Reports

Interstellar Sulfur Hydride: A Search for the 111-Megahertz Lines

Abstract. *Similarities in the energy-level structure of the sulfur hydride radical and the hydroxyl radical suggest that sulfur hydride in the interstellar medium might be detectable because of a population inversion or anti-inversion similar to that of the hydroxyl radical. We have searched for the 111.54-megahertz transition* [F (*total angular momentum quantum number*) $= 2 \rightarrow 2$] *and for the 111.22-megahertz transition* (F $= 1 \rightarrow 1$) *in the galactic radio source W49, one of the brightest hydroxyl emission sources. No sulfur hydride emission lines with half-power widths of 130 hertz or greater were detected with the 1000-foot Arecibo antenna. The upper limits established with 100-hertz filters were 50 and 60 flux units* (*1 flux unit* $= 10^{26}$ *watt meter*$^{-2}$ *hertz*$^{-1}$), *respectively, for the two lines.*

Although we have thus far been unsuccessful in detecting emission lines from interstellar sulfur hydride (SH), we here report on the source that was searched and the upper limits that were established. The energy-level structure of the SH radical is strikingly similar to that of the hydroxyl radical (OH), which has been detected in the interstellar medium. The ground state of both molecules consists of a Λ-doublet with each of the two energy levels further subdivided by hyperfine splitting into sublevels with $F = 2$ and $F = 1$, where F is the total angular momentum quantum number. The four 18-cm transitions of OH, now familiar in radio astronomy, have their analogies in the microwave spectrum of SH. Radford and Linzer (*1*) have measured the frequency of these SH transitions by paramagnetic resonance absorption. The most precise frequencies (Table 1) are based on Radford's corrected values (*2*), which differ slightly from published values (*1*). The errors (Table 1) are the experimenters' estimates of the accuracy of their laboratory determinations.

Litvak *et al.* (*3*) suggested that similarities in the energy-level structure of these two hydrides might cause SH in the interstellar medium to show anomalous behavior similar to that of OH. Computations based on the ultraviolet-pumping model of Litvak *et al.* (*4*) indicate that the pumping efficiency for SH is about 15 percent of that for OH, and that the SH molecule could be anti-inverted or inverted, depending on the amount of selective absorption to which the ultraviolet-pumping radiation was exposed. In spite of the very low intensity predicted for the SH line on the basis of thermal population distributions (*5*), we now believe that the prospects for detecting this component of the interstellar medium are good.

The abundance of sulfur relative to oxygen, as estimated for stars of the early type (*6*), is about 1 : 10. We might therefore expect, on the basis of pumping efficiency and abundance alone, that a saturated SH emission source could produce about 0.015 times as many photons per second as an OH source. Furthermore, SH would have a smaller linewidth because of its greater mass and its lower resonant frequency. These two considerations lead one to expect a reduction in linewidth of 0.048. Bright OH features (for example, from the sources W3 and W49) have peak fluxes of about 500 flux units (1 flux unit $= 10^{-26}$ watt m^{-2} hz^{-1}) and half-power linewidths of about 2.6 khz. Our scaling estimates thus suggest that a small number of sources might produce SH emission features with peak fluxes of 10 flux units (meter-kilogram-second) and half-power linewidths of 130 hz. The estimated flux is uncertain for many reasons. The ionization potential of SH may be lower than that of OH, and SH may thus be more vulnerable to photodecomposition. We have estimated the flux on the basis of the ultraviolet-pumping model, but other pumping mechanisms that work for OH should also invert SH with a relative efficiency which we cannot presently estimate. The linewidth estimate assumes that the OH line-broadening is entirely thermal. If the linewidth were due entirely to turbulence with no thermal broadening, we would predict an SH linewidth of 170 hz.

Table 1. Sulfur hydride ground-state transitions.

Transition*	Frequency (Mhz)
F 2 → 2	111.54 ± 0.1
F 1 → 1	111.22 ± .1
F 2 → 1	122.60 ± .1
F 1 → 2	100.16 ± .1

* Emission transitions; parity of the upper state is positive, and that of the lower state is negative.

