SPECTROSCOPIC DIAGNOSTICS APPLICABLE TO THE UV AND EUV SPECTRA OF ASTROPHYSICAL SOURCES

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Abstract. A bibliography is provided of the most reliable emission and absorption line ratio diagnostic calculations currently available for application to the spectra of astrophysical sources in the UV and EUV wavelength region (50–3000 Å). References are listed containing diagnostics for species in the Li through P isoelectronic sequences, as well as the iron ions Fe II–Fe XXIII and nickel ions Ni XVII –Ni XXV. Also given is the wavelength range for which diagnostic calculations are presented in each reference, along with the type of diagnostic considered. These include, for example, emission line ratios for determining electron temperatures and densities, and absorption line diagnostics for evaluating hydrogen densities.

1. Introduction

Line ratios involving transitions in the ultraviolet (UV) and extreme ultraviolet (EUV) regions of the spectrum frequently provide excellent temperature and density diagnostics for the emitting or absorbing plasma. Over the past 20 years, many such diagnostics have been developed for application to astronomical spectra, such as those of the solar transition region/corona [33, 154], and stellar and interstellar observations from the *International Ultraviolet Explorer* and *Copernicus* satellites [65, 66, 68]. More recently, new observing opportunities, such as those afforded by the *Hubble Space Telescope* (HST), *Extreme Ultraviolet Explorer* (EUVE) and *Hopkins Ultraviolet Telescope* (HUT), have lead to a large increase in both the quality and quantity of astronomical UV and EUV observations, and there is clearly an urgent requirement for diagnostics which may be applied to the analysis of such data.

There have been several recent reviews on the importance of diagnostics for analysing UV and EUV astronomical spectra [47, 55, 57]. However of particular importance is that of Mason and Monsignori Fossi [141], which discusses the spectroscopic techniques used to study astrophyical plasmas, the atomic processes involved, recent observations and plans for future space missions. My aim therefore is to complement the Mason and Monsignori Fossi review by providing a bibliography of the most reliable emission and absorption line ratio diagnostics currently available for transitions observable in the UV and EUV spectra of astronomical sources. Such diagnostics will not only be applicable to observations from, for example, *Skylab*, HST, EUVE, and HUT, but will also be useful for analysing

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data from upcoming missions such as the *Solar and Heliospheric Observatory* (SOHO).

2. Bibliography of Diagnostic Calculations

In Tables II–XV, I list references to the most reliable diagnostic calculations currently available for application to astronomical spectra in the UV and EUV wavelength range, 50–3000 Å. Species are listed by isoelectronic sequence, apart from ions of Fe and Ni which are considered separately. After each species, I summarise the wavelength range for which diagnostic calculations are presented in the relevant reference. In some instances, references contain diagnostics involving transitions over a wider wavelength range than that considered here; in these instances I list the full wavelength coverage of the diagnostics. For example, the Fe XIII diagnostic calculations of [156] consider not only the EUV lines at ~202 Å, but also the IR transitions at ~1.08 μm, while [26] similarly provide data for both UV (~910 Å) and optical (~6731 Å) lines in S II. Also listed in the tables are one or more of the letters a–j, which indicate the type of diagnostic given in the relevant reference, the index to the different types being summarised in Table I. It is clear from an inspection of the tables that the vast majority of the diagnostics are emission line electron temperature or density diagnostics; this is not surprising as most work in this area has been performed in order to analyse solar or nebular emission line spectra.

Omitted from Tables II–XV are diagnostics for H-like, He-like, and F-like ions, as to the best of my knowledge there are no calculations for these sequences applicable to spectra in the 50–3000 Å wavelength range, apart from electron temperature sensitive emission line ratios involving the He II 256–304 Å lines [27] and the Ar X 165–4257 Å transitions [54]. Nor do I list diagnostics that involve lines from different elements, as these are rather limited in number and are summarised by [52, 106, 108] and references therein.

I would like to apologize in advance to anyone whose work has been inadvertently omitted from the tables. For the future, I would be grateful if readers would inform me of such omissions, and also of any of their more recent diagnostic work that could be included in future versions of these tables.

