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A COMPILATION OF FLUORESCENT MOLECULAR LINES ORIGINATING IN OR AROUND STELLAR OBJECTS WITH STRONG ATOMIC EMISSION LINES

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A catalogue of fluorescent lines of diatomic molecules is presented. The lines may originate in regions of low to moderate thermal energies in or around objects showing strong emission in the Lyman and Balmer lines of hydrogen and/or in the resonance doublets of Mg II and Ca II. Possible identifications of such lines with unidentified emission lines in various astrophysical objects are discussed.

Key words: diatomic molecules – fluorescence – planetary nebulae – Mira variables

1. INTRODUCTION

A table of fluorescent atomic lines that could originate in objects with strong emission lines has been prepared by Gahm (1974). The present paper represents an extension of that work to fluorescent processes in diatomic molecules. There is a number of possible exciting lines in astrophysical objects. As in the previous compilation we have restricted ourselves to some of the Lyman and Balmer lines of hydrogen and the resonance doublets of Mg II and Ca II. It is clear that different kinds of astrophysical objects may develop molecular emission and in fact, the fluorescent process may be a way of detecting such molecules.

Some possibilities of molecular fluorescence have been considered by Swings and Swings (1970). Evidence of molecular fluorescence has been reported for some astrophysical objects and we have searched the literature for possible identifications of fluorescent molecular emission.

2. DESCRIPTION OF THE TABLES

When listing fluorescent molecular lines, the following restrictions were imposed.

a) Included are diatomic molecules for which the product of the cosmical abundances (as given by Cameron 1968 and Reeves 1974) is equal to or larger than 7.8×10^8 on a scale where the abundance of Si is set at 10^6. This lower limit is the product of Sc and O.

b) We consider primarily regions of low to moderate temperatures and therefore we require that the excitation is from the ground state. Moreover, the original vibrational quantum number v'' is zero and the rotational quantum number J is such as to provide a large population of this level for these temperatures.

c) The following exciting lines are considered: α, β, γ, δ and ε of the Lyman and Balmer series of hydrogen; the resonance doublets of Mg II at 2795 Å and 2802 Å and of Ca II at 3933 Å and 3968Å.

d) The wavelength difference between the exciting line and the excited line should not exceed 100 kms^{-1} as expressed in radial velocity shift. It should be noted that some astrophysical objects show emission lines that are broader than this.

e) Only transitions that have been observed in the laboratory are considered. Some of these transitions may be weak, however, The procedure when searching laboratory data was the following: Molecules which possibly could be excited were taken from the compilations by Kopp *et al.* (1974, 1976). The details of the laboratory analysis of a given molecule were taken from the references quoted by Rosen (1970), Barrow (1973) and complementary references were obtained from the "Physical Abstracts" for the period 1971 to 1974.

f) For certain molecules excitation is suggested over several (more than 10) rotational levels. These molecules were omitted from the tables, since the fluorescent lines are numerous and the chances of detection are small. Notes on some of these molecules follow in a separate section.

In table 1 the so-compiled fluorescent lines are listed according to increasing wavelength. The details of the transitions are given for each molecule in table 2.

Table 1

Column 1: Wavelength of the fluorescent line in Ångström units. Wavelengths shorter than 2000 Å refer to laboratory wavelengths in vacuum.
Column 2: Chemical symbol of fluorescent molecule.
Column 3: Exciting line with shortened wavelength.

Table 2

Column 1: Chemical symbol of the fluorescent molecule in alphabetic order. The accompanying number gives the product of atomic abundances.
Column 2: Exciting line with shortened wavelength.
Column 3: Electronic transition (excitation).
Column 4: Vibrational transition (excitation).
Column 5: Rotational transition (excitation).
Column 6: The temperature in K for which the thermal distribution of the rotational levels in the ground state has a maximum at the J given in column 5. For the sake of simplicity the approximate formula $J_{max} = 0.5896\,(T/B)^{1/2} - 0.5$ (Herzberg 1950) has been used.
Column 7: The wavelength difference in Ångström between the exciting line in column 2 and the excited line.
Column 8 to 10: Data for fluorescent line, with notations as in columns 3 to 5.
Column 11: Wavelength in Å for the fluorescent line.
Column 12: Notes to table 2.

