributions of resonances to collision strengths for inter system transitions should be examined. It would be equally important to have excitation rates for weaker transitions of the emitting ions.

Table 2: Interesting transitions of abundant elements in the wavelength range 100-1200 A*

Ion	λ (A)	Ion	λ(A)
H,D	912-1025	OI	900-1040
HeI	505-584	II	430, 539, 833
II	228-303	III	507, 732, 832
			228-374
CI	945-1100	IV	554, 608, 787
II	1036, 687		195-279
III	977, 1175	V	629, 172, 135
	270-386	VI	105, 115
IV	212-312	NeI	735, 744
NI	950-1200		587-629
II	915, 1084	II	384-460
	529, 533	III	227-283
III	989		313, 488, 489
	374-684	IV	150-208
	268-332		541
IV	765, 211, 247	V	568, 480, 356
V	148, 165		119-174
		VI	465
		VII	111-443
			558
		VIII	775

* Courtsey G. Gahm[1] (1984).

At x-ray wavelengths FeXVII produces some of the brightest lines observed not only in solar corona but also in non-solar cosmic objects. Smith et al[7] have made a synoptic study of this neon-like ion, and have suggested the computation of excitation rates to a wide variety of levels in order to obtain correct net population rates of upper levels of important line

Table 3: Line identifications and intensities for the spectrum of a sunspot PLUMI*

λ_{obs}	Identification	Note	$\int I d\lambda$	Note	C_{max}	Comments
1342.9	Si III λ1342.4	2	48	2	2.1	sum of Si III components
1335.5	C II λ1335.7	4	2590	4	86	sum of CII components
1329.2	C I λ1329	3	80	3	4.2	sum of CI components
1326.7	SV λ663.2(2)	4	[56]		3.8	
1323.6	SIV λ661.4(2)	4	[140]		9.6	
1319.6	SV λ659.9(2)	2	[27]		1.6	
1316.8	SV λ658.3(2)	2	[23]		2.3	
1314.9	SIV λ657.3(2)	3	[81]		4.9	
1309.4	SII λ1309.3	3	145	3	7.8	
1305.4	O I λ1305	4	1830	4	75	sum of OI $\lambda\lambda$1304.9, 1306.0
1302.3	O I λ1302.2	4	800	4	44	
1298.9	Si III λ1299.0	3	105	4	4.4	
1293.7	Ca V λ646.6(2)	3			7.1	
1291.4	Mg VIII λ430.5(3)	1			3.4	
1288.4	unidentified		95	3	6.0	
1284.0	Ca VI λ641.9(2)	3			5.6	
1278.2	Ca VII λ639.2(2)	3			13	
1275.7	Ca V λ637.9(2)	3			4.0	
1267.6	Ca VI λ633.8(2)	3			4.8	
1264.9	Si II λ1264.7	4	301	4	24	
1259.6	O V λ629.7(2)	4			2200	
1256.5	Si I λ1256.5	2	50	2	3.6	
1253.5	S II λ1253.8	2	44	2	3.1	
1251.4	O IV λ625.8(2)	3	[52]		5.4	
1249.7	Mg X λ624.9(2)	4	[349]		44	
1242.9	N V λ1242.8	4	1020	4	93	
1238.9	N V λ1238.8	4	2000	4	180	
1233.7	O IV λ617.0(2)	4			7.4	

