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METAL ABUNDANCES IN THE HOT DA WHITE DWARFS WOLF 1346 AND FEIGE 24

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ABSTRACT

Photospheric metal lines observed in high-dispersion *IUE* spectra of the hot DA white dwarfs Wolf 1346 and Feige 24 are analyzed with detailed model synthetic spectra in order to derive metal abundances in these two stars. The following results are obtained: $\log [N(\mathrm{Si})/N(\mathrm{H})] = -7.7 \pm 0.6$ in Wolf 1346; $\log [N(\mathrm{C})/N(\mathrm{H})] = -6.4 \pm 0.6$, $\log [N(\mathrm{N})/N(\mathrm{H})] = -5.3 \pm 1.0$, and $\log [N(\mathrm{Si})/N(\mathrm{H})] = -6.3 \pm 0.9$ in Feige 24. The observed photospheric metal line profiles in Feige 24 are also used to set an upper limit of $v \sin i < 30$ km s^{-1} on the projected rotational velocity of that object. The implications of these abundance determinations for theories of element diffusion in, and accretion onto, the envelopes of hot DA stars are discussed.

Subject headings: stars: abundances — stars: individual — stars: rotation — stars: white dwarfs — ultraviolet: spectra

I. INTRODUCTION

The photospheres of hydrogen-rich white dwarfs are usually thought to be monoelemental, with only a handful of these stars showing traces of helium or heavier elements. While this global deficiency is easily understood within the context of classical element diffusion theory, those stars with residual abundances of elements heavier than hydrogen pose interesting problems for that theory and may be the signature of additional physical processes that compete with downward element diffusion.

Only one hydrogen-rich star has a *measured* metal abundance: the cool DA white dwarf G74-7, whose spectrum exhibits a sharp Ca II K line (Lacombe *et al.* 1983). For the bulk of the other hydrogen-rich stars, only upper limits based on the nonappearance of optical transitions (Strittmatter and Wickramasinghe 1971; Shipman 1972), or on a preliminary interpretation of low-dispersion *IUE* spectra (Shipman 1980) were available up to now. However, recent work with the *IUE* in the high-dispersion mode has added two DA stars with detectable photospheric metal features, thereby significantly increasing the available sample of such objects. The cooler of the two, the bright DA star Wolf 1346, exhibits a photospheric Si II λ1263 feature in its *IUE* spectrum (Bruhweiler and Kondo 1983). The photospheric nature of this feature is strongly suggested by its measured radial velocity, which agrees with that measured from the Hα and Hβ cores by Greenstein *et al.* (1977), and also by the fact that the $\lambda\lambda$1264.737 and 1265.001 components—with their lower state 287 cm^{-1} above the ground state—have no interstellar counterparts. The other DA star with photospheric metal features is the close binary Feige 24, which was shown by Dupree and Raymond (1982) to exhibit Si IV, C IV, and N V lines in high-dispersion *IUE* spectra. The photospheric nature of these features is established by their high-velocity shift with respect to both other high-excitation (presumably circumstellar) lines, and the low-velocity ISM lines.

In order to gain further insight into the pattern of metal abundances in DA stars, we present here a detailed abundance analysis of the observed photospheric metal lines in Wolf 1346 and Feige 24. This analysis is based on the extensive set of metal line profiles and equivalent widths recently calculated by Henry, Shipman, and Wesemael (1985, hereafter HSW). Additional synthetic spectra are used to determine the rotational velocity of Feige 24. The rotational velocity of Wolf 1346 has already been estimated by Greenstein and Peterson (1973) and Greenstein *et al.* (1977) but is not discussed here because of the improper background subtraction in the data near 1265 Å (see § II*a*)[1].

This paper is organized as follows: In § II, the *IUE* images used in this analysis are discussed, together with the theoretical framework, provided by the work of HSW, used in the fitting procedure. The results of the abundance analyses are summarized in § III, where we also discuss the determination of the projected rotational velocity of Feige 24 based on our synthetic profiles calculations. The importance of these new abundance determinations is emphasized in § IV, where we discuss them within the context of the occurrence of diffusion and accretion processes in white dwarf photospheres.

