

Fig. 4. Interstellar absorption map in magnitude units of IC1795 = W3 and IC1805 = W4 at $\lambda 6563 \text{ \AA}$.

Figs. 1-4 show a comparison for a complex region near the galactic equator (l_{II} is about 134 degrees). Fig. 1 is a photograph in $H\alpha$ light, Figs. 2 and 3 are the contour maps in $H\alpha$ and in microwave radio emission at 4,170 MHz (ref. 2), and Fig. 4 shows the surface distribution of interstellar absorption over the region. The two emission nebulae in the field are IC1795 and IC1805 (W3 and W4, respectively, as radio sources).

Small scale structure of absorption is clearly seen in Fig. 4 as well as the general tendency towards heavier absorption in lower galactic latitude³. The absorption obtained is chiefly that within the H II region, but also includes a contribution from the space between the Earth and the H II region. In any case, this is an independent method of obtaining a map of interstellar absorption. Interstellar absorption is currently obtained by stellar photometry. The observational data, however, are not an absorption value but a colour excess, and the ratio of space absorption to colour excess is still not well known. The technique presented here is one of the methods for deriving an absolute value of absorption and it will help to clarify the role of the interstellar dust grains in the H II regions.

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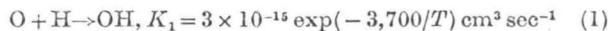
³ Ishida, K., and Kawajiri, N., *Publ. Astro. Soc. Japan* (in the press).

Production of OH Molecules in Interstellar Shock Waves

MEASUREMENTS made recently at Berkeley have shown that there is interstellar OH absorption in most low latitude radio sources¹. Most indications are that the excitation, unlike that in the intensely emitting regions², is fairly normal, and that the state temperature is $T < 10^{\circ} \text{ K}$. If it is assumed that $T = 3^{\circ} \text{ K}$ (a minimum value, from the cosmic microwave background), the median value of OH/H is about 4×10^{-8} in sources in which both OH and H lines can be measured. This ratio, which corresponds to $\text{OH}/\text{O} \sim 6 \times 10^{-5}$, is not far from that of CH and CH^+ , seen optically. An attempt by Bates and Spitzer to explain the abundance of CH by two body radiative association³ failed by more than three orders of magnitude. This led Stecher and Williams⁴ to propose that chemical exchange reactions on grains of the form $\text{GX} + \text{Y} \rightarrow \text{G} + \text{XY}$ (where $\text{X} = \text{H}$, $\text{Y} = \text{O}$ for OH) could operate in the heated regions behind interstellar shock fronts. They calculated

that $\text{OH}/\text{H} = 3 \times 10^{-9}$ after a shock passes. Photodissociation ($\tau = 10^4$ yr) between shock passages ($T = 10^7$ yr) reduces OH/H to an average value of 3×10^{-12} , which is four orders of magnitude too low. According to Carroll and Salpeter⁵, the chemical exchange reaction $\text{O} + \text{H}_2 \rightarrow \text{OH} + \text{H}$ produces comparable amounts of OH if $\text{H}_2/\text{H} \sim 10^{-4}$. According to Stecher and Williams⁶, however, H_2/H is kept to the extremely low value of 10^{-7} by photodissociation of H_2 .

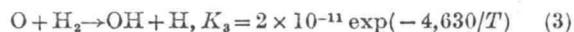
We have calculated the OH production caused by pre-association, as suggested by Solomon⁷,



where $K_1 = \dot{n}(\text{OH})/n(\text{O})n(\text{H})$. Obviously this reaction proceeds even if H_2 is absent, but, like the reactions involving H_2 and grains, it requires the high temperatures present behind a shock wave. The primary destruction mechanism is⁸



