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ON THE OPACITY OF THE INTERSTELLAR MEDIUM TO ULTRASOFT X-RAYS AND EXTREME-ULTRAVIOLET RADIATION

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ABSTRACT

The opacity of the interstellar medium at soft X-ray and extreme-ultraviolet wavelengths has been reexamined in the light of recent evidence that the density of interstellar hydrogen in the solar neighborhood may be quite low. It is shown that the distance at which significant attenuation occurs is not negligible, especially in the 50–300 Å region.

Subject headings: interstellar matter — opacities — ultraviolet — X-rays

In dim eclipse disastrous twilight sheds
On half the nations, and with fear of change
Perplexes monarchs.

[Milton, *Paradise Lost*]

I. INTRODUCTION

More than ten years ago Aller (1959) argued that the interstellar medium should be opaque to radiation at wavelengths between 912 Å and the X-ray region of the spectrum. Since then, although considerable work has been carried out to calculate the absorption expected at X-ray wavelengths (Felten and Gould 1966; Bell and Kingston 1967*a*; Brown and Gould 1970) and much has been learned about the structure of the interstellar medium, there has been little inclination to extend these calculations to wavelengths beyond 100 Å, much less to question Aller's basic conclusion.

We have reexamined in detail the transmission of the interstellar medium to soft X-rays and extreme-ultraviolet radiation, using the most recent determinations of the relevant cross-sections and abundances. We conclude that if the density of the interstellar medium is as low and nonuniform as some observations suggest, then soft X-ray or extreme ultraviolet radiation may be observed over considerable distances.

II. THE EFFECTIVE ABSORPTION CROSS-SECTION

The opacity of the interstellar medium depends on two factors, the absorption cross-section per atom of each species of atom in the medium and the total number of atoms in the line of sight. We have computed an effective absorption cross-section per hydrogen atom as defined by the relation

$$\sigma_e = \frac{1}{n_\mathrm{H}} \sum n_i \sigma_i \,,$$

where n_H is the number density of hydrogen atoms and n_i and σ_i are, respectively, the number density and cross-section of the species *i*.

Figure 1 shows the photoabsorption cross-section of all elements which contribute appreciably to the opacity between 2000 and 1 Å. The cross-section of the hydrogen atom has been obtained by blending the results of calculations below the Lyman edge by Samson (1966), who used Gaunt factors given by Karzas and Latter (1961), with the results of calculations made at wavelengths below 128 Å (0.1 keV) by Brown and Gould (1970). These calculations agree with the measurements of Beynon and Cairns (1965) at 850 Å, and Denne (1970) between 82 and 23 Å, to within 15 percent. The cross-section of the helium atom has been obtained by matching the work of Bell and Kingston (1967*b*) at longer wavelengths with the results of Brown and Gould (1970) at shorter wavelengths. These calculations agree to within 15 percent with measurements by Samson (1966) and Lowry, Tomboulian, and Ederer (1965) between 500 and 200 Å, Lukirskii, Brytov, and Zimkina (1964) between 230 and 44 Å, and by Denne (1970) between 82 and 44 Å. The cross-sections of the heavier elements were obtained from the sources summarized in table 1.

The adopted relative abundances of the elements are listed in table 2. The helium abundance was obtained from the work of Palmer *et al.* (1969), who measured the strength of radio frequency transitions of recombining helium atoms. The abundances of the heavier elements are those given by Felten and Gould (1966) and by Bell and Kingston (1967*a*), except in the case of neon, for which the reduced value suggested recently by Brown and Gould (1970) was taken. The abundance of aluminum is that quoted by Allen (1963).

The resultant effective cross-section of the interstellar medium, σ_e, has been plotted against wavelength in figure 2, under the assumption that ionization