II. OBSERVATIONAL MATERIAL AND SYNTHETIC SPECTRA

a) The Observational Material

The observational data for this investigation consist of several high-dispersion ultraviolet spectra obtained with the *IUE* satellite. A discussion of some of the individual images can be found in Dupree and Raymond (1982) and Bruhweiler and Kondo (1983), respectively, and the reader is referred to these papers for further details. An additional spectrum of Feige 24 has recently been secured by Dupree and Raymond,

[1] A correction alogrithm for order overlap in high-resolution *IUE* spectra obtained with the SWP camera has become available after completion and submission of the present work (Bianchi and Bohlin 1984).

TABLE 1

MEASURED EQUIVALENT WIDTHS USED IN THE FITS

Star	Line	W (mÅ)	Notes[a]
Wolf 1346	Si II λ1264.737	51.4 ± 7.8	1
	Si II λ1265.001	44.3	2
Feige 24	C IV λ1548.185	104	3
	C IV λ1550.774	108	3
	N V λ1238.821	63.6	4
	N V λ1242.804	60.9	4
	Si IV λ1393.755	97.9	4
	Si IV λ1402.770	75.6	4

[a] NOTES.—(1) Unweighted average of SWP 13542 and SWP 14415. (2) SWP 14415 only. (3) SWP 16292. (4) SWP 20614.

image SWP 20614, and this spectrum has kindly been made available to us by its owners. In contrast to the earlier image (SWP 16292), which was overexposed near N V λ1240 and Si IV λ1400, this latest image is properly exposed at these wavelengths. Hence, we have not used the published equivalent widths of Dupree and Raymond (1982) for these lines but rather measured the widths on the more recent spectrum. In the case of the N V λ1240 line, a correction of 19% was applied to the measured width, to take into account the improper background subtraction due to order overlap, as discussed by Bruhweiler and Kondo (1982). For the C IV λ1550 line, the widths from the earlier image, optimized for this wavelength range, were used. The data used for the fits are summarized in Table 1.

Two images of Wolf 1346 were obtained by Bruhweiler and Kondo (SWP 13542 and 14415), and the equivalent widths of the Si II $\lambda\lambda$1264.737, 1265.001 components were kindly measured for us by F. C. Bruhweiler. The λ1260.421 component, which is blended with the interstellar component, was also measured on one image. Because of that blend, this component is not used for the formal fitting, but provides nevertheless useful information (see § III*a*). The widths of the photospheric components are given in Table 1 and include, in this case, a 17% correction for the improper background subtraction in the observatory reduction procedure.

b) *The Synthetic Spectra*

Our analysis makes extensive use of the recent comprehensive calculations of metal lines in hot DA stars of HSW. Briefly, these calculations are based on grids of hydrogen-rich model atmospheres at $\log g = 8.0$. Synthetic spectra were calculated for values of the metal-to-hydrogen number ratio ranging from 10^{-3} to 10^{-7}, and for effective temperatures between 15,000 K and 100,000 K. For the present analysis, the results of HSW for the C IV λ1550, N V λ1240, Si II λ1263, and Si IV λ1400 lines were used to obtain preliminary estimates of the metal abundances; additional models, with a closer spacing both in metal-to-hydrogen ratio and in effective temperature, were then computed to constrain the abundance further. The reader is referred to the paper of HSW for further details on the model atmosphere calculations, the atomic physics used in these computations, as well as the uncertainty in the predicted equivalent widths.

III. METAL ABUNDANCES IN TWO DA STARS

a) *The Silicon Abundance in Wolf 1346*

To fit the Bruhweiler and Kondo (1983) data for this star, we have adopted an effective temperature of $T_e = 21{,}500 \pm 500$ K, a value based on the determinations of Shipman (1972, 1979), Wesselius and Koester (1978), and Greenstein and Oke (1979). Our result for the longward, photospheric components of Si II λ1263 yields slightly discrepant values. This follows from the fact that the line at 1265.001 Å is observed with a strength comparable to that at 1264.737 Å (see Table 1, and Bruhweiler and Kondo 1983, Fig. 2). Our calculations, however, predict a much weaker λ1265 component, because the ratio of the oscillator strengths is $f_{1265}/f_{1264} = 0.11$ (Wiese, Smith, and Glennon 1966; Morton and Smith 1973). Accordingly, a much higher silicon abundance is required to fit the λ1265 component $\{\log [N(\text{Si})/N(\text{H})] = -6.8\}$ than the λ1264 component $\{\log [N(\text{Si})/N(\text{H})] = -7.7\}$.

