THE ASTROPHYSICAL JOURNAL, 308:240–245, 1986 September 1

A SURVEY OF INTERSTELLAR SULFUR ABUNDANCE AND IMPLICATIONS FOR P II OSCILLATOR STRENGTHS[1]

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Received 1985 November 25; accepted 1986 February 13

ABSTRACT

A study of interstellar gas-phase sulfur abundance is presented which is based mainly on abundances for 39 sight lines newly derived from recently published *Copernicus* UV absorption line measurements and archival *IUE* data. A trend of increasing depletion with increasing mean hydrogen volume density $\bar{n}$(H) is evident which is similar to that already established for another volatile element, chlorine, but weaker than the dependence of depletion on $\bar{n}$(H) exhibited by refractory elements such as Ca, Ti, and Mg. The correlation of sulfur depletion with reddening per kpc is relatively poor. The results confirm that sulfur is not a major constituent of interstellar grains. A comparison of Doppler widths derived for S II and P II in the same sight lines reveals an unexpected systematic discrepancy of a factor of ~1.7. The possibility that this is due to inaccuracy of the normally adopted oscillator strengths for the P II λλ1153 and 1302 lines is discussed.

Subject headings: interstellar: abundances — ultraviolet: spectra

I. INTRODUCTION

On the basis of early studies of individual sight lines with the *Copernicus* satellite, sulfur and zinc have been classed together as elements which show little or no gas-phase depletion, relative to hydrogen, in the interstellar medium (see, for example, Morton 1975; Spitzer and Jenkins 1975; Morton 1978). Under the assumption of nondepletion, these elements offer a useful means of estimating hydrogen column densities (Phillips, Gondhalekar, and Pettini 1982; Harris, Bromage, and Blades 1983). The survey of Harris, Gry, and Bromage (1984) supported the view that sulfur is at most only slightly depleted by showing that previously published S II abundances in 15 sight lines do not follow the density-dependent depletion pattern exhibited by depleted refractory elements such as Ca, Ti, Mg, and Fe.

However, authors of more recent studies, such as Snow and Joseph (1985) and Crutcher (1985), claim to have found evidence for substantial depletion of sulfur in particular sight lines through regions of high density. In the light of these recent studies, Gondhalekar (1985) has reconsidered the question of sulfur depletion by investigating the correlation of previously published S II abundances with hydrogen column density N(H) and volume density $\bar{n}$(H) [$\bar{n}(H) = N(H)/r$, where r is the sight-line length], for 22 sight lines, including some through high-density regions. With the exception of the sight lines to ζ and χ Oph and ζ Per he finds a strong, roughly linear trend of depletion increasing with log [$\bar{n}$(H)]. The three anomalous sight lines exhibit relatively little depletion of sulfur, but all have large values of $\bar{n}$(H) and N(H) and are in general associated with large depletions of other elements. Clearly, the depletion behavior of sulfur is not well understood, and further investigation is required to determine its relation to the pattern of density-dependent depletion established for other elements (Phillips, Gondhalekar, and Pettini 1982; Harris, Gry, and Bromage 1984; Jenkins, Savage, and Spitzer 1986; Harris and Mas Hesse 1986).

Here we report on a detailed study of the depletion/density behavior of sulfur based on gas-phase abundance determinations for 49 sight lines, including a homogeneous set of 36 abundance values calculated from the equivalent widths of the S II λλ1251 and 1260 lines published by Bohlin *et al.* (1983). In addition, comparison of Doppler widths (b-values) for S II derived in the course of this work with those derived from the P II λλ1153 and 1302 equivalent widths (Bohlin *et al.* 1983) for the same sight lines has enabled a useful check to be made on the validity of the normally adopted oscillator strengths for the P II lines.