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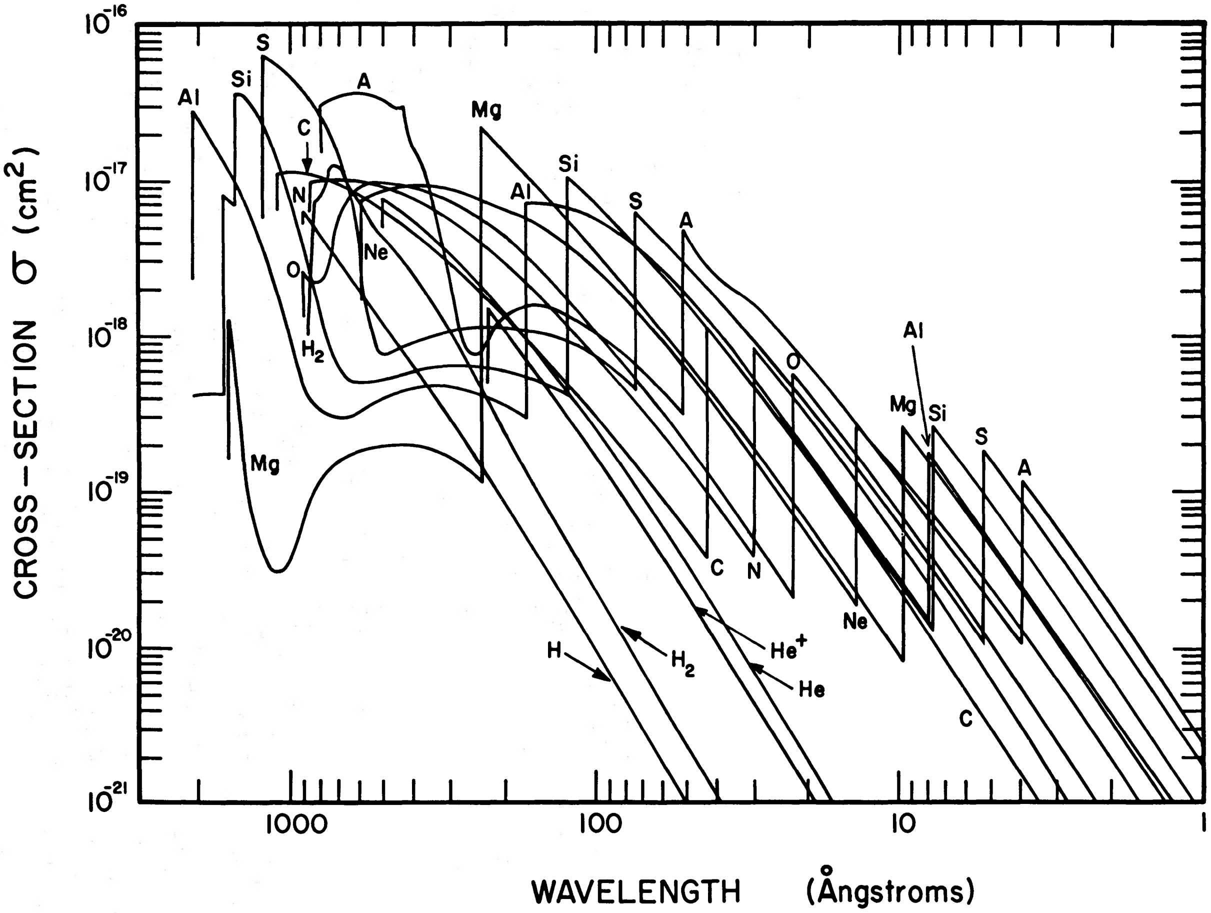

FIG. 1.—Photoabsorption cross-sections of the abundant elements in the interstellar medium as a function of wavelength

of the gas has little influence on σ_e at soft X-ray and extreme ultraviolet wavelengths. This assumption is reasonable at X-ray wavelengths (~ 10 Å), because single ionization does not change the K-shell photoabsorption cross-section of the heavy elements significantly, and these elements dominate σ_e at wavelengths shortward of the oxygen K-edge (22.3 Å). However, at longer wavelengths most of the absorption is caused by hydrogen and helium, and as a consequence calculations of the opacity may contain errors because the degrees of ionization of these two species are unknown. In drawing figure 2, we have made the further assumption that, for the purpose of calculating σ_e at wavelengths longward of the H I edge, the degree of ionization of the heavy elements is 99 percent.

