1948ApJ...108..526S

THE SPECTRUM OF COMET 1947n*

P. Swings and Thornton Page
McDonald Observatory
Received August 12, 1948

ABSTRACT

The spectrum of Comet 1947n has been observed from heliocentric distance $r = 0.504$ to $r = 1.135$ between λ 3000 and λ 8900. The *OH* band is unusually weak relative to *NH*. The (0, 0) band of *CN* reveals a complex rotational structure due to fluorescence, similar to that observed in previous comets. Features appearing within the Swan bands are described and discussed. The red region is mainly due to NH_2. Two intense infrared emissions have been found for the first time at λ 7906 and λ 8106. A detailed discussion seems to indicate that they may be attributed to the red system of *CN*. This *CN* emission in the infrared does not result from fluorescence but probably from the photodissociation of a parent-molecule. No atomic lines have been found other than the D lines of *Na*. The two components of the nucleus reveal exactly the same spectrum.

The solution of a number of important problems in cometary physics must await the apparition of bright comets. Hence, when news was received that an extremely bright comet had been seen in the Southern Hemisphere, a special effort was made at the McDonald Observatory to observe this object, in spite of the difficulties caused by the proximity of the comet to the sun. The comet was first seen a few minutes before setting on December 14.05 (U.T.). We decided to try, first, to obtain some information on the infrared part of the spectrum.[1]

A plane-grating spectrograph equipped with a solid Schmidt $f/0.65$ camera and focused for the region λλ 7000–9000 was installed at the prime focus of the 82-inch reflector. The first spectrogram, obtained on December 15.05 (U.T.)[2] on ammonia hypersensitized IN emulsion, revealed two emission bands near λ 7906 and λ 8106. As far as we know, these cometary radiations have not been observed previously. Other spectrograms on Eastman IN film, obtained with the same instrument on several of the following evenings, confirmed the presence of these intense emissions. For three of the exposures, a Wratten *a* filter, the complete absorption of which between λ 3100 and λ 5200 had been checked, was placed on the slit, in order to absorb the second-order violet which would have been superposed on the infrared emission. On two evenings an attempt was made to extend the spectral range beyond the limit of the IN emulsion by using hypersensitized IM emulsion, but without success. On December 18.06 and 20.05, two grating spectrograms were obtained on Eastman 103*a*-F emulsion, with excellent definition from λ 4400 to λ 6700 (see Fig. 1, *a*).

During the period of spectrographic observation at the prime focus, December 15–23, it was impracticable to obtain the individual spectra of the two components of the nucleus,[3] and we guided on the brighter component. On December 24 we started a series of exposures at the Cassegrain focus, in order to cover the ultraviolet and visual regions. By that time the comet had faded to about the sixth magnitude; and, since the exposure could not exceed 90 minutes under the best conditions, only fairly low dispersions could

* *Contributions from the McDonald Observatory, University of Texas*, No. 157.

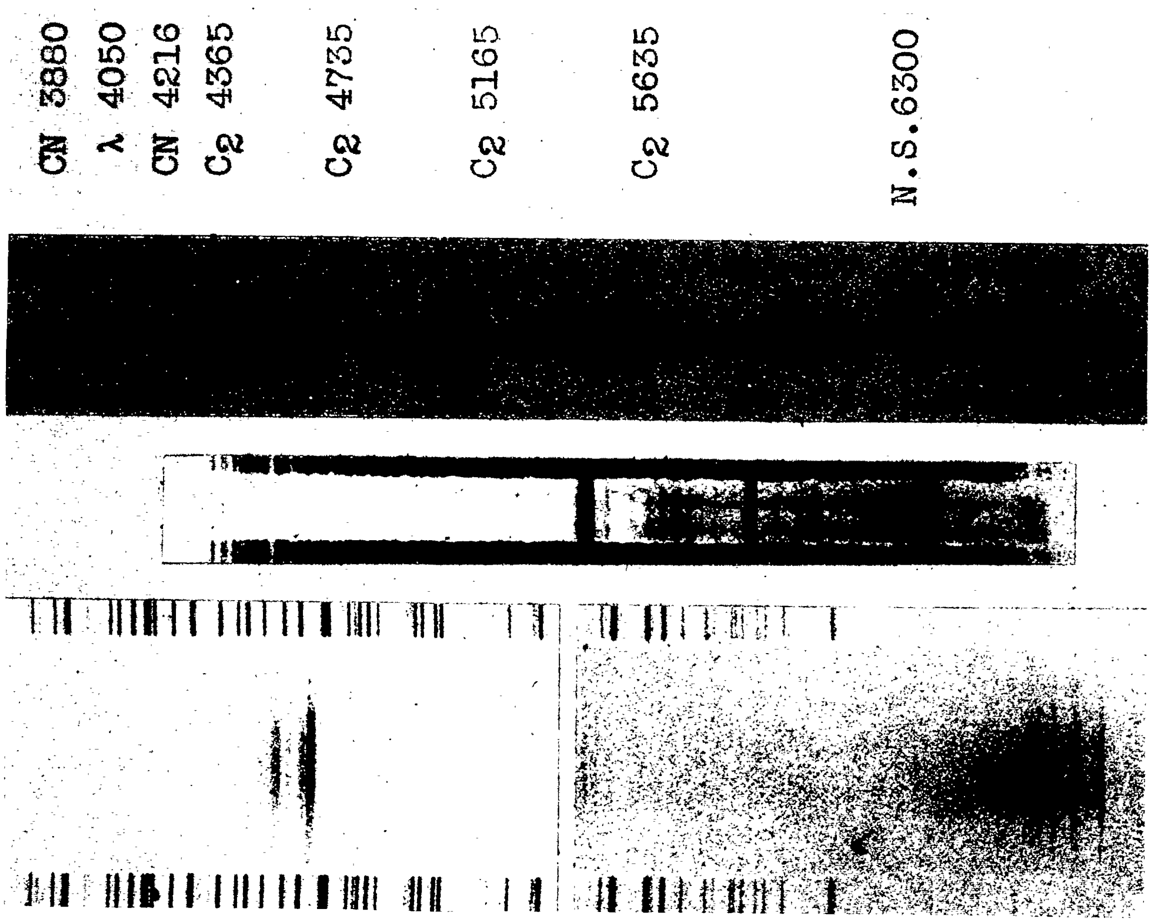
[1] It has been recognized that observations of comet spectra in the red and the infrared are especially desirable (see N. T. Bobrovnikoff, *Rev. Mod. Phys.*, **14**, 164, 1942, at 172; P. Swings, *M.N.*, **86**, 103, 1943, at 109).

