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Na I AS A TRACER OF H I IN THE DIFFUSE INTERSTELLAR MEDIUM[1]

ROGER FERLET AND ALFRED VIDAL-MADJAR
Institut d'Astrophysique de Paris

AND

CÉCILE GRY
Astrophysics Division, Space Science Department, *IUE* Observatory, European Space Agency, Madrid, Spain
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ABSTRACT

From a compilation of interstellar atomic sodium and neutral hydrogen absorption measurements, together with new high signal-to-noise ratio Na I observations and detailed analysis through a profile fitting method, we derive the column-density correlation N(Na I) versus N(H). Extending now over more than three orders of magnitude, especially toward low–column density clouds, a slope of unity is found instead of the previous quadratic dependence. Still valid for mean space densities, this new result leads us to deduce that in the diffuse interstellar medium, what is probably to be observed is that the product of the recombination coefficient of Na II and the electron space density (αn_e) is nearly constant. The n_e evaluations are consistent with the three-phase model of the interstellar medium, while at high densities, the shielding of UV photons by dust becomes the dominant factor.

Subject headings: interstellar: abundances — interstellar: matter

I. INTRODUCTION

With the extensive work of Hobbs during the 1970s based on interferometric, photoelectric scans of the absorption lines of species like K I, Na I, and Ca II observable from the ground, several basic properties of the neutral interstellar gas in the solar neighborhood have been described. From the detailed velocity distributions of these ions and the strengths of their absorptions toward many lines of sight, moderately direct appraisals were possible concerning, for instance, their depletions and the ionization equilibrium in the diffuse interstellar clouds.

In particular, Hobbs (1974*a*, *b*) compared the K I and Na I column densities with the corresponding H I ones and found nearly quadratic relations, from which he deduced that the fractional ionization n_e/n(H) is nearly constant for a range in space densities n(H) covering a factor of 15. Later, gathering new data, Hobbs (1976*a*) strengthened his earlier conclusions, while Stokes (1978), including newly determined molecular hydrogen column densities, refined the slopes of these quadratic correlations of N(K I) and N(Na I) versus N(H). It must be noted also that because the Na I D lines are observed in many kinds of objects, this relation is widely used to deduce the corresponding total neutral hydrogen column density.

The purpose of the present work is to reinvestigate the variations of N(Na I) with N(H) and thus the ionization problem in H I regions, using new data of three kinds. First, we report new observations of the Na I D lines around 5893 Å for some stars. Second, high-quality column densities have been obtained elsewhere since 1978 for Na I as well as for H I and H_2. Third, we used the evaluation of these quantities for individual clouds along a few lines of sight, instead of the usual integrated values. All these new data will be added to those of Hobbs (1976*a*) in order to rediscuss earlier analyses.

[1] Partly based on observations collected at the European Southern Observatory, La Silla, Chile.

II. NEW DATA

a) *The* Na I *Observations*

The observations were acquired during 1983–1984 using the coudé echelle spectrometer (CES) of the European Southern Observatory at La Silla, Chile, fed by a 1.4 m telescope. Designed to provide a resolving power $R = 10^5$ (or 3 km s^{-1}, FWHM) along with a clean instrumental profile and a very low level of stray light, the CES is equipped with a cooled Reticon array of 1872 photodiodes giving a free spectral range of about 50 Å and allowing a very high signal-to-noise ratio ($\gg 100$) to be reached. The wavelength calibration is provided by many narrow lines emitted by a thorium lamp and is internally accurate to 0.1 km s^{-1}. The details of the observational and reduction procedures can be found in Ferlet and Dennefeld (1984); all these operations were performed with the ESO Image Handling and Processing software. (IHAP).

Being interested in the very local interstellar medium, we mainly concentrated on sight lines for which low sodium equivalent widths are expected. Therefore, special care was taken to delineate the contributions due to weak telluric water absorptions, which are very numerous in that wavelength region, by recording spectra at different epochs; and a new method was developed using IHAP to remove these atmospheric contributions (Vidal-Madjar *et al.* 1985). Wherever the D lines are obviously free of saturation, we derive the Na I column densities through the usual relation applying to the linear part of the curve of growth, independent of the unknown velocity spread parameter b. If saturation effects were present, we only give the rigorous lower limit on N(Na I) provided by assuming complete unsaturation.