If the interstellar medium is ionized by extreme-ultraviolet radiation (500 Å $> \lambda >$ 100 Å), the large photoionization cross-section of helium may result in it being ionized preferentially with respect to the hydrogen (Bergeron and Souffrin 1971). The cross-section of the helium ion has been plotted in figure 1, by combining the results of Allen (1963) for wavelengths between 228 and 120 Å with those of Brown and Gould (1970) for shorter wavelengths. As the cross-section of the ion is less than that of the helium atom, the effect of extreme-ultraviolet radiation might be to depress σ_e at wavelengths below the He I edge at 504 Å. However, if the interstellar medium is ionized by far-ultraviolet radiation ($\lambda >$ 500 Å), as in an H II region, the hydrogen is ionized preferentially and the effect on σ_e is very different.

In figure 2 we have plotted the effective cross-section in an H II region for two cases, one in which only the hydrogen is ionized and the other in which helium also is singly ionized. Only wavelengths greater than 50 Å are considered, so that the heavy elements may be ignored. Which of these conditions prevails is determined by the temperatures of the exciting stars, and Rubin (1969) has shown that the onset of helium ionization is rather sudden. The transition occurs when the class of the exciting stars is about O7. In such regions the major effect of the ionizing radiation is a

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TABLE 1

SUMMARY OF THE SOURCES OF PHOTOABSORPTION CROSS-SECTIONS USED IN THIS STUDY

Element	Wavelength (Å)	Source Reference
Carbon.....	1102–44	McGuire 1968
	23–82	Denne 1970
	44–1	Brown and Gould 1970
Nitrogen....	852–600	Comes and Elzer 1968
	600–30	McGuire 1968
	23–82	Denne 1970
	30–1	Brown and Gould 1970
Oxygen.....	910–500	Comes, Speier, and Elzer 1968
	500–124	McGuire 1968
	124–1	Brown and Gould 1970
	23–82	Denne 1970
Neon.......	575–50	Samson 1966
	23–82	Denne 1970
	50–1	Brown and Gould 1970
Magnesium .	1622–1500	Peach 1970
	1500–197	McGuire 1968
	197–10	Henke, White, and Lundberg 1957
	10–1	Brown and Gould 1970
		Guttman and Wagonfeld 1967
Silicon......	1978–1500	Peach 1970
	1500–105	McGuire 1968
	105–8	Henke *et al.* 1957
	8–1	Brown and Gould 1970
		Guttman and Wagonfeld 1967
Sulfur	1197–64	McGuire 1970
	64–5	Henke *et al.* 1957
	5–1	Brown and Gould 1970
		Guttman and Wagonfeld 1967
Aluminum ..	2074–1500	Peach 1970
	1500–3	McGuire 1968
Argon......	786–209	Samson 1966
	250–4	Lukirskii and Zimkina 1963
	23–82	Denne 1970
	5–1	Brown and Gould 1970
		Guttman and Wagonfeld 1967

drastic reduction of σ_e at wavelengths longward of the He I or He II edge.

The assumed composition of the interstellar medium strongly influences the calculated value of σ_e. The presence of heavy elements, particularly oxygen, is decisive at wavelengths shortward of the oxygen K-edge (22.3 Å), but rapidly becomes negligible at longer wavelengths. Heavy elements account for 10 percent of σ_e at 50 Å and barely 3 percent at 200 Å. Helium is responsible for about 65 percent if σ_e is between 50 and 100 Å, beyond which its contribution decreases approximately linearly with wavelength to about 33 percent at the He I edge, 504 Å. Therefore, if the interstellar medium is inhomogeneous in composition, the value of the effective absorption cross-section will depend upon the line of sight.

Recent observations (Carruthers 1970; Spitzer *et al.* 1973) indicate that in some regions most or all of the hydrogen is in molecular form. We show in figure 1 the photoabsorption cross-section of the hydrogen molecule. This is a composite of the results cited by Cook and Metzger (1964) between 860 and 550 Å, by Samson and Cairns (1965) between 452 and 209 Å, by Denne (1970) between 82 and 23 Å, and by Craseman *et al.* (1973) at wavelengths of 2.3 and 1.5 Å. Interpolations have been made among the various experimental points. The experimental points are about 50 percent larger than twice the cross-section for atomic hydrogen. The cross-sections for molecular hydrogen shown in figure 1 differ markedly from the calculated cross-sections given by Brown and Gould (1970) between 124 and 1.24 Å (0.1 and 10 keV). Their results are greater than those shown in figure 1 by a factor 10 at 100 Å and a factor 14 at 10 Å. The curve in figure 2 shows the effective absorption cross-section of the interstellar medium when all the hydrogen is in molecular form.