Starting with no molecules, reaction (1) builds up OH behind the shock front, while reaction (2) converts some of these molecules to H_2 . The inverse of reaction (2),



and the low-temperature reaction,



were also included; we assumed that O_2 is photo-dissoci-

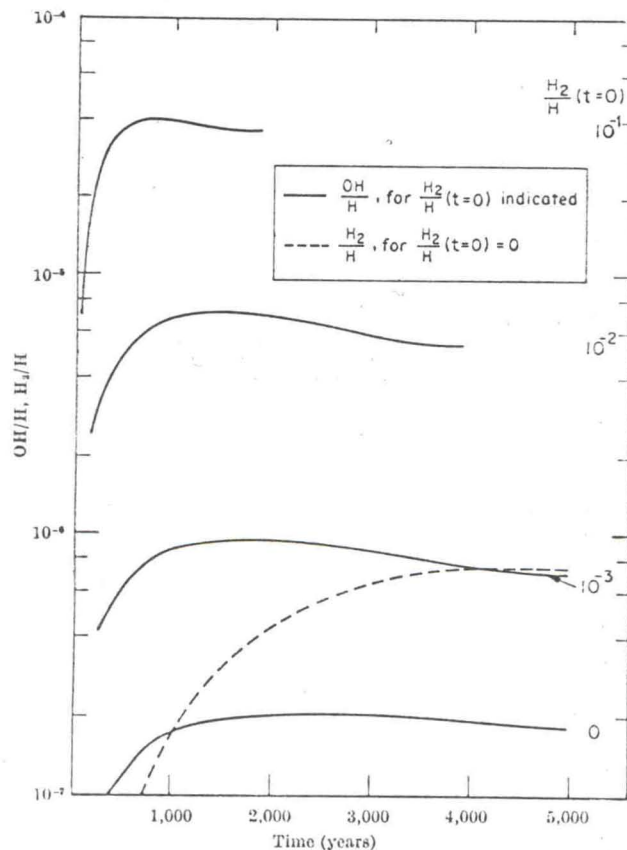


Fig. 1. Production of molecules as a function of time elapsed since passage of a shock front in an H I region. The shock speed is 8 km/sec, and the temperature varies from 2,000° K at $t=0$ to 100° K at the end of the calculation. OH is produced by reaction (1) when $\text{H}_2/\text{H} = 0$, and also by reaction (3) when $\text{H}_2/\text{H} \neq 0$. The hydrogen produced by reaction (2), starting with $\text{H}_2/\text{H} = 0$, is also shown.

ated immediately. The reaction $\text{OH} + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{H}$ was neglected because it becomes comparable with reaction (2) only when H_2/H approaches 10 per cent.

Both Stecher and Williams⁴ and Carroll and Salpeter⁵ used estimated postshock temperature density profiles. We used a grid of profiles depending on mach number, initial H_2 abundance and preshock magnetic field strength calculated by Field, Rather, Aannestad and Orszag⁸. Their calculations, for preshock densities $n(\text{H}) = 10 \text{ cm}^{-3}$ and $n(\text{O}) = 6.8 \times 10^{-3} \text{ cm}^{-3}$, show that the cooling time ($\sim 10^4$ yr) is reduced from previously accepted values because of frequent inelastic OH collisions with subsequent 63μ radiation. The short cooling time tends to limit molecule production, although it is somewhat compensated by increased densities far behind the shock.