These new Na I measurements include β CMa, γ^2 Vel, θ Car, λ Sco, β Cen, γ Ara, θ Ara, ζ Pup, ϵ Ori, and α Vir. The three last stars were also observed by Hobbs, and the results are in very close agreement.

b) *Other Results*

Besides our Na I observations, other N(Na I) not included in Hobbs (1976*a*) come from Hobbs (1978*a*, *b*), who performed as usual very high resolution (1 km s^{-1}) interferometric scans or, in a few cases, quoted earlier measurements. As for the observations described above, only the total column densities contained in all velocity components scanned are used here, except when more detailed analysis is available (see below). This is due to the intended comparison with the corresponding, necessarily total, column densities of neutral hydrogen $N(\mathrm{H}) = N(\mathrm{H\ I}) + 2N(\mathrm{H_2})$. These have been derived from UV *Copernicus* scans of Lyman-α for a large number of stars by Bohlin, Savage, and Drake (1978) and Bohlin *et al.* (1983). Note that the N(H) are, in general, accurate to $\pm 20\%$ because Lyα lies on the square root portion of the curve of growth, but they relate to the whole line of sight because of the strength of Lyα and the poorer resolution of *Copernicus* when compared with ground-based observations. The precision of N(Na I) is of the same order for about half the present sample, but for the rest can be considerably lower when multiple absorption components or saturation effects or both occur. Sometimes these effects are severe enough to allow only a lower limit to be given for N(Na I).

c) *Individual Clouds*

It is well known that in about half the lines of sight the integrated column density is actually a combination of smaller clouds with different velocities and physical conditions. This can be a source of large error when used with curves of growth. To partially overcome this difficulty in the case of lower resolution UV data, a profile-fitting method was developed (see Vidal-Madjar *et al.* 1977) and applied in particular to the hydrogen observations toward certain stars, thus yielding knowledge of physical properties in individual interstellar diffuse clouds. For a number of these individual kinematic components, we have access to the N(Na I), either computed by Stokes (1978) from the original high-resolution scanner data, or derived by profile-fitting from our own observations.

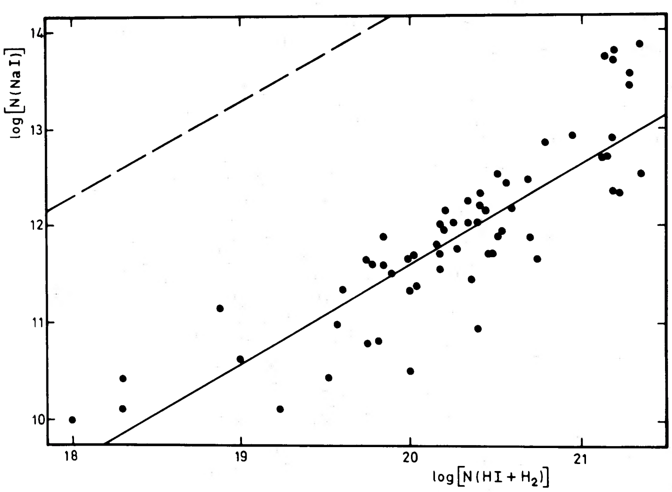

FIG. 1.—Logarithmic correlation between the interstellar column densities of Na I and (H I + H$_2$), in units of cm^{-2}. Lines of sight for which only limits are quoted in Table 1 were excluded. The slope of the least-squares straight line is 1.04 ± 0.08. The dashed line is the solar abundance of sodium from Ross and Aller (1976).

The numerical results for 78 stars of Na I and H column densities, along with some other physical data, are collected in Table 1. We list also the heliocentric radial velocity of the absorbing regions as seen in Na I, with some indications about their multiplicity. Figure 1 shows the correlation diagram log N(Na I) versus log $N(\mathrm{H\ I} + \mathrm{H_2})$. The 17 lines of sight for which only limits on column densities are known were excluded. With all the new data described above, we have significantly extended (and sometimes improved) the previous compilation of Hobbs (1976*a*), especially toward low column densities. Our data sample now covers more than three orders of magnitude, improving the previous sample by a factor of ~ 100.

