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THE SPECTRUM OF COMET WHIPPLE-FEDTKÉ-TEVZADZE (1942g)

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ABSTRACT

The results of wave-length measurements on eight spectrograms of Comet Whipple-Fedtké-Tevzadze (1942g) are presented. The spectrograms, obtained with relatively high spectral purity (projected monochromatic image of the slit at the plate $\sim$ 0.5 angstroms for λ 3880), cover the ordinary photographic region. In addition to a general consideration of the spectrum of the comet, several points of particular interest are discussed. These include, first, the resolution of the *R* branch of the λ 3883 0, 0 *CN* band into its individual lines and, second, results of increased resolution in the cases of several features of the λ 4050 group of CH_2 bands, in particular the duplicity of the main maximum at λ 4051. Third, reasons are given for believing that the emission at λ 4752, which for other comets has been attributed to the $C^{13}C^{13}$ isotopic carbon molecule, is not in the present instance due to this molecule. Fourth, the interesting but possibly fortuitous wave-length coincidences between certain weak cometary emissions and bands, ascribed tentatively to the molecule SiO_2, are noted.

INTRODUCTION

Comet Whipple-Fedtké-Tevzadze (1942g) was a relatively bright object, being between the third and fourth magnitude for a few days.[1] At the time of its maximum brilliance it was unusually well situated for observation from northern latitudes. During late February and early March, 1943, some time after perihelion, which occurred on February 6, 1943, the comet unexpectedly increased in brightness; and during this period twelve spectrograms of its head were obtained at Victoria. In securing these observations two purposes were kept in mind. The first was to obtain spectrograms of the heretofore neglected visible spectral region to the red of λ 5000. The second was to photograph the spectrum of the comet in the ordinary photographic region, below λ 5000, under conditions of the highest practicable spectral purity. Some of the twelve plates were obtained with panchromatic emulsions and were useful in both these spectral regions.

The study of the visual region of the spectrum of Comet 1942g has been completed and was published[2] in a joint paper with P. Swings and R. Minkowski, who had secured data on the same region of cometary spectra at the McDonald and the Mount Wilson observatories. The main point of interest in that study was the tentative identification of the molecule NH_2 as the source of several of the strongest visible emission bands. The present article presents the results of measurements on eight spectrograms covering the ordinary photographic region. While most of the emission features of which wave-length measurements are given have been measured as such in the spectra of previous comets, our increased spectral purity has made possible the resolution of others among them into components not detected up to the present time.

THE OBSERVATIONAL MATERIAL

The plates were obtained with the single-prism form of the universal spectrograph. Two different cameras were employed, one having a focal ratio f/3 and the other f/5. All the data concerning the spectrograms thought to be of interest or value are assembled in Table 1, and they require little comment. In addition to the high spectral purity mentioned earlier, one further point may be noted, namely, that during the period over

[1] See, e.g., J. Ashbrook, *Pop. Astr.*, **51**, 362, 1943; N. T. Bobrovnikoff, *Pop. Astr.*, **51**, 481, 1943.

[2] P. Swings, A. McKellar, and R. Minkowski, *Ap. J.*, **98**, 142, 1943.

which the plates were taken the comet was at the relatively large heliocentric distance, $r = 1.4$ astronomical units. Most slit spectrograms of comets have been secured at values of r of 1 astronomical unit or less. Further reference will be made to this later. The distance of Comet 1942g from the earth in late February and early March, 1943, was ~ 0.5 astronomical unit.

THE MEASUREMENTS

The results of the measurements on the eight plates are given in detail in Table 2. After a brief description of the spectral feature measured, the wave length as found from

TABLE 1

DATA ON SPECTROGRAMS OF COMET WHIPPLE-FEDTKÉ-TEVZADZE (1942g)