TABLE 2

ASSUMED COMPOSITION OF THE INTERSTELLAR MEDIUM

Element	Number Abundance
H	1
He............	8.31×10^{-2}
C.............	3.98×10^{-4}
N.............	1.12×10^{-4}
O.............	8.91×10^{-4}
Ne............	1.00×10^{-4}
Mg	2.51×10^{-5}
Al	1.9×10^{-6}
Si.............	3.10×10^{-5}
S	2.24×10^{-5}
A.............	7.59×10^{-6}

The effect of interstellar dust on σ_e has been estimated using the reddening curve between 1000 and 2000 Å obtained from measurements by OAO-2 (Bless and Savage 1972). The effective cross-section of a dust particle is related to the normalized color excess, $\epsilon(\lambda)$, by the equation

$$\sigma_d = \frac{A_V}{1.086\, n_{\rm H}} \left[\frac{\epsilon}{R} + 1\right],$$

where A_V = absorption in magnitudes at visual wavelengths, per unit distance, $R = A_V/E_{B-V}$, and $\epsilon = E_{\lambda-V}/E_{B-V}$.

We assume $R = 3.0$, and make the simple approximation that the ratio $A_V/n_{\rm H}$ is independent of the direction of view. For example, in obscured regions we might observe $A_V \simeq 1.5\, M\, \rm kpc^{-1}$ and $n_{\rm H} \simeq 1\ \rm H\ cm^{-3}$, and in clear regions $A_V \simeq 0.3\, M\, \rm kpc^{-1}$ and $n_{\rm H} \simeq 0.2\ \rm H\ cm^{-3}$, so that in both cases the ratio is 1.5. Taking this value, we obtain

$$\sigma_d = 1.5 \times 10^{-22}(\epsilon + 3)\ \rm cm^2 .$$

This cross-section is plotted in figure 1 as two curves, corresponding to the upper and lower bounds of the OAO-2 results for $\epsilon(\lambda)$. Little is known of the opacity of interstellar dust at wavelengths below 1000 Å. However, if the scattering is primarily Mie scattering, it

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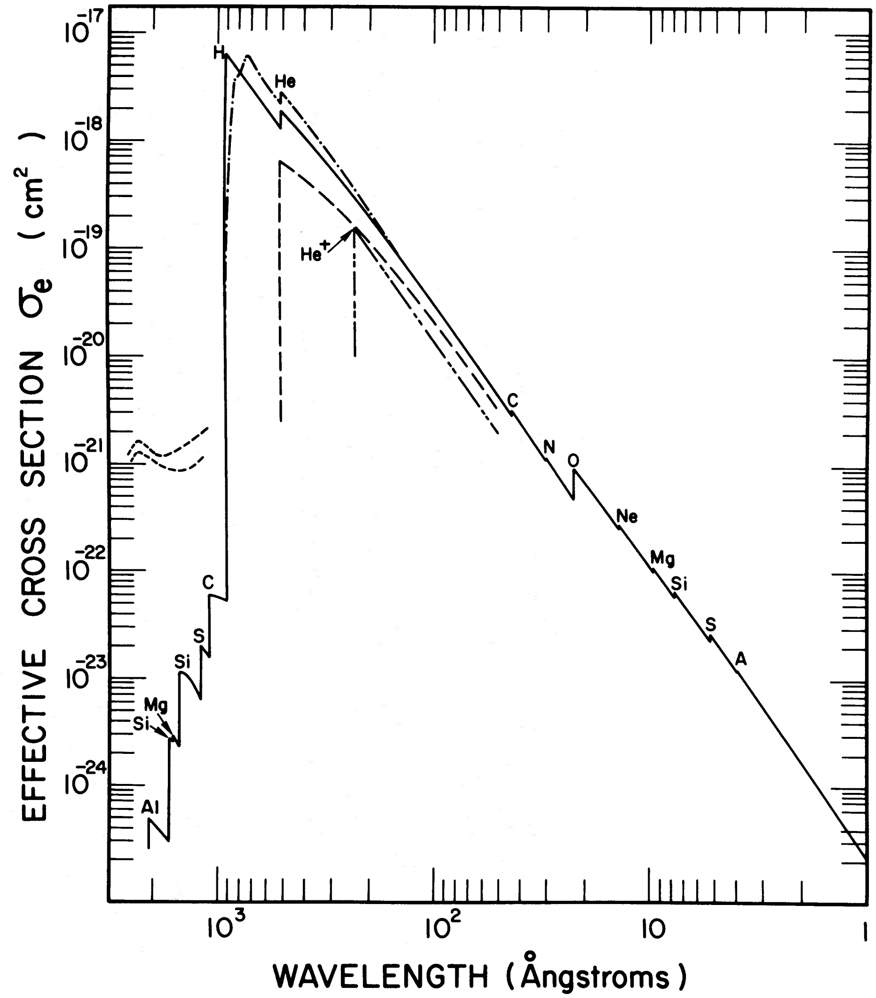