1228.2	N I λ1228.8	2	23	1	3.2	sum of several N I components
1218.0	O V λ1218.4	4	5000	3	540	
1215.3	H I λ1215.7	4	216000	4	24000	
1209.4	unidentified				14	
1206.3	Si III λ1206.5	4	2820	4	352	
1202.0	unidentified		201	3	15	
1199.1	O III λ599.6(2)	3			79	
1193.7	S III λ1194.2	4	353	4	45	blend with Ca VIII λ596.9(2)
1190.1	S III λ1190.2	4	321	4	40	
1185.0	N III λ1184.5	1	9	1		
1175.1	C III λ1175.8	4	1150		148	sum of several C III components
1171.1	Ar VII λ585.8(2)	4			32	possible blend (see first-order line)
1168.4	He I λ584.3(2)	4			402	
1165.5	Ca VIII λ582.8(2)	2			17	
1163.5	unidentified		305	4	49	
1161.7	unidentified		29	3	5.2	
1158.3	C I λλ1555.8-1159.0	3	120	2	10.6	sum of many C I lines
1152.1	O I 1152.2	2	39	2	5.7	
1148.1	Ca X λ574.0(2)	4			20.7	blend
1144.8	Ne V λ572.3(2)	4			113	
1139.6	Ne V λ569.8(2)	4			83	
1136.6	Ne V λ568.4(2)	4			33	
1133.7	N I λ1134.5	3	42	3	7.1	
1128.6	Si IV λ1128.3	4	258	4	40	
1125.5	Ne VI λ562.8(2)	4			176	
1122.7	Si IV λ1122.5	4	283	4	45	
1118.9	unidentified					
1117.5	Ne VI λ558.6(2)	4	[910]		100	
1115.5	Ca X λ557.7(2)	2	[70]	1	30	
1113.2	Si III λ1113.3	3	91	3	16	

1108.6	O IV λ554.4(2)	4			910	sum of all O IV components
1103.2	Ca VII λ551.5(2)	4			39	
1100.1	Al XI λ550.0(2)	4			27	
1097.8	Ar VI λ548.9(2)	3			11.4	
1095.2	unidentified		65	2	12.6	
1087.6	Ne IV λ543.9(2)	4			57	
1084.6	N II λ1084.6	4	439	3	73	sum of several N II components
1082.2	Ne IV λ541.1(2)	2			16	
1078.7	Cl II λ1079.1	1	50	2	11	
1076.8	S III λ1077.1	2	64	2	11	
1073.0	S IV λ1073.0	3	173	2	68	I corrected for blend with He 537(2)
1068.9	unidentified		37	1	12	
1067.0	Si IV λ1066.6	1	36	1	8	blend with Ar I λ1066.7
1062.6	S IV λ1062.7	4	10	3	24	
1060.1	Ca VI λ530.3(2)	1			5.2	
1056.4	unidentified		17	1	4.4	
1053.4	Fe IV λ526.6(2)	2			6.9	
1051.3	O III λ525.8(2)	4			31	
1048.9	unidentified		40	3	12	blend, with Ar I λ1048.2
1043.8	He I λ522.2(2)	4			19	
1041.2	Si XII λ520.7(2)	4			14	
1037.6	O VI λ1037.6	4	8270	4	2420	
1032.2	O VI λ1031.9	4	14600	4	4450	
1027.9	O I λ1027.4	3	71	2	25	
1025.8	H I λ1025.7	4	3380	4	1050	
1020.5	S III λ1021.2	2	28	2	9	blend with Si II λ1020.7
1016.0	O III λ508.2(2)	4			35	
1012.6	S III λ1012.5	2	20	2	7.1	
1010.2	C II λ1010.2	4	58	3	15	blend of three C II components

1006.0	Ne VI λ1006.1	4	71	4	25	
999.8	Ne VI λ999.6	4	144	4	49	
997.7	Si XII λ499.4(2)	4			12	blend with Si III λ997.4
995.6	Si III λ994.8	2	22	2	8.0	
992.2	N III λ991.5	4	264	3	85	sum of N III λλ991.51, 991.58, blend with He II λ992.4
989.9	N III λ989.8	4	163	3	59	
983.4	Na VII λ492.0(2)	4			15	
979.5	N III λ978.8	1	20	3	8	
977.0	C III λ977.0	4	2630	4	1070	
972.5	H I λ972.5	4	798	4	322	
966.2	Ne V λ483.0(2)	4			43	
962.6	Ne V λ481.3(2)	4			24	
960.7	Ne V λ480.4(2)	4			10	
958.8	He II λ958.7	4	26	3	10	
949.9	H I λ949.7	4	365	4	160	
944.6	S VI λ944.5	4	428	4	195	
942.3	He II λ942.5	3	19	2	8	
940.0	Ne IV λ469.8(2)	4			20	
937.9	H I λ937.8	4	186	4	85	
933.4	S VI λ933.4	4	787	4	366	
930.7	Ne VII λ465.2(2)	4			230	blend with H I λ930.7
926.0	H I λ926.2	4	85	3	38	
923.2	N IV λ923.3	4	252	3	125	blend with H I λ923.2
918.7	P III λ918.7	1	17	2	10	
915.8	N II λ916.0	3	35	3	23	
904.5	C II λ904.1	4	92	3	22	sum of several C II components
895.2	Ne VII λ895.2	4	135	3	61	
885.8	unidentified		12	1	14	
873.3	Mg VIII λ436.7(2)	4	[1210]		49	
871.9	Ne VI λ435.6(2)	2	[560]		30	blend with Ca VIII λ 436.1(2)
869.3	Mg VII λ434.9(2)	3	[2650]		69	