II. DATA BASE AND COLUMN DENSITY DETERMINATIONS

The set of equivalent widths for the S II λλ1251 and 1260 lines published by Bohlin *et al.* (1983) formed the main source of data for this work. However, the $\bar{n}$(H) range covered by the study has been extended by including the sight lines to ν and σ Sco and χ Oph, for which abundance values were derived from archival *IUE* data. The *IUE* images used are listed in Table 1, together with the equivalent widths measured after co-adding the individual spectra of each star. The S II lines are situated in well-defined stellar continua and are free of blends with neighboring lines, thus facilitating the accurate measurement of equivalent widths. Column densities were calculated assuming a single Gaussian curve of growth and using oscillator strengths from Morton and Smith (1973). The S II lines are generally quite strong, and many of the Bohlin *et al.* line ratios indicate severe saturation. The sight lines concerned were excluded from our data base, as were others for which the quoted equivalent widths have relatively large uncertainties associated with them. The total number of Bohlin *et al.* sight lines used in this study is 36, all of which have S II equivalent widths of quoted accuracy 10 σ or greater. Calculated column

[1] Partly based on data from the *International Ultraviolet Explorer* obtained from the Villafranca Data Archive of the European Space Agency.

TABLE 1

IUE IMAGE NUMBERS AND EQUIVALENT WIDTHS

HD	NAME	SWP	W_λ (mÅ) 1251 Å	W_λ (mÅ) 1260 Å
145502..........	ν Sco	4214	117 ± 20	145 ± 30
147165..........	σ Sco	5124, 5125, 5126, 5127	103 ± 10	130 ± 20
148184..........	χ Oph	5956, 7753, 15059	113 ± 9	138 ± 8

densities, abundances and b-values are listed in Table 2. The abundance values are relative to total hydrogen column density $[N(\mathrm{H}) = N(\mathrm{H\ I}) + 2N(\mathrm{H_2})]$ and scaled to log $N(\mathrm{H}) = 12$. Errors quoted for the abundances were derived from the errors associated with the equivalent widths (Bohlin *et al.* 1983 and Table 1) and those given with the published hydrogen column densities (Savage *et al.* 1977; Bohlin, Savage, and Drake 1978; Bohlin *et al.* 1983). In the case of the *IUE* sight lines, the equivalent width uncertainties do not exclude the possibility that a measured line ratio is unity, indicating complete saturation. In these cases no upper bounds to log N(S II) and a(S II) are given. The large uncertainties associated with fitting two lines to a single Gaussian curve of growth are well known and have been discussed by a number of authors (e.g.,