Date (U.T.)	Comet's Heliocentric Distance, r	Radial Velocity of Comet with Respect to Earth	Spectrographic Dispersion		Spectral Purity, Projected Slit-Width*		Photographic Emulsion	Qualiy of Spectrogram
			At λ 3880	At λ 4740	At λ 3880	At λ 4740		
	Astronomical units	km/sec						
1943, Feb. 24.535....	1.38	+7.9	57 A/mm	130 A/mm	0.85 A	1.94 A	Eastman 103a0	Good
25.485....	1.38	8.0	32	72	0.57	1.30	Eastman 103a0	Good
27.486....	1.39	8.3	57	130	0.85	1.94	Eastman 103F	Fair
28.481....	1.39	8.5	32	72	1.14	2.60	Eastman 103F	Good
Mar. 1.468....	1.40	8.6	57	130	0.50	1.14	Cramer Hi-speed	Excellent
3.467....	1.40	8.9	57	130	0.41	0.94	Cramer Hi-speed	Fair
7.469....	1.42	9.5	57	130	0.57	1.30	Eastman 103a0	Weak
9.460....	1.43	+9.8	57	130	0.50	1.14	Eastman 103a0	Good

* In expressing "spectral purity" in terms of the width in angstrom units of a monochromatic image of the slit at the plate, as we have done, it is assumed that the spectral lines have rectangular profiles. Therefore we are not adhering to the strict definition of "spectral purity" as given originally by Schuster. The latter definition makes it a function, among other things, of the aperture of the collimator. However, our usage indicates the maximum resolution to be expected and would seem to provide important information on resolving-power not shown by presenting the dispersion alone.

each plate is listed and is succeeded by the mean value from all the plates. Then follows the identification of the emitting molecule where this is known, and, finally, the laboratory wave length of the feature is given. Directly below the date in the second to the ninth columns, the quality of the spectrogram is noted.

Results of the individual wave-length measurements, obtained from the micrometer settings by the Hartmann dispersion formula, were calculated to the hundredth of an angstrom unit. Many of the emissions were so diffuse that the last figure has little significance. Thus, in obtaining the mean cometary wave length, in cases where either the number of individual measurements was only one or two or the feature was diffuse, the wave length has generally been given only to the tenth of an angstrom. In deriving the mean value, the wave lengths found from the plate of March 1.468, in view of its excellent quality, were given double the weight of each of the others.

TABLE 2

DETAILED WAVE-LENGTH MEASUREMENTS ON THE SPECTRUM OF COMET WHIPPLE-FEDTKÉ-TEVZADZE (1942g)