FIG. 2.—Effective cross-section (cross-section per hydrogen atom or proton) of the interstellar medium. ——— gaseous component with normal composition and temperature; —·—hydrogen, molecular form; —— —— H II region about a B star; —— -- H II region about an O star; ---- dust.

would be expected that the curves in figure 2 would flatten and become independent of wavelength at shorter wavelengths. At high photon energies, scattering by dust particles occurs mainly in the forward direction, and although the resulting effects may be observable, the opacity will not affect wide field-of-view measurements (Bowyer, Lampton, and Mack 1970). To summarize, the opacity of the interstellar medium appears to be affected significantly by dust only at wavelengths greater than 912 Å.

III. THE OPACITY OF THE INTERSTELLAR MEDIUM

The optical depth in the interstellar medium is the product of the effective cross-section and the column density of hydrogen atoms in the line of sight. Early estimates of the optical depth relied upon measurements of 21-cm emission and absorption in the galactic plane, which were interpreted in terms of an essentially uniform gas of density ~ 1 cm^{-3}. Such a number led immediately to the forbidding view of soft X-ray and extreme-ultraviolet observations which was described by Aller (1959). This simple picture has been changed radically by the discovery that the interstellar medium is inhomogeneous and may contain extensive regions of tenuous gas.

The cloudy structure of galactic hydrogen has been known for a long time, but only recently was it realized that it might be far from isothermal. In 1968 Spitzer suggested that observations of H I regions might be interpreted in terms of cool, dense clouds in pressure equilibrium with a hot, tenuous intercloud gas, and Field, Goldsmith, and Habing (1969) proposed a two-phase medium heated by low-energy cosmic rays, in which the temperature and density were 18° K and

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100 cm^{-3} for the clouds and 9000° K and 0.2 cm^{-3} for the intercloud gas. The clouds would contain about 75 percent of the mass but occupy less than 1 percent of the volume. Weaver (1970) and Silk (1973) have reviewed measurements of 21-cm emission and absorption in the interstellar gas, which seem to support the existence of two phases but do not verify the temperatures and densities predicted by Field *et al.* (1969).

We shall confine our attention to a region around the Sun extending to distances of about 1000 pc, which is believed (Weaver 1970) to lie in a large spur projecting from a galactic spiral arm. Heiles (1967) has examined 21-cm emission in detail from a small portion of the sky and found a few clouds with $\langle \text{radius} \rangle \simeq$ 19 pc, $\langle \text{density} \rangle \simeq 4$ cm^{-3}, and $\langle \text{column density} \rangle \simeq 2 \times 10^{20}$ cm^{-2}. He also found many "cloudlets" containing about 10 percent of the total cloud mass, with $\langle \text{radius} \rangle \simeq 2.2$ pc, $\langle \text{density} \rangle \simeq 2$ cm^{-3}, and $\langle \text{column density} \rangle \simeq 1.2 \times 10^{19}$ cm^{-2}. Radhakrishnan *et al.* (1972) have examined the 21-cm emission and absorption spectra in the direction of 35 extragalactic sources, most of which lie at intermediate and high latitudes. In these cases the gas being examined lies within 1000 pc. They conclude that about half the mass of the interstellar gas resides in clouds with column densities ranging from 2.5×10^{19} to 10^{21} cm^{-2}. The average cloud has a column density of 3×10^{20} cm^{-2} and a temperature of 80° K, and the average spacing between clouds is about 200 pc.

