The relation between CH and CN molecules and carriers of 5780 and 5797 diffuse interstellar bands

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ABSTRACT

Optical absorption bands of the interstellar CN (near 3875 Å) and CH molecules (the violet and blue ones near 4300 and 3886 Å, respectively) were applied to determine the column densities of these two radicals in a statistically meaningful sample of 84 reddened OB stars. Equivalent widths of the major 5780 and 5797 diffuse bands (DIBs) were measured along the lines of sight toward the same stars in spectra acquired using four echelle spectrographs situated in both the northern and southern hemispheres. The mutual relation between abundances of CH and CN molecules shows a large scatter; and especially the CN molecule abundance varies strongly from cloud to cloud. The carriers of the major 5780 and 5797 DIBs seem to be spatially correlated with column densities of CH rather than of the CN molecule. This is most likely true in the case of a narrower feature: the 5797 DIB correlates with CH column density better than 5780 does. The correlations do suggest that the DIB carriers are likely hydrocarbons. They apparently occupy molecular clouds since the H₂ abundance is closely related to that of methylidyne (CH), as has already been demonstrated.

Key words. ISM: molecules

Introduction

The diffuse interstellar bands (DIBs) remain unidentified since the discovery by Heger (1922) of two DIBs centered near 5780 and 5797 Å. Until now, more than 300 DIBs have been detected in spectra of reddened OB stars (Galazutdinov et al. 2000; Weselak et al. 2000). The same spectra usually contain interstellar CH and CN radicals as shown more than 60 years ago by McKellar (1940a,b). He identified the features of the CH A-X system (near 4300 Å), as well as B-X and C-X systems centered near 3886 and 3140 Å, respectively. The CN R(0) line at 3874 Å was also identified in the same paper (see also Swings & Rosenfeld 1937).

During the past 20 years it has been shown that DIB intensity ratios vary from cloud to cloud and their ratios seem to be related to the strengths of the spectral features of CH and CN molecules (Krełowski et al. 1992). The observed relations of strong DIBs to $E(B - V)$ seem quite tight, but there is evident scatter, which is not of instrumental origin. These relations reflect the different physical parameters of individual clouds (Krełowski et al. 1999). However, most of the collected samples, like those by Federman et al. (1994), are reasonably scarce. This may create an additional scatter in the datasets created by means of compilation. In certain cases the compiled column densities of the CH molecule, given in the paper by Welty & Hobbs (2001), differ from those available at the website <http://astro.uchicago.edu/home/web/welty/\coldens.html>, and this even happened to HD 23180 (o Per), which is a very popularly observed target.

Such disagreements motivate new research, based on statistically meaningful samples of spectra – sets of homogeneous measurements, not on compilations alone. It seems important to relate DIB strengths to the column densities of CN and CH molecules as DIBs are now commonly believed to be carried by some complex molecules (Fulara & Krełowski 2000). Methylidyne (CH) is closely related to the hydrogen molecule (H₂) as already shown by Mattila (1986) and Weselak et al. (2004). Contrary to this spatial relations between column densities of CH cation and molecular hydrogen show large scatter suggesting no relation between abundances of CH⁺ and H₂ (Weselak et al. 2008).

The molecular origin of at least some DIBs seems probable because of the complexity of the profiles of these fascinating features. Evident substructures have been demonstrated in profiles of 6614 and 5797 DIBs by Sarre et al. (1995) and by Kerr et al. (1998). The same substructures have also been found in ultra-high resolution spectra by Galazutdinov et al. (2003) and by Walker et al. (2000). Observed central wavelengths of DIBs may not be constant. Krełowski & Greenberg (1999) found red-shifted DIBs (in relation to atomic lines) in some objects belonging to Ori OB1 association. On the other hand, a blue-shift was found in the spectrum of AE Aur (HD 34078) star (Galazutdinov et al. 2006). It is to be emphasized, however, that such cases are very uncommon. A close relation between any of the DIBs and any of the identified molecular features may facilitate e.g. a determination of a DIB rest wavelength. Moreover, by relating DIB strengths to column densities of known simple molecular

species, one can try to answer the question of whether DIBs are carried by hydrocarbon species or instead by cyanogens.

It also seems important to check whether the abundance ratio of the well-known simplest interstellar molecules is constant or if it shows substantial variations. The latter case may demonstrate various physical properties for translucent interstellar clouds. It is interesting to know whether interstellar molecules are formed and maintained in the same abundance ratios.

The observational data

Our observational material, listed in Table 1, was obtained during many observing runs between 1999 and 2007 using four Coudé échelle spectrographs:

- The first of them is the MAESTRO fed by the 2-m telescope of the Observatory at Peak Terskol (t) in the Northern Caucasus (Musaev et al. 1999), see also <http://www.terkskol.com/telescopes/3-camera.htm>. The spectrometer is equipped with a Wright Instruments CCD 1242×1152 matrix (pixel size $22.5 \mu\text{m} \times 22.5 \mu\text{m}$) camera. The instrument forms échelle spectra that cover the range from 3500 to 10 100 Å, divided into up to 92 orders. The existing set of gratings and cameras allows several resolutions: from $R = 45\,000$ through 80 000 to 120 000. In this project we used the $R = 80\,000$ resolution as a compromise, because it allows discrepancies to be seen in the profiles of single Gaussians and also relatively heavily reddened stars to be observed.
- The second one, covering the southern hemisphere, is the FEROS spectrograph (f), fed with the 2.2 m ESO telescope (see- <http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/FEROS/>). The resolution of these spectra, covering the southern hemisphere, is constant ($R = 48\,000$). This instrument can record the whole available spectral range ($\sim 3700\text{--}9200$ Å, divided into 37 orders) in a single exposure. The flatfielding can be done very precisely in the case of FEROS as it is the fiber-fed spectrograph. Even though this is not of basic importance while measuring EW s (equivalent widths) of reasonably narrow features, it may be important in cases of reasonably broad DIBs.
- The most recent observations were carried out using the fiber-fed échelle spectrograph installed at the 1.8-m telescope of the Bohyunsan Optical Astronomy Observatory (BOAO) in South Korea (b). The spectrograph has three observational modes providing a resolving power of 30 000, 45 000, and 90 000. In all the cases it allows recording of the whole spectral range from ~ 3500 to $\sim 10\,000$ Å divided into 75–76 spectral orders. We used the highest resolution mode in our project.
- The spectra of 10 objects were obtained with the HARPS spectrometer (H), fed with the 3.6 m ESO telescope in Chile (see <http://www.ls.eso.org/lasilla/sciops/3p6/harps/>). This spectrograph allows coverage of the range $\sim 3800\text{--}6900$ Å with resolution of $R = 115\,000$. As the instrument designed to search for exoplanets, it guarantees very precise wavelength measurements.

All the spectra were reduced with the standard packages: MIDAS and IRAF, as well as our own DECH code (Galazutdinov 1992), which provides all the standard procedures image and spectra processing. Using different computer codes to the data reduction procedures reduces the possibility of inaccuracies following the slightly different ways of dark subtraction, flatfielding, or excision of cosmic ray hits.

Fig. 1. The 5780 and 5797 diffuse bands in the spectrum of the heavily reddened star HD 168607 (*the top panel*). The dots mark the continuum level used to measure the equivalent widths of 5780 and 5797 DIBs blended with broad ones: 5778 and 5795. We also compare our DIB equivalent width measurements with those of Herbig (1993) in the case of 5780 (*middle panel*) and 5797 (*bottom*).

For this project we selected the sample of 84 reddened OB stars, with both CN and CH features detected in all these targets. Table 1 presents the HD number, spectral type, and luminosity class, as well as the $E(B - V)$ color excess for each star, EW s (in mÅ) of CN and CH molecular features, calculated column densities (in 10^{12} cm^{-2}), and EW s of diffuse 5797 and 5780 bands with errors in brackets. Column densities of CN and CH molecules were obtained on the basis of f -values published by Gredel et al. (1993) in the case of the CH molecule, and Roth & Meyer (1995) (CN). We also designate the lines of sight with $EW_{\text{CN}} > 14 \text{ mÅ}^a$ and $EW_{\text{CH}} > 20 \text{ mÅ}^b$ (since such strong lines may be saturated). The $E(B - V)$ s were estimated on the basis of the average color indices currently available in the SIMBAD database and the intrinsic colour indices published by Papaj et al. (1993).

Figure 1 presents 5780 and 5797 DIBs in the spectrum of the most heavily reddened star (HD 168607) of our sample. The broader one may be considered as a part of the broad 5778

Table 1. Observational and measurement data. Given are: star name (observed at t – Terskol (Russia), f – FEROS, H – HARPS La Silla (Chile), b – Bohyunsan (S. Korea), spectral and luminosity class, reddening, EW s (in mÅ) of CN and CH molecules, their calculated column densities (in 10^{12} cm $^{-2}$), and EW s (in mÅ) of diffuse 5797 and 5780 bands with errors in each bracket. We also designate the lines of sight with $EW_{\text{CN}} > 14$ mÅ a and $EW_{\text{CH}} > 20$ mÅ b . With symbol: we mark lines of sight with uncertain column density of CN molecule based on measurements of R(0) line and uncertain column densities of CH molecule based on measurements of saturated CH A-X band at 4300 Å. In the case of the 5797 DIB blended with the stellar C IV 5801.313 Å line we avoid the EW measurement as being very uncertain (bl).