TABLE 2

COLUMN DENSITIES AND ABUNDANCE DETERMINATIONS FOR S II

HD	Name	Log($\bar{n}$(H) cm^{-3})[a]	Log(N(SII) cm^{-2})	a(S II)	b(SII)[b] (km s^{-1})	b(PII)[c] (km s^{-1})	b*(PII)[d] (km s^{-1})
5394	γ Cas	-0.62	15.20 (15.15 , 15.26)	7.04 (6.91 , 7.20)	5.2	3.8	7.2
24760	ε Per	-0.48	15.24 (15.18 , 15.32)	6.73 (6.59 , 6.91)	4.9	3.5	5.0
29248	ν Eri	-0.48	15.17 (15.03 , 15.46)	6.72 (6.43 , 7.23)	3.1	2.1	2.3
31237	π^5Ori	-0.43	15.03 (14.97 , 15.10)	6.62 (6.45 , 6.84)	6.9	...	...
35149	23 Ori	-0.38	15.26 (15.12 , 15.52)	6.52 (6.30 , 6.88)	7.4	3.4	3.7
35439	25 Ori	-0.52	15.27 (15.18 , 15.37)	6.80 (6.62 , 7.03)	9.7	...	...
36486	δ Ori	-0.84	15.27 (15.25 , 15.28)	7.04 (6.94 , 7.15)	11.6	...	...
36822	ϕ^1Ori	-0.27	15.87 (15.66 , 16.25)	7.03 (6.74 , 7.51)	6.2	4.6	5.3
36861	λ Ori A	-0.42	15.51 (15.46 , 15.57)	6.71 (6.56 , 6.89)	11.0	7.4	10.1
37043	ι Ori	-0.97	15.23 (15.22 , 15.25)	7.09 (7.01 , 7.17)	12.1	10.7	∞
37128	ε Ori	-0.66	15.30 (15.28 , 15.32)	6.85 (6.75 , 6.97)	10.0	5.0	7.0
37468	σ Ori	-0.52	15.45 (15.42 , 15.49)	6.94 (6.82 , 7.07)	10.8	8.7	∞
38771	κ Ori	-0.68	15.31 (15.30 , 15.32)	6.78 (6.74 , 6.85)	11.8	4.9	6.4
52918	19 Mon	-0.80	15.43 (15.30 , 15.72)	7.09 (6.86 , 7.50)	7.1	5.8	11.8
64740		-0.68	15.02 (14.93 , 15.15)	6.76 (6.56 , 7.04)	6.9	...	...
64760		-1.22	15.51 (15.48 , 15.54)	7.25 (7.11 , 7.43)	15.2	10.2	∞
65818	V Pup	-0.41	15.58 (15.47 , 15.79)	7.04 (6.82 , 7.40)	8.1	5.2	6.1
68273	γ^2Vel	-1.28	15.34 (15.29 , 15.42)	7.57 (7.47 , 7.69)	7.9	4.4	11.2
74575	α Pyx	-0.51	15.42 (15.34 , 15.54)	6.90 (6.71 , 7.17)	10.3	...	...
106490	δ Cru	-0.60	15.08 (15.06 , 15.10)	7.04 (7.18 , 6.92)	8.5	17.5	∞
108248	α^1Cru	-0.64	15.14 (15.13 , 15.15)	7.29 (7.20 , 7.40)	7.5	3.5	8.3
118716	ε Cen	-0.85	15.19 (15.17 , 15.21)	7.28 (7.19 , 7.41)	8.3	3.8	7.2
120324	μ Cen	-0.15	15.16 (15.09 , 15.25)	6.76 (6.58 , 7.00)	7.2	2.8	3.9
127972	η Cen	-0.35	15.00 (14.97 , 15.03)	6.89 (6.76 , 7.04)	6.2	...	...
136298	δ Lup	-0.64	15.04 (15.01 , 15.06)	6.86 (6.73 , 7.00)	8.0	3.9	∞
138690	γ Lup	-0.40	14.84 (14.79 , 14.88)	6.61 (6.45 , 6.80)	9.5	...	...
143118	η Lup A	-0.55	14.83 (14.81 , 14.85)	6.79 (6.69 , 6.91)	9.2	...	...
145502	ν Sco	0.46	15.78 (15.35 , ...)	6.60 (6.01 , ...)	9.7	4.6	5.1
147165	σ Sco	0.72	15.65 (15.31 , ...)	6.30 (5.90 , ...)	8.4	6.0	6.9
148184	χ Oph	0.74	15.80 (15.50 , ...)	6.50 (6.10 , ...)	8.0	6.9	8.3
148605	22 Sco	0.13	15.11 (15.00 , 15.24)	6.15 (5.96 , 6.38)	12.3	3.8	4.1
151890	μ^1Sco	-0.36	15.16 (15.13 , 15.18)	6.76 (6.65 , 6.88)	9.2	5.4	∞
157246	γ Ara	-0.62	15.54 (15.48 , 15.62)	6.83 (6.69 , 7.01)	7.4	4.3	4.9
160578	κ Sco	-0.43	15.08 (15.07 , 15.10)	6.72 (6.63 , 6.84)	10.3	4.6	∞
165024	θ Ara	-0.52	15.32 (15.28 , 15.35)	6.48 (6.35 , 6.62)	9.5	4.7	5.3
202904	υ Cyg	0.02	15.75 (15.49 , 16.42)	7.04 (6.67 , 7.86)	5.6	7.0	∞
214080		-1.38	15.15 (15.04 , 15.29)	6.51 (6.25 , 6.87)	14.9	...	...
214680	10 Lac	-0.54	15.65 (15.58 , 15.74)	6.93 (6.75 , 7.17)	10.8	13.3	∞
214993	12 Lac	-0.47	15.66 (15.47 , 16.15)	6.81 (6.51 , 7.45)	7.6	8.9	14.2

NOTE.—Parentheses enclose lower and upper limits to the ranges allowed by error analysis.

[a] Total hydrogen mean volume densities [$\bar{n}(\mathrm{H}) = N(\mathrm{H})/r$] were taken from Bohlin, Savage, and Drake 1978 and Bohlin *et al.* 1983.

[b] S II b-values derived from the λλ1260, 1251 lines.

[c] P II b-values derived from the λλ1153, 1302 lines using the oscillator strengths of Livingston *et al.* 1975.

[d] P II b-values rederived using the empirical oscillator strength ratio $f(1153)/f(1302) = 9.2$.