A resolution to this problem may be provided by the third silicon component at 1260.421 Å. Despite its blending with the interstellar feature, this line was sufficiently separated from the ISM component to be used to clarify our abundance determination. Bruhweiler's width, corrected for improper background subtraction, is $W_{1260} = 51$ mÅ, based on a single spectrum (SWP 13542). While this measurement is somewhat more uncertain than those listed in Table 1 because of the ISM blend, it is entirely consistent with the width of the λ1264 component; indeed, the corresponding abundance is $\log [N(\text{Si})/N(\text{H})] = -7.5$.

The origin of the apparent discrepancy between the results derived from the λ1265 component and those from the other two lines is unknown. The recent work of Migdalek (1976) and Nussbaumer (1977) yields oscillator strengths for the three Si II components in reasonable agreement with those of Wiese, Smith, and Glennon (1966) and Morton and Smith (1973). The possibility that noise in the SWP images might explain the abundance discrepancy was also considered, but appears unlikely; for example, to fit the abundance obtained on the basis of the λ1264 feature, the equivalent width of the λ1265 component would have to be ~13 mÅ, less than a third of the measured width. The two different images obtained by Bruhweiler and Kondo (1983) appear sufficiently consistent with each other to render that possibility unlikely (see their Fig. 2). We also investigated the alternative that the λ1265 component is strengthened by a blend with another atomic line. To this end, we search the list of Kelly and Palumbo (1973) but found no reasonable candidate. The essentially monoelemental nature of white dwarf photospheres renders this last possibility very improbable anyway.

Thus, while we cannot, at this stage, suggest a proper explanation for this abundance discrepancy, we believe that the current evidence strongly favors the lowest of the abundance values discussed above. Accordingly, we have adopted the abundance based on the λ1264 fit as our final result for Wolf 1346; the associated error bars in Table 2 allow for uncer-

TABLE 2

METAL ABUNDANCE DETERMINATIONS

	ABUNDANCE[a]		
STAR	C	N	Si
Wolf 1346	...	...	−7.7 ± 0.6
Feige 24	−6.4 ± 0.6	−5.3 ± 1.0	−6.3 ± 0.9
Sun[b]	−3.5	−4.0	−4.5

[a] Abundances given as log [N (metals)/N(H)].

[b] Solar abundances from Allen 1973.

tainties in both the effective temperature determination and the equivalent width measurements, with an additional allowance made for the discrepancy in the results based on the two photospheric components.

b) The Carbon, Nitrogen, and Silicon Abundances in Feige 24

In order to fit the metallic lines observed in Feige 24, we have adopted for that star an effective temperature of $T_e = 63{,}000 \pm 10{,}000$ K; this value is consistent with the determinations of Margon *et al.* (1976), Holm (1976), Wesselius and Koester (1978), and with Shipman's unpublished fits to the *Apollo-Soyuz* data. The resulting best fitting abundances are listed in Table 2. In general, the error bars given incorporate three uncertainties: (*i*) that due to the effective temperature determination; (*ii*) that due to the equivalent width measurement, which we estimate to be of the order of 15%–20% in this range of equivalent widths; and (*iii*) that due to the abundance fits obtained from the individual components of the doublet. Tests made with different oscillator strengths (e.g., Wiese, Smith, and Glennon 1966 vs. Morton and Smith 1973) and various metallic model atoms yielded abundances well within the quoted error bars. The uncertainties introduced by these various input quantities are discussed in more detail by HSW.

The helium abundance can also be estimated from the Dupree and Raymond (1982) spectra, as these show no evidence of He II λ1640. This null detection leads to an approximate upper limit of $\log [N(\text{He})/N(\text{H})] \lesssim -3$ in Feige 24 (e.g., Wesemael, Liebert, and Green 1984).