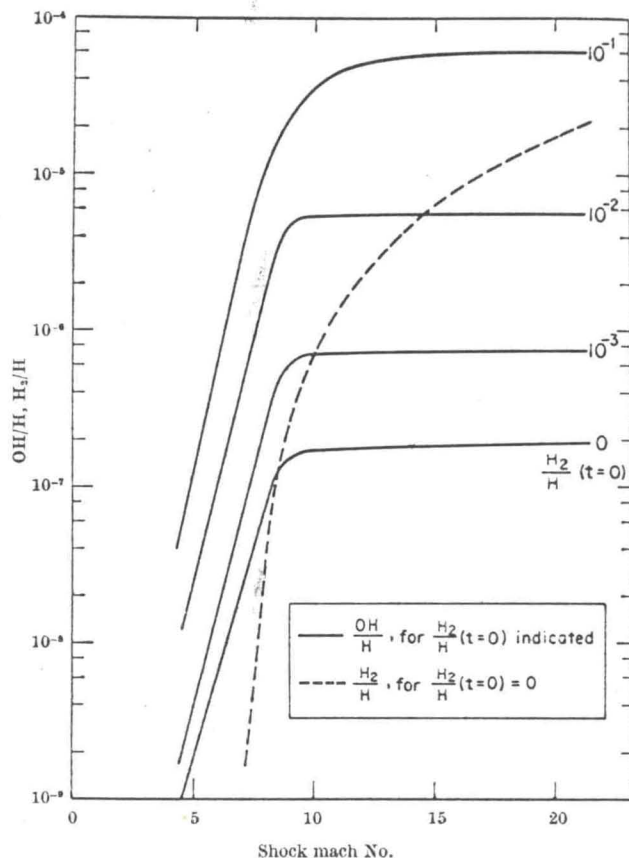


Fig. 2. The final molecular abundances after shock passage as a function of mach number (= speed/0.8 km/sec). Significant contribution by reaction (3) requires $\text{H}_2/\text{H} > 10^{-3}$.

Fig. 1 shows the OH production for a mach 10 (8 km/sec) shock; the abscissa represents time elapsed since shock passage. The calculations are terminated when the material behind the shock has returned to its preshock temperature, assumed to be 100° K. For $\text{H}_2/\text{H} = 0$, equilibrium between reactions (1) and (2) is rapidly attained behind the shock, at $\text{OH}/\text{H} = 2 \times 10^{-7}$, independent of temperature. Reaction (2) produces some H_2 as shown, but the amount is so small that reaction (3) and the reaction $\text{OH} + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{H}$ are safely neglected.

Although at present it seems likely that the interstellar hydrogen abundance is very low⁹, calculations were made for $\text{H}_2/\text{H} = 10^{-3}$, 10^{-2} and 10^{-1} to assess the importance of reaction (3). Photodissociation of H_2 was ignored.

PLANETARY SCIENCE

Fractionation of Iron in the Solar System

BANERJEE¹ has argued against the influence of ferromagnetism on the aggregation of particulate matter in a theory of Harris and myself² on chemical fractionation within the solar system.

His objection is based on one of the more unsatisfactory parts of magnetic theory—the prediction of spin structure. I quote a reference³ he used (page 367): "Some calculations on small multidomain particles have been made but it is fair to say that to date such particles are not understood" (see also ref. 4, chapter 8). Calculations of the likely magnetization of any system are usually hampered by at least the following uncertainties: (a) proper enumeration and comparison of all the possible spin configurations; and (b) the occurrence of metastable spin configurations.

Assuming that the exact shape of particles formed in the conditions envisaged in the solar nebula is known, the difficulty of satisfying (a) is especially great near the Curie point. The simplified enumeration achieved by assuming a domain structure breaks down because of the extremely small crystalline anisotropy constants in the vicinity of the macroscopic Curie point. For the very slowly cooling particles in the completely thermalized environment postulated in the fractionation theory, metastable spin configurations become a real possibility for any particles much larger than the superparamagnetic size limit.

Thus I am surprised at the faith Banerjee has in his method of multidomain calculation and in the significance of his numerical results for the theory². If the validity of his method is accepted, a trivial adjustment to the theory would remove the numerical discrepancy. It would be wrong, however, to conceal the ignorance that surrounds the magnetization of small particles and therefore the effectiveness of ferromagnetism in enhancing collision rates of ferromagnetic particles. In the conditions envisaged, the ratio of collision cross-section to optical cross-section of ferromagnetic particles probably rises from unity as the size exceeds the superparamagnetic limit, could reach very large values and probably declines towards unity for particles greater than 10⁻⁴–10⁻³ cm. This size range probably includes a significant fraction of the particle size distribution of the primary condensate².