The uncertainty in the line frequencies (± 0.1 Mhz) is roughly a thousand times the expected linewidth; therefore considerable effort is required to search in the frequency domain. Our search thus far has concentrated on W49, one of the brightest OH sources, and we have used the 1000-foot spheroidal reflector at the Arecibo Ionospheric Observatory in Arecibo, Puerto Rico. The antenna feed for these observations consisted of two linearly polarized dipoles which illuminated a sector of the spheroid approximately 680 feet in diameter. The sensitivity of the system was measured on 3C 433. Assuming an unpolarized flux of 80 flux units (mks) for 3C 433, we found that the antenna-temperature equivalent of 1 flux unit (mks) was 4.3°K. The noise temperature of the receiver was 500°K. The received signals were heterodyned down to 150 khz and recorded with a Mincom magnetic tape recorder (bandwidth 250 khz). The frequency search was made by playing back the recorded tapes through a filter bank consisting of 100 contiguous filter channels, each with a width of 100 hz. A total of 20 passes through the filter bank was required in order to cover the 200-khz uncertainty in the line frequency.

We observed W49 on two occasions: in July 1967 we searched the interval 111.22 ± 0.1 Mhz (the transition $F = 1 \rightarrow 1$); in May 1968 we searched 111.54 ± 0.1 Mhz ($F = 2 \rightarrow 2$). Ten-minute integrations were made on and off source. We compensated for instrumental errors in the filter bank by subtracting the integrated filter outputs off source from the corresponding data on source. Different pointing offsets were

Table 2. Summary of W49 observations.

Frequency (Mhz)	Number of 10-minute integrations		Detection limit	
	On source	Off source	Flux (mks)*	Antenna temperature (°K)
111.22	5	3	60	260
111.54	1	1	50	210

* One flux unit (mks) equals 10^{-26} watt m^{-2} hz^{-1}.

used during the two observing periods: in July 1967 the off-source measurements were made with a declination offset of 2°, and in June 1968, with a right ascension offset of 3°. (The half-power beamwidth was 51 minutes of arc.) The radio source W49 lies on the ridge of galactic background emission such that the difference in the antenna temperature between on and off source was 800°K in both cases.

Mezger *et al.* (*7*) have measured the combined flux of the two components, thermal and nonthermal, that constitute W49. Their data show the 111-Mhz flux to be 60 flux units (mks), due almost entirely to the nonthermal source. Thus W49 contributes about 260°K to the on-off difference in antenna temperature; the remaining 540°K is due to the galactic background (Table 2). The upper limits for detectable emission- or absorption-line intensities were set by unforeseen instabilities in the 100-channel filter bank. These limits were based on the assumption that a valid signal would appear in two or more contiguous channels; therefore the limits apply to linewidths greater than 100 hz. On this assumption, we found no signals in our data that exceeded the detection limit of Table 2. If features were confined to a single channel and if this filter channel happened to be one of the ten that show instabilities from time to time, then detection would have been much more difficult.

In view of the estimated magnitudes of SH-line intensities, it is perhaps not surprising that we have thus far failed to detect the line. However, we are optimistic about the possibilities for detection once the transition frequencies have been measured to greater precision. This would make it feasible to improve the sensitivity by a factor of 50 and extend the search to many more sources.