Spectral Feature	Feb. 24.535 (Good)	Feb. 25.485 (Good)	Feb. 27.486 (Fair)	Feb. 28.481 (Good)	Mar. 1.468 (Excellent)	Mar. 3.467 (Fair)	Mar. 7.469 (Weak)	Mar. 9.460 (Good)	Mean Cometary Wave Length	Identification	Laboratory Wave Length
Emission feature	3806.85(½)	...	...	...	...	...	...	...	3806.8(0+)	...	...
Emission line	...	...	...	...	3866.18(0+)	...	...	...	3866.18(0+)	0, 0 *CN* Band, *R*(12) line	3865.99*
Emission line	...	...	...	...	66.89(1s)	3867.20(1)	...	...	66.89(1s)	0, 0 *CN* Band, *R*(11) line	66.82*
Emission line	...	...	...	...	...		...	...			
Emission line				3867.49(2)	67.71(1+s)			3867.79(1s)	67.68(1+s)	0, 0 *CN* Band, *R*(10) line	67.62*
Emission line					68.44(1+s)			...	68.44(1+s)	0, 0 *CN* Band, *R*(9) line	68.41*
Emission line	68.91(5d)	3869.85(1d)	3868.80(2d)	69.88(3)	69.23(1+s)	69.85(1)	3868.87(1d)		69.23(1+s)	0, 0 *CN* Band, *R*(8) line	69.18*
Emission line					70.00(1½s)			70.11(1s)	70.04(1½s)	0, 0 *CN* Band, *R*(7) line	69.92*
Emission line					70.71(1½)			...	70.71(1½)	0, 0 *CN* Band, *R*(6) line	70.67*
Sharp minimum of intensity	71.53	72.07	71.49	71.06	71.43	71.79	71.80	71.24	(71.54)	Due to very strong *Fe* absorption lines λ 3878.0 and λ3878.7 in solar spectrum†	
Emission line	...	...	...	...	...	...	...	72.06(1s)	72.06(1s)	0, 0 *CN* Band, *R*(4) line	72.06*
Emission line	72.89(3)	73.32(1+)	73.00(½)	72.53(2d)	72.45(1½)	...	...	...	72.47(1½)	0, 0 *CN* Band, *R*(4)+ *R*(5) line	72.06* 72.72*
Emission line				...	73.45(1−)	73.25(½)	73.56(½)	73.51(1s)	73.47(1−s)	0, 0 *CN* Band, *R*(2) line	73.36*
Emission line				...	74.25(½−)	...	...	...	74.25(½−)	0, 0 *CN* Band, *R*(1) line	74.00*
Deep minimum (band origin)	74.93	74.75	74.70	75.09	75.08	74.87	75.09	74.93	(74.95)	0, 0 *CN* Band origin	75.20*
Emission feature	77.55(5)	77.04(2d)	77.27(2)	77.24(5)	77.33(2+d)	77.21(2)	77.43(2)	77.32(4)	77.30(4d)	0, 0 *CN* Band, *P*(3), (4), (5) lines	77.35*
Sharp minimum of intensity	78.43	78.56	78.49	78.44	78.67	78.52	78.42	78.52	(78.52)	Due to very strong *Fe* absorption lines λ 3878.0 and λ 3878.7 in solar spectrum†	
Center of intense remaining *P*-branch maximum of *CN* band	80.14(10)	79.67(3) 80.72(3)	80.08(4)	80.04(8)	80.24(5d)	80.15(5)	80.22(4)	80.15(6)	80.16(8d)	0, 0 *CN* Band, *P*-branch intensity maximum at about *P*(10) and *P*(11) lines	79.97* 80.33*
Possible minimum in this maximum	...	80.22	...	...	80.05	...	...	...	(80.11)	Possibly due to dip in solar spectrum from λ 3880.0 to λ 3880.4†	
Head (redward edge) of 0, 0 *CN* band	81.59	81.11	81.55	81.55	81.81	81.38	81.82	81.48	81.57	0, 0 *CN* band head, at about the *P*(15) line	3883.4‡*
Emission feature	3978.27(0+d)	...	...	...	...	...	...	...	3978.3(0d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	86.86(½d)	...	...	...	...	...	...	...	86.9(0+d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	92.17(1d)	...	...	...	...	...	...	...	92.2(½d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§

* H. S. Uhler and R. A. Patterson, *Ap. J.*, **42**, 434, 1915; F. A. Jenkins and D. E. Woolridge, *Phys. Rev.*, **53**, 137, 1938.

†See P. Swings, *Lick Obs. Bull.*, **19**, 131, 1941; A. McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942.

‡ Laboratory wave length dependent on excitation conditions, so exact coincidence with cometary wave length not to be expected.