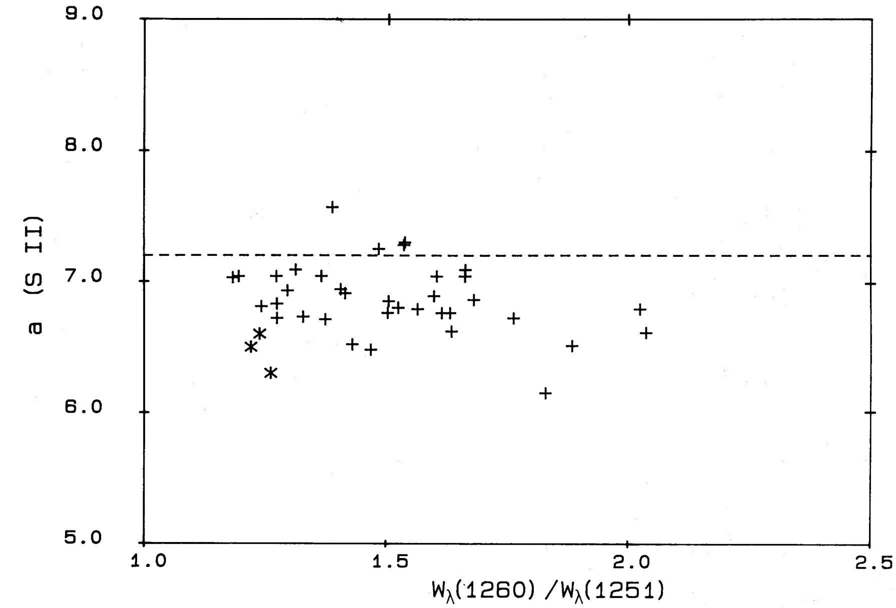

FIG. 1.—Sulfur abundance plotted vs. ratio of the λ1260/λ1251 equivalent widths. The dashed line represents the solar abundance (Hauge and Engvold 1977). Crosses are data derived from the *Copernicus* measurements of Bohlin *et al.* (1983); stars are data derived from *IUE* spectra. A correlation of a(S II) with this ratio would indicate the presence of systematic errors in the abundance determinations due to saturation of the S II lines.

Nachman and Hobbs 1973; Savage and Bohlin 1979). Nachman and Hobbs have shown that there is a tendency for the method to lead to underestimates of column densities if the lines concerned are blended with unresolved narrow saturated components. This tendency is greatest when the line ratios are near unity, indicating heavy saturation. Since the strong S II lines used in the survey suffer saturation, it is necessary to bear in mind that in some cases the actual errors in the column density and abundance values may be considerably larger than the formal uncertainties quoted in Table 2. However, the plot of S II abundance against the λ1260/λ1251 equivalent width ratio in Figure 1 shows that the line ratios are spread throughout the range 1.2–2.0, confirming that in general the S II lines used in the survey are not severely saturated. The theoretically possible range for the ratio is 1–3.0, where the upper limit corresponds to the optically thin case. In addition, the absence of a positive correlation in Figure 1 demonstrates that any saturation-related errors in the column density derivations are *not systematic* and, although some individual sight lines may be affected, such errors are unlikely to invalidate the overall conclusions drawn from this large-scale survey.

III. THE DEPENDENCE OF SULFUR ABUNDANCE ON $\bar{n}$(H) AND OTHER SIGHT-LINE PARAMETERS

It is now well established that for a number of elements depletion correlates well with the mean hydrogen volume density $\bar{n}$(H), while the dependence on H column density is significantly weaker (Phillips, Gondhalekar, and Pettini 1982; Harris, Gry, and Bromage 1984; Jenkins, Savage, and Spitzer 1986). Spitzer (1985) has shown that this correlation can be understood in terms of an idealized theoretical model of interstellar gas based on random distributions of cold clouds together with a more uniform H I gas component of lower density. In Figure 2 the S II abundances in Table 2 are shown plotted against log $\bar{n}$(H). The plot also includes S II abundance data for other sight lines from the compilation of Tarafdar, Prasad, and Huntress (1983). A clear trend of depletion increasing with $\bar{n}$(H) is apparent, although this is weaker than that found for refractory elements such as Ca, Ti, and Mg (Harris, Gry, and Bromage 1984). The mean abundance, based on the entire data set plotted in Figure 2, is 6.98, which is a factor of 1.7 below the solar abundance (Hauge and Engvold 1977). A linear regression analysis gives a gradient of -0.41, with a correlation coefficient of 0.65 (based on all 49 data points in Fig. 2). Linear regression analyses were also performed for log N(H) and log $[E(B-V)/r]$ (where r = sight-line length). The corresponding gradients (and correlation coefficients) are -0.48 (0.64) and -0.29 (0.45) respectively. There appears to be no difference between the quality of the correlations with $\bar{n}$(H) and N(H), in contrast to the pattern found for refractory elements (Harris, Gry, and Bromage 1984). The fact that sulfur abundances show a relatively weak correlation with log $[E(B-V)/r]$ indicates that the number density of grains is a less important factor than gas density for the depletion of sulfur (in contrast, Savage and Bohlin 1979 found good correlations between the depletion of Fe and both log $\bar{n}$(H) and log $[E(B-V)/r]$). These results confirm that very little interstellar sulfur is tied up in the bulk mass of grains. However, the correlation of depletion with mean gas density suggests that sulfur does take part in the surface chemistry of grains and may be an important constituent of grain mantle material.