HD Sp	$E(B - V)$	CN(R1)	CN(R0)	CN(P1)	CH(3886)	CH(3890)	CH(4300)	$N(\text{CN})$	$N(\text{CH})$	$EW(5780)$	$EW(5797)$
12953 f A1Iae	0.60	12.8(0.5)	28.5(1.5)	6.2(0.7)			13.5(1.3)	16.53(0.50) a	16.30(1.57)	221(3.9)	58.3(1.7)
13854 f B1Iabe	0.47		3.1(1.1)				17.3(1.2)	0.68(0.24):	20.89(1.45)	270(5.3)	75.9(2.0)
14143 f B2Ia	0.68	3.6(0.7)	13.0(0.6)	1.5(0.2)			17.1(1.3)	4.05(0.36)	20.65(1.57)	291(5.4)	92.8(2.9)
20041 f A0Ia	0.69	2.5(0.2)	12.1(0.9)	1.8(0.3)	5.2(0.2)		21.7(0.4)	3.49(0.26)	26.21(0.48)	397(7.7)	106(3.0)
21291 f B9Ia	0.41	2.6(0.2)	8.4(0.2)	1.6(0.3)	4.1(0.8)		17.0(0.3)	2.67(0.11)	20.53(0.36)	178(5.1)	60.5(1.5)
23180 b B1III	0.27	1.7(0.2)	5.7(0.4)	1.2(0.1)	4.2(0.3)	3.7(0.2)	15.0(0.2)	1.82(0.15)	18.11(0.24)	90.6(1.5)	66.2(1.9)
24398 b B1Iab	0.29	2.9(0.1)	10.0(0.5)	1.6(0.1)	4.3(0.2)	2.8(0.2)	15.8(0.2)	3.16(0.14)	19.08(0.24)	99.0(1.9)	58.4(1.7)
24534 f O9.5pe	0.56	7.8(0.6)	16.1(1.0)	4.6(0.4)	8.1(0.8)	5.5(0.3)	24.6(0.5)	7.53(0.42) a	38.49(0.60) b	84.2(1.7)	59.2(1.8)
25638 f B0III	0.66		1.0(0.2)		9.5(0.3)		26.0(3.0)	0.22(0.04):	31.40(3.62)	287(4.7)	122(3.5)
27778 b B3V	0.37	12.4(0.3)	32.6(0.7)	7.1(0.5)	7.7(0.9)	5.1(0.6)	23.3(0.3)	20.75(0.25) a	36.14(0.36) b	90.8(1.6)	43.2(1.1)
34078 f O9.5Ve	0.49	2.8(0.3)	5.8(0.1)	1.5(0.1)	16.2(0.3)	10.6(0.2)	50.3(1.8)	2.20(0.21)	75.80(2.17) b	175(3.6)	55.3(1.7)
45314 f O9:pe	0.43	2.3(0.2)	6.5(0.3)	1.8(0.1)	4.1(0.1)		13.7(2.0)	2.19(0.13)	16.54(2.41)	185(3.5)	59.1(1.9)
46150 f O6e	0.46	1.7(0.3)	3.9(0.3)	0.8(0.1)	3.2(0.1)	2.3(0.1)	12.1(0.7)	1.42(0.17)	14.61(0.85)	342(6.8)	101(2.9)
46223 f O5e	0.48	1.2(0.2)	4.7(0.4)	0.8(0.1)	7.4(0.2)	5.2(0.2)	18.6(1.0)	1.43(0.15)	22.46(1.21)	347(7.1)	116(3.4)
46573 f O7	0.63	2.6(0.3)	9.7(0.5)	1.0(0.1)	7.5(0.4)	5.5(0.3)	28.1(1.7)	2.99(0.21)	37.09(2.05) b	329(6.2)	152(4.3)
47432 f O9.5III	0.42		1.5(0.1)		2.5(0.2)	1.5(0.2)	9.7(0.5)	0.33(0.02):	11.71(0.60)	199(3.7)	53.6(1.5)
48434 f B0III	0.21	2.3(0.1)	5.5(0.3)	1.3(0.1)	2.3(0.2)	1.5(0.2)	8.4(0.2)	1.97(0.10)	10.14(0.24)	114(2.3)	38.2(1.2)
75149 f B3Ia	0.39	1.3(0.2)	3.8(0.3)	0.7(0.1)	4.3(0.2)	3.0(0.5)	14.7(0.4)	1.27(0.13)	17.75(0.48)	224(4.0)	50.9(1.4)
80558 f B6Iae	0.60	2.2(0.3)	7.1(0.3)	1.2(0.1)	6.7(0.2)	3.8(0.2)	19.2(0.5)	2.29(0.17)	23.19(0.60)	393(7.3)	132(3.8)
93130 f O6	0.56		2.5(0.4)				9.3(0.3)	0.55(0.09):	11.23(0.36)	252(5.0)	bl
94367 f B9Ia	0.17		0.9(0.1)				3.3(0.3)	0.20(0.02):	3.99(0.36)	107(2.5)	27.0(1.1)
99264 f B2IV-V	0.27		0.5(0.1)				5.5(0.3)	0.11(0.02):	6.64(0.36)	184(3.4)	26.9(0.6)
99872 f B3V	0.34		3.1(0.2)		2.6(0.2)	1.7(0.1)	10.8(0.9)	0.68(0.04):	13.04(1.09)	174(3.2)	30.9(0.8)
101191 f O8	0.37		4.0(0.1)				7.8(0.5)	0.88(0.02):	9.42(0.60)	194(2.9)	51.0(1.2)
101205 f O8V	0.33		2.6(0.1)		2.2(0.3)	0.9(0.3)	6.6(0.3)	0.57(0.02):	7.97(0.35)	183(3.1)	bl
101223 f O7	0.45	6.1(0.2)	18.5(0.8)	3.7(0.2)	4.1(0.3)		13.5(0.7)	8.04(0.24) a	16.30(0.85)	193(2.7)	47.8(1.3)
104841 f B2IV	0.09		0.5(0.1)				2.9(0.2)	0.11(0.02):	3.50(0.24)	48.6(0.6)	10.4(1.2)
110432 f B2pe	0.48	2.1(0.3)	5.3(0.3)	1.4(0.2)	3.5(0.2)	1.5(0.1)	12.1(0.4)	1.86(0.17)	14.61(0.48)	136(2.5)	34.7(1.0)
116072 f B2.5Vn	0.21	1.1(0.2)	2.4(0.3)		1.8(0.2)	0.8(0.2)	6.8(0.3)	0.89(0.13)	8.21(0.36)	101(1.0)	16.1(0.5)
141637 f B1.5V	0.16		0.5(0.1)				1.3(0.1)	0.11(0.02):	1.57(0.12)	75.6(1.2)	10.9(0.3)
147165 H B1III	0.34		0.17(0.01)		0.8(0.2)		2.9(0.1)	0.04(0.005):	3.50(0.12)	241(4.0)	34.3(1.0)