TABLE 2—Continued

Spectral Feature	Feb. 24.535 (Good)	Feb. 25.485 (Good)	Feb. 27.486 (Fair)	Feb. 28.481 (Good)	Mar. 1.468 (Excellent)	Mar. 3.467 (Fair)	Mar. 7.469 (Weak)	Mar. 9.460 (Good)	Mean Cometary Wave Length	Identification	Laboratory Wave Length
Emission feature	...	...	...	...	4007.06(1−dd)	...	...	...	4007.1(½d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature					12.75(1)	...	...	...	12.8(1)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	4013.84(2dd)	4014.50(½)	...	4014.00(0+)	14.45(1)	...	...	...	14.37(1)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature					16.19(1)	...	...	...	16.2(1)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	19.48(3+)	19.26(½)	4019.92(0+)	19.57(½)	19.80(2+d)	4019.74(0+d)	...	4019.76(1d)	19.67(2d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	39.14(4)	39.01(1−d)	39.45(0+)	39.74(1)	39.70(3+d)	39.75(½)	...	39.53(2−d)	39.50(3)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Sharp minimum of intensity	40.96	41.05	...	41.26	41.33	41.16	...	41.25	(41.19)	Possibly due to strong sharp absorption lines in solar spectrum, *Fe*, λ 4041.28 and *Mn*, λ 4041.38	...
Emission feature	43.01(4)	42.48(2)	42.88(0+)	42.57(1)	43.30(3+d)	43.72(½)	...	43.27(2−d)	43.07(3)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Sharp minimum of intensity or absorption line	...	...	...	...	45.70	...	...	...	(45.70)	Due to very strong *Fe* absorption line in solar spectrum at λ 4045.83	
Emission feature	...	50.29(1+s)		50.39(2)	50.40(3s)		4050.65(½)		50.43(3s)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	51.53(8)	51.68(4)	51.57(4)	51.61(5)	51.79(6s)	51.49(3)	51.86(1+)	51.76(4)	51.75(6s)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	...	...	...	64.88(0)	...	...	...	...	64.9(0)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature					66.04(½d)	...	...	66.43(0+)	66.17(½)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	68.10(2dd)	...	...	67.80(½)	69.64(½+d)	...	...	70.17(½)	69.99(½+)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Sharp minimum of intensity or absorption line	71.68	...	...	...	71.47	...	...	71.80	(71.61)	Due to very strong *Fe* absorption line in solar spectrum at λ 4071.75	
Emission feature	74.01(6)	4074.44(½d)	7376.(1½)	74.44(2d)	73.96(3)	73.79(½d)	73.89(0+)	73.74(3)	74.00(3)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	89.14(1dd)	...	...	...	...	...	...	...	89.1(0+d)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	99.19(2−)	...	...	4100.39(½)	99.05(½s)	...	...	98.76(0+d)	99.29(½)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	...	...	...	...	4136.15(½d)	...	...	...	4136.2(0+)	λ 4050 group of CH_2 bands§	Lab λ not yet pub.§
Emission feature	4212.87(2)	4214.07(½+)	...	...	4212.68(1+)	4212.92(0+)	...	4212.23(½d)	4212.91(1+)	0, 1 *CN* band, intensity maximum of *P* branch	‡
Head (redward edge) of 0, 1 *CN* band	15.16	...	...	...	14.98	15.37	...	15.50	15.20	0,1 *CN* band head	4216.0‡