Based on these two sets of observations, we adopt for further discussion an interstellar medium containing standard clouds of radius 20 pc, density 4 cm^{-3}, and temperature 80° K. In addition, we should consider the possibility that cloudlets of the kind found by Heiles inhabit most of the region we are considering, with a mean spacing of 20 pc. To be in pressure equilibrium with the same gas as the clouds, the cloudlets should have a mean temperature of about 170° K, a value in agreement with the velocity dispersion in cloudlets measured by Heiles. More recent observations by Heiles (1973) suggest that the dense phase of the interstellar medium is more likely to be found in filamentary structures than in clouds of a roughly spherical shape, so that the above picture may be naïve. However, this new picture of the cool hydrogen should not impede our arguments that the interstellar medium is very inhomogeneous.

The intercloud medium has been studied by Mebold (1972), who obtained 21-cm emission spectra at a galactic latitude of about 30° and at all longitudes. He concludes that the intercloud gas has a mean density of 0.2 cm^{-3}, a scale height of about 200 pc, and a mean velocity dispersion, after allowance has been made for line broadening due to galactic rotation, of 8.8 km s^{-1}. The latter figure, which agrees well with the value of 8 km s^{-1} measured by Heiles (1967), places an upper limit on the gas temperature of 9400° K. A lower limit which is less than 1000° K is given by Radhakrishnan *et al.* (1972).

The contribution of turbulence to the velocity dispersion is a major stumbling block in estimating the temperature of the intercloud gas. However, Baker (1973) has analyzed statistically the 21-cm emission spectra in two regions of the sky ($l = 87.5°$, $b = 24.5°$, and $l = 180°$, $b = -24°$), in order to separate the turbulent and thermal velocity dispersions, and has deduced that the temperatures in these two regions are 5300° and 600° K, respectively. The latter value does not appear typical, as the velocity dispersion in the second region is lower than the mean derived from the extensive sky surveys of Mebold (1972) and Radhakrishnan *et al.* (1972).

If we assume that the density and temperature in the intercloud gas are, respectively, 0.2 cm^{-3} and 5000° K, then the resulting kinetic pressure, 1000 cm^{-3} ° K, is 3 times greater than the pressure in the clouds. If the clouds are not to collapse, then either the clouds must be supported internally by magnetic or turbulent pressure, and/or the values we have assumed for the density and temperature of the intercloud gas may not be typical and may be too large.

Observations of Lα radiation lend some support to the latter conclusion. The OAO measurements (Savage and Jenkins 1972) of Lα absorption in the spectra of O and B stars lying within 1000 pc of the Sun, suggest that in many regions of the local spur the intercloud gas density is less than 0.2 cm^{-3}. A histogram of values of the mean hydrogen density in the line of sight shows a maximum near 0.2 cm^{-3}, and the measurements may be divided approximately equally among the intervals 0–0.2, 0.2–0.4, and 0.4–1.0 cm^{-3}. Similar observations of 10 of the stars observed by OAO have been made by an instrument in the *Mariner 9* spacecraft. The results (Bohlin 1973) corroborate those obtained from OAO, and yield column densities which on the average are 30 percent lower. As most of the stars observed by OAO are over 200 pc from the Sun, in most cases at least one cloud should lie in the line of sight and only one-half of the column density should be attributed to the intercloud medium. Therefore, there should be extensive regions in which the intercloud density is about 0.1 cm^{-3}.

Information on the properties of the interstellar medium near the Sun has been provided by measurements (Thomas and Krassa 1971; Bertaux and Blamont 1971) of solar Lα radiation scattered by interstellar atomic hydrogen streaming toward the Sun. The results have been fitted to a model (Thomas 1972), which predicts upper limits to the density and temperature of the local hydrogen. These are, respectively, 0.12 cm^{-3} and 3650° K for the results of Thomas and Krassa (1971), and 0.09 and 5870° K for the results of Bertaux and Blamont (1971). The upper limit to the gas pressure is about 500 cm^{-3} ° K, which is only 50 percent greater than the kinetic pressure in our standard cloud. Thomas' results imply that the solar system is moving through the intercloud gas, in a region which is less dense than the average.