147888 f B3/B4V	0.46	2.2(0.3)	6.5(0.4)	1.0(0.1)	5.4(0.2)	3.5(0.3)	17.5(0.5)	2.16(0.19)	21.13(0.60)	238(5.5)	56.0(1.6)
147889 H B2III/IV	1.00	17.4(0.9)	30.0(1.2)	9.1(0.5)	20.2(0.3)	15.1(0.5)	50.2(1.7)	21.87(0.56) a	100.9(2.48) b	370(4.7)	152(4.3)
147932 f B5V	0.47	7.2(0.8)	14.8(0.5)	4.0(0.3)	6.4(0.2)	3.8(0.5)	15.9(0.5)	6.78(0.37) a	19.20(0.58)	222(7.0)	57.5(1.3)
147934 H B2V	0.45	2.22(0.05)	6.47(0.2)	1.31(0.05)	5.50(0.08)	4.22(0.2)	17.86(1.2)	2.16(0.26)	21.57(0.48)	207(4.0)	51.0(1.4)
148184 H B2Vne	0.48	1.6(0.1)	3.7(0.1)	0.6(0.1)	7.2(0.2)	5.2(0.2)	23.7(0.2)	1.36(0.09)	35.32(0.24) b	101(2.1)	46.7(1.4)
148379 f B2Iab	0.77	0.5(0.2)	1.8(0.1)		3.3(0.2)		15.0(0.5)	0.56(0.09)	18.11(0.60)	413(9.0)	90.6(2.6)
148688 f B1Ia	0.52	0.3(0.1)	1.4(0.2)		3.6(0.2)	2.7(0.2)	14.2(0.6)	0.41(0.08)	17.15(0.70)	343(9.0)	85.2(2.5)
148937 f O6e	0.61	2.5(0.2)	9.2(0.3)	1.3(0.2)	5.0(0.2)		16.2(0.6)	2.85(0.13)	19.56(0.72)	353(6.8)	bl
149404 f O9Ia	0.71	2.5(0.4)	8.7(0.8)	1.0(0.2)	5.7(0.1)	3.2(0.1)	22.5(0.9)	2.74(0.31)	27.17(1.09)	389(7.3)	bl
149757 H O9.5V	0.28	2.7(0.3)	8.2(0.3)	1.4(0.13)	5.5(0.2)	3.6(0.1)	18.5(0.1)	2.75(0.17)	22.34(0.12)	78.9(1.1)	31.4(0.9)
150136 f O5	0.42		1.6(0.1)				9.6(0.3)	0.35(0.02):	11.59(0.35)	232(4.2)	48.2(1.5)
150168 f B1Iab/Ib	0.16		1.5(0.1)		2.4(0.1)	1.1(0.1)	8.5(0.2)	0.33(0.02):	10.26(0.23)	107(1.9)	29.3(0.8)
152076 f B0.5III	0.43		7.9(0.3)		4.6(0.3)	3.0(0.3)	17.9(0.4)	1.74(0.07):	21.62(0.48)	183(3.2)	67.8(1.9)
152218 f O9V	0.45	1.5(0.2)	4.1(0.4)	0.9(0.2)	4.5(0.2)	3.3(0.3)	16.5(0.6)	1.40(0.15)	19.93(0.72)	181(3.1)	73.9(1.9)
152219 f O9IV	0.44		1.0(0.2)		1.8(0.2)	1.1(0.2)	10.7(0.5)	0.22(0.04):	12.92(0.59)	239(4.4)	53.5(1.7)
152233 H O6III	0.42	0.61(0.04)	1.60(0.06)		3.30(0.07)	1.71(0.05)	13.07(0.10)	0.55(0.03)	15.78(0.24)	225(3.6)	bl
152234 f B0.5Ia	0.40	0.7(0.1)	2.0(0.2)	0.3(0.1)	1.9(0.2)	1.3(0.1)	12.8(0.3)	0.67(0.08)	15.46(0.35)	233(3.3)	65.6(2.0)
152235 H B0.7Ia	0.78	1.5(0.3)	3.5(0.2)	0.6(0.1)	8.9(0.4)	6.2(0.2)	30.2(0.7)	1.27(0.14)	42.85(1.65) b	384(7.5)	95.0(3.1)
152236 f B1Iape	0.65	2.1(0.3)	8.3(0.3)	1.0(0.1)	5.0(0.4)	2.7(0.4)	22.1(0.5)	2.52(0.17)	26.69(0.61)	349(7.0)	111(3.2)
152246 f O9Ib	0.44	0.9(0.1)	1.6(0.2)	0.5(0.1)	4.6(0.2)	2.3(0.2)	14.7(0.5)	0.65(0.08)	17.75(0.58)	227(3.9)	bl
152249 H O9Ib	0.48	1.0(0.2)	1.8(0.1)	0.5(0.1)	3.4(0.2)	2.4(0.3)	11.5(0.2)	0.73(0.09)	13.89(0.24)	242(3.8)	bl
152314 f B0.5Iab	0.39	1.5(0.2)	3.2(0.2)	0.8(0.2)	5.5(0.2)	4.2(0.2)	16.2(0.5)	1.20(0.11)	19.56(0.60)	257(4.1)	bl
152667 f B0.5Iae	0.47	2.4(0.2)	5.9(0.4)	1.8(0.3)	4.8(0.1)	3.7(0.1)	15.4(0.5)	2.09(0.15)	18.60(0.59)	300(5.6)	78.5(2.1)
154090 f B1Iae	0.45	8.5(0.3)	18.1(1.0)	4.5(0.3)	7.2(0.3)	5.8(0.3)	22.6(0.8)	8.65(0.32) a	37.46(1.77) b	143(2.7)	61.3(1.8)
154368 f O9.5Iab	0.73	16.2(0.5)	28.9(1.3)	11.3(0.7)	14.5(0.6)	10.3(0.6)	41.8(1.1)	20.03(0.45) a	70.52(1.33) b	218(4.2)	106.4(3.1)
154445 f B1V	0.35	1.4(0.2)	2.4(0.3)	0.8(0.2)	4.8(0.4)	3.8(0.5)	15.5(0.4)	0.99(0.13)	18.72(0.48)	192(3.9)	62.1(1.9)
163800 H O7	0.57	2.97(0.03)	9.56(0.02)	1.88(0.01)	7.1(0.02)	5.5(0.03)	22.2(0.7)	3.08(0.02)	36.16(0.94) b	256(2.0)	107(1.5)
164794 f O4V	0.33		2.0(0.2)				6.9(0.3)	0.44(0.04):	8.33(0.35)	154(2.3)	40.3(1.4)
165688 f WN	1.00	5.4(0.2)	15.7(0.5)		12.1(0.7)	7.0(0.9)	38.9(1.7)	6.57(0.18) a	46.98(2.05)	484(8.1)	150(4.2)