It is also possible to set useful limits on the projected rotational velocity of Feige 24 as the metal lines are intrinsically quite narrow. For this purpose, we have used synthetic profiles which were calculated at the best fitting abundances given in Table 2. The analysis was restricted to the C IV and Si IV lines; the N V doublet was omitted as the true continuum level at wavelengths below 1350 Å is set systematically too low in the current *IUE* observatory reduction procedure (see § IIa and footnote 1). The computed spectra were first corrected for instrumental broadening by performing a convolution with a Gaussian profile of appropriate FWHM. Our adopted instrumental FWHM values were 0.11 Å at λ1400 and 0.13 Å at λ1550 (Holm 1982; Imhoff 1983). The resulting profiles were then further broadened by rotation, neglecting limb darkening and following standard techniques (e.g., Gray 1976).

Sample results of this procedure are displayed in Figure 1. The best fitting velocity was obtained by visual comparison of both unsmoothed and smoothed *IUE* data with a template of theoretical profiles such as that of Figure 1. The projected rotational velocity appear small, as the theoretical profiles at high velocities become much too shallow. We find that an upper limit of $v \sin i < 30$ km s^{-1} can be set from both the C IV and Si IV data. Above that value, the discrepancy between observed and computed profiles becomes larger than can be accounted for by the noise level in the high-dispersion spectra. This result is insensitive to reasonable ($\sim$30%) uncertainties in the instrumental profiles. The theoretical profiles for a nominal best fitting value of $v \sin i = 10$ km s^{-1} are shown in Figure 2. The red Si IV component (λ1402.770) is not shown, as those data are noisier than those for the other three components. The rotation period corresponding to our upper limit is $P > 1.46$ hr, to be contrasted with the orbital period of $4^{\mathrm{d}}2319$ (Thorstensen *et al.* 1978). The low projected rotational velocity determined for this hot DA white dwarf is consistent with the

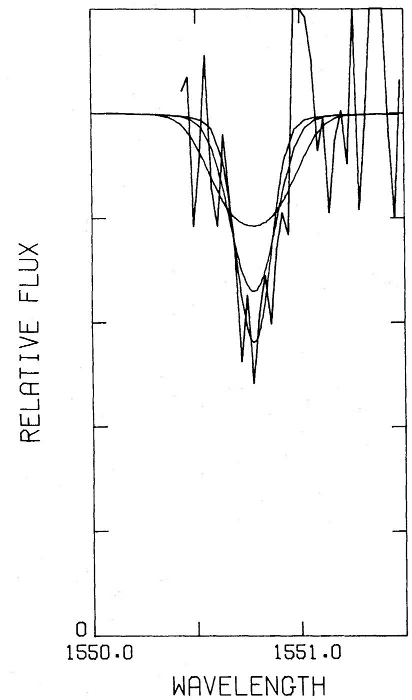

FIG. 1.—The C IV λ1550.774 component in Feige 24 observed by Dupree and Raymond (SWP 16292). The theoretical profiles superposed are corrected for instrumental broadening and are further broadened by rotation. The profiles displayed are, from bottom to top, for $v \sin i = 0$, 25, and 50 km s^{-1}. The observations have been shifted to the laboratory rest frame. The continuum shown is that set on the high-dispersion spectra by Dupree and Raymond.

small velocities inferred or calculated by Greenstein and Peterson (1973), Bessell and Wickramasinghe (1975), Greenstein *et al.* (1977), and Pilachowski and Milkey (1984) for a sample of generally cooler DA stars, based on the sharpness of the cores of the low Balmer lines (Hα, Hβ).

IV. THE ORIGIN OF THE OBSERVED METALS

Our analysis of Wolf 1346 and Feige 24, together with the recent calcium abundance determination in the cooler DAZ star G74-7 (Lacombe *et al.* 1983), represent the first heavy element abundances available for hydrogen-rich white dwarfs. These analyses thus provide fundamental information on the occurrence and efficiency of various processes, such as element diffusion and accretion, which can affect the elemental composition of white dwarf envelopes.