866.8	Ne VI λ433.2(2)	3	[570]		30	
862.6	Mg VII λ431.3(2)	4	[1550]		35	
860.9	Mg VIII λ430.5(2)	4	[850]		27	
858.5	Mg VII λ429.1(2)	4	[440]		12	
854.9	S V λ854.8	4	49	3	30	
851.7	S V λ852.2	2	14	2	9	
849.5	S V λ849.2	1	13	1	7.5	
844.3	Ar IV λ843.8	1	13	1	8.6	
840.0	Ar IV λ840.0	1	9	1	10	
835.1	O III λ835.2	4	648	4	300	blend with O II λ834.5
833.5	O III λ833.3	4	456	4	245	blend with O II λ833.1
829.2	unidentified		11	2	9.4	
827.5	Ar V λ827.1	1	8	1	6.5	
822.2	Na VII λ411.1(2)	4			16	
817.9	Si IV λ818.1	3	13	2	7.5	
815.8	S IV λ816.0	4	24	3	10.5	blemd with Si IV λ815.0
809.6	S IV λ809.7	4	13	3	8	
806.7	Mg VI λ403.3(2)	4			75	blemd with Ne VI λ403.3(2)
803.7	Ne VI λ401.9(2)	4			63	
801.4	Mg VI λ400.7(2)	4			62	
798.8	Ne VI λ399.8(2)	3			23	blend with Mg VI λ399.3(2)
790.3	O IV λ790.2	4	3320	4	1575	
788.0	O IV λ787.7	4	1920	3	925	
786.9	S V λ786.5	3	700	1	480	on wings of O IV λ788
782.6	Mg VIII(see text)		27	3	13	
780.2	Ne VIII λ780.3	4	380	4	403	
775.0	O V λ774.5	4	80	4	35	
772.3	Mg VIII (see text)		53	3	27	
770.4	Ne VIII λ770.4	4	672	4	290	
767.4	Ar VI λ767.1	3	17	3	8.7	
765.1	N IV λ765.1	4	876	4	385	blend with N III λ764.4
760.3	O V λ761.1	4	2320	4	626	sum of several O V components

754.0	S IV λ753.8	4	27	3	12	blend with Ar VI λ754.9
749.9	S IV λ750.2	4	110	3	43	
748.0	S IV λ748.4	4	49	3	23	
745.1	S IV λ744.9	4	28	3	12	blend with K IV λ745.3
743.2	unidentified		6	2	3	
740.4	unidentified		48	3	15	possible blend
736.1	Mg VII λ367.7(2)	4			38	blend with Mg IX λ368.1(2)
730.8	Mg VII λ365.2(2)	3			12	
728.4	Mg VII λ363.8(2)		16	3	7	blend with S III λ728.7
725.7	unidentified		8	2	5	
724.2	K VI λ724.3		15	3	5	
721.2	unidentified		60	3	23	
718.3	O II λ718.6	4	60	3	19	
716.2	Ne V λ338.5(2)	3			6	blend with K VI λ716.0
712.8	S VI λ712.7	4	68	3	26	blend with Ar VIII λ713.8
710.5	K VI λ710.5	1	27	2	18	
706.3	Mg IX λ705.8	4	121	4	45	blend with Ar V λ705.4
703.3	O III λ703.3	4	833	3	275	sum of several components
700.4	Ar VIII λ700.4	4	61	4	22	
697.2	unidentified		80	3	28	
694.4	Na IX λ694.2	4	58	4	21	
691.1	unidentified		57	3	18	
685.7	N III λ685.8	4	155	3	51	sum of several components
681.2	Na IX λ681.7	4	106	3	30	blend with Ar II λ679.4
677.4	Ar II λ677.9	1	21	2	8	
671.1	unidentified		42	3	14	
663.0	S V λ663.2	4	56	4	34	
660.9	S IV λ661.4	4	140	3	54	
657.0	S IV λ657.3	4	81	4	32	blend with S V λ658.3
651.5	Ca V λ651.5	4	11	3	6	
646.8	Ca V λ646.6	4	32	4	15	