The result that sulfur depletion correlates with $\bar{n}$(H) is in general agreement with the conclusion of Gondhalekar (1985). However, the gradient of ~ -1 found by Gondhalekar is much steeper than the value of -0.41 derived from our data set. The data used by Gondhalekar include the exceptionally high depletion value given by Snow and Joseph (1985) for the very dense sight line to HD 147889, which critically influences the depletion/density relation. However, Snow and Joseph point out that their analysis of the sight line to HD 147889 [$V = 7.92$, $E(B-V) = 1.08$] is unavoidably based on relatively poor quality *IUE* data. On the basis of their measured equivalent widths for the S II λλ1254 and 1260 lines (namely, 103 ± 94 and 95 ± 40 mÅ respectively), only a crude estimate for the

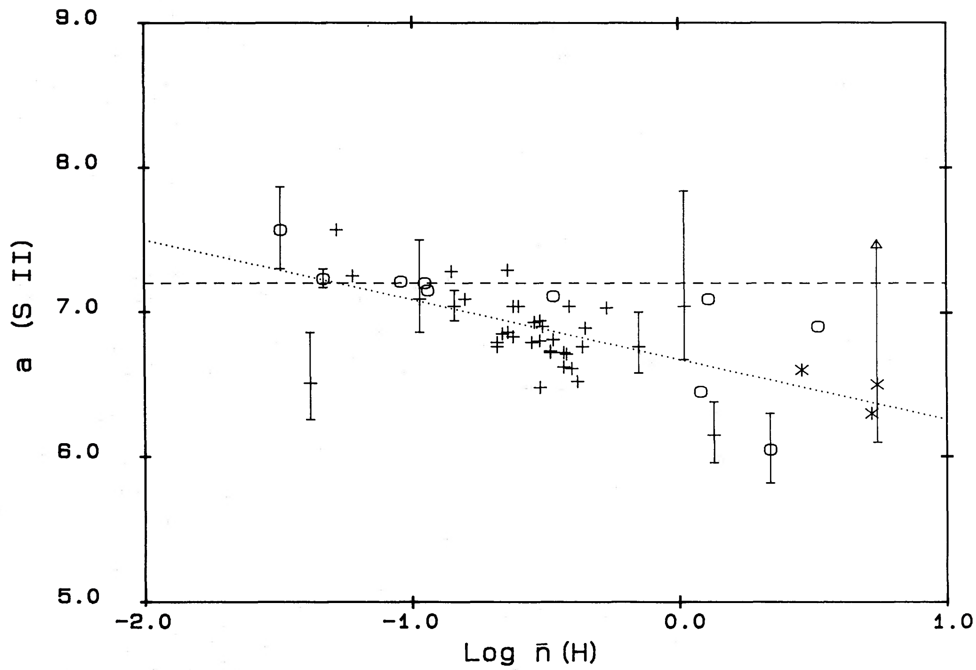

FIG. 2.—Sulfur abundance vs. log of the total hydrogen volume density. The dashed line represents the solar abundance and the dotted line the least-squares linear fit corresponding to a(S II) = 6.67 − 0.41 log $\bar{n}$(H). Some representative error bars are given. Plotted symbols are as in Fig. 1, with the addition of circles which represent data from the compilation of Tarafdar, Prasad, and Huntress (1983).