[2] At that time the comet was no longer extremely bright; its visual magnitude was about 3–4.

[3] The duplicity of the nucleus was discovered on December 10, by W. H. van den Bos, at the Union Observatory, Johannesburg, South Africa. We observed it independently on December 19.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S



c *d*

FIG. 1.—The spectrum of Comet 1947n. *a*) Grating spectrogram of 1947, December 20.054 U.T. *b*) Quartz-prism spectrogram of 1948, January 04.065 U.T., showing spectra of two components. *c*) Glass-prism spectrogram of 1947, December 27.065 U.T., showing structure of *CN* (0, 0) band near λ 3880. *d*) Glass-prism spectrogram of December 27.065 U.T., showing structure of C_2 ($\Delta v = +1$) bands near λ 4735.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

be used. On all the exposures after December 23, the slit was placed in the position angle of the two components of the nucleus, hence revealing the spectra of both these components (Fig. 1, *b*). The list of observations, including the essential optical data, is given in Table 1.

Except for the difference in total intensity, the spectra of the components are practically identical. The separation between the two spectra is well marked in the case of bands such as those of CH, CH_2, and NH_2, which are concentrated close to the nucleus. On the other hand, the bands of CN, C_2, and NH, which always extend far into the head, show only an inconspicuous intensity drop between the two nuclei. As far as can be ascertained by visual examination of the spectrograms, not only are the relative intensities of the different bands (NH, CN, CH_2, CH, C_2, NH_2) the same in both components, but also the rotational intensity distributions within the individual bands are identical. On all exposures begun late enough to avoid twilight the solar spectrum is extremely weak.

TABLE 1

SPECTROGRAMS OF COMET 1947n OBTAINED AT THE McDONALD OBSERVATORY

U.T. Date*	Heliocentric Distance (r)	Dispersion in A/mm at			Projected Slit Width at			Eastman Emulsion	Quality of Spectrogram
		λ 3880	λ 6300	λ 8000	λ 3880	λ 6300	λ 8000		
1947, Dec.									
15.049	0.504 A.U.	......	......	320	......	......	28 A	IN†	Good in I.R.
16.050	0.534	......	......	320	......	......	28	IN†	Fair; sky strong
18.058	0.594	410	339	......	7.1 A	5.9 A	......	103*a*-F†	Good
19.054	0.622	......	......	320	......	......	21	IN†	Good in I.R.
20.054	0.649	410	339	......	14	12	......	103*a*-F†	Good
21.054	0.676	......	......	320	......	......	45	IN†	Weak (clouds)
22.052	0.703	......	......	320	......	......	34	IN†	Weak (clouds)
24.062‡	0.757	(130)§	......	......	(2.3)§	......	......	103*a*-O	Good in U.V.
25.06‡	0.782	115	......	......	2.7	......	......	103*a*-O	Good
26.06‡	0.807	46	......	......	0.83	......	......	103*a*-O	Good at λ 3880
27.065‡	0.832	46	......	......	0.83	......	......	103*a*-O	Very good
1948, Jan.									
02.06‡	0.976	91	610	......	2.0	13.7	......	103*a*-F†	Fair
04.065‡	1.022	222	......	......	4.0	......	......	103*a*-O	Fair
06.065‡	1.068	......	610	......	......	11.0	......	103*a*-F†	Good
09.06‡	1.135	......	610	......	......	13.7	......	103*a*-F†	Poor

* Two spectrograms on IM emulsion, exposed on December 17.052 and 23.061, were too weak and did not show any infrared emission.

† The emulsion was hypersensitized in ammonia.

‡ After December 24, all spectrograms were taken with the slit across both components of the comet.

§ At λ 3370.

The absolute magnitude of Comet 1947n is approximately[4] $M = 6.2$. Since absolute magnitudes of comets have been observed from 0 to 15,[5] the present object should be considered of average luminosity.

ULTRAVIOLET AND VIOLET REGION OF THE SPECTRUM

The OH band near λ 3090 is extremely weak. In fact, it is much weaker, relative to NH, than in Comet Cunningham, 1941 I, which was observed at the McDonald Observatory under nearly the same conditions of heliocentric distance, zenith distance, season,

[4] L. E. Cunningham, *Pub. A.S.P.*, **60**, 27, 1948.

[5] B. A. Vorontsov-Velyaminov, *A.J. Soviet Union*, **22**, 317, 1945.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

weather, and instrument. Of the seven comets for which ultraviolet spectrograms have been obtained at the McDonald Observatory, only Comet de Kock–Paraskevopoulos, 1941 IV, observed at heliocentric distance 0.9 A.U., reveals such weak *OH* emission relative to *NH*. Comet 1941 IV is the only comet, besides 1947n, which was observed after perihelion passage. However, its perihelion distance ($q = 0.79$ A.U.) was large compared with that of 1947n ($q = 0.1$ A.U.).