644.1	O III λ644.4	2	11	2	6	
642.1	Ca VI λ641.9	4	77	4	33	
638.8	Ca VII λ639.2	4	113	4	50	
636.2	K IX λ636.3	3	17	3	7.1	
633.7	Ca VI λ633.8	4	49	3	24	
629.7	O V λ629.7	4	18700	4	9060	
	Mg X λ624.9	4	357	3		Deconvolved from
624.9	O IV λ625.8	4	44	3	178	ratio of second-order lines
621.1	K IX λ621.4	4	24	3	10	
	O IV λ617.0	4	44	4	21	sum of three components deconvolved assuming
616.8	O IV λ609.3	4	1220	3	750	I(Mg Xλ610) = 2I(Mg Xλ625) blend with Ca VIλ600.9
609.6	Mg X λ609.8	4	732	3		
601.6	Ca VI λ601.7	4	92	2	51	blend with Ca VI λ600.9
599.5	O III λ599.6	4	342	4	165	
597.2	O III λ597.8	4	135	4	74	blend with Ca VIII λ596.9
592.5	unidentified		13	3	7	
586.3	Ar VII λ585.8	4	173	3	72	
584.4	He I λ584.3	4	2780	4	1230	
582.8	Ca VIII λ582.8	4	77	2	29	
581.2	Si XI λ581	1	41		20	
574.3	Ca X λ574.0	3	42	2	39	15% C III λ574.3 assuming I(CaX λ574)= 1/2 I(Ca Xλ558)
572.5	Ne V λ572.3	4	637	4	247	
569.9	Ne V λ569.8	4	480	4	170	
568.3	Ne V λ568.4	4	172	4	71	
564.9	Ne VII λ564.5	4	47	3	18	
562.9	Ne VI λ562.8	4	1080	4	390	
558.4	Ne VI λ558.6	3	980	3	220	blend with Ca Xλ557.7 see second order sum of several O IV components

554.2	O IV λ554.3	4	7590	4	2230	
551.0	Ca VII λ551.5	4	224	3	69	
549.3	Al XI λ550.0	3	112	2	45	
543.9	Ne IV λ543.9	4	355	4	110	
541.9	Ne IV λ541.6	4	247	4	75	sum of two components
539.0	unidentified		68	3	22	
537.3	He I λ537.0	4	336	4	91	
535.0	F VI λ535.2	1	80	3	19	
530.3	Ca VI λ530.3	1	32	2	5.9	
526.0	O III λ525.8	4	235	4	53	probable blend with Fe IV 526
522.0	He I λ522.2	4	194	4	38	
	K VIII λ519.4	4	70	3	23	deconvolved assuming
519.9	Si XII	4	70	3		I(Si XII λ521)= 1/2I(Si XII λ499)
515.7	He I λ515.6	4	73	4	13	
511.8	He I λ512.1	4	57	2	12	
508.0	O III λ508.2	4	360	4	57	
499.4	Si XII λ499.4	4	141	4	19	
494.8	Na VI λ494.4	4	89	3	10	
491.8	Na VII λ492.0	4	194	4	20	blend with Na VI λ491.3
489.2	Na VI λ489.6	3	52	2	6	
487.1	Na VII λ486.7	4	128	4	12	
482.9	Ne V λ483.0	4	583	4	49	
	Ne V λ481.3	4	331	2	35	deconvolved using resolved second-order lines
480.9	Ne V λ480.4	4	135	2		
476.7	Ar VII λ475.7	2	17	1	2.7	
474.3	Ar VII λ473.9	2	17	1	2.3	
471.1	Ca VIII λ471.2	2	34	2	3.8	
465.2	Ne VII λ465.2	4	3860	4	213	
461.8	Ar VI λ462.0	4	286	4	14	
457.3	Si IV λ457.8	3	57	2	4.0	