Table 1. continued.

HD Sp	$E(B - V)$	CN(R1)	CN(R0)	CN(P1)	CH(3886)	CH(3890)	CH(4300)	$N(\text{CN})$	$N(\text{CH})$	$EW(5780)$	$EW(5797)$
166734 ^f O8e	1.38	4.5(0.1)	16.1(0.6)	2.5(0.3)	13.2(0.7)	9.0(1)	44.6(1.6)	6.44(0.17) ^a	53.86(1.93)	686(15.0)	249(8.0)
168075 ^f O7V	0.74	2.5(0.4)	6.6(0.5)				30.1(1.4)	2.28(0.24)	36.35(1.69)	465(8.1)	194(6.1)
168137 ^f O8.5V	0.68	4.7(0.6)	14.2(0.6)				21.6(1.5)	5.73(0.33) ^a	26.08(1.81)	478(8.6)	152(4.4)
168607 ^f B9Ia	1.55	5.2(0.2)	11.1(0.6)	3.5(0.3)	16.0(1.0)	7.9(0.7)	50.4(1.8)	4.16(0.20)	60.86(2.17)	807(15.6)	249(9.0)
168625 ^f B6Ia	1.52		5.0(0.3)		13.8(0.4)	7.0(0.2)	42.7(1.7)	1.10(0.07):	57.15(2.05) ^b	810(17.0)	216(6.3)
179406 ^H B3V	0.31	3.51(0.2)	11.7(0.5)	1.74(0.03)	4.18(0.1)	2.81(0.1)	14.1(1.7)	3.73(0.18)	17.03(2.05)	164(3.1)	66.0(3.0)
184915 ^t B0.5III	0.19	0.5(0.3)	1.0(0.2)		2.0(0.5)		5.5(0.4)	0.39(0.14)	6.64(0.48)	153(2.8)	25.0(0.7)
190603 ^t B1.5Iae	0.71		1.0(0.2)				11.2(0.4)	0.22(0.04):	13.53(0.48)	357(7.1)	86.7(3.0)
203064 ^t O8V	0.25		1.15(0.2)		2.9(0.4)	1.8(0.1)	9.2(0.3)	0.25(0.04):	11.11(0.36)	170(3.4)	bl
203938 ^t B0.5IV	0.70	3.8(0.2)	14.6(0.5)		9.2(1.5)		28.6(0.1)	5.58(0.18) ^a	36.44(2.48):	320(6.4)	117(3.5)
204827 ^b B0V	1.06	30.5(1.0)	64.0(2.5)	17.7(0.9)	19.6(0.6)	13.4(0.4)	60.7(1.8)	34.00(0.88) ^a	73.30(2.82)	232(4.6)	165(5.0)
206165 ^t B2Ib	0.46	2.4(0.2)	6.9(0.6)	1.1(0.2)	5.3(0.2)	3.3(0.2)	20.2(1.0)	2.31(0.13)	24.39(1.21)	200(4.1)	80.4(2.3)
206267 ^t O6	0.49	7.8(0.3)	17.2(1.2)	4.0(0.2)	6.1(0.8)	3.5(0.3)	22.5(0.4)	8.02(0.36) ^a	27.17(0.48)	217(4.5)	88.8(3.0)
207198 ^t O9II	0.55	2.8(0.3)	15.3(1.3)	1.5(0.2)	11.7(0.3)	6.9(0.2)	29.2(0.4)	5.54(0.39) ^a	35.26(0.46)	237(4.8)	133(3.9)
207538 ^b B0V	0.59	3.9(0.3)	11.5(0.6)	2.0(0.4)	8.5(0.6)	6.9(0.8)	29.9(1.3)	3.82(0.23)	44.41(3.50) ^b	240(5.3)	164(4.7)
208501 ^t B8Ib	0.77	14.2(0.6)	29.4(2.3)	8.2(0.6)	10.9(0.3)	8.2(0.8)	37.5(1.9)	12.67(0.70) ^a	54.64(3.55) ^b	222(4.6)	99.2(3.7)
209481 ^t O9V	0.35		3.5(0.7)				7.5(1.0)	0.77(0.15):	9.06(1.21)	172(3.0)	52.0(2.9)
210839 ^t O6e	0.56	2.2(0.2)	8.8(0.4)		7.2(0.3)	4.6(0.4)	21.6(0.4)	2.66(0.15)	33.19(0.48) ^b	249(5.1)	bl
213087 ^t B0.5Ibe	0.56	2.0(0.3)	4.1(0.5)	1.0(0.2)	5.4(0.6)	4.5(0.5)	23.5(1.0)	1.56(0.21)	28.63(1.21) ^b	284(5.7)	72.5(2.1)
326331 ^f B	0.30	1.3(0.2)	2.7(0.3)		2.1(0.1)	1.2(0.2)	13.7(0.3)	1.02(0.13)	16.54(0.35)	222(3.5)	bl
BD-134927 ^f O7II	1.16	10.5(0.5)	19.8(0.8)	4.7(0.2)			44.5(2.0)	10.13(0.34) ^a	53.74(2.42)	499(8.9)	208(7.0)
BD-134930 ^f O9.5V	0.53		7.5(0.3)		10.0(1.0)	7.0(1.0)	36.9(1.7)	1.65(0.07):	48.27(2.05) ^b	412(7.2)	156(7.0)
CPD-417733 ^f O9III	0.49	0.5(0.1)	1.2(0.1)		2.8(0.2)	1.2(0.2)	11.0(0.6)	0.43(0.06)	13.28(0.72)	217(3.9)	bl
CPD-417735 ^f O9V	0.43		1.2(0.2)				10.9(0.6)	0.26(0.04):	13.16(0.72)	214(3.8)	62.8(1.8)

