11. — CONSIDERATIONS ON THE FORBIDDEN LINES OF IRON IN THE STATES FROM Fe^0 TO Fe^{6+}

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ABSTRACT

The iron atom which has a fairly high cosmic abundance presents the great interest of appearing in a wide variety of stars and nebulae, at many stages of ionization, and of revealing forbidden transitions in emission in many of these ionization stages. The present paper discusses the following topics :

(a) the case of the as yet undiscovered forbidden lines of neutral iron (Fe^0) ;

(b) some recently acquired astronomical information on the forbidden lines of the stages Fe^+ to Fe^{6+} ;

(c) general considerations on the important information revealed by these forbidden lines of iron on the physical structure and excitation mechanisms which are present in the emission line stars of early and late types.

For lack of time we give only a very summarized version of our paper ; a complete text will appear later.

* * *

In the usually covered spectral range (*), λ 3000 Å to λ 1 μ forbidden transitions of the following stages of ionization are observed : II, III, IV, V, VI, VII, X, XI, XIII, XIV, XV. Since Fe VIII, IX, XII, XVI and XVII have no forbidden line in the spectral range accessible from the ground, and since the ionization potential increases abruptly when passing from Fe^{16+} to Fe^{17+}, it appears that [Fe I] is the only forbidden spectrum of iron which has not yet been observed (P. Swings, 1951, 1952). In this paper we shall confine ourselves to the states from Fe^0 to Fe^{6+}. Of course it is known that the « coronal » transitions play also an important role in certain novae, but the ions from Fe^0 to Fe^{6+} are present in a greater number of objects, from the Be stars, the gaseous nebulae, novae and symbiotic objects to the long period variables and other cool stars.

To illustrate the striking difference in transition probabilities between the low ionization stages (up to Fe^{6+}) and the « coronal » stages (beginning at Fe^{9+}) we have collected in Table I the transition probabilities of a few of the strongest lines from [Fe II to XIV].

The probabilities of the characteristic lines of [Fe X] and [Fe XIV] are approximately one hundred times greater than those of [Fe VII to II]. This high probability ratio affects the influence of the density ; moreover the exciting radiation departs often from the black body type and presents strong discrete emission or absorption

(*) Of course strong emissions whose wave lengths lie shortward of λ 3000 may be shifted into the observable region in the case of quasars. Moreover, there are forbidden lines in the far ultraviolet and especially in the infrared (J. P. Swings, 1965a) which may play an important role : the [Fe II] transitions, in particular, may produce strong infrared emissions in planetary nebulae and Be stars. The transitions at 25.98 μ and 35.34 μ between the sub-levels of the ground a ^6D state may be of importance in various types of objects. Moreover, the infrared [Fe II] emissions may play a « cooling » role. A systematic discussion of all the forbidden and permitted lines of the iron ions in the far ultraviolet (in all the stages of ionization) would be of interest.

Table 1

Transition probabilities of a few characteristic forbidden lines of iron from [Fe II] *to* [Fe XIV]

