AN INTERSTELLAR CLOUD WITH A HIGH CONCENTRATION OF CN MOLECULES

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ABSTRACT

A group of stars embedded in an emission nebula near the cluster NGC 7822 has been discovered to have a unique interstellar spectrum, characterized by exceedingly strong CN lines. Evidence is presented favoring the hypothesis that the CN molecules arise in the immediate neighborhood of the H II region boundary. It is further suggested that the CN molecules are formed in the solid particles of the H I region when flashed by the *UV* radiation in the advancing ionization front.

I. INTRODUCTION

The interstellar absorption lines due to the CN molecule have been observed only in a few bright stars, on spectrograms obtained on high-contrast emulsions with the highest spectral resolving powers available (Adams 1943, 1949). The intensity of the strongest CN line, $R(0)$ of the (0, 0) band in the $B^2\Sigma^+ \rightarrow X^2\Sigma^+$ system, at λ 3874.61 Å, as measured by Dunham (1941) in seven stars, does not exceed 7 mÅ in strength, while the $R(1)$ line at λ 3874.00 Å is between two and three times weaker and the $P(1)$ line is only marginally detected. The absorption lines due to interstellar CH and CH^+ are relatively stronger than those of CN and have been observed by Adams (1949) in the spectra of some sixty stars. It was actually on the basis of Adams' observations that their truly interstellar nature was established, dispelling some doubts raised earlier by Merrill (1942, 1946) as to whether the molecular lines should be regarded as circumstellar. The example of the Pleiades stars in particular, where the CH^+ lines are comparable in strength to those of Ca II, provided some support to Merrill's suggestion. The analysis of Adams' material by Bates and Spitzer (1951) showed that the Pleiades stars are not unique, since the CH^+ lines appear in unreddened stars of types B2–B5 more often than would be expected from the strength of their interstellar atomic lines. And on this basis the same authors advanced a hypothesis for the origin of the CH^+ ions, in terms of the sublimation of CH_4 from the interstellar solid particles, followed by dissociation and ionization, produced by the stellar radiation. While this same process does not account quantitatively for the observed CH concentration, Bates and Spitzer (1951) considered it highly probable that photochemical reactions involving the interstellar grains are also operating in the formation of CH.

It has been realized by several investigators that further understanding of the processes leading to the formation of interstellar molecules depends to some extent on the possibility of obtaining more observational data. In particular, the observation of very distant stars would provide information about the degree of uniformity in the relative concentration of interstellar molecules. The material gathered by the writer for studying the structure of the interstellar atomic lines in a galactic scale is a source of information in this respect. And, indeed, many of the spectrograms of several hundred stars so far obtained have been noticed to show the CH or CH^+ lines more or less conspicuously at the dispersions employed, 4.5 or 9 Å/mm. At a later date these observations will be discussed in detail. In this paper the unique case of a group of stars associated with an emission nebula in Cepheus showing CN lines, so strong as to be outstanding in the casual inspection of a spectrogram with 9.2 Å/mm dispersion, will be discussed. Only one other star (HD 202124, Sp 09.5 Ib, $V = 7.80$, $B - V = +0, 22$), among several hundred that have been inspected, has been found to show definitely the CN lines in a spectrum at 4.5 Å/mm.

II. THE OBSERVATIONS

The emission nebula we are going to consider has been identified by Sharpless (1959) with the number 171 in his catalogue and has been briefly described by Osterbrock (1957) who fixes its distance as 900 pc. It consists of a bright central region roughly circular, with diameter around 15 pc, surrounded to the North by an arc with radius near 35 pc. The "comet-tail" structure appearing in the arc, pointing to the central region, suggests that quite likely we are dealing with a single emission complex of very large dimensions. The central part appears to be overlaid by heavy obscuration, apparently taking place at the very boundaries of the H II region, since it also shows several bright rims and "comet-tails" that can be seen in the *Palomar Sky Survey* E-plate No. 555. A list of

TABLE 1

HELIOCENTRIC RADIAL VELOCITIES (km/sec) OF THE INTERSTELLAR ABSORPTION LINES IN STARS NEAR NGC 7822

STAR	PLATE	Ca^+	CH*	CN†						He I λ 3889
				$R(1)$	$R(0)$	$P(1)$	$P(2)$	$P(3)$	Mean	
+66°1675.....	Pc6006	−15.3	−22.0	−17.6	−16.4	−24:	....	....	....	−16:
	Pc6131	−15.0	−20.8	−23.1	−17.6	−21:	....	....	−18.8	−18.7
+66°1661.....	Pc6992	−16.6	−21.1	−19.9	−16.6	....	....	....	−17.7	....
+66°1674.....	Pc7517	−18.1	−16:	....	....	....	....	....	....	....
	Pc7520	−17.2	−17.6	−14:	−17.4	−15.7	−16.5	−14:	−16.8	....
HD 224938....	Pb6996	−10.8	....	....	....	....	....	....	....	....