III. DISCUSSION

The least-squares straight line fit to the data in Figure 1 gives the following relation:

$$\log N(\mathrm{Na\ I}) = 1.04[\log N(\mathrm{H\ I} + \mathrm{H_2})] - 9.09\ , \qquad (1)$$

where N(Na I) and N(H) are in cm^{-2}. The correlation coefficient is 0.85, and the slope is 1.04 ± 0.08. Therefore, there is a *linear* relation between the neutral sodium and neutral hydrogen column densities in the diffuse interstellar medium.

This is clearly different from the previous common belief, since the slope of the least-squares straight line for the earlier logarithmic correlation Na I/H was found to be 2.11 (Stokes 1978). Obviously, the inclusion of lower column densities gives rise to a linear (instead of quadratic) relation, at least over three orders of magnitude, up to $N(\mathrm{H}) \approx 10^{21}$ cm^{-2}. Around that value, N(Na I) seems to increase very steeply; we will come back later to this point. It is interesting to note that the idea $N(\mathrm{H}) \propto N(\mathrm{Na\ I})$ had first been guessed by Ferlet *et al.* (1980*a*) and also suggested by Tarafdar (1977) in his discussion of the quadratic dependence of Hobbs, but this last author rejected it as in clear disagreement with the observations.

The correlation in Figure 1, first, confirms that Na I samples the H I regions fairly well.

Another consequence is that in the diffuse interstellar medium for lightly reddened stars [$E(B-V) \leq 0.3$; see Table 1], the abundance of neutral sodium relative to hydrogen (H I + H$_2$) is independent of reddening. Comparison with the solar sodium abundance (the dashed line in Fig. 1, from Ross and Aller 1976) does not allow one to deduce the interstellar Na depletion, because most of the interstellar sodium exists as Na II, which has no accessible lines. This comparison simply proves that $N(\mathrm{Na\ I}) \ll N(\mathrm{Na})$, or $N(\mathrm{Na\ II}) \approx N(\mathrm{Na})$, which is implied by the ionization potentials of Na I and Na II, 5.1 and 47.3 eV respectively.

The observed quantities in Figure 1 are column densities $N = \int n(l)dl$, where l is the column length of absorbing gas in front of any given star, and not local or volume densities n. But since the correction required to go from N to $\langle n \rangle$ is $\log \langle n \rangle = \log N - \log l$, this change should conserve the slope unity, and thus the correlation found with column densities must still be valid with average space densities, i.e., $\langle n(\mathrm{Na\ I})\rangle / \langle n(\mathrm{H\ I} + \mathrm{H_2})\rangle$ is constant.

We will now adopt the usual assumptions that the ionization is due solely to the ambient general interstellar UV radiation field and that recombination occurs by collision between ions and free electrons. Then, the sodium equilibrium is governed by:

$$\frac{n(\text{Na II})}{n(\text{Na I})} = \frac{(\Gamma/\alpha)_{\text{Na}}}{n_e}, \quad (2)$$

where Γ is the photoionization rate of Na I, α the recombination coefficient of Na II, and n_e the electron space density.

Since $n(\text{Na II}) \approx n(\text{Na})$, one has $n(\text{Na II}) \approx \delta_{\text{Na}} A_{\text{Na}} n(\text{H})$, where A_{Na} is the cosmic sodium abundance relative to hydrogen and δ_{Na} is the depletion factor of sodium in the gas phase, defined by $\log \delta_{\text{Na}} = \log [n(\text{Na})/n(\text{H})] - \log A_{\text{Na}}$. Hence, from equation (2), we derive

$$n(\text{Na I}) = n_e \delta_{\text{Na}} A_{\text{Na}} n(\text{H})(\alpha/\Gamma)_{\text{Na}} . \quad (3)$$