S II column density can be derived: the authors quote log N(S II) = 14.6–18.9, with a probable value of ~16.9. Furthermore, the authors state that the estimate of N(H) is based on indirect techniques, and consequently their adopted value of 4×10^{22} cm^{-2} is also uncertain. We feel that the low reliability of the S II depletion derived for this sight line does not justify its inclusion in the present survey.

The steeper gradient of Gondhalekar's (1985) depletion/density relation causes the abundances for the high $\bar{n}$(H) sight lines to ζ and χ Oph and ζ Per to appear anomalously high. However, in the present study, which includes these three sight lines, there is a better representation of data with $\bar{n}$(H) > 1 cm^{-3}, and the plot of Figure 2 shows no such anomalies. Moreover, the correlation coefficient of the linear fit remains unchanged if the data with n(H) > 1 cm^{-3} are omitted from the regression analysis, demonstrating that these data are fully consistent with an overall linear trend.

IV. COMPARISON OF S II AND P II b-VALUES

Since S II and P II have very similar ionization potentials and atomic masses, the b-values for these ions in interstellar gas should also be similar. It is possible to test this, since Bohlin *et al.* (1983) also give reliable measurements of the P II $\lambda\lambda$1153 and 1302 lines for many of the sight lines in our data set. The b-values implied by the P II lines were calculated and are listed in Table 2 alongside those derived from the S II lines. Figure 3a shows the two sets of b-values plotted against each other and, although the scatter is large, reveals an unexpected systematic difference of a factor of b(S II)/b(P II) ≈ 1.7. The oscillator strengths (f-values) used for the P II lines are those derived by Livingston *et al.* (1975) and quoted by Morton (1975). However, Shull and York (1977), in their study of the sight line to μ Col, question these values and favor a ratio of P II λ1153/λ1302 f-values intermediate between the value of 13.6 from Livingston *et al.* and the value of 4.7 from Morton and Smith (1973).

The S II f-values, on the other hand, are generally considered to be accurate. We have confirmed this by comparing the b-values implied by the S II $\lambda\lambda$1260, 1251 line pair with those implied by the S II $\lambda\lambda$1254, 1251 line pair in those studies in the compilation of Tarafdar, Prasad, and Huntress (1983) in which the equivalent widths of all three S II lines are given. The results, which are plotted in Figure 4, show that there is reasonable agreement between the two sets of b-values.

Assuming that the adopted S II f-values are accurate, we calculated the P II f-value ratios required to give b(P II) = b(S II) for each sight line. The resulting mean ratio of 9.2 was used to rederive the P II b-values. The new values are listed in the final column of Table 2 under the heading b^*(P II). The plot of b(S II) against b^*(P II) in Figure 3b demonstrates that a greater degree of consistency is achieved with the new P II b-values. With an f-value ratio of 9.2, the maximum possible value of $W_\lambda(1153)/W_\lambda(1302)$ is 7.2, corresponding to the optically thin case in which both P II lines lie on the linear portion of the curve of growth. In contrast, for $f(1153)/f(1302)$ = 13.6, the maximum possible W_λ ratio is 10.7. A number of sight lines in Table 2 have $W_\lambda(1153)/W_\lambda(1302) \approx 7$, and in these cases b^* is indeterminate (indicated by " ∞ " in Table 2). In fact, with only two exceptions, all ~60 sight lines in the list of Bohlin *et al.* (1983) which have reliable P II equivalent width measurements (> 2 σ) have $W_\lambda(1153)/W_\lambda(1302) \leq 7.1$. This alone suggests that the value of 13.6 for $f(1153)/f(1302)$, and the corresponding optically thin W_λ ratio of 10.7, are too large.