* CH: Adopted rest wavelength λ 4300.325 Å.

† CN: Adopted rest wavelengths: $R(0)$ λ 3874.61 Å, $R(1)$ λ 3874.00 Å, $P(1)$ λ 3875.77 Å, $P(2)$ λ 3876.30, $P(3)$ λ 3876.84 Å (Jenkins and Wooldridge 1937). The mean radial velocity was derived by giving double weight to the $R(0)$ line and disregarding values indicated by a colon as uncertain. The spectrogram Pc6006 was given only half-weight with respect to Pc6131.

stars probably associated with the emission nebula Sh171 has been published by Blanco and Williams (1959). The main source of excitation of Sh171 apparently is BD+66°1675 (Sp O7, $V = 9.05$, $B - V = +1.09$), a star which was observed in the course of a survey of interstellar absorption lines in stars associated with H II regions. The inspection of the first spectrogram obtained for this star revealed the presence of two well-marked lines near the positions expected for $R(0)$ and $R(1)$ of CN at λλ 3874.61 and 3874.00, besides the lines of Ca^+ and CH λ 4300. The line He I λ 3888.65, produced by absorption of the nebular material, is also present and proves that unquestionably the star is well embedded in the nebula (Münch and Wilson 1962). The measurement of wavelengths in two spectrograms of this star leads to the radial velocities given in Table 1. The equivalent width of the K-line is 260 mÅ and the Ca^+ doublet ratio is 1.30. The intensity of the $R(0)$ line of CN is 80 mÅ and that of CH λ 4300 is only about half as much. The CN absorption is thus an order of magnitude larger than in any other star heretofore known, and evidently is produced in a region with unusually high density of CN molecules. In order to establish the likely location along the line of sight of such a region, we have observed additional stars in directions near that of +66°1675, which might also be involved in the emission nebula Sh171.

The bright star HD 224938 (HD Sp B9, $V = 7.30$), at a distance of about 1° almost