454.3	Ne VI λ454.1	1	36	2	3.5	
443.5	Mg IX λ444.0	2	122	1	5.1	
440.8	Mg IX λ441.2	1	226	1	6.0	probable blend: line too strong with respect to Mg IX λ444.0
435.2	Mg VII λ434.9	4	4990	4	65	heavily blended: see second order
430.2	Mg VII λ430.6	4	2840	3	41	heavily blended: see second order
416.0	Ne V λ416.2	3	1970	4	21	
410.9	Na VIII λ411.1	4	960	4	10.3	
407.3	Ca VII λ407.8	1	293	2	2.3	
403.1	Mg VI λ403.3	4	8100	3	64	blend with Ne VI λ 403.3
401.1	Mg VI λ400.7	4	9720	2	57	heavily blended: see second order
395.2	O III λ395.6	2	420	1	2.5	blend with Ca VI λ 396.9
392.3	Al IX λ392.4	2	477	1	3.8	
387.6	Mg VI λ387.9	4	1250	4	7.9	sum of two components
384.4	Al IX λ385.0	2	780	1	3.4	possible blend: line too strong with respect to Al IX λ392.4
379.1	unidentified		1240	1	5.3	
373.6	O III λ374.1	4	920	1	3.4	
367.7	Mg VII λ367.7	4	8950	4	27	blend with Mg IX λ368.1
364.9	Mg VII λ365.2	3	3550	2	8.3	blend with Mg VII λ363.8
359.1	Ne V λ359.4	3	2750	3	5.8	
353.1	Mg V λ353.1	3	5860	2	7.8	
348.9	Mg VI λ349.2	1	4600	2	5.9	
338.9	Mg VII λ339.0	2	2050	1	1.9	
335.1	Mg VII λ335.2	2	2500	1	2.0	
314.6	Mg VI λ314.7	1	3120	1	1.1	
303.8	He II λ303.8	4	25500	2	4.8	

NOTES - Identification are as follows :

(4) certain; (3) nearly certain; (2) probable; (1) possible.

Intensities are as follows:

(4) well determined: $|\Delta \log I| \lesssim 0.05$ (10 1.12); (3) reasonably well determined : | log I | 0.15 (10 1.4); (2) approximately determined: | log I| 0.25 (10 1.8); (1) poorly determined:| log I| 0.35 (10 2.2)

* Courtsey Noyes et al$^{5)}$ (1985).

transitions. Similar synoptic calculations are very much needed for FeXVIII through FeXXII and FeXII to FeXVI.

In addition to the study of x-ray spectra of FeXVII, two very detailed theoretical investigations have been reported in literature concerning x-radiation. Doschek and Cowan8) have prepared a solar spectral line list between 10 and 200 Å for application to high resolution x-ray astronomy. The spectral line list contains 600 lines dominated by highly stripped iron ions relevant to the temperature range 10^5 to 10^7 K. In another extensive study Mewe et al9) have tabulated intensities of 2131 x-ray lines over the temperature range of 3×10^4 to 10^9 K. These two analyses highlight the crucial need for large number of reliable atomic data to facilitate the interpretation of stellar spectra.

Let us now examine another interesting cosmic source not far away from our Sun. Recently Voyager flyby of Jupiter has revealed bright extreme ultraviolet lines of oxygen and Sulphur ions in the vicinity of the satellite Io. UV spectra of Io torus have also been observed by IUE as well as rocket borne faint object telescope (FOT). FOT has revealed, for the first time, emission features of neutral sulphur and oxygen. Ho and Henry10) have computed oscillator strengths and collision strengths for neutral sulphur. There is need to improve upon their calculations. In a more recent paper Ho and Henry11) presented results of collision strengths for intercombination lines of SIII. They have ignored the contribution of resonances. This contribution, has to be considered for arriving at more reliable collision strength values. Dufton et al12,13) have considered the contribution of resonances to excitation cross sections of SV transitions.