Since the observed correlation links $\langle n(\text{Na I})\rangle$ to $\langle n(\text{H})\rangle$, the question is therefore to study the behavior of $\langle n_e \delta_{\text{Na}} A_{\text{Na}} n(\text{H}) (\alpha/\Gamma)_{\text{Na}}\rangle$ as a function of $\langle n(\text{H})\rangle$. A_{Na} is more than likely constant, at least on scales smaller than a few kpc, where Galactic abundance gradients should be negligible. It is also clear, from the definition of δ_{Na} and relation (1), that the sodium depletion is about constant up to $N(\text{H}) \approx 10^{21}$ cm^{-2}. Phillips, Pettini, and Gondhalekar (1984) effectively found a sodium depletion essentially constant and independent of density for the lightly reddened stars they observed [up to $E(B-V) \approx 0.3$]. Furthermore, it seems unlikely that there are systematic changes in the shielding by dust sufficiently large as to appreciably affect the photoionization rate Γ_{Na} in the low-density clouds. Finally, and to satisfy relation (1), i.e., $\langle n(\text{Na I})\rangle/\langle n(\text{H})\rangle$, which is nearly constant, we should have for the diffuse interstellar medium in the solar neighborhood, over a column density range of three orders of magnitude, $\langle n_e n(\text{H})\alpha_{\text{Na}}\rangle/\langle n(\text{H})\rangle$ also constant.

The simplest explanation is to consider that $n(\text{H})$, n_e, and α_{Na} are constant, i.e., a unique physical medium is sampled but no information is then gathered on its physical state. However,

TABLE 1

INTERSTELLAR NEUTRAL HYDROGEN AND SODIUM COLUMN DENSITIES

Star	$E(B-V)$[a]	d[a] (pc)	$V_\odot$(Na I) (km s^{-1})	$N(\text{H I} + \text{H}_2)$[a] ($10^{20}$ cm^{-2})	N(Na I)[b] (10^{11} cm^{-2})
γ Peg	0.01	145	+9	1.1	<0.17
κ Cas	0.35	1000	complex	19.8	310.
γ Cas	0.08:	195	−5	1.5[c]	5.5[d]
			+6	0.02[c]	0.13[d]
ϕ Per	0.20:	140	−5	3.7	31.
HD 14633	0.10	2040	+2	3.6	>19.
δ Per	0.04	130	+6	0.25[e]	1.8
			+14	0.023[e]	<0.23
40 Per	0.24	410	+13	16.8	>57.
o Per	0.30	240	+13 bl	16.1	676.1
ζ Per	0.33	395	+14	15.8	549.5
ϵ Per	0.08	310	+7.5 bl	1.60[f]	15.85[d]
			+19	0.02[f]	0.27[d]
ξ Per	0.32	540	blend	19.8	407.40
HD 28497	0.02	465	+21	1.6	10.
α Cam	0.32	1165	complex	12.4	>120.
ν Eri	0.02	275	+24	2.8	16.
π^5 Ori	0.06	230	+24	2.6	18.
λ Lep	0.03	500	+23	1.5	5.3
γ Ori	0.01	110	blend	0.65	0.72
23 Ori	0.11	430	+24	5.5	>78.
25 Ori	0.05	315	+21	2.9	5.8
ψ Ori	0.04	275	+26	4.	17.
δ Ori	0.07	385	+10	0.37[g]	1.05[d]
			+16	0.56[g]	0.68[d]
			+25 bl	0.78[g]	3.55[d]
ϕ^1 Ori	0.11	415	+25 bl	6.9	>65.
λ Ori	0.12	530	+26	6.3	80.
ι Ori	0.07	430	complex	1.44[g]	7.1
ϵ Ori	0.08	410	+12	0.55[g]	4.9[d]
			+18	0.4[g]	2.4[d]
			+26 bl	1.5[g]	11.5[d]
σ Ori	0.06	360	+23 bl	3.3	38.
ζ Tau	0.05	145		1.1	2.7
ζ Ori	0.08	350	+25 bl	2.6	24.
μ Col	0.01	700	+23	0.7	4.3
139 Tau	0.15	1250	complex	9.1	95.
β CMa	0.00	205	+21	0.01 − 0.022[h]	0.1[i]
15 Mon	0.07	705	+22 bl	2.5	12.
ϵ CMa	0.01	190		<0.06	<2.
19 Mon	0.06	460	+13 bl	2.2	12.
o^2 CMa	0.04	1000	+20 bl	1.5[j]	4.
κ CMa	0.01	190	+23	1.	0.35
τ CMa	0.15	930	complex	5.	34.
η CMa	0.02	760	+20 bl	0.7[j]	8.3
ζ Pup	0.04	670	complex	0.97	5.
γ^2 Vel	0.05	380	+12	0.6	4.4[i]
α Pyx	0.07	340	+14	3.3	8.7