The (0, 0) band of *NH*, transition $^3\Pi \rightarrow {}^3\Sigma$ near λ 3360, shows strongly. It is not so well resolved as in Comet 1941 I. Four components appear, as indicated in Table 2.

The (1, 0) band of *CN*, transition $^2\Sigma \rightarrow {}^2\Sigma$ near λ 3580, is too weak to show any structure. The (0, 0) band of *CN*, near λ 3880, was obtained with a projected slit width of 0.83 A (Fig. 1, *c*). Since the intervals between successive lines of the *R* branch are about 0.7–0.8 A, the present resolution is unable to bring out completely the individual lines of the *R* branch, as McKellar succeeded in doing for Comet 1943 I.[6] The profile of the (0, 0) band presents the same type of complexity as that observed previously. On the spectrogram of December 27.065, sharp maxima are observed at:

TABLE 2

NH LINES IN COMET 1947n

λ*	Int.	Identification	λ*	Int.	Identification
3349.6..........	1	$R_2(1)$	3365.0..........	1	$P_2(2)$
3353.7..........	2	$R_2(0)+R_1(1)$	3369.3..........	1	$P_1(2)$
3358.1..........	10	$R_1(0)+Q_2(2)$			

* From micrometer measures on spectrograms and from measurement of separate microphotometer tracings of the brighter and fainter components of the comet.

P branch: λ 3876.9 (int. 18); λ 3877.6 (20); λ 3879.9 (40);
λ 3881.4 (30);
R branch: λ 3872.8 (6); λ 3871.9 (5); λ 3868.9 (20);
λ 3867.4 (15); λ 3865.0 (6); λ 3862.8 (5);
λ 3862.1 (4)

and sharp minima at:

P branch: λ 3878.7 (15)
R branch: λ 3871.3 (2); λ 3865.6 (4); λ 3864.0 (2).

This profile may be explained, as in previously published cases,[7] by the influence of the solar absorption lines on the resonance fluorescence spectrum excited by the solar radiation in the *CN* molecules of the comet. Owing to the peculiar rotational intensity distribution, several sharp peaks observed in the *R* branch (for example, λ 3865.0) are actually individual rotational lines.

The measurements of the spectrograms of December 27.06 and December 26.06 are in good agreement. On a spectrogram of lower resolution obtained on December 25.06, the *R* branch appears to extend to λ 3847, maxima being observed on a tracing at λλ 3859.7, 3854.2, and 3850.6, beyond the limits found on December 26 and 27. These maxima can barely be recognized on the original film.

Nothing unusual appears in the "λ 4050 group,"[8] the (0, 1) band of *CN* near λ 4216, the *CH* lines near λ 4313, and the C_2 sequence near λ 4382.

[6] *Ap. J.*, **99**, 162, 1944.

[7] P. Swings, *Lick Obs. Bull.*, **19**, 131, 1941, and *M.N.*, **103**, 86, 1943; A. McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942, and *Ap. J.*, **99**, 162, 1944.

[8] Tentatively identified as CH_2 by G. Herzberg, *Ap. J.*, **96**, 314, 1942.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

VISUAL REGION OF THE SPECTRUM

The best material from λ 4400 to λ 6700 is provided by the two grating spectrograms of December 18 and 20 and by the glass-prism spectrogram of December 27; however, the latter extends only to approximately λ 5000.

Interesting features are observed on the glass-prism spectrogram of December 27 in the region of the $\Delta v = +1$ Swan bands (projected slit width at λ 4700: 1.87 A; see Fig. 1, *d*). These features are listed in Table 3. The measured wave lengths are those of intensity maxima, not of edges; hence they have not been corrected for projected slit width.

The maxima observed between the main Swan bands have, for the most part, been mentioned previously,[9] although possibly not so completely as in Table 3. It may be significant that the two doublets, λλ 4708.8–4704.0 and λλ 4692.6–4687.7, have practically the same separation. The weak feature at λ 4742.9 is distant from the (1, 0) band, λ 4734.9, by the amount expected for the (1, 0) band of $C_{12}C_{13}$; it is probably a faint isotopic carbon band.

TABLE 3

FEATURES IN THE REGION λλ 4665–4750

λ	Int.	Identification	λ	Int.	Identification
4669.5	8	?C_2(6, 5)	4708.8	10	....
4676.2	15	C_2(5, 4)	4713.2	30	C_2(2, 1)
4682.7	15	C_2(4, 3)	4719.0	3	....
4687.7	8	....	4728.1	3	....
4692.6	10	....	4734.9	20	C_2(1, 0)
4695.5	25	C_2(3, 2)	4742.9	1	?$C_{12}C_{13}$(1, 0)?
4704.0	5	....	4746.4	2	....

On the two grating spectrograms of December 18 and 20, the Swan bands are very intense, and emission features are observed to the violet of λ 4670. Those extending from λ 4504 to λ 4662 may be found in Table 4, in which the measurements of the two grating spectrograms have been tabulated. However, Table 4 does not contain the region λλ 4670–4746, which is better represented on the prism spectrogram (wave lengths in Table 3). Table 4 shows that emission features appear in addition to the usual Swan bands, violetward of (2, 2); between (0, 0) and (1, 1), (2, 3) and (3, 4), and (3, 4) and (4, 5).

It is not clear at present whether the origin of these fairly sharp features in the region of the Swan bands is due to some emission by an as yet unidentified molecule[10] or whether some effect of the solar absorption lines on the fluorescence excitation is responsible. For example, abnormal emission features between the (1, 0) and (2, 1) bands could be due to an abnormal distribution among the rotational levels of the $v' = 1$ state. This state is reached by absorption of solar radiation within the (1, 0) λ 4737, (1, 1) λ 5129, and (1, 2) λ 5586 bands. While solar absorption lines are not so numerous in these three regions as in the λ 3880 region of *CN*, they may be able to affect appreciably the profile of the Swan bands. It would be interesting to draw the synthetic profiles, in order to separate the emissions due to the excitation mechanism from those due to molecules other than C_2.