The intersystem lines of SIII were first detected in Io torus which lead to their identification in the laboratory plasma by Smith et al14). In another study, concerning Io torus plasma, Carol Johnson et al15) have measured the decay rate $^5S_2^o$ metastable level of OIII ion.

In intersystem lines of low Z ions, as mentioned above, are observed in many types of astronomical objects: the solar transition zone, cool stars, novae, symbiotic stars HII regions, diffuse interstellar clouds, planetary nebulae, and many others. Several line intensity ratios for an allowed to an intersystem line have been found to be electron density sensitive.

The planetary nebulae constitute rich and challenging atomic physics laboratories but the atomic processes therein are difficult to reproduce and measure in terrestrial laboratories. The atomic data required to interpret the conditions in planetary nebulae are therefore obtained mainly by calculation. In an extensive review article Mendoza[16)] has mentioned a few specific areas for systematic investigations for future work.

Specifically, there is need for cross sections and A-values for transitions in iron ions like FeIII, FeV, FeVI and FeVII [Aller et al[17)]]. In a recent paper, Czyzak et al[18)] have made a critical appraisal of atomic structure calculations and nebular diagnostics.

Among the variety of astronomical objects, there is one group called chemically peculiar stars (CP stars). These CP stars show strong deviation from "standard cosmical chemical and isotope abundances", upto 3-5 orders of magnitude (on the higher or lower side). Some of these stars show great overabundance of rare earth elements. Problems relating to the need of atomic data for the study of CP stars have been addressed to in detail by Cowley[19)] and Dworetsky et al[20)].

Apart from the individual astronomical objects, the physical understanding of the overall pervading interstellar medium (ISM) also needs a wide variety of atomic parameters. For instance, high resolution spectra provided by Copernicus and IUE satellites has raised problems concerning line identifications and accurate oscillator strengths for many spectral lines of neutrals. Even for the most abundant elements in the universe like C,N,O f-values of many strong UV lines have large uncertainties, and f-values of weaker lines are often uncertain. A couple of most recent studies in this context are by Dufton et al[12,13)] and by Goldbach et al[21)].

For the analysis of stellar spectra, we need to know not only various cross sections but also ionization equilibrium fractions of elements in question. It is known that many astrophysical plasmas are actually in non-equilibrium ionization state and we need ionization and recombination rate coefficients over a wide range of temperatures. Arnaud and Rothenflug[22] have carried out an updated evaluation of recombination and ionization rates. More recently Pe'quignot and Aldrovandi[23] have studied the ionization balance in ISM. Some of the charge exchange rates that enter into ionization equilibrium calculations need to be recalculated. Some of the most recent studies by Opradolce et al[24], Clegg and Walsh[25] and by Clegg et al[26] are notable.

3. MOLECULAR DATA

At present about 100 different molecules and molecular ions have been found in spectra of astrophysical objects: planetary and stellar atmospheres, comets, interstellar medium, and circumstellar envelopes. The main problem here is identification of faint molecular bands in optical and ultraviolet ranges. In cometry spectra we have optical fluorescence of CH, CH^+, NH, OH, OH^+, CN, C_2, CO^+, NH_2, H_2O^+, C_3, CO_2^+ by solar radiation and planetary atmospheres exhibit molecular bands of CO, N_2, O_2, HF, HCl, H_2O, SO_2, HCN, NH_3, PH_3, CH_4, C_2H_2, C_2H_6 in the infrared range.

The greatest variety of molecule's have been detected in the interstellar medium. Upto now, more than fifty molecules or radicals have been identified in the ISM [Kutner[27]]. Most of the molecules were detected at radio wavelengths and mainly in millimeter range.

Two recent investigations in the submm band are in M42 by Viscusso et al[28];a line search of the Orion molecular cloud core by White et al[29].