The newly derived P II f-value ratio of 9.2 is in good agreement with the findings of Shull and York (1977) and indicates that the normally adopted f-values for the P II $\lambda\lambda$1153 and 1302 lines may be inaccurate. However, the large degree of scatter in Figure 3a and in other b-value comparison plots (e.g., Jenkins,

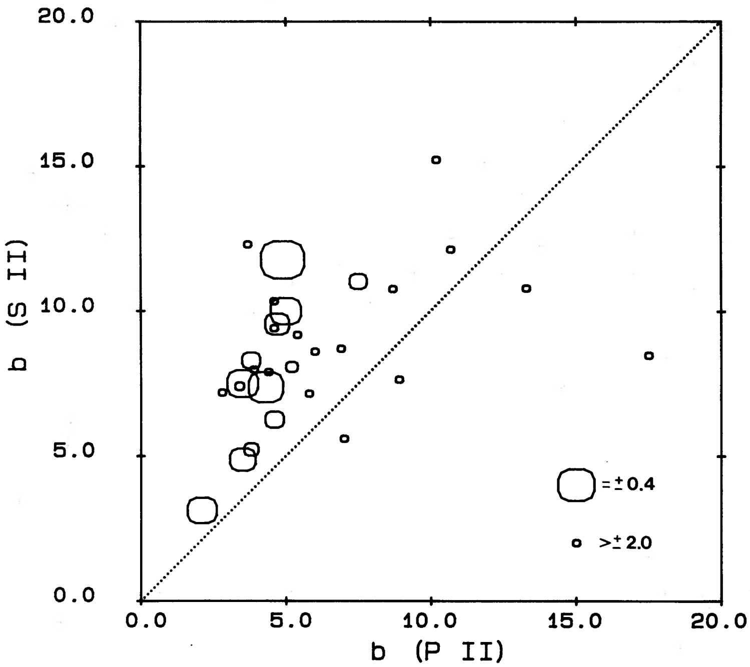

FIG. 3*a*

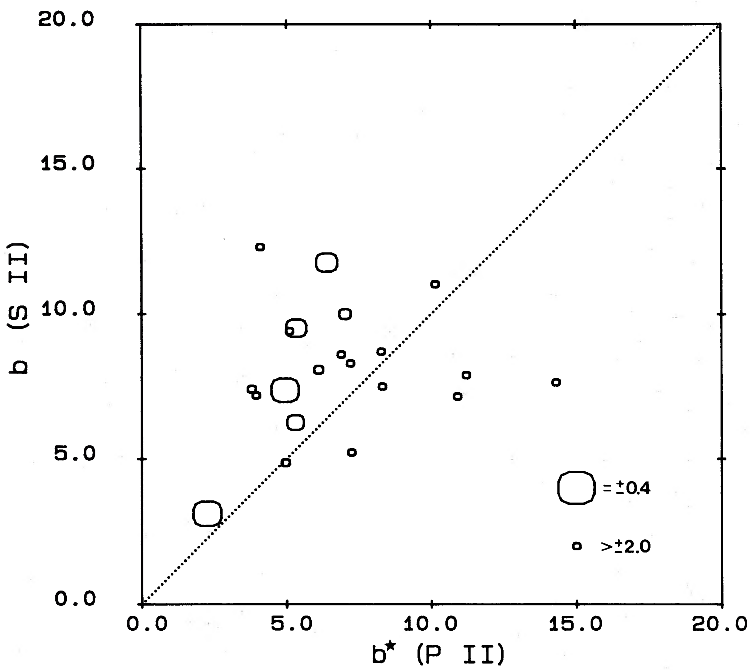

FIG. 3*b*

FIG. 3.—(*a*) S II *b*-values derived from the λλ1260, 1251 lines vs. P II *b*-values derived from the λλ1153, 1302 lines and the oscillator strengths of Livingston *et al.* (1975). The diameters of the plotted symbols (with the exception of the smallest) are proportional to $(\delta b_S{}^2 + \delta b_P{}^2)^{-0.5}$, where δb_S and δb_P are the errors on the S II and P II *b*-values respectively. The mean ratio *b*(S II)/*b*(P II) is ~1.7. (*b*) Same with P II *b*-values derived using the empircal oscillator strength ratio $f(1153)/f(1302) = 9.2$. This ratio gives better overall agreement between the two sets of *b*-values.

Savage, and Spitzer 1986, Figs. 1 and 2) demonstrates that a systematic discrepancy of the kind revealed in this large-scale survey would not necessarily be evident in studies of individual sight lines, such as those of Morton (1975, 1978). Table 3 summarizes the P II *f*-values discussed above.

