ON THE INTERPRETATION OF FE II EMISSION PROFILES IN SEYFERT GALAXIES AND QSOS

by

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ABSTRACT

Recent high-resolution spectral scans of several QSOs and Seyfert galaxies show broad Balmer lines and permitted FeII lines in emission. We suggest that a careful comparison of the FeII and Balmer profiles may distinguish between the different proposed mechanisms for broadening of the lines. In particular, if the FeII profile is much narrower than the hydrogen profile, the suprathermal particle mechanism is most likely present.

Permitted FeII emission lines have recently been identified in two QSOs by Baldwin (1975), they seem to be definitely present in spectra published by Shectman and MacAlpine (1975) for the Seyfert galaxy NGC 7469, and in two other Seyfert spectra reported by Shields and Oke (1975). Osterbrock (1975) reports that most Seyfert galaxies of type I show these permitted FeII lines in emission. The purpose of this letter is to suggest that a careful comparison of the profiles of the observed FeII emission lines with the profiles of Balmer emission lines could provide a critical test of theoretical models for the origin of the broad emission lines in these objects.

Three mechanisms for the production of broad permitted lines have been proposed, with varying degrees of success in fitting observed profiles: 1) electron scattering, 2) mass motions, 3) emission from suprathermal particles. If the permitted iron emission arises in the same physical location as the broad hydrogen emission, then any combinations of the first two mechanisms should produce nearly identical profiles for FeII and Balmer lines. But if the FeII emission comes from a gas excited by suprathermal hydrogen which is responsible for the broad Balmer lines, then the profiles should be different.

It is important to determine whether the FeII lines are as broad as the Balmer lines or substantially narrower. Rough visual estimates from the published spectra, especially those obtained by Baldwin (1975), indicate to us that the permitted FeII lines are substantially narrower than the Balmer lines. If this visual estimate is substantiated by detailed analysis of the spectra, then, as we discuss below, the suprathermal particle mechanism is the most viable of the three mentioned.

The suprathermal particle model is described elsewhere (Stoner, Ptak and Ellis 1974 and Ptak and Stoner 1975); in this model, the broad permitted lines observed in type I Seyfert galaxies and QSOs represent emission from suprathermal atoms and ions interacting with a dense ambient gas of low ionization. The Balmer emission from the atoms of the ambient gas is largely self-absorbed, and the narrow component of the hydrogen lines as well as the narrow forbidden lines arise from a separate, lower density region. Narrow permitted lines of other species could be produced in either of these regions. However, since forbidden lines of FeII are not seen, the FeII emission must originate from a gas of fairly high density, with $Ne \gtrsim 10^7 cm^{-3}$. If the FeII lines were produced by suprathermal Fe^+ ions, they would be slightly broader than the Balmer lines. Since this does not appear to be the case, we conclude that the FeII emission is produced by the ambient gas with which the suprathermal particles interact.

There is a range of physical conditions of the ambient gas which is compatible with the required flux of suprathermals. Such conditions have been calculated by Ptak and Stoner (1975), by Kimmer (1976) and by Stoner and Ptak (1975). Typical values for the electron density and temperature are $Ne \approx 10^9 cm^{-3}$ and $T \approx 10^{4\circ}K$. If we assume these values for the ambient gas, we can easily calculate the abundance ratios for the various ionic species of iron. In equilibrium, there must be a balance between the ionization rate for a given ionic species and the recombination rate to form that ion. Applying this balance to neutral iron, we have:

$$N(Fe^{o})\ N_e\ \gamma_{12} = N(Fe^{+})\ N_e\ \alpha_1\ , \tag{1}$$

where $N(fe^{o})$ and $N(Fe^{+})$ are the number densities of the two ionic stages, N_e is the electron number density, γ_{12} is the ionization rate, and α_1 is the recombination rate. Simple approximate formulas for the required rates are given by Allen (1973), and using these, we obtain from equation (1):