TABLE 1—*Continued*

Star	$E(B-V)$[a]	d[a] (pc)	$V_{\odot}$(Na I) (km s^{-1})	N(H I + H_2)[a] (10^{20} cm^{-2})	N(Na I)[b] (10^{11} cm^{-2})
ρ Leo	0.08	960	complex	1.8	12.
θ Car	0.06	210	+8	1.9	6.45[i]
HD 93521	0.03	1780	−10	1.3	>24.
α Vir	0.03	85	−10	0.1	0.45[i]
β Cen	0.00	85	−05	0.33	0.3[i]
1 Sco	0.20	230	complex	15.8	26.
π Sco	0.08	170	−15 bl	5.6	5.2
δ Sco	0.16	155	−11 bl	14.5	58.9
β^1 Sco	0.20	160	−08 bl	13.7	56.25
ω^1 Sco	0.22	230	complex	17.3	25.1
ν Sco	0.27	175	complex	15.6	91.2
σ Sco	0.38	140	complex	23.2	39.8
ρ Oph	0.47	175	complex	72.	>76.
χ Oph	0.53	135	−26	0.2[j,k]	≤0.85[k]
			−10 bl	22.6	790.
τ Sco	0.06	235	−07 bl	3.1	5.8
ζ Oph	0.32	140	−28	0.076[k]	1.48
			−14 bl	14.1	600.
μ^1 Sco	0.05	185	−05	2.5	1.
γ Ara	0.08	690	blend	5.1	>17.2[i]
υ Sco	0.02	135	−04	<0.18	<0.15
λ Sco	0.03	100	−27	0.17[l]	0.14[m]
			−19	≤0.02[l]	0.12[m]
κ Sco	0.03	200	−02	2.3	3.2
α Oph	0.00	17	−25 bl	≤3.6[j,k]	0.3[k]
μ Oph	0.20	140	−15 bl	12.6:[n]	1000.
θ Oph	0.01	200	−11	3.5	9.9
67 Oph	0.12	760	−14	13.7	>160.
θ Ara	0.10	745		7.	>18.5[i]
σ Sgr	0.00	55	−26	<0.3	<0.1
59 Cyg	0.18	260	complex	2.2	20.
υ Cyg	0.16	160	complex	5.1	8.6
68 Cyg	0.28	890	−13 bl	14.	>120.
19 Cep	0.38	1100	−14 bl	15.4	>230.
β Cep	0.04	310	−17	1.	2.4
λ Cep	0.56	990	−12	25.	>239.9
10 Lac	0.11	590	blend	5.3	>37.
12 Lac	0.11	670	complex	7.1	>71.
1 Cas	0.22	620	blend	11.8	>91.2
σ Cas	0.17	380	−16 bl	10.9	>120.

[a] Bohlin, Savage, and Drake 1978; Bohlin *et al.* 1983.
[b] Hobbs 1976*a*, 1978*a*, *b*.
[c] Ferlet *et al.* 1980*b*.
[d] Stokes 1978
[e] Martin and York 1982.
[f] Vidal-Madjar *et al.*, 1982.
[g] Laurent, Vidal-Madjar, and York 1979.
[h] Gry, York, and Vidal-Madjar 1985.
[i] This work.
[j] Only atomic hydrogen has been observed, but the molecular contribution is expected to be small, according to the extinction; from 21 cm observation for α Oph.
[k] Frisch 1981.
[l] York 1983.
[m] Vidal-Madjar *et al.* 1985.
[n] Cardelli and Böhm-Vitense 1982.

depletion studies (see, e.g., Harris, Gry, and Bromage 1984) emphasize that n(H) is a more useful sight line parameter than N(H) and show a clear correlation of element depletion with n(H). The simplest hypothesis of a uniform type of medium seems thus ruled out (see in addition Spitzer 1985).