Spectrum (1)	Transition (2)	λ (3)	A (4)	gA (5)	$\chi^{(ev)}_{exc.}$ (6)
[Fe II]	$^{6}D_{4\frac{1}{2}} - {}^{6}S_{2\frac{1}{2}}$	4287.40	1.12	6.7	2.9
	$^{6}D_{3\frac{1}{2}} - {}^{6}S_{2\frac{1}{2}}$	4359.34	0.82	4.9	2.9
	$^{6}D_{4\frac{1}{2}} - {}^{4}F_{4\frac{1}{2}}$	4416.27	0.46	4.6	2.8
	$^{4}F_{4\frac{1}{2}} - {}^{4}G_{5\frac{1}{2}}$	4243.98	0.90	11.8	3.1
	$^{4}F_{3\frac{1}{2}} - {}^{4}G_{4\frac{1}{2}}$	4276.83	0.65	6.5	3.1
	$^{4}F_{4\frac{1}{2}} - {}^{2}G_{4\frac{1}{2}}$	7155.14	0.15	1.5	2.0
[Fe III]	$^{5}D_{4} - {}^{3}F_{4}$	4658.10	0.44	3.96	2.7
	$^{5}D_{3} - {}^{3}P_{2}$	5270.3	0.40	2.0	2.5
[Fe V]	$^{5}D_{4} - {}^{3}F_{4}$	3891.28	0.74	6.66	3.3
	$^{5}D_{3} - {}^{3}F_{3}$	3839.52	0.40	2.8	3.3
	$^{5}D_{3} - {}^{3}P_{2}$	3895.52	0.71	3.5	3.3
	$^{5}D_{2} - {}^{3}P_{1}$	4071.29	1.1	3.3	3.3
[Fe VII]	$^{3}F_{3} - {}^{1}D_{2}$	6086.9	0.49	2.45	2.2
	$^{3}F_{2} - {}^{1}D_{2}$	5721.1	0.30	1.5	2.2
	$^{3}F_{4} - {}^{1}G_{4}$	3760.3	0.37	3.33	3.6
	$^{3}F_{3} - {}^{1}G_{4}$	3587.8	0.26	2.34	3.6
[Fe X]	$^{2}P_{1/2} - {}^{2}P_{3/2}$	6374.5	69.1	276.4	1.9
[Fe XIV]	$^{2}P_{1/2} - {}^{2}P_{3/2}$	5302.9	60.04	240.2	2.3

Note :

Column 4 gives the theoretical transition probabilities A ;
Column 5 takes the statistical weight g into account.

[Fe II] λ : Moore, 1959
A : Garstang, 1962

[Fe III] λ : Bowen, 1960
A : Garstang, 1957

[Fe V] λ : Bowen, 1960
A : Garstang, 1957

[Fe VII] λ : Bowen, 1960
A : Garstang, 1964 ; 1967

[Fe X] λ : Bowen, 1960
A : Krüger and Czyzak, 1965

[Fe XIV] λ : Bowen, 1960
A : Krüger and Czyzak, 1965

features ; finally the ionizing radiation may be distributed between various atoms or ions, as in the case of H and O which have pratically the same ionization potential (Bowen and P. Swings, 1947). These three reasons may explain why the coronal lines behave very differently from the [Fe VII to II] lines in the solar corona, novae or other peculiar objects; also why apparently peculiar ionization distributions are observed. In numerous objects [Fe II] and [Fe VII] appear simultaneously, while the intermediate ionizations are not observed; in other objects all the stages from [Fe II] to [Fe VII] appear, except [Fe IV]. Of course stratification (as in planetary nebulae) and geometrical effects, including asymmetries may also have an important bearing on the relative intensities of the emission lines. The relaxation times should not be neglected either. As an example, let us consider [Fe VII]; this emission is probably excited in regions which are fairly close to the exciting « nucleus », hence may react more rapidly to a change in temperature or density. The time lags should be considered in all variable objects, especially the novae, the symbiotic objects and many peculiar bright line stars.

There are stars with strong [Fe III], but no [Fe II], and vice versa; others which are intermediates between pure [Fe II] and [Fe III] objects, reveal both [Fe II] and [Fe III] with various intensity ratios.

This behavior may be extended to the whole sequence [Fe II to VII]. Until a few years ago the assignments and the intensity ratios could be discussed only on the basis of observations of a few peculiar stars. The situation has improved recently. First we have now detailed descriptions of the spectra of a few representative [Fe II to VII] stars, the best example of [Fe II] object being η Carinae which has been thoroughly studied, especially by A. D. Thackeray. Second: we have now excellent transition probabilities for [Fe II to VII], for which we must thank Dr. Garstang and a few other colleagues. We owe them a great debt of gratitude. But the consideration of the transition probabilities, important as it is to the stellar spectroscopists, does not suffice. The collisional cross-sections play also a major role when the densities are too low to produce a Boltzmann distribution on the lower levels; wonderful work has been done recently in this direction, especially by Dr. Seaton and other colleagues, but a great amount of work is still needed in this field. A good many published assignments of stellar or nebulae lines to [Fe II to VII] appear erroneous on the basis of the gA-values (*) and the excitation potentials (**); but some doubt remains on account of our ignorance of the collisional cross-sections. Many examples could be listed; here is one: the [Fe VI] lines in the planetary nebulae (recent work of Aller and Walker, 1967), and in novae (N Her 1960, work by J. Dufay, M. Bloch and D. Chalonge, 1964; N Her 1963, by Y. Andrillat, 1964).