[9] See N. T. Bobrovnikoff, *Ap. J.*, **99**, 173, 1944, Pl. VI and Table 1, and *Pub. Lick Obs.*, **17**, 436, 1931; A. McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942, Fig. 7, and *Ap. J.*, **99**, 162, 1944.

[10] Nothing is known of the spectra of NH^+, CN^+, and C_2^+, which may be present in comets.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

TABLE 4*

EMISSION LINES IN COMET 1947n, λ>4400

COMET 1947n							EARLIER MEASURES McD. AND MT.W.	VICTORIA MEASURES	COMET 1911 V	NUCLEAR FEATURES	COMETS 1910 II AND 1941 I	LYON MEASURES	IDENTIFICATION
Dec. 18.058			Dec. 20.054			ADOPTED λ							
I (1)	l (2)	λ (3)	I (4)	l (5)	λ (6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	5	4414.6	2	20n	19.0	4416.8	19.2	...	...	12.–21.	13.3	...	...
			1	20s	84.5	4484.5	{74.8–86.0 –96.8}	85.6	...	77.–86.	85.	...	...
1	10	4503.	1	20n	04.7	4504.	10.6	...	...	...	...	...	NH_2?
1	25	4541.	...	...	...	4541.	40.8	42.3	47. (tail)	...	...	...	NH_2
1	25	4573.	1	20	67.5	4570.2	75.0	...	72. (tail)	...	69.	...	*CN* (0, 2)?†
			1	20	85.9	4585.9	89.1	89.1	...	...	90.	...	*CN* (0, 2)?†
2	30	4597.	1	20	98.7	4598.	03.6	...	...	...	...	...	...
			1	20	12.9	4612.9	07.3–17.0	08.1–15.0	08.	14.	07.4	...	*CN* (0, 2)
2	40	4625.1	2	40	32.3	4628.7	29.8	...	...	31.	...	...	...
2	50	4645. }	2	50	53.7	{4645.	...	...	...	45.6	46.8	...	...
3	60	4662.2 }				{4662.2	...	...	60.	61.3	60.7	...	C_2 (6, 5)?
			0.5	20n	91.	4791.	...	...	...	91.9	...	85.2–94.6	NH_2?
1	10n	4841.5	1	20n	37.2	4839.4	38.9	36.3	37.8	40.4	...	38.8	NH_2 plus C_2
1	10	4868.1	1	20n	76.6	4872.4	68.2–76.0	...	...	74.–79.5	73.0	68.2–75.3	NH_2
1	10	4898.2	...	...	...	4898.2	...	...	...	...	...	...	...
1	10	4925.6	2	20n	23.0	4924.3	25.7	...	25.5	28.5	...	25.9	NH_2
2	10	4997.	...	...	...	4997.	...	...	...	...	...	...	...
0.5	50n	4997.	...	...	...	4997.	...	...	...	...	...	...	...
...	...	...	3‡	20s	07.6	5007.6	07.0	...	...	08.	...	07.1	...
...	...	...	3‡	20s	29.0	5029.0	...	...	...	33.0	...	...	...
...	...	...	2‡	50	54.4	5054.4	...	...	...	50.9	...	...	...
...	...	...	2‡	60n	69.	5069.	...	...	...	...	?81.2	...	...
4	50	5097.6	2	60s	97.0	5097.3	...	...	94.	...	01.4	...	C_2 (2, 2)
5	70	5130.2	3	70	26.2	5128.2	...	...	28.0	...	27.1	...	C_2 (1, 1)
...	...	...	1	60	44.0	5144.0	...	...	...	...	...	...	C_2 (0, 0)§
8	100s	5167.4	5	100	62.4	5164.9	...	...	64.0	...	67.4	...	C_2 (0, 0)
...	...	...	1	20s	82.4	5182.4	86.5	...	78.	78.	...	...	...
...	...	...	1	20s	01.1	5201.1	...	...	...	...	...	...	...
...	...	...	1	20n	49.1	5249.1	43.1–59.0	...	...	...	...	43.1–58.9	NH_2
...	...	...	1	20n	83.7	5283.7	83.5	...	...	...	...	...	...
...	...	...	1	30	16.0	5316.0	18.5	...	...	...	...	19.2	N_2?
...	...	...	1	40	32.7	5332.7	36.5	...	...	...	...	31.0	N_2?
1	20n	5349.9	1	40n	53.2	5351.6	55.3	...	...	...	...	54.4	...