It is interesting to note that Jenkins, Savage, and Spitzer (1986) found good agreement between *b*(P II) and *b*(Fe II) for the Bohlin *et al.* (1983) sight lines. There is, in fact, no theoreti-

TABLE 3

P II OSCILLATOR STRENGTHS

Reference	$f_1(1153)$	$f_2(1302)$	f_1/f_2
Morton and Smith 1973	0.187	0.0402	4.65
Livingston *et al.* 1975	0.236	0.0173	13.64
This paper	...	...	9.2

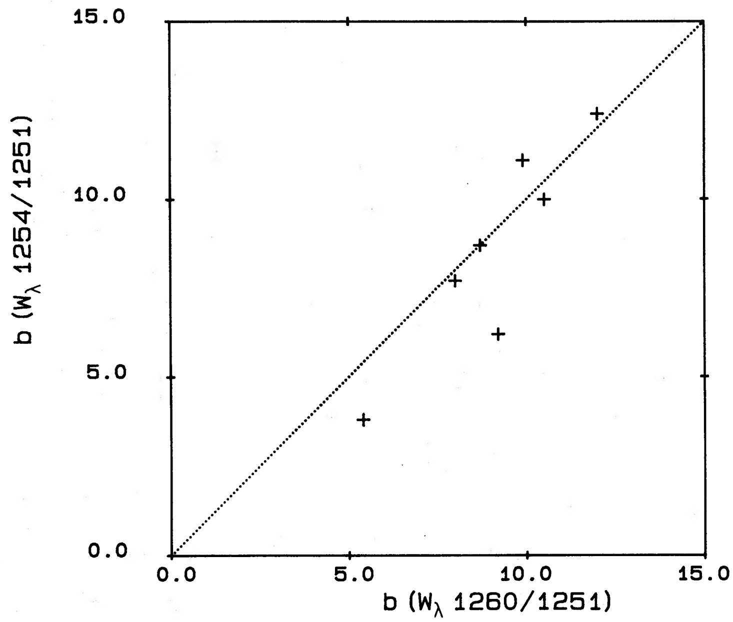

FIG. 4.—Comparison of b-values implied by the S II $\lambda\lambda$1254, 1251 and $\lambda\lambda$1260, 1251 equivalent width pairs from studies in the compilation of Tarafdar, Prasad, and Huntress (1983). Consistency supports the assumption that the S II oscillator strengths used are accurate.

cal foundation for this agreement: since the first ionization potential of P is higher by a factor of 1.33 than that of Fe, and the atomic mass lower by a factor of 1.81, the b-values of P II would be expected to be somewhat higher, in general, than those of Fe II. However, if the P II f-values are revised, in the sense suggested above, then b(P II)/b(Fe II) would become ~ 1.7, in accord with simple theoretical considerations. Finally, we note that a revision of the P II f-values could have significant implications for abundance derivations of other elements in which b-values were assumed to be similar to those derived for P II (e.g., Murray *et al.* 1984; Jenkins, Savage, and Spitzer 1986).

V. CONCLUSIONS

A survey of S II abundances in 49 sight lines, including 39 for which the abundance data were newly derived, indicates a trend of increasing depletion with increasing mean hydrogen volume density over the $\bar{n}$(H) range 0.4–5.5 cm^{-3}. A linear regression analysis gives $a(\mathrm{S}) = 6.67 - 0.41 \log [\bar{n}(\mathrm{H})\ \mathrm{cm}^{-3}]$, with a correlation coefficient of 0.65. The abundance values range between a(S) = 6.1 and 7.6, with a mean value of 6.98. The mean depletion is 0.2 dex. The very steep linear dependence of sulfur depletion on log $\bar{n}$(H) (slope ≈ -1) found in a recent study based on a smaller set of previously published S II abundances is not confirmed. However, the correlation of sulfur depletion with mean gas density is stronger than the correlation with an indicator of grain number density, suggesting that sulfur takes part in the surface chemistry of grains but does not constitute a major part of their bulk mass. A comparison of S II and P II b-values, derived from the Bohlin *et al.* (1983) *Copernicus* equivalent width measurements, has revealed a systematic difference of a factor of b(S II)/b(P II) ≈ 1.7, which is unexpected given the similar atomic properties of these elements. A possible explanation is inaccuracy of the normally adopted oscillator strengths for the P II $\lambda\lambda$1153 and 1302 lines, which are less well established than those of the S II lines used in the survey. The results suggest that a ratio $f(1153)/f(1302)$ of ~ 9.2 is more reasonable than the presently accepted value of 13.6 and highlight the need for new laboratory measurements of the P II oscillator strengths.

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