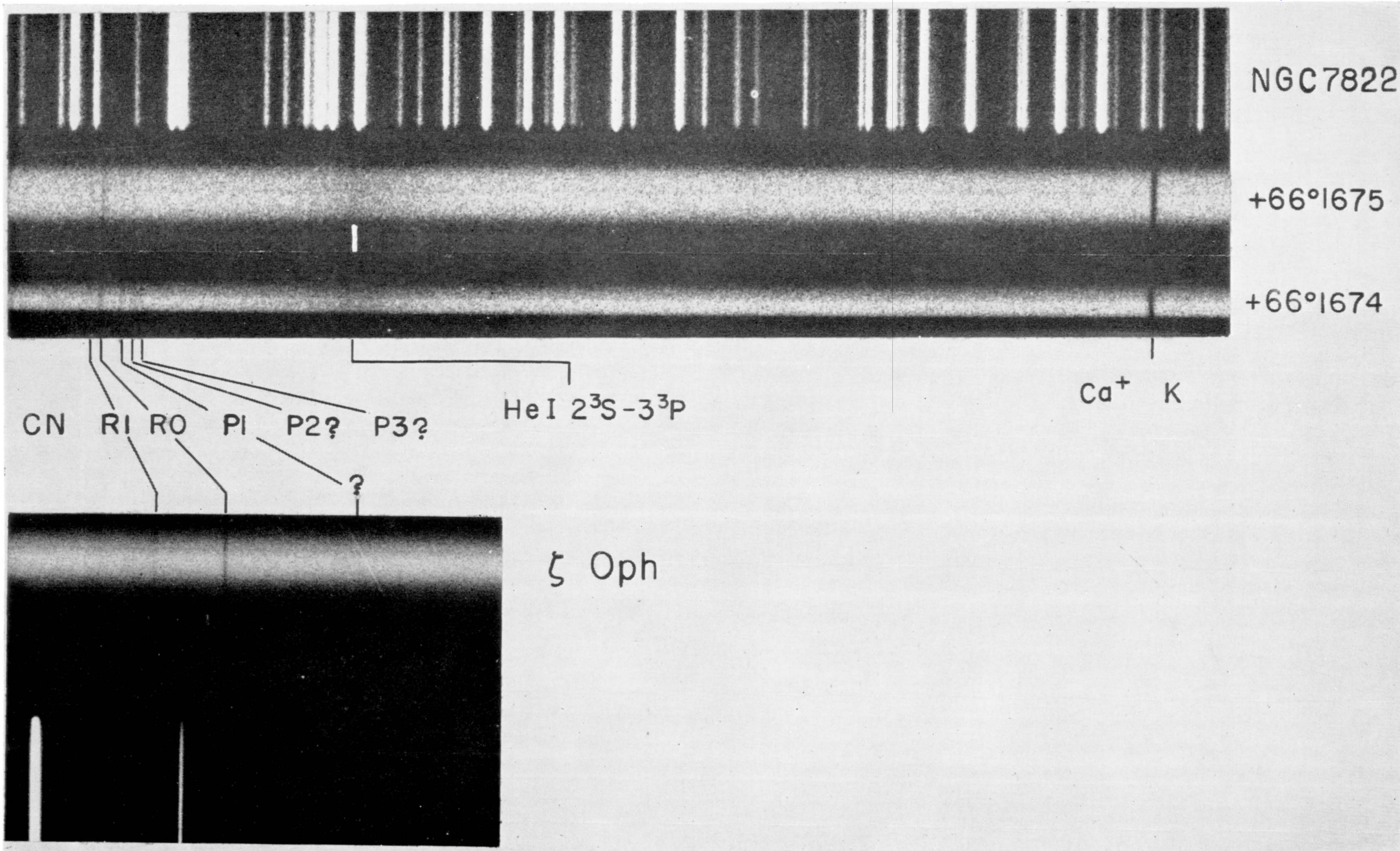

FIG. 1.—The interstellar absorption lines of CN and K of Ca^+ in the spectrum of two stars embedded in the emission nebula Sh171, near NGC 7822. The original spectrograms have a dispersion of 9.2 Å/mm. The lower spectrum is that of ζ Oph in the region of the CN lines, obtained with the Mount Wilson coudé spectrograph at 1.1 Å/mm.

due south from +66°1675 is erroneously given by Sharpless (1959) as possible source of excitation for Sh171. A 4.5 Å/mm spectrogram shows only interstellar Ca^+, with a shift considerably less than that measured in +66°1675, and with an equivalent width for K near 120 mÅ. On the further basis of its spectral type it seems that the distance of this object from the Sun is less than 200 pc.

The star +66°1661 (Sp 09.5, $V = 8.72$, $B - V = +0.81$) appears at a distance of 27′ in position angle 287° from +66°1675. Its spectroscopic distance modulus would place it nearly at the adopted distance of Sh171. Although the nebular absorption line of He I is not visible in its spectrum, it appears highly probable that both stars belong to the same association. Its spectrum shows the interstellar CN lines somewhat weaker than +66°1675 besides those of Ca^+ and CH λ 4300.

The O-type star +66°1674 is about half a magnitude fainter than, and is located 1′ south of, +66°1675, in what appears to be a rather compact cluster. A 9.2 Å/mm spectrogram of this fainter star, reproduced in Figure 1, shows the $R(0)$ line as conspicuously or more so than +66°1675 does. The $P(1)$ line is very clearly present, and immediately redward two more lines are distinctly seen, the positions of which agree, within the errors of measurement, with those of the $P(2)$ and $P(3)$ lines of the same CN band, as shown by the Doppler shifts given in Table 1. There is little question about the reality of these lines, although their identification is made uncertain by the absence in this particular spectrogram of the corresponding $R(2)$ and $R(3)$ lines, which should be in the intensity ratios $\frac{3}{2}$ and $\frac{4}{3}$ to the corresponding P-lines if unsaturated. The possibility of an accidental complexion of plate grain obliterating the $R(2)$ and $R(3)$ lines cannot at present be discounted. Another spectrogram, twice as broad as Pc7520, will be obtained to settle the question, when the appropriate conditions to make a 6–8-hour exposure with the 200-inch coudé are encountered.

III. DISCUSSION

The simple observation of strong CN interstellar lines in only three stars associated with an emission nebula showing signs of interaction with surrounding H I material suggests the possibility that the molecules are somehow related to the interaction process, and that they are thus located in the immediate neighborhood of the H II region. Examples of stars associated with emission nebulae and showing strong molecular lines are known, although it is not possible in most cases to locate precisely where along the line of sight the molecular absorption takes place. The star AE Aur, associated with an emission nebula (IC 405) which shows areas with a reflection spectrum (Herbig 1958), has very strong CH and CH^+ lines. The star ζ Oph, where most of the molecular lines have in fact been discovered, has a Strömgren sphere around it upon which several dark filaments are seen (Sharpless and Osterbrock 1952; Morgan, Strömgren, and Johnson 1955). In this case, however, it might well be the case that the molecular lines arise in the extended dark nebula covering the late B-type stars ρ Oph and χ Oph, which also have strong interstellar molecular lines. We have, on the other hand, the outstanding example of the Orion Nebula, obviously interacting with surrounding H I material, but where no stars are found with any molecular lines. The relation of molecular lines with reflection nebulae was made apparent by the case of the Pleiades. But, as in the case of emission nebulae, it is not true in general, as the case of the star HD 200775, associated with the brightest of all reflection nebula (NGC 7023), shows. In order to understand the observed relationship between molecular absorption and the dust and gas surrounding reflection emission and reflection nebulae, account will have to be taken of the finite lifetimes of the molecules. The lifetime of one CH molecule against photodissociation by a black body at 10000° K, diluted by a factor of 3×10^{-15}, for example, is only 2000 years (Bates and Spitzer 1951). In general, however, the reaction rates of the various processes determining the lifetimes are very poorly known, and the geometric factors entering into particular situations would be difficult to specify. It is of interest to emphasize, nevertheless, that the suggested association of the CN molecules observed in the stars embedded in Sh171 with the H I material surrounding the nebula has some antecedents.