3. NOTES ON CERTAIN MOLECULES

AlS In addition to the excitation described in table 2, AlS can be excited by Hδ 4101 in the transition $P(18)$ λ 4101.69 of the (2,0) band of $A\ ^2\Sigma - X\ ^2\Sigma$ (MacKinney and Innes 1959). No other transitions from the upper level of this line have been observed.

ClO It is seen from the work by Durie and Ramsay (1958) that Mg II 2795 could possibly excite ClO through the (11,0) band of $A\ ^2\Pi - X\ ^2\Pi$. The bands are weak, however, and have not been measured.

CO Exciting line: Lα 1215
Excitation: System $A\ ^1\Pi - X\ ^1\Sigma^+$
Transitions: (14,0): $P(8)-P(11)$; $Q(10)-Q(13)$; $R(12)-R(15)$
Reference: Simmons *et al.* (1969)

Especially the $P(10)$ and $R(15)$ lines fall close to Lα. Guided by the computed Franck-Condon factors we expect fluorescent lines in the bands (14,4), (14,7), (14,9), (14,10), (14,11), (14,12), (14,22) and (14,23) in the same system. Of these only the (14,7) and (14,23) have been observed. All transitions give emission in the UV region.

NH^+ Exciting line: Hγ 4340
Excitation: System $A\ ^2\Sigma^- - X\ ^2\Pi$
Transition: (1,0) $R_{11d}(7.5)$ λ 4340.2 Å
Reference: Colin and Douglas (1968)

Fluorescence in the (1,1) band is possible but this band has not been observed and is probably weak. In the (1,0) band we expect fluorescence in the *P* branch at 4438.9 Å.

N_2 Exciting line: Lγ 972
Excitation: System $b\ ^1\Pi_u - X\ ^1\Sigma^+g$
Transition: (3,0)
Reference: Carroll and Collins (1969)
Within ± 3 cm^{-1} of Lγ we find the three lines $P(5)$, $R(10)$ and $Q(7)$ but 12 other lines are within 100 kms^{-1} of Lγ. The only fluorescent line that we can predict is $P(12)$ at 973.38 Å in the same system and band as above. We also expect excitation of N_2 by Lε 937 in the (14,0) band of the system $b\ ^1\Sigma_u^+ - A\ ^1\Sigma_g^+$, analysed by Tilford and Wilkinson (1964).

MgS Exciting line: Hγ 4340
Excitation: System $B\ ^1\Sigma - X\ ^1\Sigma$, band (0,0)
Reference: Marcano and Barrow (1970)
The 20 lines $P(1) - P(20)$ are within 100 kms^{-1} of Hγ, $P(8)$ being central. Fluorescence might be observed e.g. at the head of the (0,1) band of the same system at a wavelength of 4439.28 Å.

O_2 In addition to the two fluorescent lines in tables 1 and 2, fluorescence is possible in the bands (1,5), (1,6) and (1,7) at the approximate wavelengths 3541, 3732 and 3940 Å. The relative intensities according to Degen and Nicholls (1969) favour the (1,6) band, but all these bands are expected to be weak.

ScO Exciting line: Hβ 4861
Excitation: System $B\ ^2\Sigma^+ - X\ ^2\Sigma^+$, band (0,0)
References: Åkerlind (1962), Adams *et al.* (1968)
About 20 lines fall within 100 kms^{-1} of the exciting Hβ line resulting in many fluorescent lines. We expect fluorescence to occur at about 5101 Å in the *P* branch and at about 5098 Å in the *R* branch of the above system.