system, as already suggested by Krelowski et al. (1997). The narrower one is very likely blended with the broader but weaker 5795 Å DIB. The dots indicate the continuum level we used to obtain precise EW s of both 5780 and 5797 DIBs. This is a basic consideration as the literature data sometimes contain EW of 5797 measured as shown in Fig. 1 and sometimes – the blends of 5797 and 5795 together. We also compare our EW measurements of 5780 and 5797 DIB with those of Herbig (1993). In both cases the relation is very good, with a correlation coefficient equal to 0.99, as presented in the middle and bottom panels of Fig. 1.

We measured the EW s of the selected features in the spectra obtained using different instruments. Some of our targets have been observed several times, which facilitates an error estimate. If a target was observed just once, the features were measured several times to allow calculation of the average and standard deviation. We emphasize that it is more reliable to compare EW s (between different publications) than column densities as the latter depend on oscillator strengths used and the applied method of calculating. We compared our EW s with those available in the literature. Figure 2 presents the comparison of our EW measurements of the narrow A-X methylidyne band at 4300 Å with those of Megier et al. (2005). The agreement is very good with a correlation coefficient equal to 0.99. We also compare of our measurements of the CN 3874.6 Å feature with those of both Palazzi et al. (1992) and Federman et al. (1994). In this case, our results also agree very well with those published previously (correlation coefficient equal to 0.96).

Figure 3 presents the spectral regions of CN, CH, and KI lines, as seen in the spectra of four heavily reddened targets. In the case of HD 154368, 165688, and 166734, the additional Doppler components are easily seen in both the CH and KI profiles. The profile of KI in the spectrum of HD 204827 probably splits into two Doppler components. We would like to emphasize that all these components seen in KI and CH profiles should be measured for a precise column density calculation. The similarity of CH and KI profiles is also demonstrated in the paper

by Welty & Hobbs (2001), which is based on very high resolution spectra. Being stronger than any of the CH features, KI line may facilitate determination of the integration borders of those features. The presence of several Doppler components in an interstellar line greatly extends the linear relation between the EW and column density. This complicates precise determination of the latter. By using the linear relation one can avoid serious errors unless some optically thick cloud is present along the chosen sightline. On the other hand, an application of the procedure taking saturation into account to Doppler-split features may lead to underestimates of the column densities.