M. L. Meeks
M. A. Gordon
M. M. Litvak
Lincoln Laboratory, Massachusetts Institute of Technology, Lexington

References and Notes

1. H. E. Radford and M. Linzer, *Phys. Rev. Lett.* **10**, 443 (1963).
2. H. E. Radford, personal communication.
3. M. M. Litvak, A. L. McWhorter, M. L. Meeks, H. J. Zeiger, *Astron. J.* **72**, 812 (1967).
4. ———, *Phys. Rev. Lett.* **17**, 821 (1966).
5. A. H. Barrett, *IEEE (Inst. Elec. Electron. Eng.) Trans. Mil. Electron.* **MIL-8**, 156 (1964).
6. L. H. Aller, *Handbuch der Physik* (Springer-Verlag, Berlin, 1958), vol. 51, p. 343.
7. P. G. Mezger, J. Schraml, Y. Terzian, *Astrophys. J.* **150**, 807 (1967).
8. We acknowledge helpful discussions with Drs. F. C. Drake and G. H. Pettengill. We thank Dr. H. E. Radford for providing revised values for the transition frequencies, and we thank the staff of the Arecibo Ionospheric Observatory for their assistance during observing and data processing. The Arecibo Ionospheric Observatory is operated by Cornell University with the support of the Advanced Research Projects Agency. Lincoln Laboratory is operated with support from the U.S. Air Force.

4 December 1968

Nitrogen Abundances in Chondritic Meteorites

Abstract. *Carrier-gas fusion extractions of total nitrogen in 22 chondritic meteorites indicate a wide variation in total nitrogen contents, ranging from 660 parts per million for an enstatite chondrite to 18 parts per million for an ordinary chondrite. Total nitrogen and total carbon contents of individual chondrites do not show a positive correlation.*

The abundances of nitrogen have been determined in 22 chondritic meteorites by a carrier-gas fusion extraction technique with a LECO Nitrox-6 nitrogen analyzer. Powdered samples (50 to 200 mg) were burned in a graphite crucible in an inert atmosphere (helium) with a LECO induction furnace. The powdered samples in capsules made of nitrogen-free tin were kept in a vacuum for 48 hours, and sealed under helium in a dry box. The combustion products (all nitrogen-containing compounds and dissolved nitrogen having been converted to molecular nitrogen) were passed over a catalyst, consisting of rare earth and copper oxide, at 400°C to convert any carbon monoxide present to carbon dioxide. A trap containing ascarite and anhydrone in the flow system removed the carbon dioxide and water and allowed other combustion products to pass on through. This procedure was necessary to allow resolution of the nitrogen peak on the chromatogram, otherwise the excess carbon monoxide produced from oxygen in the chondrites would have overlapped the nitrogen peak. The remaining combustion products were collected in a molecular-sieve trap at liquid-nitrogen temperature. After the collection period, the trap was warmed, and the condensed gases were flushed into a gas chromatograph molecular-sieve column. As the gases were eluted from the column, they were detected in sequence as they passed over a thermal conductivity cell in the chromatograph. Nitrogen counts from an integrator were plotted against standard samples to obtain a calibration curve.

Studies of artificially prepared standards containing nitrogen as nitrides, ammoniacal ions, and nitrates, as well as standard NBS steels (National Bureau of Standards), with nitrides and dissolved nitrogen, indicated that complete extraction and detection was achieved for each sample. Eleven analyses of different NBS steels ranging in nitrogen content from 6.3 to 165 ppm gave an average percentage difference from the certified values of only 1.4 percent. Background values that were subtracted from individual analyses had a maximum of 5 ppm nitrogen. This background included atmospheric contamination and a combustion crucible blank.

The data obtained for the abundances of nitrogen in enstatite, olivine-bronzite (H), olivine-hypersthene (L) and (LL), and carbonaceous chondrites are given in Table 1. Replicate analyses on the same powdered meteorite sample provide an index of the reproducibility of the meteorite sample taken.

The problem of whether the trace nitrogen contents are inherent in the chondrites or whether the nitrogen has been added during the terrestrial life of the meteorite has been studied by a heating experiment. A powdered sample of the Richardton chondrite was heated at 110°C for 48 hours. An analysis of the heat-treated sample gave nitrogen values of 47 and 61 ppm compared to values of 48 and 58 ppm for the untreated sample. We interpret this to indicate that the nitrogen in chondrites recovered immediately after falling is firmly bound and not a loosely adsorbed contamination product.

Previous determinations of nitrogen in chondrites have been largely limited