4. SEARCH FOR ASTROPHYSICAL IDENTIFICATIONS

Many unidentified emission lines in the spectra of various objects are listed in the literature. We have searched the references quoted by Meinel *et al.* (1969) as well as a number of more recent works and compared the observed wavelengths with those of table 1. When comparing wavelengths the observed radial velocity shifts must be considered. In no case can fluorescent molecular emission be established for certain. Coincidences in wavelength do occur for a number of objects but in general only a few of the predicted fluorescent lines of one and the same molecule appear. Quite often, however, some of the predicted lines are hidden in strong atomic emission and thus no final conclusions can be drawn. The following is a brief description of the findings for different classes of objects.

Novae and nova-like stars. Two unidentified features observed in RR Pic by Jones (1931, 1932, 1933) do coincide with violet-displaced C_2^- excited by Hβ. It seems possible, however, that these lines are allowed or forbidden lines of highly ionized metals.

Planetary nebulae. For NGC 7027 and 7662 and IC 4997, Aller *et al.* (1963), Aller *et al.* (1966), Aller and Kaler (1964) found an unidentified line at around λ 3956.7. Considering the radial velocity shift involved in the fluorescent process, this line could be identified with violet-displaced CH^+ λ 3957.70 excited by Hε. We note that the remaining two CH^+ lines excited by Hβ come near unidentified and identified features as well, if violet-displaced by the same amount. Moreover, in the peculiar object V 1016 Cyg, which is believed to be a planetary nebula in formation, FitzGerald and Pilavaki (1974) found an unidentified line at λ 4455.67 which is just on the red side of the λ 4455.03 line of CH^+.

Furthermore, C_2^- at λ 5313.56 excited by Hβ is near an unidentified line observed by Aller and Walker (1970) in NGC 6302, 7009 and 7662. The λ 5313 – feature has been reported present also in IC 5217 by Wyse (1942).

The planetary nebulae therefore represent the best case we have found for possible fluorescent molecular emission and more work is necessary before any conclusions can be drawn.

Gaseous nebulae. Objects of this type are known to be molecular sources, but in terms of coincidences in wavelength, very little of interest was found.

Symbiotic stars. None of the many unidentified lines listed for this class of objects coincide with the lines of table 1.

Emission-line stars of spectral types O to G. Although many objects of these types have been investigated, very few coincidences in wavelength were found. It would be interesting, however, if high-sensitivity data were obtained for objects believed to be in a phase of pre-main-sequence evolution.

Ke, Me and N stars. The Mira variables are known sources of molecular emission (AlO, AlH, CN) and Maehara (1970) reported evidence of fluorescent SiH. We note coincidences between the CH^+ line at λ 4455.03, excited by Hε, and an unidentified line in R And (Merrill 1947a), o Cet (Joy 1926, 1954) and χ Cyg (Merrill 1947b, Herbig and Zappala 1968). No evidence for other fluorescent CH^+ lines is at hand and the unidentified feature at λ 3956.082 in o Cet (Joy 1954) seems to be too distant from the CH^+ λ 3957.70 and behaves differently from the λ 4455 feature with phase. The SiH fluorescence reported by Maehara originates from relatively high J values and was therefore excluded from our compilation.

For other late-type emission-line stars very little is found. We note that in the spectrum of the VV Cep type star BD +54°2698 there is an unidentified line (Barbier 1974) in close coincidence with the λ 4455 line of CH^+ discussed above.

T Tauri stars. We have made a detailed investigation of the spectral tracings of RW Aur (described by Gahm 1970) and of the integrated spectral tracings of 28 individual spectrograms of RU Lup (Gahm *et al.* 1974). For RW Aur a strong unidentified feature at λ 4155 coincides with fluorescent NaH at λ 4154.82 excited by Hε. The other fluorescent NaH line is definitely absent, however, and no other traces of molecular emission can be found. In the spectrum of RU Lup an unidentified line is present at the position of the fluorescent SiH^+ line at λ 4285.57 excited by Ca II, K at λ 3933. The other fluorescent SiH^+ line falls in a spectral region of strong Fe II emission and no conclusions can be drawn. No other evidence of molecular emission can be found.