Results

Our observations cover a very broad range of $E(B - V)$ s: up to 1.55 in the case of HD 168607. High reddening may lead to saturation effects in some molecular features. In Table 1 we mark the lines of sight where saturation effects are likely to be present in CN and/or CH lines. In the case of spectral features that were unsaturated ($EW < 20$ mÅ for single CH components), the following relation were applied (van Dishoeck & Black 1989) to obtain the column density (in cm^{-2}):

$$N = 1.13 \times 10^{20} (EW/f\lambda^2),$$

where EW is equivalent width of the line, λ its wavelength (both in Å), and f its oscillator strength. In the case of CN features with $EW > 14$ mÅ, we used curve of growth method (Roth & Meyer 1995) with the Doppler parameter $b = 1 \text{ km s}^{-1}$. In the case of the only R(0) line seen in our spectra the calculated column density is uncertain as a result of R(0) transition. (In this case, R(1) line was not detected in our spectra.)

For the saturated CH band of the A-X system at 4300 Å, we used the sum of column densities determined with the unsaturated 3886 Å and 3890 Å lines of the B-X system (see Fig. 2 in publication of Lien 1984). Objects with a saturated CH line at 4300 Å are more numerous than those with a saturated CN line

Fig. 2. Our measurements of the equivalent widths of the CH A-X feature compared to the already published ones of Megier et al. (2005) (*top panel*). A similar comparison for the CN R(0) line at 3874 Å is given in the *lower panel*. Here the published data come from Palazzi et al. (1992) (circles) and Federman et al. (1994) (triangles). The (tight) correlation coefficients are shown in the plot.

observed in the spectrum (see Table 1). However, we have to emphasize that the observed interstellar features are composed in many cases of many Doppler components that, even if not resolved, make the lines unsaturated up to relatively high EWs.

The relation between EWs of A-X (near 4300 Å) and B-X (near 3886 Å) bands of methylidyne, measured in our sample, is given in Fig. 4. The oscillator strength of the 3886 Å feature is more than 3 times less than that of A-X (Lien 1984). In cases of a vast majority of our points, the slope of the relation clearly resembles the above-mentioned oscillator strengths ratio. We emphasize that, in most of cases when observed lines are composed of many individual Doppler components, the effects of saturation may be negligible for even relatively strong lines (Weselak et al. 2008). The effects of saturation are seen also in the stronger A-X band at 4300 Å, observed towards HD 147889 and 204827. In the above cases, no additional Doppler components were seen in the A-X band, as well as in the KI line in our spectra. However, additional components in the A-X band at 4300 Å and that of KI at 7699 Å observed toward HD 204827 are clearly visible using higher resolution (Pan et al. 2004). This is why the effects of saturation are so weak.

In Fig. 5 we compare the calculated column densities of CH and CN molecules with those published previously by Federman et al. (1994). The relation in both cases is similar, because the correlation coefficient is close to 0.94 and 0.97 in the cases of CN and CH, respectively, but our column densities are usually

Fig. 3. The CN B-X system centered at 3875 Å in the radial velocity scale (*the top panel*); the CH A-X feature near 4300.313 Å (*middle panel*) and KI line at 7698.959 Å (*bottom panel*) in the spectra of the same four heavily reddened stars. In the middle panel spectra of HD 154368, 165688, 166734, and 204827 are presented in a different order to avoid intersecting each other.

lower than those obtained previously. This may be caused by column densities published by Federman et al. (1994) being based on literature compilations, while our, are determined from the homogeneous system of our own measurements. The method used to calculate column densities from saturated features may play a significant role. In the case of HD 27778 the value of $N(\text{CN})$ published by Roth & Meyer (1995) ($20.64 \times 10^{12} \text{ cm}^{-2}$) is close to our value presented in Table 1, but different from that of Federman et al. (1994).

The collected column densities of CN and CH molecules along 84 lines of sight allow a comparison of their column densities. The relation between column densities of methylidyne and cyanogen have been extensively studied theoretically and observationally (see Federman et al. 1994). The relation between $N(\text{CN})$ and $N(\text{CH})$ is plotted on a linear scale, in Fig. 6, with one point (HD 204827) out of the plot's range. Several points with very high abundance of the CN (HD 12953, 27778, and 204827) and very high abundance of the CH (HD 34078) make the relation poor with a correlation coefficient equal to 0.63. We

Fig. 4. Correlation plot between equivalent widths of the CH A-X 4300 Å band and B-X 3886 Å. The stronger 4300 Å band saturates in the spectra of HD 147889, 165688, and 204827. (We also present the line which fits the data.)

Fig. 5. A comparison of column densities determined in our sample with those from the publication of Federman et al. (1994). Small systematic differences are seen, but the values generally agree well. The correlation coefficients are equal to 0.94 and 0.97 in the case of CN and CH, respectively.

emphasize that the abundance ratio of the two most popularly observed interstellar molecules is variable, because of the different physical parameters of individual clouds.