A second alternative is to assume that both n_e and $\alpha_{\rm Na}(T)$ are constant, i.e., different media with the same temperature and n_e and variable n(H). This might be a plausible interpretation, since observations are not incompatible with n_e being relatively constant in the solar neighborhood ($n_e \approx 0.03$ cm^{-3} from the dispersion of pulsar signals).

A third, less restrictive possibility is that $\alpha_{\rm Na}\, n_e$ is constant. In this case, it is possible from relation (1) to estimate the quantity $\alpha_{\rm Na}\, n_e = (\Gamma/A\delta)_{\rm Na}[n(\text{Na I})/n(\text{H})] \approx (\Gamma/A\delta)_{\rm Na}[N(\text{Na I})/N(\text{H})]$, by assuming that the cosmic abundance is equal to the solar abundance of Ross and Aller (1976) ($A_{\rm Na} = 1.9 \times 10^{-6}$), and by adopting a sodium depletion factor of 4, for $N(\text{H}) \leq 10^{21}$ cm^{-2} (Phillips, Pettini, and Gondhalekar 1984). The numerical value $\Gamma_{\rm Na} = 7.2 \times 10^{-12}$ s^{-1} is also taken from these authors. We obtain

$$\alpha_{\rm Na}\, n_e \approx 1.2 \times 10^{-14}\ \text{s}^{-1}\ . \qquad (4)$$

Thus, the linear N(Na I) − N(H) relationship observed in

Figure 1 up to $N(\mathrm{H}) \approx 10^{21}$ cm^{-2} implies a slow recombination rate $\alpha(T)n_e$ for sodium, the mutual variations of α and n_e being approximately canceled out. The relation $\alpha(T)n_e \approx$ constant can in this case be satisfied by the presence along the sampled light paths either of warm gas at kinetic temperatures well above 100 K and relatively higher ionization, or of cool gas with lower ionization. Hobbs (1976*b*, 1978*a*) has already explored these two alternative possibilities, without being able to favor one or the other for similar reasons.

Using Seaton's (1951) tabulation of $\alpha(T)$, we can evaluate from relation (4) the electron density in the interstellar medium as a function of temperature. In cold regions at about 80 K, $n_e \approx 1.8 \times 10^{-3}$ cm^{-3}, which is in good agreement with the value predicted by the three-phase model of the interstellar medium of McKee and Ostriker (1977). For warm regions at about 8000 K, we find $n_e \approx 0.04$ cm^{-3}, which is about 10 times smaller than the corresponding predicted values. Nevertheless, the different uncertainties involved (for instance, Γ depends on the adopted UV background radiation field, which is known within a factor of 3) might be responsible for the discrepancy. Moreover, as already noted, the mean electron density deduced from the dispersion of pulsar signals is 0.03 cm^{-3}.

A fourth possibility, in which n_e, $n(\mathrm{H})$, and α_{Na} are variable but still yield $\langle n_e n(\mathrm{H}) \alpha_{\mathrm{Na}} \rangle / \langle n(\mathrm{H}) \rangle \approx$ constant, certainly remains. In that case, it is very difficult to draw any conclusions, essentially because we have only one relation linking at least three unknowns.

The last point we must mention is the apparent change in the slope of relation (1) when $N(\mathrm{H}) \geq 10^{21}$ cm^{-2}: that is, when the contribution of molecular hydrogen becomes nonnegligible.

This occurs for the known lines of sight which are more obscured, such as those in the Sco-Oph or Perseus regions with a reddening $E(B-V) \geq 0.2$. A similar sharp transition has been found by Savage *et al.* (1977) in their $N(\mathrm{H}_2)$–$E(B-V)$ diagram. In these media, the shielding of the UV photons by dust and molecular hydrogen is certainly appreciably increased and results in an exponential decrease of the photoionization rate Γ [factor of 3 from $E(B-V) = 0.3$ to $E(B-V) = 0.5$, for instance]. Furthermore, the recombination coefficient α varies as $T^{-0.7}$ (Seaton 1951).