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

TABLE 4—*Continued*

Comet 1947n							Earlier Measures McD. and Mt.W.	Victoria Measures	Comet 1911 V	Nuclear Features	Comets 1910 II and 1941 I	Lyon Measures	Identification
Dec. 18.058			Dec. 20.054			Adopted λ							
I (1)	*l* (2)	λ (3)	I (4)	*l* (5)	λ (6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	20n	5379.9	1	20s	82.2	5381.1	86.4	...	...	...	...	85.9	NH_2
0.5	15s	5416.9	...	...	...	5416.9	18.3	...	18.5	18.5	...	18.2	NH_2
1	40s	5429.1	1	30s	26.8	5427.9	28.0	...	28.3	...	...	27.7	NH_2‖
1	30s	5445.6	1	40s	42.7	5444.2	45.0	...	...	...	...	49.7	NH_2‖
1	30	5464.2	2	50s	68.2	5466.2	...	...	70.	...	...	...	C_2 (4, 5)
1	30	5478.8	1	50s	87.3	5483.1	...	...	...	...	...	...	C_2§
2	50	5498.3	2	60s	99.5	5498.9	...	...	...	...	...	...	C_2 (3, 4)
1	40	5519.2	1	50s	18.0	5518.6	...	...	...	...	?05.8	...	C_2 plus NH_2?§
3	50	5538.8	2	60s	38.3	5538.5	...	...	40.0	...	39.4	...	C_2 (2, 3)
4	60	5582.8	3	100	81.8	5582.3	...	...	84.8	...	89.5	...	C_2 (1, 2)
4	50	5634.5	4	80	33.8	5634.1	...	...	34.8	...	39.3	...	C_2 (0, 1)
...	...	...	1	20s	79.0	5679.0	87.1	94.6	92.5	92.5	...	88.–96.3	NH_2
2	15n	5702.7	2	30s	01.7	5702.2	01.5	04.0	05.	05.	...	08.2	NH_2
1	15n	5732.8	2	20n	32.2	5732.5	31.2–39.6	31.4	32.	32.	...	?42.7	NH_2?
...	...	...	1	10s	97.8	5797.8	05.0	...	...	...	...	04.	NH_2?
...	...	...	1	10s	17.4	5817.4	...	...	...	...	...	...	NH_2?
...	...	...	1	10s	36.2	5836.2	...	...	...	...	...	...	...
...	...	...	1	10s	68.9	5868.9	...	...	...	...	...	...	NH_2
2	20n	5888.8	3	30n	90.4	5889.6	92.8	88.3	(*Na*)	...	...	92.5	*Na* plus NH_2
...	...	...	1	30s	33.4	5933.4	...	...	...	...	...	...	NH_2
...	...	...	1	40s	59.6	5959.6	49.	...	...	...	...	...	NH_2 plus C_2 (4, 6)
2	15s	5973.2	2	40s	76.6	5974.9	77.7	76.6	77.	77.	72.	77.4	NH_2
1	15s	5990.2	...	...	...	5990.2	...	...	94.	94.	92.	93.4	NH_2?
0.5	15s	5999.8	2	40s	96.1	5998.0	96.0	95.8	...	...	...	...	NH_2 plus C_2 (3, 5)
1	15s	6015.8	1	40s	18.6	6017.2	19.4	13.1–20.2	20.5	20.5	...	19.8	NH_2
0.5	15s	6034.0	1	20s	33.6	6033.8	36.9	36.5	...	...	...	31.4	NH_2
1	15s	6052.6	1	20s	56.1	6054.4	53.5	59.5	...	...	...	...	NH_2 plus C_2 (2, 4)
1	15s	6092.9	2	30s	96.6	6094.8	98.7	96.9	...	...	...	99.4	NH_2
1	15s	6106.6	...	...	...	6106.6	10.3	10.0	...	...	...	...	NH_2
1	15s	6116.7	2	30s	19.2	6118.0	20.9	20.9	...	...	...	...	NH_2 plus C_2 (1, 3)
1	15n	6157.1	...	...	...	6157.1	48.6–70.6	47.6	...	...	...	...	NH_2
1	15n	6185.9	1	60?	87.2	6186.5	...	84.8	...	...	...	...	NH_2 plus C_2 (0, 2)
3	¶	6296.1	3	¶	98.4	6297.3	98.0	00.7	00.	00.	...	98.8	NH_2
0.5	20n	6327.	2	30s	31.9	6329.5	33.2	35.2	...	...	20.	29.4	NH_2
...	...	...	2	50	45.2	6345.2	45.6	45.7	...	...	...	45.4	NH_2**
1	¶n	6359.	1	¶	62.1	6360.6	64.1	64.3	...	...	...	54.	NH_2

© American Astronomical Society • Provided by the NASA Astrophysics Data System

TABLE 4—*Continued*

Comet 1947n							Earlier Measures McD. and Mt.W.	Victoria Measures	Comet 1911 V	Nuclear Features	Comets 1910 II and 1941 I	Lyon Measures	Identification
Dec. 18.058			Dec. 20.054			Adopted λ							
I (1)	l (2)	λ (3)	I (4)	l (5)	λ (6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
2	50n	6541.1	1	20n	36.	6538.6	46.	....	....	....	29.	39.7	NH_2††
2	50s	6556.4	1	20	57.6	6557.0	....	....	....	....	....	59.5	NH_2
2	50n	6571.9	....	....	....	6571.9 }	81.	79.5	78.	78.	....	79.8	{ NH_2
1	40n	6583.9	2	20	76.8	6580.3 }	(see above)	(see above)	(see above)	(see above)	....	(see above)	{ NH_2
2	30n	6594.7	2	30	98.3	6596.5	98.	97.0	98.	98.	....	....	NH_2††
3	15s	6614.1	3	40	17.0	6615.6	22.	19.8	19.	19.	....	....	NH_2
1	30s	6636.5	2	20	37.3	6636.9	42.	41.6	....	....	35.	....	NH_2
1	15s	6668.1	2	20n	72.	6670.	....	74.6	....	....	77.	....	NH_2††
2	5s	6722.1	....	....	....	6722.1	....	....	....	....	....	....	NH_2
2	10s	6748.8	2	20n	48.6	6748.7	....	....	....	....	....	....	NH_2
2	7s	6762.1	....	....	....	6762.1	....	....	....	....	....	....	NH_2