The [Fe II to VII] lines appear essentially in hot stars. However [Fe II] is also observed in cool young stars such as the Herbig-Haro objects and in long period variables of type M as well as S: a discussion of the relative intensities is desirable, and is under way in Liège.

(*) When comparing intensities, using theoretical transition probabilities, such as those of Garstang, one should not forget the statistical weights and the excitation potentials. Many examples may be given of multiplets in which the strongest line does not have the highest transition probability A, but the highest value of gA.

(**) If the electron temperature is of the order of 5000° K, a difference of 1 eV in the excitation potential leads to a ratio of 10 in the populations on the excited levels, at least if a Boltzmann distribution prevails or if the collisional cross sections are equal. Such an effect of the excitation potential is often observed; examples will be given later on.

I. FORBIDDEN LINES OF NEUTRAL IRON

It seems reasonable to think that [Fe I] should appear in certain objects of low excitation (P. Swings, 1951, 1952), such as

— shells cooler than those of Be-stars revealing [Fe II] ;

— cool objects, such as T Tauri stars or long period variables at specific phases (just as [Fe II] appears in such stars) ;

— novae in a [Fe I] stage which would possibly precede the η Carinae [Fe II] stage (*) ;

— novae at the time of apparition of C_2 or CN bands.

Unfortunately, we have no estimate of the transition probabilities. According to Garstang the most promising [Fe I] multiplet is $a\,^5D - a\,^3P$ ($\lambda\lambda$ 5220.56, 5303.99 and 5565.68). The sometimes mentioned $a\,^5D - a\,^3F$ multiplet (λ 8347.56 and λ 8231.56) would be weaker and would fall in an unfavorable spectral region (strong continuum and complex absorption spectrum).

Examination of solar tracings obtained by L. Delbouille and G. Roland at Jungfraujoch does not reveal the presence of absorption lines of the $a\,^5D - a\,^3P$ and $a\,^5D - a\,^3F$ multiplets. But a more refined search may be desirable, at least if the transition probabilities of [Fe I] turn out to be greater than those of [Fe II], thus compensating for the higher population of Fe^+ relative to Fe^0 (J. P. Swings, 1965b, 1968).

We hope that the transition probabilities of [Fe I] will be computed, and eventually that we shall also have some idea of the collisional cross sections.

II. FORBIDDEN LINES OF Fe^+

The [Fe II] lines were first identified by P. W. Merrill (1928) in η Carinae which is the most characteristic [Fe II] star. These forbidden lines play a very important role in many objects : gaseous nebulae (such as Orion), novae (**) (in the η Carinae stage), symbiotic objects (practically all of them, especially Z And), Be stars (binaries such as B 1985, WY Gem and VV Cep or single stars, such as HD 45677 and MWC 17), long period variables near minimum (such as χ Cygni).

Among the hot [Fe II] stars HD 45677 is particularly interesting, as it has never revealed any binary character, hence shows the infrared emissions without any disturbing blend by late type features. Moreover its emission lines of Fe II and [Fe II] are sharp (***).

The remarkable work of Garstang on the transition probabilities opened new possibilities of discussion of the [Fe II] identifications. The [Fe II] assignments in η Carinae and in W Serpentis may now be considered as quite satisfactory. We have examined systematically the lists of wavelengths of many symbiotic or other objects containing [Fe II], taking into account the computed probabilities, the excitation potentials and the spectrum of η Carinae. While a few new suggested assign-

(*) Many novae — essentially of the slow type — go through the [Fe II to XIV] stages.

(**) [Fe II] is observed in fast — as well as slow novae.

(***) The forbidden lines of HD 45677 (essentially those of Fe II, Ni II and S II) are sharper than the permitted Fe II lines. The same has been observed in W Ser by C. A. Bauer (1945). We are at present investigating this difference in profiles, which is presumably due to the stratification effects.

ments turn out to be correct (as in C I Cyg.), many appear now unjustified. However caution is required on account of the absence of data on collisional cross sections; the great complexity of the [Fe II] spectrum is also a source of difficulty on account of the blends. The differences of behavior of [Fe II] in objects as different as cool stars (such as χ Cygni) and hot stars (such as HD 45677) is at present under investigation in Liège.