Downward element diffusion is expected to be very efficient in the high-gravity photospheres of white dwarfs. Settling time scales of metals have been computed by several authors (Fontaine and Michaud 1979; Vauclair, and Greenstein 1979; Alcock and Illarionov 1980*a*; Muchmore 1984) and are generally much shorter than the cooling time of the star. To further investigate the diffusion processes in the two objects analyzed here, we have used the method of Fontaine and Michaud (1979), together with the recent transport coefficients of Paquette (1983). In this latest investigation, the collision integrals are evaluated numerically under the assumption of a Debye-Hückel interaction potential. As the envelopes of both Feige 24 and Wolf 1346 are radiative, the diffusion time scales were estimated at an optical depth of $\tau_{\text{Ross}} \approx 10$, in order to insure that the photosphere will be completely depleted of heavy elements. The following time scales were obtained: $\tau_{\text{Si}} =$

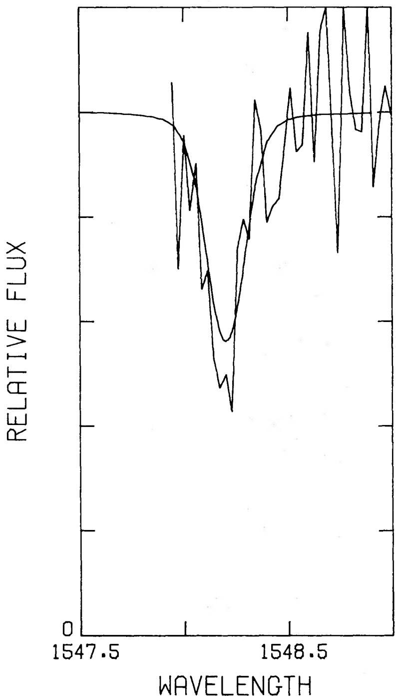

FIG. 2a

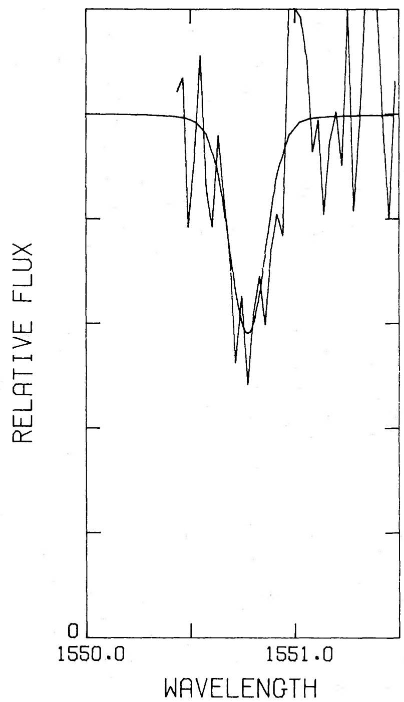

FIG. 2b

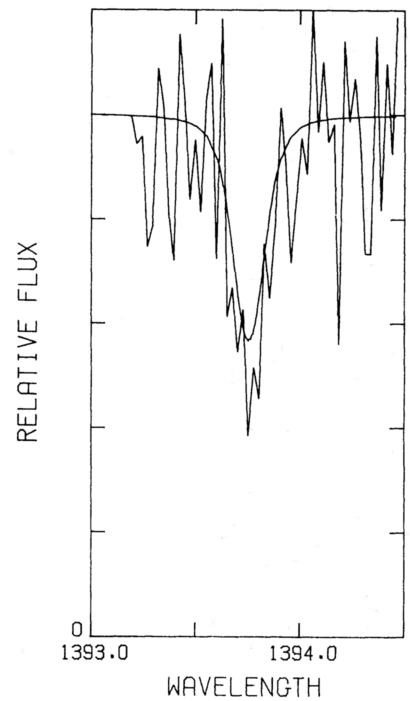

FIG. 2c

FIG. 2.—(*a*) Theoretical profile of the C IV λ1548.185 component in Feige 24, together with the observations of Dupree and Raymond (SWP 16292). The theoretical profile is corrected for instrumental broadening and is further broadened by rotation, assuming $v \sin i = 10$ km s^{-1}. The continuum shown is that set on the high-dispersion spectra by Dupree and Raymond; the observations have been shifted to the laboratory rest frame. The low-velocity, high-ionization component blueward of the photospheric feature is omitted. (*b*) Same as (*a*), but for the C IV λ1550.774 component. (*c*) Same as (*a*), but for the Si IV λ1393.755 component (SWP 20614). There is little evidence for a low-velocity, high-ionization counterpart to this feature (Dupree and Raymond 1982).