* The columns list the following:
1 and 4 are intensity estimates on a scale from 0 to 5.
2 and 5 are estimated lengths of lines, in seconds of arc, together with a description: "s" = sharp, "n" = broad.
3 and 6 are measured wave lengths, corrected for radial velocity and line curvature.
7 contains the means of wave lengths in cols. 3 and 6.
8 contains mean values of earlier measurements made at the McDonald and Mt. Wilson observatories on spectra of the following: Comet Cunningham, 1941 I (P. Swings, *Ap. J.*, **98,** 142, 1943, and unpublished), Comet 1943 I (R. Minkowski, *Ap. J.*, **98,** 142, 1943; and P. Swings and O. Struve, *Pub. A.S.P.*, **55,** 150, 1943), Comet Peltier, 1936 II (W. Baade and R. Minkowski, *Pub. A.S.P.*, **48,** 227, 1936), Comet Finsler, 1937 V (R. Minkowski, *Pub. A.S.P.*, **49,** 276, 1937). For the region λλ 4419–4839, only the unpublished measurements of Comet 1941 I by P. Swings are listed.
9 contains mean values of measurements made at Victoria in the spectra of Comet Cunningham, 1941 I (A. McKellar, *Ap. J.* **98,** 142, 1943), Comet 1943 I (*ibid.*, and *Ap. J.*, **99,** 162, 1944).
10 contains wave lengths measured in the spectrum of Comet Brooks, 1911 V, by W. H. Wright, *Lick Obs. Bull.*, **7,** 8, 1912.
11 contains mean wave lengths of nuclear emissions, measured or compiled by F. Baldet, *Ann. Obs. Astr. Phys. Paris*, **7,** 1926. (Many of Baldet's features were taken from Wright's list of lines in Comet Brooks.)
12 contains the means of wave lengths measured in the spectra of Comet Halley, 1910 II, and Comet Cunningham, 1941 I (N. T. Bobrovnikoff, *Pub. Lick Obs.*, **17,** 309, 1930; and *Ap. J.*, **99,** 173, 1944).
13 contains the means of wave lengths measured in the spectra of Comet Peltier, 1936 II, Comet Encke, 1937 VI, Comet Finsler, 1937 V, Comet 1943 I, and Comet 1939 III by J. Dufay, *C.R.*, **222,** 51, 1946.
14 contains identifications. For the wave lengths of the NH_2 lines see P. Swings, A. McKellar, and R. Minkowski, *Ap. J.*, **98,** 142, Table 3, 1942.

† Feature in *R* branch.
‡ Complex structure.
§ Feature in Swan bands.
‖ Identification not satisfactory, since the cometary line is long.
¶ Estimation of length impossible because of night sky line.
** Doubtful minor contribution from *CN* (red system).
†† Possible minor contribution from C_2.

1948ApJ...108..526S

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

It is possible but not probable that some of the faint features listed in Table 4 are spurious. Although the blue region may not be so well resolved as on previously investigated prism spectrograms, the measured wave lengths agree well with earlier results. Since the projected slit widths are 7 A and 14 A, respectively, the resolution is limited. However, in the red region the resolution is better than in most lists of wave lengths previously published.

Besides C_2, the only certain identification in the red region is that of the α band of ammonia, presumably due to NH_2. It is interesting to note that, except for weak and doubtful C_2 contributions, the whole region $\lambda > 6000$ appears due to NH_2. A laboratory analysis of the NH_2 spectrum is urgently needed.

Table 4 reveals a certain number of emissions still unidentified. A systematic examination reveals coincidences with the spectra[11] of NO, NO_2, Na_2, O_2^+, formaldehyde, benzene derivatives, and various oxides, for example, CaO and MgO. However, it is felt that these coincidences may be accidental. It is planned to extend this work in the visual region with the same spectrograph to other comets; such material has recently been secured for Comet Bester (1947k). Table 4 differs appreciably from previously published lists, such as the one by Swings, McKellar, and Minkowski.[11] It is noted that most of the lines listed by these authors above λ 6300, and not present in our Table 4, are unidentified features; this points toward the presence of some as yet unidentified compound. Since Table 4 applies to small heliocentric distances, differences should be expected from the table by Swings, McKellar, and Minkowski, which combines observations at both small and large heliocentric distances.

Special attention was given to possible identifications of NH_3, HCN, and C_2H_2, which were expected as parent molecules and possibly as the source of the infrared bands. Ammonia has a weak vibration rotation band $5\nu_1$, with a maximum near λ 6440. Lists of individual lines have been published by R. M. Badger[12] and by S. H. Chao.[13] A comparison shows that these lines are absent from Comet 1947n.[14] Hydrogen cyanide and acetylene, which also have vibration rotation bands in the red region, lead to the same conclusion. The result of this simple comparison is confirmed by synthetic low-temperature profiles[15] for the red bands of NH_3, HCN, and C_2H_2.

INFRARED REGION OF THE SPECTRUM

When no red filter is interposed, the spectrograms on IN emulsion show the second order of the CN band at λ 3880 in addition to the emissions at λ 7906 and λ 8106. This second-order band appears less intense than λ 7906. Yet the IN emulsion is very sensitive to violet light—in fact, more sensitive than to λ 8000.[16] This indicates that the

[11] Striking coincidences with the O_2^+ bands (0, 1) and (0, 0) and (2, 0) at low temperatures are found in the list of lines of the visual region compiled by Swings, McKellar, and Minkowski (*Ap. J.*, **98**, 142, Table 3, 1943).

[12] *Phys. Rev.*, **35**, 1038, 1930.

[13] *Phys. Rev.*, **50**, 27, 1936.

[14] Some coincidences are found in the comets 1941 I and 1943 I, but they are not sufficient to warrant an identification.

[15] These synthetic profiles, as well as those for the molecules considered in the next section, were kindly drawn by Dr. J. Hunaerts, of Uccle.