The Fe^+ and Ni^+ ions play parallel roles in peculiar bright line stars of early type, as it appears from the simultaneous presence of [Fe II] and [Ni II]. As in solar absorption (J. P. Swings, 1965b and 1966) the lower abundance of nickel relative to iron is probably compensated by the higher probability.

The simultaneous presence with similar intensities of [Fe II] and [S II] in stars such as HD 45677, B 1985 and WY Gem, while [S II] is much stronger than [Fe II] in gaseous nebulae led to believe around 1940 that the transition probabilities of [Fe II] were much higher than those of [S II], thus compensating for the low cosmic abundance of iron relative to sulphur (P. Swings and O. Struve, 1940). It has been shown that the probabilities of the strong [Fe II] and [S II] lines were of the same order of magnitude (Garstang, 1962 and Czyzak and Krüger, 1963). The interpretation given around 1940 must thus be abandoned. We now know the collisional cross sections of [S II] (Czyzak, 1964) but not those of [Fe II]. The problem remains open.

Strong [Fe II] lines are observed in the photographic infrared region of η Carinae. An example is $a\,^4F - a\,^2G$, especially λ 7155.14; actually this line has also been observed in solar absorption (J. P. Swings, 1966). As a matter of fact λ 7155 may be present in emission whereas the usual lines of the blue-violet region are absent; this behavior which is probably due essentially to the difference in excitation potential is observed in upsilon Sagittarii.

Certain stars show [Fe II] and no [Fe III]: this is the case for HD 45677 ([Fe III] is weak in η Carinae); others (such as MWC 17 and V 1016 Cyg (*)) show [Fe II] and [Fe III] and are thus intermediate between HD 45677 and the pure [Fe III] objects, such as RY Scuti.

Since [Fe III] is absent in HD 45677, the [Fe II] lines must be excited by collisions and not in a recombination process. Actually the relative intensities of Fe II and [Fe II] depend not only on the electron densities, but also on the electron temperatures: a low T_e enhances [Fe II].

III. FORBIDDEN LINES OF Fe^{++}

The [Fe III] transitions were obtained by B. Edlén and P. Swings (1942) as a result of their analysis of the Fe III spectrum. The transition probabilities have been computed by R. H. Garstang (1957) for all the essential transitions, except $a\,^5D - a\,^7S_3$. We do not have the collisional cross sections as yet. The essential transitions are $a\,^5D - a\,^3F$, $a\,^3P$ and $a\,^3D$. The strongest lines ($gA > 1$) are given in Table 2.

[Fe III] has been observed in many objects: gaseous nebulae (including Orion, NGC 7027, etc.) peculiar stars (RY Scuti, BF Cygni, V 1016 Cygni, MWC 17, FR Scuti, RR Telescopii, Z Andromedae, RX Puppis, RS Ophiuchi, MWC 349, AX Persei, CI Cygni, etc.) and novae (RT Serpentis, RR Pictoris, DQ Herculis, etc.).

(*) V 1016 Cyg = MHα 328116.

Table 2

Characteristic [Fe III] *lines*

Multiplet	Exc. Pot. (ev)	Transition	λ	gA
$a\ ^5D - a\ ^3F$	2.7	4 — 4	4658.1	3.96
		3 — 3	4701.6	1.89
$a\ ^5D - a\ ^3P$	2.5	3 — 2	5270.4	2.00
		2 — 1	5011.3	1.59
$a\ ^5D - a\ ^3D$	3.8	4 — 3	3239.7	1.61

Notes : λ : Bowen, 1960
A : Garstang, 1957

The most characteristic [Fe III] line is λ 4658, but attention should be paid to the possibility of blending by λ 4658 C IV ; if the observed emission is due to C IV, the doublet λ 5801 — λ 5812 should be strong. When the star is extremely reddened — as is the case for MWC 349 — λ 5270 may be stronger than λ 4658.