9.6×10^{-2} yr in Wolf 1346; $\tau_C = 9.6 \times 10^{-1}$ yr, $\tau_N = 8.8 \times 10^{-1}$ yr, and $\tau_{Si} = 4.1 \times 10^{-1}$ yr in Feige 24. Diffusion time scales based on somewhat different formalisms available in the literature all yielded results within a factor ~ 4 of those quoted here (see Paquette *et al.* 1985). Clearly, the settling of the primordial heavy elements, if unhindered, should have long been completed; mechanisms competing with this efficient downward settling must thus be examined.

The two mechanisms currently thought to be the most effective in competing with downward element diffusion are accretion and radiative element support. In the DAZ star G74-7, Lacombe *et al.* (1983) argued that a recent encounter with an interstellar cloud was a likely source of the observed calcium, as radiative forces are unimportant in this much cooler star. The situation may be quite different in the two stars analyzed here, where radiative forces are likely to play an important role.

The accretion-diffusion model of Vauclair, Vauclair, and Greenstein (1979) and Alcock and Illarionov (1980*a*) is based upon the assumption of a steady state balance in the atmosphere between accretion and downward diffusion, *and neglects radiative element support*. Under these conditions, the observed photospheric abundance of element Z is related to that in the infalling ISM material by

$$\left.\frac{N(\mathrm{Z})}{N(\mathrm{H})}\right|_{\mathrm{photosphere}} = \frac{\dot{M}}{4\pi R^2 \rho v_Z + \dot{M}} \left.\frac{N(\mathrm{Z})}{N(\mathrm{H})}\right|_{\mathrm{ISM}}, \qquad (1)$$

where $\dot{M}$ is the accretion rate, R is the stellar radius, and ρ and v_Z are the mass density and element diffusion velocity, respectively, both evaluated at the photosphere. For accretion of matter of solar composition, the observed silicon abundance in Wolf 1346 can be achieved with a steady state accretion rate of $2 \times 10^{-18}\ M_\odot$ yr^{-1}. This rate is roughly a factor 3000 larger than that expected from a star traveling at 20 km s^{-1} in a tenuous medium ($n \approx 0.1$ cm^{-3}), and accreting steadily at the Eddington rate. The required accretion rate can, of course, be achieved if Wolf 1346 is crossing (or has recently crossed) a cloud of moderate density and accretes at the fluid rate (e.g., Wesemael 1979; Alcock and Illarionov 1980*b*). Based on the cloud filling factor discussed by Bruhweiler and Kondo (1983), this could be the case for one out of every 15 DA stars (see also Lacombe *et al.* 1983). The observations of Bruhweiler and Kondo suggest, however, that Wolf 1346 is located in a rather tenuous and hot region of the ISM, with no evidence for clouds or cloudlets on its line of sight.

The accretion-diffusion model, under the assumption of solar abundances in the infalling material, also predicts relative abundance ratios in the atmosphere. A computation of the carbon diffusion velocity at the photosphere of Wolf 1346 suggests that the carbon abundance should be $\log [N(\mathrm{C})/N(\mathrm{H})] \approx -6.5$ in that object. At that abundance, the calculations of HSW predict an equivalent width of the order of 200 mÅ for both the C II λ1335 and C III λ1176 lines. As these lines are not reported in the high-dispersion spectra of Wolf 1346, the C/Si ratio in the accreting material must be much less than solar. While this argument, in itself, cannot be used to dismiss the accretion scenario, it suggests—if accretion is indeed the source of the heavy elements observed—that element fractionation must have occurred in the accreting material (Alcock and

Illarionov 1980*b*). This result would join other evidence, based on results obtained in cooler helium-rich stars (e.g., Shipman and Greenstein 1983; Shipman 1983), which points in that direction.

An attractive alternative to the accretion hypothesis is the possibility that the observed traces of silicon in Wolf 1346 are supported by radiative forces. This idea is discussed in some detail by Bruhweiler and Kondo (1983), who show that radiative element support can be important even in intermediate-temperature white dwarfs and provides a natural explanation for the low C/Si ratio inferred for Wolf 1346. The evidence currently available thus favors the idea that Si is supported by radiative forces in Wolf 1346; silicon should be considered in further studies of radiative accelerations in white dwarf stars.