Therefore, toward more obscured and colder absorbing regions, the quantity $n(\mathrm{H})[\alpha/\Gamma]_{\mathrm{Na}}$ increases while $n_e \delta_{\mathrm{Na}}$ should decrease, the cosmic abundance A_{Na} probably being constant. From equation (3), one sees that $n(\mathrm{Na\ I})$ is governed by the competition between these two factors. Since the slope of relation (1) at high densities seems to steepen and recover the quadratic behavior found earlier, we thus conclude that the increasing factor dominates, i.e., the shielding prevents the formation of Na II and overcompensates the sodium depletion onto grains (see also Federman 1981). In these dense cold cores of diffuse interstellar clouds, n_e should be given by $A_{\mathrm{C}} n_{\mathrm{H}}$ (A_{C} being the cosmic abundance of carbon, the more abundant element supplying electrons), which is roughly constant and of the order of 10^{-3}; a value also in good agreement with the one we found above for $T \approx 80$ K.

It is important to note that the present discussion is based on the assumed equilibrium of Na I, as described in equation (2), while still other possibilities could be envisaged. In particular, sodium could be primarily ionized through charge exchange with C^+, yielding then a simple explanation of the observed linear relation in the case of $\alpha(T) =$ constant. However, toward the denser parts of the clouds, this mechanism seems to fail to account for the observed rise of the slope.

IV. CONCLUSION

Having reinvestigated the interstellar atomic sodium absorption, particularly in low–column density diffuse clouds, an empirical relationship between $N(\mathrm{Na\ I})$ and $N(\mathrm{H})$ surprisingly appeared which differs from that previously reported by Hobbs (1976*a*). The slope of the linear regression is found to be nearly unity for absorbing regions with $N(\mathrm{H}) \leq 10^{21}$ cm^{-2}, indicating that $N(\mathrm{Na\ I})/N(\mathrm{H}) \approx$ constant over a three-order-of-magnitude density range, a relation also true for the corresponding average spatial density.

With the likely assumptions that both the sodium depletion onto grains and the photoionization rate are constant in the solar neighborhood, we deduce that $\langle n_e n(\mathrm{H}) \alpha_{\mathrm{Na}}(T) \rangle / \langle n(\mathrm{H}) \rangle$ must also be nearly constant.

Among the different possibilities, $\alpha(T)n_e \approx$ constant seems likely. It shows that in slightly reddened lines of sight, which can, however, present very different kinetic temperatures T, the electron density n_e varies as $T^{0.7}$, which is in reasonable agreement with our present understanding of the local interstellar medium. We find, for those lines of sight with a negligible amount of molecular hydrogen which intercept typical warm regions at 8000 K, that the electron density is 0.04, which is in close agreement with the mean value derived from the dispersion of pulsar signals.

For lines of sight with $N(\mathrm{H}) \geq 10^{21}$ cm^{-2}, the UV shielding by dust and H_2 must be sufficiently important to increase $N(\mathrm{Na\ I})$ so much as to imply a much steeper slope in the correlation $N(\mathrm{Na\ I})$ versus $N(\mathrm{H})$. These two different regimes (linear or quadratic correlation) are qualitatively consistent with the probability of a line of sight intercepting either the cold dense neutral core, or the warm (8000 K) less dense regions of the interstellar medium, in the framework of the filling factors predicted by McKee and Ostriker's model. In particular, the probability of detecting dense cores by using stars in reddened regions like Sco-Oph or Perseus is obviously larger than by using other, less reddened stars.

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ROGER FERLET and ALFRED VIDAL-MADJAR: Institut d'Astrophysique de Paris, 98 bis, bd Arago, 75014 Paris, France

CÉCILE GRY: *IUE* Observatory, ESA Tracking Station, Villafranca del Castillo, Apartado 54065, Madrid 28080, Spain