With the discovery of more and more complex molecules, chemical modelling of interstellar clouds has been attempted. Inspite of numerous studies some problems remain unsolved, such as the question of the abundances are very sensitive to the physical condition prevailing in interstellar clouds (density, temperature, element abundances in the gas phase, gas to dust ratio) and in their environment (interstellar fluxes of cosmic rays and ultraviolet photons). Therefore, a comparison between the computed and observed abundances of chemical species is a powerful tool to get insight into the physical properties of interstellar clouds.

The use of interstellar cloud models to derive the properties of a real observed cloud requires a good knowledge of the chemical reaction rates at low temperatures and absorption cross sections of ultraviolet photons. Perhaps, the most significant advance recently is a measurement by Adams et al$^{30)}$ of the electronic recombination of the H_3^+ ion, which appears to have a very low rate: $< 2 \times 10^{-8}$ cm^{3}s^{-1} at T = 95 K. This rate is about 40 times lower than the previous measurement of McGowan et al$^{31)}$ which has been used so far in interstellar cloud models [Viala$^{32)}$].

In a detailed study Viala$^{32)}$ has considered chemical equilibrium from diffuse to dense interstellar clouds. The chemical scheme comprised 1074 reactions among 80 species formed from H, C, N and O. He, Mg, Si, Fe and S were included because of their importance in ionization equilibrium. Only simple molecules such as C_2, N_2, O_2, CN, CO, NO, HCN, HCO, HNO, H_2CO and corresponding ions were considered. More complex molecules, observed in interstellar clouds (e.g. C_4H, CH_2NH, CH_3OH, CH_2CO, CH_3NH_3, C_2H_5OH, the cyanopolynes $HC_{2n+1}N$) were not considered. Data on rate constants were available only for half the reactions considered and a Langevin rate constant for ion-molecule reactions or an estimated value (by comparison with similar reaction) were used. Most reactions have several different channels. When product distributions were unknown, same probability was assumed for each channel.

Tarafdar et al$^{33)}$ have studied the chemistry in dynamically evolving clouds. The motivation is to explore the possible existence of a unifying link underlying the great diversity exhibited by interstellar clouds. On the one end of the spectrum are very diffuse clouds (n $\sim$ 10-100 cm^{-3} ; 60 $<$ T $<$ a few hundred Kelvin), where the matter is mostly in atomic form. On the other end of the spectrum we have dense clouds (n $\sim 10^5$-10^6 cm^{-3}) which are very cool (T $\lesssim$ 10-20 K). Some of the rate constants used by Tarafdar et al need revision. For instance, reported rate constants of the radiative association reactions $C^+ + H_2 \longrightarrow CH_2^+ + h\nu$ and $CH_3^+ + H_2 \longrightarrow CH_5^+ + H$ span a wide range of values. e.g. 10^{-15} - 10^{-11} cm^{3}s^{-1} at 10 - 20 K for the reaction of CH_3^+ with H_2. Moreover, accurate f-values for the discrete transitions in CO are not well established.

Finally, I would like to draw attention to the induction of a new important component into the interstellar medium, namely Polycyclic Aromatic Hydrocarbons (PAH). Lager and Puget[34)] have suggested that these PAH's could be responsible for most of the unidentified infrared emission bands which are associated with ultraviolet rich regions of planetary and reflection nebulae, HII regions, stellar objects, and extragalactic sources. PAH's may also be the likely carriers of more than 40 broad diffuse interstellar absorption bands which extend from about 4400 Å into the near infrared. A great deal of laboratory and theoretical work is called for. (van der Zwet and Allamanda[35)], Omont[36)]].

In conclusion, astronomical observations at high spectral resolution, in recent years, have generated data over a wide spectral range. To improve our understanding of physical conditions in astrophysical environments, on the basis of the extended data set, we need many more reliable atomic and molecular parameters than in the past. It might be appropriate, at this point, to cite a few specific reference material as guidelines, to further atomic and molecular research relevant to astronomical interpretations. These are the following :

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   Lund, August 17-19, 1983 Edited by U. Litzen, Physica Scripta Vol.78, (1984).
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