The Doppler shifts of the interstellar lines given in Table 1 provide some specific evidence in favor of the idea that they originate in a volume near to the emission region. Applying a correction for solar motion of +7.5 km/sec, with a value $A = 15$ km/sec kpc for Oort's constant (Kraft and Schmidt 1963), we find that the mean shift of the Ca^+ lines in the stars +66°1661 and +66°1675 corresponds to the galactic rotation of a point at a distance of 0.7 kpc, while that of the molecular lines results close to 0.9 kpc. The small difference in radial velocity between the CH and CN lines in these two stars would appear significant, when the probable errors involved in the measurements are considered. It may well be the case, then, that the two radicals are not coexistent or coeval. In the star +66°1674 the Doppler shifts of the molecular lines do not result as large as in the other two stars. Whether the effect is due to the lower quality of the spectrogram on which they were measured, or is a result of high turbulence in the H II region boundary, will be settled by future observations. It can be noticed, further, that in all cases the Doppler shifts of the Ca^+ lines are somewhat larger in absolute value than would be expected for a uniform density distribution along the line of sight. The net radial velocities of the Ca^+ components arising through the whole Orion spiral arm, observed in a few distant stars at galactic longitudes l^{II} in the range 116°–119° (Münch 1957), appear also somewhat smaller than those observed in stars of Sh171. Considering, further, that this cluster is about 100 pc from the galactic plane, it appears plausible that the shift of the Ca^+ in the stars under discussion results from an appreciable concentration of H I gas near to the emission nebula. Observations of the 21-cm line in this direction would be helpful to settle this question firmly. One final argument can be given in favor of the idea that the CN (and the CH) lines observed in the stars of NGC 7822 arise near the H II regions boundary: the close agreement of their radial velocity with that of the He I absorption line 2^3S–3^3P observed in +66°1675. It is known that the He I absorption-line components observed in the stars embedded in the Orion nebula are mostly displaced to the violet with respect to the surrounding H I gas (Wilson, Münch, Flather, and Coffeen 1959), and only one star (θ^1Ori D) shows a nearly undisplaced component. In six stars associated with the M8–M20 complex, the He I absorption is shifted to the violet of the Ca^+ lines by amounts between 2 and 8 km/sec (Münch 1964). A few other emission nebulae producing He I absorption are known also to be expanding around the exciting stars, but a case with motion in the opposite sense is yet to be discovered. Because of the sign of the galactic rotation shift in this direction, then, the near equality of the radial velocities of the molecular and He I absorption lines observed in +66°1675 indicates that the CN lines arise in the immediate neighborhood of the H II region.

The impossibility of forming the interstellar molecules by two-body radiative association in the observed concentrations has been long realized. The hypothesis of Bates and Spitzer (1951) explaining the presence of CH^+ and possibly also of CH, in unreddened B-type stars, removed the difficulty for these two molecules. Now, on the basis of our preceding discussion we wish to put forward the hypothesis that the interstellar CN molecules are found and originate in dust-rich complexes. Unlike the case of CH^+, however, we cannot ascribe its origin to the sublimation and subsequent dissociation of a stable parent molecule present in the grains. The abundant constituents of the grains should be CH_4, NH_3, and H_2O, and once the stable parent molecule is sublimated the chances of forming CN become vanishingly small. Might it not be the case, then, that the CN is formed in the grains upon being flashed by an ionization-pressure front advancing into the cool medium? Observation in the laboratory of radicals formed in solid inert matrices when exposed to *UV*-, *X*-, or γ-radiation (Pimentel 1960) raises this interesting question. Evidently an answer could be obtained only on the basis of laboratory experiments, as has been emphasized by Donn (1960), who has also suggested that free radicals can be trapped in solid cosmic particles.

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