On the basis of Garstang's probabilities it is possible to revise or suppress a number of prior tentative assignments to $a\ ^5D - a\ ^3H$ and $a\ ^5D - a\ ^3G$ in RY Scu, Z And, AX Per, etc. The $a\ ^5D - a\ ^3D$ multiplet is very weak ; actually it has been observed only in the case of BF Cygni, with extremely long exposures (P. Swings and Swensson, 1953), and some uncertainty remains with regard to the reality of the measured features. This weakness may be due to the higher excitation potential. But it may actually be interesting to re-examine theoretically the whole problem of intensities once collisional cross-sections become available.

[Fe III] may appear together with [N II] and [O III] as in RY Scuti ; or together with [O I], [N II], [S II] and [Fe II] as in MWC 17.

IV. Forbidden lines of Fe^{3+}

The [Fe IV] transitions have been determined by B. Edlén (*) (1966), the transition probabilities by R. H. Garstang (1958). The strongest transition $a\ ^6S - a\ ^4P$, λ 2829.6 — λ 2835.9 (exc. pot. 4.35 ev. ; $gA \simeq 8.4$ and 3.5) is not observable from the ground, except in a quasar ; it may appear in spectrograms taken from space vehicles. All the transitions appearing in the usual spectral range correspond to high excitation potentials. The most characteristic transitions which have a gA-value greater than 1.0 are given in Table 3.

Many coincidences appear between the [Fe IV] lines and emissions in RR Telescopii (Thackeray, 1953, 1954, 1955), a slow postnova which had previously gone

(*) Theoretical estimates of the essential low levels of Fe IV had been made by Garstang (1958) but these had fairly great unavoidable uncertainties, and could not lead to convincing identifications.

TABLE 3

Characteristic [Fe IV] *lines*

Multiplet	Exc. Pot. (ev)	Transition	λ	*g*A
$a\,^4\mathrm{H} - a\,^2\mathrm{H}$	7.0	5 ½ — 5 ½	4144.4	5.6
		4 ½ — 5 ½	4152.5	7.3
		5 ½ — 4 ½	4206.5	5.6
$a\,^4\mathrm{G} - a\,^4\mathrm{F}$	6.5	2 ½ — 2 ½	4867.8	1.5
		2 ½ — 1 ½	4868.2	1.3
		5 ½ — 4 ½	4906.7	3.2
$a\,^4\mathrm{G} - a\,^2\mathrm{F}$	6.4	2 ½ — 2 ½	5032.5	1.3
		3 ½ — 2 ½	5033.8	2.8
		4 ½ — 3 ½	5233.2	4.0
$a\,^4\mathrm{P} - a\,^2\mathrm{D}$	6.1	2 ½ — 2 ½	6996.8	3.2

Notes : λ : Edlén, 1966
A : Garstang, 1958

through the [Fe II] (1952-1953) and [Fe III] (1953-1954) stages (*). On the basis of the high excitation potential one would expect a low intensity. It is true that the excitation potentials of [Ne III] 3343 and [O III] 4363 are also high (resp. 6.9 and 5.33 ev.), and that their *g*A-values are a little smaller than those of [Fe IV], but the abundances of Ne and O are higher than that of Fe.

We have made a systematic search for [Fe IV] in a number of stars, sometimes over a long period : AX Per, Z And, CI Cyg, BF Cyg : no convincing assignment to [Fe IV] could be found. We used descriptions published by several observers.

RR Tel appears to be a unique case !

V. FORBIDDEN LINES OF Fe^{4+}

A. B. Wyse (1942) made a systematic search for [Fe V] in nebulae without success. Several wavelength coincidences in AX Per and CI Cyg were found in 1940, but could not be considered as convincing. The spectrum of [Fe V] appeared (**) strongly in AX Per in 1942, making it the first striking complete example of [Fe V] emission in a star (P. Swings and O. Struve, 1942a). [Fe V] is mainly characterized by the lines listed in Table 4. The transition probabilities have been computed by Garstang (1957).

A few of these lines (for ex. : λλ 3820, 3795) are generally hopelessly blended.

(*) Could it also have gone through the [Fe I] stage? Will it eventually become excited to [Fe X]? Has it also been rich in [Ni II, III, IV]? RR Tel was in the [Fe VII] stage in 1959.