The abundances observed in Feige 24 provide another testing ground for the idea that some processes competing against the downward diffusion of heavy elements must be at work in the photospheres of hot white dwarfs. In this hotter object, theoretical considerations indeed suggest that radiative element support will be extremely effective. Because of this, the accretion-diffusion model discussed above, which neglects radiative forces, is probably irrelevant. One has, instead, a situation where the downward diffusion of heavy elements, irrespective of their origin, is disrupted by the stellar radiation field. Radiative accelerations on C and N in hot DA stars have been calculated by Vauclair, Vauclair, and Greenstein (1979). Their results (see their Fig. 2*a*) show that at the photosphere of a 50,000 K star, both N and C will be supported by radiative forces; the estimated equilibrium abundances for these elements can reach 10^{-1} and 2×10^{-2} the solar value for N and C, respectively (no radiative forces have been calculated for Si). The abundances we have determined in Feige 24 are consistent with this efficiency.

Radiative forces are efficient in erasing clues to the origin of the heavy elements being supported. This is because the abundances observed, when interpreted as equilibrium values, only reflect the delicate balance between upward and downward forces on a particular element in the atmosphere and not, for example, a large primordial abundance or the occurrence of an accretion event. Thus a discussion of the origin of the heavy elements observed in Feige 24 appears, at present, of little more than academic interest. Nevertheless, the nature of the Feige 24 system and, in particular, the presence of an M dwarf companion only 0.05 AU away suggests the intriguing possibility that the material being supported in the atmosphere may originate from mass lost from the red dwarf, an origin already suggested by Dupree and Raymond (1983). To evaluate that suggestion properly, one requires a knowledge of the mass loss rate from the secondary and also an estimate of the accretion efficiency onto the white dwarf. Let us now consider both these ingredients in turn.

Little is known about potential mass loss from late-type main-sequence stars. Our current understanding of the Sun suggests that it is plausible that some mass loss does take place in M dwarfs, in the form of both a quiescent stellar wind and a stellar-flare blast wave. Mass loss rates in the latter case were examined by Coleman and Worden (1976) by considering scaling arguments based on large solar flares. They suggest rates $\sim 2 \times 10^{-13}\ M_\odot\ \mathrm{yr}^{-1}$ for a typical dM5e flare star. This estimate is also based on the ratio of the flare optical luminosity to the stellar bolometric luminosity of flare stars, so that the mass loss rate should perhaps be increased by a factor 2–4 for a dwarf like the Feige 24 secondary (M1–3.5 V; Holm 1976; Liebert and Margon 1977; Probst 1983), all other things being equal. However, the spectroscopic evidence currently available suggests that the red dwarf in Feige 24 may not be a very active flare star, if at all, as it does not display the rapid emission-line variability expected from such objects (Liebert and Margon 1977). The mass loss rate in the stellar-flare blast wave would thus be considerably reduced.

The mass loss rate in the stellar wind of red main-sequence stars is even more uncertain. Kahn (1969) estimated a typical wind mass rate in red dwarfs of $\sim 3 \times 10^{-12}\ M_\odot\ \mathrm{yr}^{-1}$, based on highly uncertain coronal models for the dM4.5e flare star YZ CMi. Coleman and Worden (1976) critically reviewed the arguments leading to this mass loss estimate and considered it to be an extreme upper limit, based on the high coronal temperatures and high energy conversion efficiency used in the original investigation. These rather uncertain arguments thus suggest the possibility that late-type main-sequence stars may be losing mass—through both a quiescent stellar wind and a stellar-flare blast wave—at a rate of a few $10^{-13}\ M_\odot\ \mathrm{yr}^{-1}$. On the basis of the solar "model," the major fraction of the mass lost would be through the quiescent stellar wind, with the flaring activity contributing only $\sim 20\%$ of the total mass loss.