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Table 1 List of fluorescent molecular lines in wavelength order

λ	Mole-cule	Exciting line	λ	Mole-cule	Exciting line	λ	Mole-cule	Exciting line	λ	Mole-cule	Exciting line
1265.68	H_2	Lβ 1025	2898.71	AlS	MgII 2802	4387.53	BiH	Hγ 4340	5032.02	BiH	Hγ 4340
1272.82	H_2	Lγ 972	2901.26	AlS	MgII 2802	4439.16	CH^+	Hε 3970	5079.85	AlO	Hβ 4861
1279.10	H_2	Lγ 972	3020.3	N_2	Lδ 949	4450.39	CH^+	CaII 3968	5079.99	AlO	Hβ 4861
1356.07	H_2	Lγ 972	3024.00	N_2	Lδ 949	4455.03	CH^+	Hε 3970	5080.14	AlO	Hβ 4861
1362.04	H_2	Lγ 972	3938.75	NaH	CaII 3933	4467.64	ZnH	CaII 3968	5080.31	AlO	Hβ 4861
1365.67	H_2	Lβ 1025	3949.99	SiH^+	CaII 3933	4472.74	ZnH	Hε 3970	5092.46	BiH	Hγ 4340
1394.25	H_2	Lγ 972	3957.70	CH^+	Hε 3970	4516.19	ZnH	CaII 3968	5098.48	AlO	Hβ 4861
1399.87	H_2	Lγ 972	4001.63	NaH	Hε 3970	4516.91	ZnH	Hε 3970	5099.27	AlO	Hβ 4861
1414.68	H_2	Lβ 1025	4009.33	ZnH	Hε 3970	4535.30	AlD	Hδ 4101	5100.09	AlO	Hβ 4861
1457.97	H_2	Lγ 972	4011.12	ZnH	CaII 3968	4535.69	AlD	Hδ 4101	5100.90	AlO	Hβ 4861
1461.97	H_2	Lβ 1025	4110.62	SiD	Hδ 4101	4536.17	AlD	Hδ 4101	5165.53	ZnH	CaII 3968
1462.31	H_2	Lγ 972	4110.67	SiD	Hδ 4101	4667.38	BiH	Hγ 4340	5180.68	ZnH	Hε 3970
1480.39	H_2	Lγ 972	4120.10	SiD	Hδ 4101	4721.42	ZnH	CaII 3968	5210.40	ZnH	CaII 3968
1483.66	H_2	Lγ 972	4120.16	SiD	Hδ 4101	4728.78	ZnH	Hε 3970	5222.14	ZnH	Hε 3970
1493.84	H_2	Lγ 972	4122.71	NaH	CaII 3933	4771.71	ZnH	CaII 3968	5313.56	C_2^-	Hβ 4861
1495.57	H_2	Lγ 972	4154.82	NaH	Hε 3970	4774.61	ZnH	Hε 3970	5359.46	C_2^-	Hβ 4861
1506.44	H_2	Lβ 1025	4188.63	NaH	Hε 3970	4778.79	AlD	Hδ 4101	5850.23	C_2^-	Hβ 4861
1546.72	H_2	Lβ 1025	4214.25	ZnH	CaII 3968	4779.08	AlD	Hδ 4101	5905.37	C_2^-	Hβ 4861
1581.10	H_2	Lβ 1025	4217.59	ZnH	Hε 3970	4779.41	AlD	Hδ 4101	6480.91	YbH	Hα 6562
1607.50	H_2	Lβ 1025	4259.22	ZnH	Hε 3970	4779.91	AlD	Hδ 4101	6483.63	YbH	Hα 6562
1623.37	H_2	Lβ 1025	4259.98	ZnH	CaII 3968	4843.33	AlO	Hβ 4861	6728.47	BiH	Hγ 4340
2746.2	N_2	Lδ 949	4285.57	SiH^+	CaII 3933	4843.55	AlO	Hβ 4861	6779.81	BiH	Hγ 4340
2749.3	N_2	Lδ 949	4304.55	SiH^+	CaII 3933	4843.75	AlO	Hβ 4861	6838.95	BiH	Hγ 4340
2795.94	O_2	MgII 2795	4309.49	AlD	Hδ 4101	4843.99	AlO	Hβ 4861	7024.97	YbH	Hα 6562
2796.28	O_2	MgII 2795	4309.81	AlD	Hδ 4101	4900.29	C_2^-	Hβ 4861	7027.98	YbH	Hα 6562
2800.34	AlS	MgII 2802	4310.22	AlD	Hδ 4101	4961.94	ZnH	CaII 3968	7119.67	YbH	Hα 6562
2811.74	ZnH	MgII 2802	4310.56	AlD	Hδ 4101	4972.45	ZnH	Hε 3970	7643.88	YbH	Hα 6562
2811.80	ZnH	MgII 2802	4311.09	AlD	Hδ 4101	5011.82	ZnH	CaII 3968	7647.24	YbH	Hα 6562
2877.9	N_2	Lδ 949	4328.20	BH	Hγ 4340	5018.09	ZnH	Hε 3970	7753.01	YbH	Hα 6562
2881.28	N_2	Lδ 949									