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TABLE I

Index to types of diagnostics

Index	Diagnostic type
a	Emission line diagnostics of electron temperature (T_e)
b	Emission line diagnostics of electron density (N_e)
c	Emission line diagnostics of photon escape probability
d	Absorption line diagnostics of hydrogen density (N_H)
e	Absorption line diagnostics of electron density (N_e)
f	Emission line diagnostics of photoexcitation rate
g	Emission line diagnostics of optical depth
h	Absorption line diagnostics of electron pressure ($N_e T_e$)
i	Emission line diagnostics of non-Maxwellian electron energy distributions
j	Absorption line diagnostics of electron temperature (T_e)

TABLE II

Diagnostics for Li-like ions

Species	Wavelength range (Å)	Type	Reference
C IV	312–420	a	124
C IV	312–1551	a, b	135
N V	209–1243	a, b	135
O VI	150–1032	a	60
O VI	150–1037	a, b	135
Ne VIII	88–780	a, b	135
Mg X	170–625	a	63

TABLE III

Diagnostics for Be-like ions

Species	Wavelength range (Å)	Type	Reference
C III	386–9710	a, b	15
C III	386–1176	c	76
C III	386–9710	a, b	13
C III	386–1176	a, b	14
C III	1176–1908	a, b	125
C III	1907–1909	b	109
N IV	765–1719	a, b	81
N IV	1486–1719	b	114
N IV	283–284	b	57
N IV	1483–1486	b	132
O V	629–1218	a, b	126
O V	172–2781	a, b	78
O V	1218–1371	b	87
O V	758–762	b	35
Ne VII	465–895	a	82
Ne VII	465–562	b	121
Ne VII	97–135	a, b	136
Mg IX	368–444	b	95
Mg IX	368–448	a	123
Si XI	358–604	a, b	112
S XIII	256–491	a	120
Ar XV	221–424	a	127
Ca XVII	19–371	b	22
Ca XVII	193–371	b	41

TABLE IV

Diagnostics for B-like ions

Species	Wavelength range (Å)	Type	Reference
C II	904–2329	a, b	145
C II	2325–158 μm	a, b	62
C II	2324–2329	b	137
C II	1036–2329	d, e	118
N III	374–57.3 μm	f	73
N III	1747–1754	b	72
N III	1747–1754	b	131
N III	686–1754	a, b	145
N III	989–992	d, e	151
O IV	554–790	a	50
O IV	554–1407	b	48
O IV	1397–1407	b	31
O IV	231–286	b	57
O IV	1343–1407	b	29
O IV	1397–1407	b	90
O IV	1401–25.9 μm	a, b	61
Ne VI	399–563	b	130
Ne VI	402–1006	a, b	133
Na VII	352–871	a, b	148
Mg VIII	75–794	b	51
Mg VIII	317–783	a, b	145
Mg VIII	430–437	b	44
Al IX	385–392	b	89
Al IX	282–392	a, b	148
Al IX	287–704	a, b	145
Si X	50–653	b	51
Si X	258–639	a, b	150
Si X	261–639	a, b	145
S XII	288–555	b	153
S XII	218–300	b	58
S XII	215–539	a, b	145
Ar XIV	187–257	b	34
Ca XVI	208–225	b	34

TABLE V

Diagnostics for C-like ions

Species	Wavelength range (Å)	Type	Reference
C I	1657–1994	g	67
C I	945–1658	d, e	80
C I	945–1658	h	66
N II	915–1086	h	1
N II	2140–6584	a, b	32
O III	1660–1666	f	77
O III	303–1666	a, f	17
O III	599–834	a	84
O III	507–599	a	119
O III	1660–5009	a, b	83
O III	1660–5009	g	75
Ne V	416–572	a, b	86
Ne V	359–572	a	94
Ne V	142–14.3 μm	b	5
Mg VII	278–319	b	49
Mg VII	319–435	b	46
Mg VII	276–435	b	139
Al VIII	285–324	b	46
Si IX	227–258	b	117
Si IX	258–350	b	46
Si IX	55–3.93 μm	b	4
S XI	38–1.92 μm	b, f	74
S XI	190–216	b	110
Ar XIII	210–249	b	92
Ca XV	181–215	b	91
Ca XV	141–161	b	85
Ca XV	22–5695	b	3

TABLE VI

Diagnostics for N-like ions

Species	Wavelength range (Å)	Type	Reference
Ne IV	172–4724	a, b	12
Ne IV	2422–4724	a, b	32
Mg VI	1190–1807	b	56
Mg VI	268–1192	a, b	149
Si VIII	944–1446	b	45
Si VIII	276–320	b	46
Si VIII	214–277	b	57
S X	776–1214	b	45
S X	177–264	b	57
Ar XII	150–225	b	19
Ar XII	650–1058	b	56
Ca XIV	128–194	b	19