Let us now turn to the problem of estimating the accretion efficiency onto the white dwarf. We neglect, for the time being, any mechanism that could prevent accretion. A first estimate can be obtained by assuming that the accretion efficiency is given by the geometrical cross-section of the white dwarf. In that case, the accretion efficiency factor is of the order of $(R_{\mathrm{WD}}/2a)^2 \approx 3 \times 10^{-7}$, where R_{WD} and a are the white dwarf radius and separation of the components, respectively. If the focusing effect of the white dwarf gravitational field is taken into account, the accretion efficiency becomes $(M_{\mathrm{WD}}/M_{\mathrm{RD}})(R_{\mathrm{WD}}R_{\mathrm{RD}}/4a^2\gamma^2) \approx 2 \times 10^{-5}$, where the index RD refers to the red dwarf, and γ is the ratio of the wind velocity to the escape velocity from the M star, which should be of order unity.[2] Finally, if fluid accretion takes place onto the degenerate star, the efficiency factor becomes $(M_{\mathrm{WD}}/M_{\mathrm{RD}})^2(R_{\mathrm{RD}}{}^2/8\gamma^4a^2) \approx 8 \times 10^{-4}$ with, once again, $\gamma \equiv 1$. This last case requires the formation of a tail shock, and the destruction of the momentum of the accreting particles in the direction perpendicular to the accretion axis. On the basis of these estimates, and with an assumed mass loss rate from the secondary of $\dot{M} \approx 10^{-13}\ M_\odot\ \mathrm{yr}^{-1}$, the accretion rate onto the primary could be in the range 3×10^{-20} to $8 \times 10^{-17}\ M_\odot\ \mathrm{yr}^{-1}$, large enough to pollute the white dwarf photosphere.

The above discussion assumes that accretion can proceed without inhibition onto the white dwarf surface. For a primary with such a high effective temperature, this assumption deserves some attention. The accreting material is likely to be fully ionized because of the coronal heating required to drive a solar-like stellar wind. However, no ensuing reduction in the accretion rate, such as that discussed by Mestel (1954) and Talbot and Newman (1977), is expected here as the accreting material will already be highly supersonic.

Another possibility is that the radiation pressure from the hot white dwarf could disrupt the accretion flow originating from the M dwarf. For a mass loss rate of $10^{-13}\ M_\odot\ \mathrm{yr}^{-1}$ (see

[2] For example, $\gamma = 0.52$ for the solar wind at Earth's orbit. For an early-type M dwarf, with a coronal temperature of the order of 5×10^5 K (Mullan 1976), the isothermal stellar wind models of Michaud *et al.* (1985) indicate a lower value, $\gamma \approx 0.1$, at a distance of 0.05 AU.

above), the ram pressure in the stellar wind midway between the two stars is

$$P_{\rm ram} \approx \rho_w v_w^2 \approx 1.7 \times 10^{-4} \text{ dyn cm}^{-2} , \qquad (2)$$

where ρ_w and v_w are the wind mass density and velocity, respectively, and where a constant value of $\gamma = 1$ has been adopted. This pressure can be compared to that obtained by integrating the radiative pressure gradient, assuming a fully ionized hydrogen and helium plasma and a photospheric temperature of 60,000 K for the white dwarf, namely

$$P_{\rm rad} \approx 1.1 \times 10^{-4} \text{ dyn cm}^{-2} , \qquad (3)$$

at the same location. These arguments suggest the existence of a stagnation point, where the dynamic pressure of the stellar wind might equilibrate that of the white dwarf radiation field (an accurate estimate of the standoff distance would require a detailed knowledge of the velocity profile in the wind of the M dwarf). It thus seems plausible that the intense white dwarf radiation field might well disrupt the accretion flow onto its surface and reduce the accretion rate well below the values quoted above.

The presence of one of the rare DA white dwarfs exhibiting metal lines in a close binary system is clearly intriguing. We reemphasize, however, that the abundances determined in this paper offer, at present, no clues to the origin of the supported elements. Thus the presence of traces of metals in Feige 24, and its absence in, e.g., HZ 43 (Malina, Basri, and Bowyer 1982) may well only reflect the different balance between upward and downward forces in the photosphere caused, for example, by slightly different surface gravities.

Additional high-dispersion observations and abundance analyses of hot white dwarfs should provide valuable information on the fraction of DA stars exhibiting traces of metals in their photosphere. Furthermore, we believe that our results call for a renewed effort in the calculation of radiative forces in the atmospheres of degenerate stars. In particular, there appears to be sufficient incentive to tackle the problem of time-dependent evolution of metal abundances in white dwarf envelopes, taking into account radiative forces, line saturation effects, and composition gradients set up by intermittent cloud accretion or by steady wind accretion from a nearby companion. In the latter case, a consideration of the chemical separation processes occurring in the stellar wind at low mass-loss rates will also be necessary (Michaud 1984).

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