TABLE 2—*Continued*

Spectral Feature	Feb. 24.535 (Good)	Feb. 25.485 (Good)	Feb. 27.486 (Fair)	Feb. 28.481 (Good)	Mar. 1.468 (Excellent)	Mar. 3.467 (Fair)	Mar. 9.460 (Weak)	Mar. 7.469 (Good)	Mean Cometary Wave Length	Identification	Laboratory Wave
Emission feature	...	28.37(0+)	...	...	28.86(0+s)	...	...	27.44(0)	28.38(0+s)	CH^+ or SiO_2?	See Table 3
Emission feature	31.88(½s)	...	...	4232.04(½−s)	31.77(0+s)	...	...	32.22(0+s)	31.94(0+s)	CH^+?	See Table 3
Emission feature	...	...	...	...	35.61(0+s)	...	...	...	35.6(0)	CH^+ or SiO_2?	See Table 3
Emission feature	...	...	...	...	39.42(0)	...	...	...	39.4(0)	CH^+ or SiO_2?	See Table 3
Emission feature	...	...	...	...	...	...	...	57.69(0+s)	57.7(0)	SiO_2?	See Table 3
Emission feature	...	...	...	...	...	...	...	63.73(0+s)	63.7(0)	SiO_2?	See Table 3
Emission feature	...	...	...	...	4300.17(½ss)	...	...	...	4300.17(0+s)	0, 0 CH band, $R_2(1)$ line	4300.31‖
Emission feature	4303.65(0s)	...	...	4304.26(½s)	03.95(1−)	...	...	4303.72(0+s)	03.91(½s)	0, 0 CH band, $R_1(1)$ line	4303.88‖
Emission feature	13.28(2−)	...	4313.28(½+)	13.48(½+)	13.18(1)	...	...	13.03(1−)	13.24(1+)	0, 0 CH band; intensity maximum of Q branches	4313‡‖
Emission feature	...	...	...	...	29.77(0s)	...	...	...	29.77(0s)	0, 0 CH band, $P(3)$ line	4329.98‖
Emission feature	63.34(0+)	...	...	...	...	...	...	...	63.3(0)	4, 2 C_2 Swan band; intensity maximum of P branches	‡
Emission feature	4429.46(0+)	...	...	...	4432.72(½)	...	...	...	4431.6(½)	...	...
Emission feature	38.18(0+)	...	4437.73(0+)	...	38.32(½)	...	...	...	38.14(½)	...	...
Emission feature	46.57(0+)	4446.22(½s)	45.55(0+)	...	45.12(0+)	...	...	...	45.72(0+)	...	...
Emission feature	77.13(0+)	77.10(½s)	...	...	...	...	...	...	77.12(0+)	...	...
Emission feature	85.65(0+)	...	...	...	...	...	...	...	85.6(0)	...	...
Emission feature	4522.28(½s)	...	...	...	...	...	...	...	4522.3(0+s)	...	...
Emission feature	42.28(0)	...	...	...	...	...	...	...	42.3(0)	...	...
Emission feature	87.81(½d)	...	4590.40(0)	...	...	...	...	...	89.1(0)	...	...
Emission feature	4609.31(0+s)	...	...	...	4607.47(0+)	...	...	...	4608.1(0+)	...	...
Emission feature	14.95(0+s)	...	...	...	...	...	...	...	15.0(0)	...	...
Intensity maximum 5, 4 Swan band	78.25(1−)	...	...	...	76.81(1d)	...	...	4675.20(½+)	76.8(1−)	5, 4 C_2 Swan band; intensity maximum of P branches	‡
Intensity maximum 4, 3 Swan band	85.09(1−)	...	...	...	85.38(1d)	...	...	...	85.3(1d)	4, 3 C_2 Swan band; intensity maximum of P branches	‡
Intensity maximum 3, 2 Swan band	97.62(1−)	...	4696.30(1)	4696.77(1)	96.21(1+d)	...	...	96.59(1−)	96.6(1)	3, 2 C_2 Swan band; intensity maximum of P branches	‡
Head of 3, 2 Swan band	4700.00	...	...	97.95	...	...	...	...	98.6	Head of 3, 2 Swan band	4697.6¶
Intensity maximum 2, 1 Swan band	14.41(3)	4713.72(1)	4713.14(2)	4713.79(2)	4713.94(2)	...	...	4713.49(1d)	4713.8(2)	2, 1 C_2 Swan band; intensity maximum of P branches	‡
Head of 2, 1 Swan band	16.04	14.82	...	16.46	17.29	...	...	...	16.4	Head of 2, 1 Swan band	4715.2¶
Intensity maximum 1, 0 Swan band	36.16(4)	...	35.32(1)	36.55(3)	36.01(2)	...	...	35.74(1)	36.0(2)	1, 0 C_2 Swan band; intensity maximum of P branches	‡
Head of 1, 0 Swan band	39.02	...	...	38.17	37.91	...	...	...	38.2	Head of 1, 0 Swan band	4737.1¶
Emission feature	51.57(1−s)	...	...	...	53.45(½s)	...	...	...	52.8(½−)	...	...
Emission feature	...	...	...	...	78.96(0+)	...	...	...	79.0(0)	...	...
Emission feature	...	...	...	...	4821.58(0+d)	...	...	...	4821.6(0)	...	...
Emission feature	4836.31(½)	...	...	...	...	...	...	...	36.3(0)	C_2? Unassigned band reported by Fox and Herzberg?	4836.1**