(**) The spectrum of AX Per is variable, and a [Fe V] stage was expected. Swings and Struve took regularly spectrogramms in the hope of getting [Fe V] some day.

TABLE 4
Characteristic [Fe V] *lines*

Multiplet	Exc. Pot. (ev)	Transition	λ	gA
$a\,^5D - a\,^3P$	3.27	3 — 2	3895.5	3.55
		2 — 1	4071.3	3.3
		1 — 0	4180.9	1.3
$a\,^5D - a\,^3F$	3.33	4 — 4	3891.3	6.7
		3 — 3	3839.5	2.8
		3 — 4	3819.8	1.44
		2 — 3	3783.6	1.12
		2 — 2	3795.2	1.0

Notes : λ : Bowen, 1960
A : Garstang, 1957

A systematic examination of the wavelength lists in many objects (AX Per, CI Cyg, Z And, NGC 7027, NGC 7662, RT Ser in 1948, RS Oph, DQ Her, RR Pic, etc.) revealed the presence of [Fe V] with satisfactory relative intensities. On the other hand several attempted assignments in CI Cyg, AX Per, Z And, RS Oph should be excluded.

Fe^{++} and Fe^{4+} have complementary electronic configurations $3d^6$ and $3d^4$ with regard to the half-closed shell $3d^5$. As a result the strongest [Fe V] lines correspond to the same transitions as the strongest [Fe III] lines. The lines λ 3891 and 3895 give a striking doublet to the red of H_8, whereas λ 3839 is near H_9 ; λ 4071 lies between the two [S II] lines and has been mistaken for [S II] in descriptions of nova spectra. The [Fe V] and [Fe III] lines have helped greatly in understanding the spectral evolution of Nova RR Pictoris (P. Swings and O. Struve, 1942b).

VI. FORBIDDEN LINES OF Fe^{5+}

The [Fe VI] transitions were found in Nova RR Pictoris by Bowen (1935). The transition probabilities were initially computed by Pasternack (1940) and corrected by Garstang (1964). The characteristic [Fe VI] lines are given in Table 5.

The strongest [Fe VI] lines were especially conspicuous in symbiotic objects, such as AX Per in 1942, and in novae (not symbiotic like DQ Her, or symbiotic at a phase of weak late type features such as RT Ser in 1940-1942). The observed relative intensities were in good qualitative agreement with the theoretical values.

[Fe VI] has been observed in several novae (DQ Her, RR Pic, N Ser 1948, N Her 1960, N Ser 1950, etc.), planetary nebulae, (IC 4997, NGC 6741, 6886, 7027, 1535, 2392, 2022, 6572, IC 2165, IC 2003, etc.), symbiotic stars (AX Per, CI Cyg, Z And, etc.), and other peculiar bright line stars (RX Pup, ...).

The characteristic line $^4F_{3\frac{1}{2}} - {}^2D_{2\frac{1}{2}}$, λ 3664, lies in a favorable spectral region which is poor in emission lines ; however λ 3664 requires the highest excitation

TABLE 5

Characteristic [Fe VI] *lines*

Multiplet	Exc. Pot. (ev)	Transition	λ	gA
$^4F - ^2D$	3.5	3 ½ — 2 ½	3663.8	5.7
		2 ½ — 1 ½	3557.5	2.7
		1 ½ — 1 ½	3493.9	1.5
$^4F - ^2G$	2.6	4 ½ — 4 ½	5176.4	5.6
		3 ½ — 4 ½	4967.3	2.2
		3 ½ — 3 ½	5145.8	1.8
		2 ½ — 3 ½	4972.1	1.6
$^4F - ^2P$	3.2	2 ½ — 1 ½	3890.1	1.7
		1 ½ — 1 ½	3814.3	1.04

Notes : λ : Bowen, 1960
A : Garstang, 1964 ; 1967

(3.5 ev.) ; on the other hand the $^4F - ^2G$ multiplet which has gA values of the same order as that of λ 3664 but requires a low excitation (2.6 ev.) falls in a spectral region of the symbiotic stars containing late type features ; its detection may thus be difficult or uncertain in these objects.