Table 2 Details of fluorescent processes

Molecule Abundance	Excitation Exc. line	Transition Electr.	Vibr.	Rotat.	T_J(K)	Δλ(Å)	Fluorescence Transition Electr.	Vibr.	Rotat.	λ_{Fl}(Å)	Comments References
AlD	Hδ 4101	$A^1\Pi - X^1\Sigma^+$	(1,0)	Q(1)	21	1.14	$A^1\Pi - X^1\Sigma^+$	(1,1)	Q(1)	4309.49	Holst 1935
3.3×10^{10}				Q(2)	60	0.83		(1,1)	Q(2)	4309.81	Nilsson 1944, 1946
				Q(3)	115	0.48		(1,1)	Q(3)	4310.22	
								(1,2)		4535.30	
								(1,3)		4778.79	
				Q(4)	190	-0.01		(1,1)	Q(4)	4310.56	
								(1,2)		4535.69	
								(1,3)		4779.08	
				Q(5)	290	-0.62		(1,1)	Q(5)	4311.09	
								(1,2)		4536.17	
								(1,3)		4779.41	
				Q(6)	400	-1.35		(1,3)	Q(6)	4779.91	
AlO	Hβ 4861	$A^2\Sigma^+ - X^2\Sigma^+$	(0,0)	P(30)	1700	0.91	$A^2\Sigma^+ - X^2\Sigma^+$	(0,0)	R(28)	4843.33	Pomeroy 1927
2.0×10^{12}								(0,1)	P(30)	5098.48	
									R(28)	5079.85	
				P(31)	1823	0.11		(0,0)	R(29)	4843.55	
								(0,1)	P(31)	5099.27	
									R(29)	5079.99	
				P(32)	1950	-0.71		(0,0)	R(30)	4843.75	
								(0,1)	P(32)	5100.09	
									R(30)	5080.14	
				P(33)	2050	-1.55		(0,0)	R(31)	4843.99	
								(0,1)	P(33)	5100.90	
									R(31)	5080.31	
AlS	MgII 2802	$C^2\Sigma - X^2\Sigma$	(0,0)	P(28)	650	-0.04	$C^2\Sigma - X^2\Sigma$	(0,0)	R(26)	2800.34	Maltsev et al.
4.3×10^{10}								(0,2)	P(28)	2901.26	1966
									R(26)	2898.71	see text also
BH	Hγ 4340	$A^1\Pi - X^1\Sigma^+$	(0,0)	P(2)	210	-1.05	$A^1\Pi - X^1\Sigma^+$	(0,0)	R(0)	4328.20	Johns et al. 1967
1.6×10^{11}											
BiH	Hγ 4340	$B\,0^+ - X\,0^+$	(1,0)	R(11)	1950	0.56	$B\,0^+ - X\,0^+$	(1,0)	P(13)	4387.53	Heimer 1935
4.3×10^{9}								(1,1)	R(11)	4667.38	
								(1,2)	R(11)	5032.02	
									P(13)	5092.46	
							$B\,0^+ - A\,1$	(1,2)	R(11)	6728.47	
									Q(12)	6779.81	
									P(13)	6838.95	
C_2^-	Hβ 4861	$^2\Sigma_u^+ - {}^2\Sigma_g^+$	(1,0)	R(22)	2550	-0.17	$^2\Sigma_u^+ - {}^2\Sigma_g^+$	(1,0)	P(24)	4900.29	Herzberg and
1.8×10^{14}								(1,1)	P(24)	5359.46	Lagerqvist 1968
									R(22)	5313.56	
								(1,2)	P(24)	5905.37	
									R(22)	5850.23	