Figure 7 presents correlation plots between calculated column densities of CH and CN molecules, plotted on a linear scale, and $E(B - V)$. The relation is better in the case of the CH than the CN molecule. In the case of the latter, the group of points (HD 12953, 27778, 147889, 154368, and 204827) with

Fig. 6. Correlation between column densities of CN and CH molecules. The relation is poor with a correlation coefficient equal to 0.63. The star HD 204827 with a high value (out of the plot range) of $N(\text{CN}) = 34.00 \times 10^{12} \text{ cm}^{-2}$ is designated with an arrow.

very high abundance of CN in relation to $E(B - V)$ completely misses the relation, or at least the main stream of points. We also present the relations between EW s of 5780, 5797 DIBs, and $E(B - V)$, and the last are different from those presented in the publication of Królowski et al. (1999). The correlation coefficient, equal to 0.94, is higher in the case of narrow 5797 DIB than 5780 DIB (0.85). We emphasize that our new result is based on the homogenous system of our own measurements, not on a compilation of the literature data.

In Fig. 8 we present the relation between column densities of CH and CN molecules normalized to $E(B - V)$, and the intensity ratio of two major 5780 and 5797 DIBs. Our result in the case of the CH molecule (correlation coefficient equal to 0.56 based on calculated column densities) is close to the previously published by Królowski et al. (1999), based on equivalent width measurements. In Fig. 8 four datapoints (HD 23180, 24534, 204827, and 207538) with a high 5797/5780 DIB ratio (ζ -type) exist. We stress that datapoints representing HDs (23180, 24534, 204827, and 207538) also miss the average relation for CN molecule shown in Fig. 8 where the correlation coefficient is equal to 0.49.

Based on this result, it is useful to compare the column densities of CH and CN molecules with the strengths of 5780 and 5797 DIBs. The correlations, presented in Fig. 9, prove reasonably poor, suggesting that direct relations between either CH or CN and the DIB carriers do not exist. The poor relation between the 5780 DIB strength and the abundance of molecular hydrogen and the relation between the 5780 DIB strength and column density of atomic hydrogen has been already demonstrated by Herbig (1993). Herbig proved thus that DIB strengths correlate better with $E(B - V)$ than with any feature originating in gaseous hydrogen. Our results clearly confirm this finding (Fig. 9). However, the column density of CH molecule correlates better with both DIBs than CN does. In the correlation plot between the column density of CH and EW s of 5780 and 5797 DIBs, one can separate two groups of objects:

1. “main stream” i.e. the majority of objects in which the CH column density seems to be well-correlated with DIB strengths. The relation between the column density of the CH molecule and the strength of the 5797 DIB, for the “main stream” objects, seen in Fig. 9b, is very tight with the correlation coefficient 0.93.
2. objects where CH is evidently overabundant in the relation to DIB carriers i.e. HD 34078, 147889, 154368, and 204827.

Fig. 7. Abundances of CH, CN molecules, strengths of 5797, 5780 DIBs correlated with $E(B - V)$. The CH molecule and narrow 5797 DIB correlate very tightly. The correlation coefficients are given in the plot.

Fig. 8. Correlation between column densities of CH and CN molecules divided by $E(B - V)$ and intensity ratio of 5797 and 5780 DIBs. Correlation coefficients are equal to 0.56 and 0.49, respectively.

The methylidyne radical correlates better with the narrow 5797 DIB than with the 5780 feature (correlation coefficients equal to 0.69 and 0.29, respectively). This result may hold for other narrow DIBs, suggesting a high abundance of their carriers in the clouds where the CH molecule (and thus – probably also H_2) is relatively abundant (Weselak et al. 2004).

The main conclusion of the present paper is that the major diffuse bands, the molecular features such as CH and CN, and interstellar extinction may be very useful in describing the physical properties of the environments in which DIB carriers are formed and preserved. Equivalent widths of 5780 and 5797 DIBs correlate better with $E(B - V)$ than abundances of CN and CH molecules do as presented in Fig. 7, this fact accords with the earlier result of Herbig (1993). This suggests that

grains, causing extinction, can effectively catalyze the formation of the major DIB carriers or protect them against destructive factors such as UV photons. Our result also supports the thesis that 5797 DIB carrier is favored in environments with the higher molecular gas content typical of CH and H_2 molecules. The CN molecule is probably connected to denser core regions of clouds (Liszt & Lucas 2001) in which production of 5797 DIB carriers is apparently not so efficient.

The relatively good correlation of the CH abundance with that of the carrier of the narrow 5797 DIB likely extends to other narrow DIBs. Such an analysis will be done soon (material in preparation). It would be very interesting to check the relations between column densities of other molecular features such as CH^+ , C_2 , or CO and the strengths of major DIBs, basing it on

Fig. 9. Molecular column densities of the CH (at the top) and the CN molecule (bottom) correlated with equivalent widths of the 5780 and 5797 DIBs. Both DIBs correlate better with CH rather than the CN molecule. The best correlation with the coefficient equal to 0.69 is observed between the methylidyne radical (the good H_2 tracer) and the narrow 5797 DIB. Objects missing the “main stream” in the case of relation between column density of the CH molecule and the intensity of the 5797 DIB are plotted with circles. The relation in the case of the “main stream” (Fig. 9b) is plotted with dotted line.

new samples of homogeneous measurements. It is certainly important to collect more spectra of the high signal-to-noise ratio to obtain correct values of column densities and check how far simple molecules are related to diffuse interstellar band carriers.

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