[16] Three other factors affect this ratio: the grating efficiency, the dispersion, and the transmission of the UV glass block in the Schmidt camera. Calculations from the Rowland formula (*Phil. Mag.*, **5–35**, 397, 1893) show that the grating efficiency in the first-order spectrum should be very closely the same at λ 3880 and at λ 7900 but that the second-order λ 3880 should be reduced to one-fifth of its normal intensity relative to the first-order λ 7900. Deviations from the theoretical formula might increase this factor to one-fourth. The dispersion in the second order is twice that in the first-order spectrum. The transmission of the UV glass at λ 3880 is over eight-tenths of that at λ 7900. The IN emulsion is about one-sixteenth as fast at λ 7900 as it is at λ 3880, but hypersensitization increases this to about one-third.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

radiations at λ 7906 and λ 8106 are actually very strong, comparable in intensity with the strongest violet emission, that of *CN*.

Only λ 7906 and λ 8106 are considered in this paper. There may be other, much weaker emissions near λλ 7088, 7381, 8242, and 8783; but these are uncertain and should be confirmed before identifications are attempted.[17]

The λ 7906 emission is stronger than λ 8106 by a factor of 2 or 3. The blue edge of the λ 7906 band is around λ 7858, and the red edge near λ 7957. In addition to a strong sharp peak at λ 7906, there is a secondary shallower maximum in the blue wing, near λ 7876. The emission centered at λ 8106 appears shallower than at λ 7906; it extends from λ 8046 to λ 8164 and does not reveal any structure. However, this lack of structure may be only apparent, resulting from the weakness of the emission and the wide slit employed.

The identification of the two infrared emissions is fraught with difficulties, one reason being the low resolution used and the other the scarcity of laboratory information in this region. Attention has been given to polyatomic, as well as to diatomic, molecules.

IDENTIFICATION WITH POLYATOMIC MOLECULES

The wave length λ 7906 is near the maximum of a vibration rotation band of NH_3, which is very prominent in absorption in the spectrum of Jupiter.[18] Further, *NH* and NH_2 are strong in Comet 1947n, and we may expect that these radicals result from the photodissociation of ammonia, which, being a chemically stable compound, may be present as a solid or an occluded gas in the meteorites forming the cometary solid nucleus. The λ 7906 band is concentrated close to the nucleus, as are the identified polyatomic molecules CH_2 and NH_2. Moreover, the NH_3 band should have a secondary maximum on the blue side of the main peak. For these various reasons, the identification with ammonia appeared promising. A synthetic low-temperature profile cannot be accurately computed, since the individual lines of the NH_3 band have not yet been classified, doubtless because of the complexity of the band, which is a superposition of several vibrational transitions. Rough sketches of the synthetic profile, based on laboratory and theoretical intensities, show a principal maximum near λ 7914, with a secondary peak near λ 7950 and a much lower (probably unobservable) maximum in the red wing. Considering the absence of data on the rotational temperature of the NH_3 molecules, the identification of the observed profile of λ 7906 with the synthetic profile of the NH_3 band seemed a possibility.

However, Dr. G. Herzberg[19] has raised a serious objection. The absorption intensity of the NH_3 band near λ 7910 is so small that it would be surprising to find the band in

---

Combining these factors with the approximate intensity ratio from the IN spectrograms, we estimate that the intensity per angstrom at λ 7900 is equal to that in the *CN* 3880 band within a factor of 2.

As a check, the intensities of 103*a*-F films and IN films can be compared very roughly, the latter having about one-tenth as great sensitivity at λ 3880. The IN exposure times and slit widths (combined) were three times larger than those used on 103*a*-F, yet the recorded intensity of λ 3880 on 103*a*-F is about ten times that of λ 7900 on IN. Combining these factors with the dispersions, we find again that the intensity per angstrom at λ 7900 is very nearly equal to that at λ 3800. The total intensity of the λ 7906 band, extending over 100 A, must therefore be greater than that of *CN* 3880, which extends over 30 A or less.

[17] It is often stated that one should expect to find the resonance doublet of potassium λλ 7665–7699, when the comet is close enough to the sun to reveal the D line of sodium, as the boiling-point of *K* is only 762° C, against 877° C for *Na*. There is no trace of the potassium doublet on our infrared spectrograms taken at heliocentric distance 0.5. However, this may be due to the relatively low sensitivity of the IN emulsion. Atmospheric absorption would not affect λ 7699 appreciably and would decrease the intensity of λ 7665 only moderately.

[18] For a good reproduction of this NH_3 band see T. Dunham, Jr., *Pub. A.S.P.*, **51**, 269, Pl. XXXI, 1939.

[19] Private communication.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

emission when there are much stronger absorption bands in the ultraviolet that would lead to photodissociation. This objection applies to any vibration rotation band likely to appear in this spectral region, including other possibilities discussed below.

Hydrogen cyanide, *HCN*, has also a vibration rotation band in the λ 7900 region.[20] However, this identification is not plausible. The synthetic profile—which, unlike that of NH_3, may be computed with a fair amount of confidence—has a primary peak near λ 7897 and a secondary one in the red wing near λ 7930; this is quite different from the observed profile. Moreover, another band of *HCN* near λ 8563 is not observed in the comet. It is true that this other band should be weaker than that near λ 7900, but an emission three or four times weaker than the observed one at λ 7906 could have been detected.

Other polyatomic molecules having bands near λ 7900 are acetylene (C_2H_2, strong band) and carbon dioxide (CO_2, weak band), but their synthetic profiles do not agree with the observed one. Moreover, Herzberg's objection applies to these molecules as well as to NH_3 and *HCN*.