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We conclude from this picture of the interstellar medium that within 200 pc of the Sun there is a high probability that the mean density along the line of sight is only 0.1 cm^{-3}, as there are few clouds in this region and any cloudlets would cover only a few percent of the sky. At greater distances cloud will tend to make as great a contribution to the column density as the intercloud gas, and we expect to find a mean density of 0.2 cm^{-3} in many directions.

In figure 3 we have used the effective cross-sections shown in figure 2 and densities of 0.1 and 0.2 cm^{-3} to estimate the distance over which radiation is attenuated by 90 percent. The opacity of the ionized fraction of the intercloud gas has been ignored. We conclude that the visibility in the interstellar medium should, in many areas of the sky, be about 800 pc at 50 Å, 200 pc at 100 Å, and 10 pc at 300 Å. Observations at longer wavelengths may be restricted to objects within approximately 6 pc of the Sun, except for those view directions in which the line-of-sight column densities are unusually low.

We have found some evidence which at least encourages the hope that in a few areas of the sky unusually low column densities will be found, making possible soft X-ray and extreme ultraviolet observations over greater distances. Lα absorption measurements (Savage and Jenkins 1972) show an extended region of tenuous gas stretching along the galactic plane from Puppis to Orion. The lowest mean density measured in this region was 0.03 (+0.03, −0.015) cm^{-3}, along the line of sight to β CMa (a distance of 220 pc). In addition, the absence of Lα absorption in the spectrum of Arcturus (Rottman *et al.* 1971), which is 11 pc from the Sun, implies an upper limit to the mean hydrogen density in this direction of 0.05 cm^{-3}. More recent results, obtained by OAO-3, suggest average densities along the lines of sight to α Leo, α Eri, and ν Sco of 0.02, 0.07, and 0.05 cm^{-3}, respectively (Rogerson *et al.* 1973).

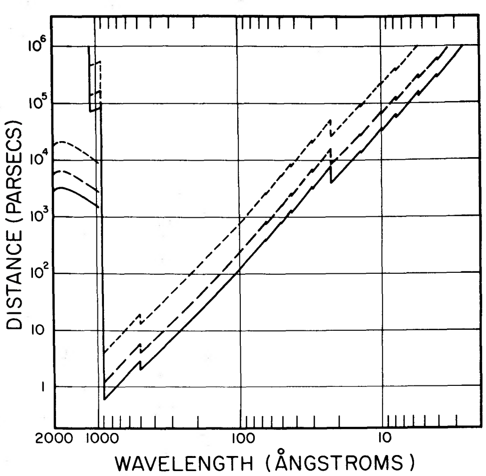

FIG. 3.—Distance at which attenuation of the incident radiation reaches 90 percent, as a function of wavelength. An un-ionized interstellar medium of normal composition is assumed, and the contribution of the dust is based on the upper curve in fig. 2. —— $\eta_H = 0.2\ cm^{-3}$; — — $\eta_H = 0.1\ cm^{-3}$; - - - $\eta_H = 0.03\ cm^{-3}$.

A number of observations suggest that the interstellar medium may be disturbed violently, and consequently the intercloud gas may be quite inhomogeneous. Baker (1973) found very different temperatures in the two regions of the sky which he analyzed, and this implies that the ratio of their mean densities may be as great as a factor of 5. Further, in both regions he found a turbulent velocity dispersion so large that the randomly moving clumps of gas must be moving supersonically, which suggests that the intercloud gas is being stirred continuously and dissipating energy through shock waves. These are not peculiar results, for large velocity dispersions in the intercloud gas are a persistent feature of 21-cm emission measurements (Heiles 1967; Mebold 1972; Radhakrishnan *et al.* 1972). The energy-dissipation rate is large, about 3×10^{-26} ergs cm^{-3} s^{-1}, and falls within the range of values which have been invoked in explanations of the heating and ionization of the interstellar medium. The range extends from $\sim 3 \times 10^{-27}$ ergs cm^{-3} s^{-1} (Field *et al.* 1969) to 10^{-25} ergs cm^{-3} s^{-1} (Silk 1973). Baker finds evidence that the larger elements in the turbulence participate in a streaming motion directed toward the Sun, and suggests that such streams may be the source of the energy. Such massive streams, moving in the galactic plane at velocities which approach 100 km s^{-1} in some instances and usually are negative, have been noted by Weaver (1970). A possible cause of these streams is convective heat transfer between the interstellar medium and a surrounding layer of hot, tenuous gas.