$$\frac{N(Fe^{+})}{N(Fe^{o})} \cong 4.7T^{5/4}\exp\left\{-\frac{91290}{T}\right\}, \tag{2}$$

where T is the electron temperature. So for $T \approx 10^{4\,o}K$,

$$\frac{N(Fe^{+})}{N(Fe^{o})} \approx 50\ .$$

Similarly, for the Fe^{+} balance, we have

$$N(Fe^{+})\ N_e\ \gamma_{23} = N(Fe^{++})\ N_e\ \alpha_2\ . \tag{3}$$

Again, using the formulas given by Allen, we find that

$$\frac{N(Fe^{+})}{N(Fe^{++})} \approx 2T^{-5/4}\exp\left\{\frac{1.87 \times 10^{5}}{T}\right\}. \tag{4}$$

For $T \approx 10^{4\,o}K$, this yields

$$\frac{N(Fe^{+})}{N(Fe^{++})} \approx 2600 .$$

Thus the self-consistent physical conditions obtained from the suprathermal particle model imply that essentially all of the iron in the ambient gas should be singly ionized.

The presence of FeII lines significantly narrower than Balmer lines, then, is compatible with a picture in which the permitted FeII lines arise from singly ionized iron in the dense, fairly neutral ambient gas. These lines may be produced via the fluorescence mechanism suggested by Wampler and Oke (1967) and discussed by several others. Since the upper levels for these lines are about 5 eV above the ground level, the collisional excitation rate at $T \sim 10^{4\,o}K$ may be more than 10^4 times greater than the ionization rate for Fe^+, which is also the recombination rate. At high enough electron density, collisional excitation of the FeII multiplets may be sufficient to replace the fluorescence mechanism as the origin of the iron emission.

If the FeII lines are significantly narrower than the Balmer widths, then this can be explained by mass motions in photoionization models only by postulating two high-density regions: a low-velocity, Fe^+-rich region and a high-velocity, Fe^+-poor region. According to the calculations of MacAlpine (1972), the FeII emitting region is located outside the H^+ zone where the free electrons come primarily from ionization of helium. If this is the case, it is difficult to see how high-velocity Balmer-line-emitting clouds with a small filling factor can shield the low-velocity clouds which emit the FeII lines and keep them from being highly ionized. If these objects are characterized by narrow permitted FeII lines and broad Balmer lines, then the photo-ionization models must be modified in some presently unforeseen way to satisfy the constraints imposed by the line profiles and by the relative line intensities.

All of this depends on the widths of the FeII lines; it appears to us that the observed FeII lines are significantly narrower than the Balmer lines in these objects. Shields and Oke (1975), however, call the FeII emission "broad". Estimates of the observed widths are hampered by blending of lines, both from the same multiplet and from different multiplets. The spectrum of NGC 7469 published by Shectman and Mac Alpine (1975) does not seem well enough resolved for a definitive statement regarding the FeII line widths. Those spectra which Osterbrock and his group have obtained for type I Seyfert galaxies are not yet published. For the QSOs 3C273 and PKS 0736+01, Baldwin (1975) obtained spectra which apparently show many FeII lines, most of them blended into broad bands. However, these spectra contain some FeII lines, notably two from multiplets (27) and (28), which Baldwin says are unblended. Since these lines are about 60 Å apart, their half widths are less than about 20 Å, which is substantially less than the Balmer line widths.

Since the determination of the profiles of individual FeII emission lines seems to be a crucial observational matter, it is very important to have high-resolution scans of the spectra of these objects, especially in those regions in which there is little blending. Perhaps the spectra already available, if carefully analyzed, are sufficient. If not, suitable spectra should soon be available.

In subsequent work, we hope to make a detailed comparison of Balmer and FeII line profiles calculated in the context of the suprathermal particle model and the observed profiles. Since in the picture described here, the motion of the ambient gas, combined with any electron scattering contributions, determines the FeII profiles, the broad wings of the Balmer lines should be obtainable by folding the theoretical suprathermal profiles from a gas at rest (Ptak and Stoner, 1973) with the observed FeII profiles.

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