Table 2 *(continued)*

Molecule Abundance	Excitation: Exc. line	Excitation Transition: Electr.	Excitation Transition: Vibr.	Excitation Transition: Rotat.	T_J(K)	$\Delta\lambda$(Å)	Fluorescence Transition: Electr.	Fluorescence Transition: Vibr.	Fluorescence Transition: Rotat.	$\lambda_{Fl.}$(Å)	Comments References
CH^+	CaII 3968	$A^1\Pi - X^1\Sigma$	(1,0)	Q(3)	490	0.92	$A^1\Pi - X^1\Sigma$	(1,1)	Q(3)	4450.39	Douglas and
3.5×10^{17}	Hε 3970	$A^1\Pi - X^1\Pi$	(1,0)	P(2)	250	-0.74	$A^1\Pi - X^1\Sigma$	(1,0)	R(0)	3957.70	Herzberg 1942
								(1,1)	P(2)	4455.03	Douglas and
									R(0)	4439.16	Morton 1960
H_2	Lγ 972	$B^1\Sigma_u^+ - X^1\Sigma_g^+$	(11,0)	P(3)	2100	-0.22	$B^1\Sigma_u^+ - X^1\Sigma_g^+$	(11,7)	P(3)	1279.10	Herzberg and
6.8×10^{20}				R(1)	380	-0.44			R(1)	1272.82	Howe 1959
								(11,9)	P(3)	1362.04	Tanaka 1944
									R(1)	1356.07	
								(11,10)	P(3)	1399.87	
									R(1)	1394.25	
								(11,12)	P(3)	1462.31	
									R(1)	1457.97	
								(11,13)	P(3)	1483.66	
									R(1)	1480.39	
								(11,14)	P(3)	1495.57	
									R(1)	1493.84	
	Lβ 1025	$B^1\Sigma_u^+ - X^1\Sigma_g^+$	(6,0)	P(1)	380	-0.23	$B^1\Sigma_u^+ - X^1\Sigma_g^+$	(6,5)	P(1)	1265.68	
								(6,7)	P(1)	1365.67	
								(6,8)	P(1)	1414.68	
								(6,9)	P(1)	1461.97	
								(6,10)	P(1)	1506.44	weak
								(6,11)	P(1)	1546.72	
								(6,12)	P(1)	1581.10	
								(6,13)	P(1)	1607.50	
								(6,14)	P(1)	1623.37	
N_2	Lδ 949	$b^1\Pi_u - X^1\Sigma_g^+$	(6,0)	P(7)	320	*)	$b^1\Pi_u - a^1\Pi_g$	(6,0)	P(7)	2749.3	*) < 0.03 cm^{-1}
6.0×10^{12}									R(5)	2746.2	Lofthus 1957
								(6,1)	P(7)	2881.28	see text also.
									R(5)	2877.9	
								(6,2)	P(7)	3024.00	
									R(5)	3020.3	
NaH	CaII 3933	$A^1\Sigma^+ - X^1\Sigma^+$	(9,0)	R(0)	3	-0.61	$A^1\Sigma^+ - X^1\Sigma^+$	(9,0)	P(2)	3938.75	Hori 1930
1.6×10^{15}								(9,1)	P(2)	4122.71	Olsson 1935
	Hε 3970	$A^1\Sigma^+ - X^1\Sigma^+$	(9,0)	R(9)	1250	0.21	$A^1\Sigma^+ - X^1\Sigma^+$	(9,0)	P(11)	4001.63	
								(9,1)	P(11)	4188.63	
									R(9)	4154.82	