In a recent paper Silk (1973) has argued that evidence for a low degree of ionization in clouds makes it difficult to accept low-energy cosmic rays as the primary source of ionization in the interstellar medium. If this were true, then heating and ionization in the interstellar medium would be confined essentially to H II regions in the intercloud gas. Alternative sources of heating and ionization in the intercloud gas are extreme-ultraviolet radiation emitted by supernova blast waves or ultraviolet stars, or convective heat transfer with a hot, tenuous halo surrounding the cooler hydrogen in the galactic disk. Such processes should result in irregular distributions of density and temperature in the intercloud gas, and in certain regions ionization of hydrogen and helium might reduce significantly the opacity of the gas at soft X-ray and extreme ultraviolet wavelengths.

Silk (1973) argues further that pulsar dispersion, and free-free emission and absorption of the radio continuum, might be ascribed for the most part to the electrons of the intercloud gas. This would call for a high ionization rate ($\zeta \simeq 10^{-14}\ s^{-1}$), and for the gas to be as much as 50 percent ionized. Care must be taken in comparing radio-continuum with pulsar-dispersion

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estimates of electron density, for the former gives an estimate of $\langle N_e^2 \rangle$ and the latter $\langle N_e \rangle$, and it is possible that free-free absorption and emission are dominated by H II regions around hot stars (Gould 1971). However, pulsar dispersion appears to be determined by the intercloud gas, and after analyzing the dispersions of 14 pulsars with latitudes greater than 25°, we find that within a few hundred parsecs of the Sun the electron density lies between 0.05 and 0.1 cm^{-3}. When these values are compared with the values we have ascribed to the atomic hydrogen density in the local intercloud gas, 0.1–0.2 cm^{-3}, a high degree of ionization is suggested.

While it is difficult to obtain a distinct picture of the intercloud gas from 21 cm, radio-continuum, pulsar-dispersion, solar Lα scattering, and stellar Lα absorption measurements, it appears equally difficult to see it as a placid, uniform continuum surrounding H I regions. There is strong evidence that it is heated, ionized, and disturbed violently by agents which produce significant inhomogeneities in density and temperature.

In particular, we draw attention to the sector of the Galaxy between longitudes of 180° and 270°, in which Lα absorption measurements over path lengths as long as 900 pc have yielded extraordinarily low values for the mean hydrogen density. Seven of the 14 high-latitude pulsars ($|b| > 25°$) which have been discovered are clustered in this sector (we include MP 0256 at $l = 271°$), from which we deduce an electron density in the plane of 0.05 cm^{-3}. This is confirmed by the dispersion of the Crab pulsar, whose distance is known well. A value more than twice as large is found for the remaining seven pulsars, which are at longitudes between 0 and 140°. This part of the Galaxy may turn out to be just an interarm region between the Sagittarius arm and the local spur, but other observations, such as the soft X-ray excess at low latitudes reported by Bunner *et al.* (1973), Yentis, Novick, and Vanden Bout (1972), and Garmire (1973), and the large jet of high-velocity hydrogen found at $l = 196\overset{\circ}{.}5$ by Weaver (1970), may be evidence of something more unusual.

Therefore, as there may well exist regions in the sky where the mean density along the line of sight is appreciably less than 0.1 cm^{-3}, we show in figure 3 the 90 percent attenuation distance in a gas of density 0.03 cm^{-3}, which is the lowest value obtained from the OAO observations (Savage and Jenkins 1972). Under such conditions the visibility at 100 Å would improve to nearly 800 pc, and at 300 Å to 40 pc.

Finally, observations of the X-ray background flux may prove very instructive. If this radiation is produced outside the galactic hydrogen layer, observations at wavelengths between 50 and 100 Å may reveal clouds or other structures in the interstellar medium. If it is produced within the layer, observations between 100 and 300 Å should reveal its origin. In either case, the position of a peak or plateau in the spectrum is of particular interest, for it may provide some insight into the sources of the soft X-ray background.

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