TABLE VII

Diagnostics for O-like ions

Species	Wavelength range (Å)	Type	Reference
O I	1025–146 μm	a, b	16
O I	916–1359	d	146
Mg V	2417–2930	a	71
Mg V	276–2784	b	147
Si VII	1894–2351	a	71
Si VII	217–2148	b	147
S IX	1553–1987	a	71
S IX	179–1715	b	147
Ar XI	151–1391	b	147

TABLE VIII

Diagnostics for Ne-like ions

Species	Wavelength range (Å)	Type	Reference
Si V	98–1465	b	11
Ar IX	43–815	b	11

TABLE IX

Diagnostics for Na-like ions

Species	Wavelength range (Å)	Type	Reference
Al III	1379–1863	a	105
Si IV	815–1128	a	100
Si IV	815–1394	a	105
S VI	706–945	a	79
Ca X	411–574	a	111

TABLE X

Diagnostics for Mg-like ions

Species	Wavelength range (Å)	Type	Reference
Al II	2660–2669	b	113
Al II	1670–2669	b	36
Si III	1883–1892	b	109
Si III	1296–1892	b	40
Si III	1301–1313	i	98
Si III	1113–1299	a, b	107
Si III	1206–1892	a, b	142
S V	1199–1502	a, b	38
S V	663–855	a	37
S V	786–1199	a	101

TABLE XI

Diagnostics for Al-like ions

Species	Wavelength range (Å)	Type	Reference
Si II	1808–2350	b	69
Si II	2328–2350	b	43
Si II	1260–1527	a	99
Si II	989–2351	d, e	116
S IV	1062–1073	b	55
S IV	1398–1424	b	39
S IV	656–1070	a	37

TABLE XII

Diagnostics for Si-like ions

Species	Wavelength range (Å)	Type	Reference
S III	1199–1729	a	64
Ar V	420–459	b	57

TABLE XIII

Diagnostics for P-like ions

Species	Wavelength range (Å)	Type	Reference
S II	910–6731	a, b	26

TABLE XIV

Diagnostics for ions of Fe

Species	Wavelength range (Å)	Type	Reference
Fe II	2260–2775	a, g	70
Fe II	921–2631	e, j	115
Fe VI	1944–19.6 μm	a, b	143
Fe VII	2015–6087	a, b	144
Fe IX	171–245	b	23
Fe IX	241–245	b	53
Fe X	170–1.94 μm	b	6
Fe X	170–366	a, b	23
Fe XI	179–353	a, b	23
Fe XI	179–353	b	34
Fe XII	186–383	b	134
Fe XII	364–1242	b	102
Fe XII	195–1242	b	122
Fe XII	1242–1349	b	30
Fe XII	1242–3072	b	152
Fe XIII–XVI	327–348	a	24
Fe XIII	202–1.08 μm	b	156
Fe XIII	252–321	b	103
Fe XIII	196–321	b	34
Fe XIII	196–368	a, b	23
Fe XIV	211–274	b	104
Fe XIV	429–485	b	128
Fe XIV	92–1.25 μm	b	18
Fe XIV	58–60	b	25
Fe XV	224–327	b	42
Fe XV	321–325	b	129
Fe XV	224–7059	b	10
Fe XVI	251–336	a	93
Fe XVII	13–1154	b	2
Fe XVII	204–410	a, b	23
Fe XVIII	94–975	b	59
Fe XIX	91–1328	b	138
Fe XIX	78–592	a, b	23
Fe XX	110–133	a, b	23
Fe XX	83–2665	b	20
Fe XXI	91–588	a, b	23
Fe XXI	121–146	b	96
Fe XXI	102–146	b	28
Fe XXI	12–2295	b	140
Fe XXII	100–247	a, b	23
Fe XXIII	133–264	a	97
Fe XXIII	11–264	a	21

TABLE XV

Diagnostics for ions of Ni

Species	Wavelength range (Å)	Type	Reference
Ni XVII	169–421	b	10
Ni XIX	12–360	b	7
Ni XX	83–695	b	88
Ni XXIII	88–127	a, b	155
Ni XXIV	9–610	b	8
Ni XXV	9–764	a, b	9

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