O_2	MgII 2795	$A^3\Sigma_u^+ - X^3\Sigma_g^-$	(1,0)	$^QP_{21}(5)$	125	0.42	$A^3\Sigma_u^+ - X^3\Sigma_g^-$	(1,0)	$^QP_{21}(7)$	2796.28	Herzberg 1952
5.6×10^{14}				$^QR_{23}(5)$							see text also
				$^QR_{12}(7)$	230	-0.55			$^QQ_1(7)$	2795.94	
SiH^+	CaII 3933	$A^1\Pi - X^1\Sigma^+$	(1,0)	R(2)	135	0.10	$A^1\Pi - X^1\Sigma$	(1,0)	P(4)	3949.99	Grevesse and
2.6×10^{16}								(1,1)	P(4)	4304.55	Sauval 1970
									R(2)	4285.57	
SiD	Hδ 4101	$A^2\Delta - X^2\Pi$	(0,0)	$^SR_{21c}(5.5)$	400	-0.70	$A^2\Delta - X^2\Pi$	(0,0)	$^RQ_{21c}(6.5)$	4110.62	Klynning and
3.9×10^{11}				$^SR_{21d}(5.5)$	400	-0.74			$^RQ_{21d}(6.5)$	4110.67	Lindgren 1966
									$^QP_{21c}(7.5)$	4120.10	
									$^QP_{21d}(7.5)$	4120.16	
ZnH	MgII 2802	$B^2\Sigma - X^2\Sigma$	(10,0)	$R_1(3)$	230	0.18	$B^2\Sigma - X^2\Sigma$	(10,0)	$P_1(5)$	2811.80	Stenvinkel 1936
3.9×10^{13}				$R_2(3)$	230	0.21			$P_2(5)$	2811.74	
	CaII 3968	$A^2\Pi - X^2\Sigma$	(1,0)	$Q_1(9)$	1890	0.01	$A^2\Pi - X^2\Sigma$	(1,0)	$^OP_{12}(11)$	4011.12	
								(1,1)	$^OP_{12}(11)$	4259.98	
									$Q_1(9)$	4214.25	
								(1,2)	$^OP_{12}(11)$	4516.19	
									$Q_1(9)$	4467.64	
								(1,3)	$^OP_{12}(11)$	4771.71	
									$Q_1(9)$	4721.42	
								(1,4)	$^OP_{12}(11)$	5011.82	
									$Q_1(9)$	4961.94	
								(1,5)	$^OP_{12}(11)$	5210.40	
									$Q_1(9)$	5165.53	
	Hε 3970	$A^2\Pi - X^2\Sigma$	(1,0)	$Q_1(8)$	1530	-0.53	$A^2\Pi - X^2\Sigma$	(1,0)	$^OP_{12}(10)$	4009.33	
								(1,1)	$^OP_{12}(10)$	4259.22	
									$Q_1(8)$	4217.59	
								(1,2)	$^OP_{12}(10)$	4516.91	
									$Q_1(8)$	4472.74	
								(1,3)	$^OP_{12}(10)$	4774.61	
									$Q_1(8)$	4728.78	
								(1,4)	$^OP_{12}(10)$	5018.09	
									$Q_1(8)$	4972.45	
								(1,5)	$^OP_{12}(10)$	5222.14	
									$Q_1(8)$	5180.68	
YbH	Hα 6563	$D^2\Pi_{1/2} - X^2\Sigma$	(0,0)	$^OP_{12}(13)$	1900	-0.71	$D^2\Pi_{1/2} - X^2\Sigma$	(0,0)	$Q_1(11)$	6483.63	Hagland et al. 1966
5.5×10^9									$^QR_{12}(11)$	6480.91	
								(0,1)	$^OP_{12}(13)$	7119.67	
									$Q_1(11)$	7027.98	
									$^QR_{12}(11)$	7024.97	
								(0,2)	$^OP_{12}(13)$	7753.01	
									$Q_1(11)$	7647.24	
									$^QR_{12}(11)$	7643.88	