A systematic examination of the tables of wave lengths of many nebulae reveals numerous unconvincing assignments, especially in the $^4F - ^4P$ multiplet. Of course such critical comments require great caution on account of our ignorance of the collisional cross sections. We plan a detailed study of these identifications.

VII. FORBIDDEN LINES OF Fe^{6+}

The [Fe VII] lines were identified for the first time in Nova RR Pictoris by Bowen and Edlén (1939). Transition probabilities were computed first by S. Pasternack (1940), later revised by R. H. Garstang (1964 and 1967). [Fe VII] plays a very prominent role in the spectra of novae (RR Pic, DQ Her, RT Ser, RS Oph, T Pyxidis, N Her 1948, ...), planetary nebulae (NGC 7027, 2440, 6741, 2392, 2165, ...), symbiotic objects (AX Per, CI Cyg, Z And, ...), and peculiar stars of uncertain symbiotic character (RX Puppis). The characteristic [Fe VII] lines are listed in Table 6.

In this table we have included the $^3F - ^3P$ multiplet, despite its weakness relative to the two other transitions ; this low theoretical probability is important in relation to the following observation which remained puzzling for many years. The spectral evolution of the slow Nova RT Serpentis has been normal. In 1942, [Fe V] and [Fe VI] were conspicuous, and [Fe VII] became very strong in 1950 (*).

(*) One may hope that RT Ser will some day show the [Fe X] coronal line. According to G. Herbig (1966), [Fe XIV] was not yet present in RT Ser in 1963-1964. The detection of [Fe X] on low dispersion spectrograms is difficult because RT Ser reveals now late type features. The transition from [Fe VII] to [Fe X] may of course require many years.

TABLE 6

Characteristic [Fe VII] *lines*

Multiplet	Exc. Pot. (ev)	Transition	λ (1)	*g*A (2) Past.	*g*A (3) Garst.
$^3F - {}^1D$	2.16	3 — 2	6086.9	2.45	2.45
		2 — 2	5721.1	1.5	1.5
$^3F - {}^1G$	3.57	4 — 4	3760.3	3.33	3.33
		3 — 4	3587.8	2.34	2.34
$^3F - {}^3P$	2.5	3 — 2	4944.0	0.65	0.325
		4 — 2	5277.7	1.0	0.3

Notes : (1) Bowen, 1960
(2) Pasternack, 1940
(3) Garstang, 1964 ; 1967

In an investigation of the 1950 spectrum, J. Grandjean (1952) noticed that the $^3F - {}^3P$ multiplet was much too weak relative to the other forbidden transitions, if the probabilities published by Pasternack were correct. A similar problem arose in other stars. The new theoretical probabilities of the $^3F - {}^3P$ multiplet computed by R. H. Garstang (1964, 1967) are 2 or 3 times smaller than those of Pasternack. The weakness of the $^3F - {}^3P$ lines is thus explained. Moreover the photographic emulsions have generally a « green dip » which may affect the photographic densities of the $^3F - {}^3P$ lines. Image tube-spectrograms may improve the situation (Aller and Walker, 1967).

The strong line λ 3760 coincides with a fluorescence line of O III ; the possible blending effect of the O III line may be checked by examining whether the other strong O III fluorescence line at λ 3444 is present ; such a blend is frequent. Similarly λ 6087 [Fe VII] is sometimes blended with [Ca V] : this was the case in RR Pic (Bowen and Edlén, 1939). Moreover the strong $^3F - {}^1D$ transition may be blended by late type features in the case of symbiotic stars. λ 3588 falls in a favorable spectral region, but requires a markedly higher excitation potential.

We have examined systematically the spectra of AX Per (at 6 phases), CI Cygni (3), Z And (3), RX Pup (1), T Pyx (2), RS Oph (2), RT Ser (3), N Ser 1948 (1), DQ Her (6), N Her 1963 (1), NGC 7027 (3), NGC 2440 (2), NGC 6741 (1), NGC 2392 (1), NGC 2165 (1). The relative intensities of the strong emissions are generally in good agreement with the theoretical values, but many uncertainties arise with regard to the $^3F - {}^3P$ mutliplet. The detailed discussion will be published later on.

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