Fortunately, it is not necessary to take refuge in such ignorance. It was pointed out² that without long range ferromagnetic attraction, the binary collision rate of iron particles, if they averaged 10⁻⁴ cm in size, was of the order 1 per year. It would therefore still be possible for large aggregates to be built up. It seems probable that short range ferromagnetic interactions would create a thermally stable bond between any colliding iron particles of greater than superparamagnetic size. With no mechanism of comparable bonding efficiency between non-ferromagnetic particles a size difference of iron and non-metallic particle aggregates would occur. This is the essential step in the theory².

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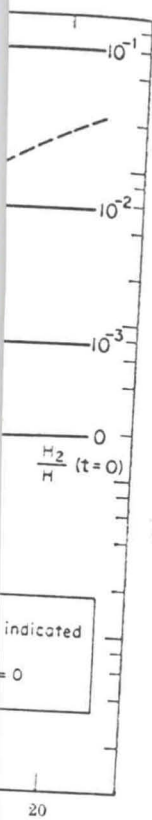
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⁴ Brown, W. F., in *Magnetostatic Principles in Ferromagnetism* (North-Holland, 1962).

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As expected, far more OH is produced by this exchange reaction. (The value for H₂/H=10⁻¹ is an overestimate because of the neglect of OH+H₂→H₂O+H). Our results agree roughly with those of Carroll and Salpeter, based on estimated cooling curves. The decrease at the end of the curves in Fig. 1 is produced by reaction (4), the only operative in the cooler regions far behind the shock. Fig. 2 demonstrates that reactions (1) and (3) require at least mach 10 shocks to be effective. Lower shock speeds do not result in sufficient temperatures, while higher speeds do not significantly increase molecule production further. In every case, the production of hydrogen is very small. A magnetic field changes the cooling times somewhat, and thus the molecular production. The minimum value achieved, OH/H=2×10⁻⁷ when H₂/H=0, is affected only in that larger fields require larger mach numbers for reactions (1) and (2) to come into equilibrium. The minimum effective mach number ranges from 10 for B=0 to 17 for B=10⁻⁶ gauss.

If, with Stecher and Williams⁴, we set H₂/H=0, the relevant OH/H from reaction (1) is 2×10⁻⁷ for shocks of mach 10 or more. This is about two orders of magnitude greater than production by chemical exchange reactions on grains (except near hot stars where radiation pressure accelerates the grains through the gas, increasing the OH production⁴). The postshock value of OH/H is reduced by reaction (4) and by photodissociation, for which the combined lifetime is τ. At time t after shock passage, the ratio has dropped by the factor e^{-t/τ}. When averaged for many shock passages (for which the mean interval is T), the reduction factor is τ/T. T is 6×10⁶ yr (ref. 9) and τ (photodissociation) from the f-values of ref. 7 and the standard interstellar radiation field is 6,000 yr (ref. 10). Because this is smaller than that for reaction (4), the latter may be neglected. The reduction factor is therefore 10⁻³, giving a mean value OH/H=2×10⁻¹⁰, about 100 times the amount caused by grains⁴. It is still, however, 200 times smaller than the observed value, so that reaction (1) behind shocks cannot be solely responsible for the observed OH.

If hydrogen is present, Fig. 2 indicates that the factor of 100 can be recovered only if H₂/H>1 per cent. This is much too high for the mean value of this quantity according to ref. 6. The possibility arises, however, that, in the immediate vicinity of shock fronts, production of hydrogen on grains is so rapid that a considerable abundance of hydrogen builds up. Although Stecher and Williams⁴ estimate that H₂/H attains only the value 4×10⁻⁵ behind shocks, this depends on the details of the postshock cooling. We hope to check this in future calculations.

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