IDENTIFICATION WITH DIATOMIC MOLECULES

Two molecules present themselves for possible identification, C_2 and *CN*. Herzberg and Phillips have recently found[21] a new system of C_2, which is a $^1\Pi_u \rightarrow {}^1\Sigma_g^+$ transition, between the lower levels of the $^1\Pi \rightarrow {}^1\Pi$ Deslandres-d'Azambuja system and the $^1\Sigma \rightarrow {}^1\Sigma$ Mulliken system. In the region considered here, four bands are present, the wave lengths of their heads being λ 7715, (3, 0), int. 5; λ 7908, (4, 1), int. 3; λ 8108, (5, 2), int. 1; and λ 8751, (2, 0), int. 10. These bands are degraded to the red. The coincidences of the (4, 1) and (5, 2) wave lengths with λ 7906 and λ 8106 are striking.

However, there are several reasons why the cometary bands could not belong to the new system of C_2. The IN emulsion is sensitive up to λ 8800 (the comparison line λ 8781 of *Ne* appears strongly); yet there is no trace of cometary emission near λ 8751, where the strongest band of the new C_2 system should be found. The comet emission λ 7906 is two or three times stronger than λ 8106. Yet no trace of emission near λ 7715 appears,[22] although one would expect the (3, 0) transition to be stronger than (4, 1) and (5, 2) in the $\Delta v = 3$ sequence, unless extremely improbable, peculiar excitation conditions prevail. The Swan systems of C_2 show the same intensity distribution in comets as they do in the laboratory. It would seem probable that this would also be true for the new C_2 bands. However, there is no trace of degradation toward the red for λ 7906 and λ 8106 in the comet.

It should be noted that the solar spectrum is very poor in absorption lines near λλ 7715, 7908, 8108, and 8750, so that the fluorescence spectrum should not be distorted if the exciting process of absorption takes place in the singlet system of C_2. A fluorescence excitation of the new system (singlet states) would be weak compared with the Swan bands (triplet states). If the primary absorption of solar radiation takes place in the new system, it affects only molecules which are in an excited state. It is true that the latter would be metastable; yet the population in it would be lower than in the ground state. If the primary absorption takes place from the ground state, one would expect the intercombination transition to have a low probability.

Finally, the infrared emission is concentrated near the nucleus, while the Swan bands of C_2 extend far into the head. All these reasons seem to rule out C_2.

The other diatomic molecule which should be considered is *CN*, whose red system has

[20] R. M. Badger and J. L. Binder, *Phys. Rev.*, **37**, 800, 1931.

[21] Communicated at the meeting of the A.A.S., December, 1947.

[22] The atmospheric *A* band does not absorb appreciably at this wave length.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1948ApJ...108..526S

its (2, 0) and (3, 1) transitions[23] in the regions of λ 7900 and λ 8100. The (2, 0) band has an R_2 head at λ 7874 and three other heads (R_1 and Q_1 being stronger than R_2) at longer wave lengths, so that a profile with maximum near λ 7906 is plausible. Similarly, the (3, 1) transition could have a maximum near λ 8106.

A synthetic profile of the red *CN* bands $\Delta v = +2$ has been prepared by Dr. Hunaerts for $T = 430°$ K. A sharp primary maximum appears at λ 7910 and a shallow one at λ 7880. These two wave lengths agree reasonably well with the observed ones; the general appearance of the synthetic profile is also very similar to that of the observed band.

On the other hand, spectrograms of these *CN* bands have been obtained in the Yerkes Observatory laboratory with the help of Mr. Rao, with the same spectrograph and slit width as used in the observations of the comet. The laboratory profiles do not agree well with the cometary ones. In the comet the secondary (lower) maximum of the λ 7906 band occurs in the blue wing, while it is on the red side of the main peak in the laboratory spectrograms. The distance between the two maxima of the laboratory emission near λ 7900 is about 45 A, while it is only 30 A in the comet. However, there may be some effect of temperature on the rotational intensity distribution; this factor could also explain why the cometary bands are narrower than the laboratory ones.

The *f*-value of the (2, 0) transition is small.[24] If the red system of *CN* is excited by fluorescence only, as is the case for the blue system, we should expect the λ 7900 band to be very weak compared with λ 3880, while in the comet the infrared radiation is as strong or stronger. From the intensity behavior in the blue system it is known that most *CN* molecules in the ground state $^2\Sigma$ are in the vibrational level $v'' = 0$. To reach the level $v' = 2$ of $^2\Pi$ from $^2\Sigma$, therefore, requires absorption in the (2, 0) band of low *f*-value, if the cometary emission results from fluorescence excitation.

However, it is possible that the *CN* molecules in the excited $^2\Pi$ level are actually formed in the process of photodissociation of a parent-molecule. In this case it would not be surprising to find a fairly high population on the level $v' = 2$. It would also be understandable that the red system does not extend so far out into the head as does the blue system.

On the whole, it appears very probable that the observed bands are actually the (2, 0) and (3, 1) transitions of the red system of *CN*, the *CN* molecules being excited to the $^2\Pi$ level in a process of photodissociation of a parent-molecule.

Our thanks are due to Dr. G. Herzberg for helpful suggestions and discussions and to Dr. J. Hunaerts for drawing the synthetic profiles. We want to acknowledge especially the considerable amount of observational help given by Dr. Jose, at the McDonald Observatory.

[23] These bands were hitherto numbered (1, 0) and (2, 1). Herzberg and Phillips have recently shown (private communication) that the vibrational numbering in the upper state must be shifted upward by one unit, the (0, 0) band being actually at 1.05 μ.

[24] A. S. King and P. Swings, *Ap. J.*, **101**, 6, 1945. The recent work by Herzberg and Phillips shows that the (0, 0) band at 1.05 μ is very strong, so that the total *f*-value of the whole red system may be of the same order as that of the blue system. However, here we are interested only in the *f*-value of the (2, 0) transition.

© American Astronomical Society • Provided by the NASA Astrophysics Data System