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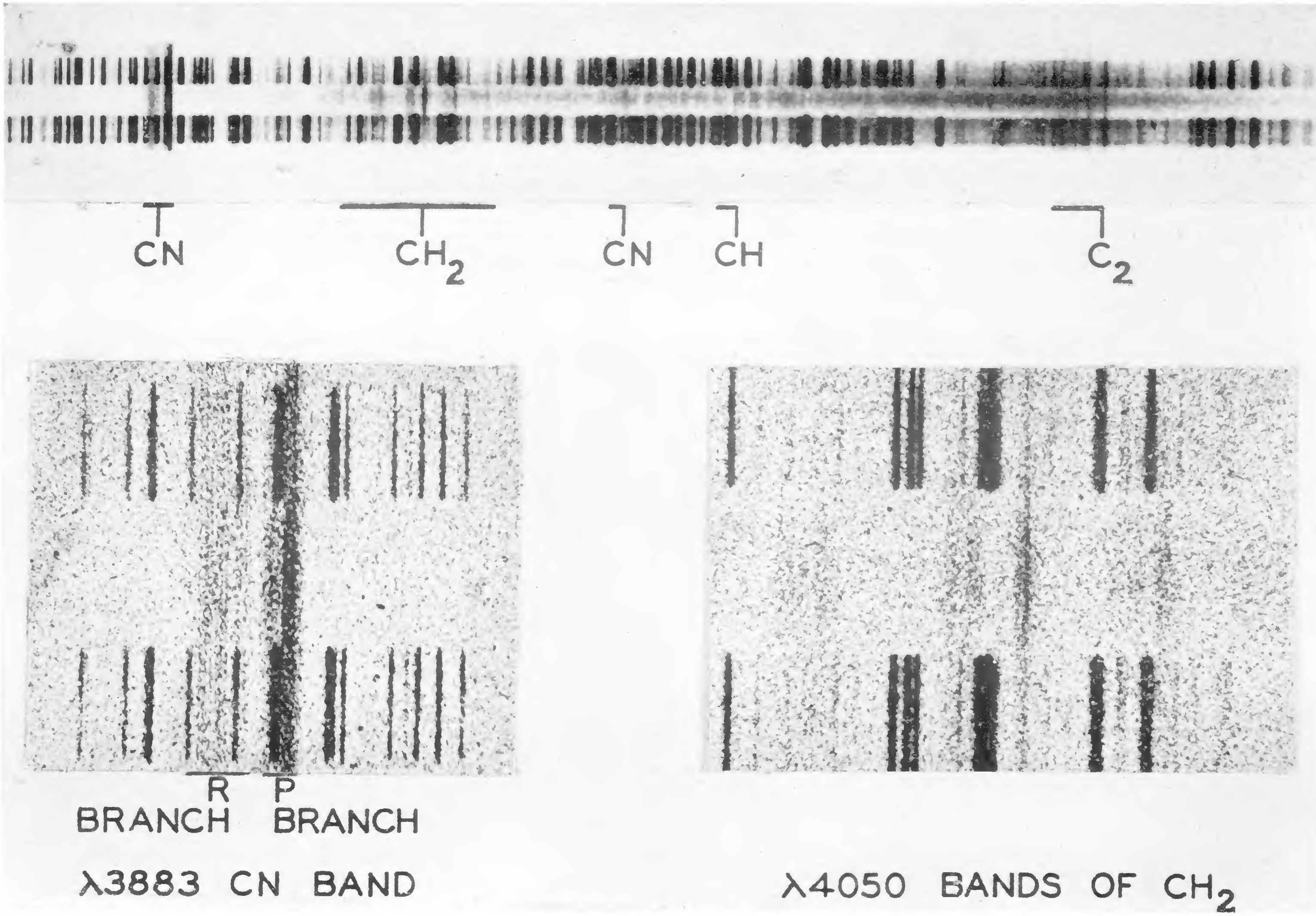
PLATE V



SPECTRA OF COMET WHIPPLE-FEDTKÉ-TEVZADZE (1942g)

Above, a reproduction of the spectrogram taken February 24, 1943. *Lower left*, λ 3883 *CN* band from the plate of March 1, 1943, greatly enlarged, showing resolution of rotational structure in the *R* branch. *Lower right*, λ 4050 group of CH_2 from the same plate. Note here the duplicity of the main maximum at λ 4051.

Three other points should be mentioned. First, the measured wave lengths were corrected to take account of the radial velocity of the comet with respect to the earth. Second, wave lengths of all band edges or band heads measured were further corrected for the effect of the lack of infinitely high spectral purity. That is, from the wave length of each red edge of an emission band measured, there was subtracted an amount equal to half the projected spectrographic slit width at that wave length, while this quantity was added to the wave lengths of the violet edges of the bands measured. Third, in the few cases in which an intensity minimum is identified as an actual Fraunhofer absorption line in the scattered solar spectrum (e.g., λ 4045) its wave length has been corrected also for the effect of the radial velocity of the comet with respect to the sun.

DISCUSSION

A reproduction of the spectrum of Comet 1942g is shown in Plate V. The most noteworthy feature of general interest regarding the spectrum of this comet, in the ordinary photographic region, is the relatively great strength of the λ 4050 group of bands due to CH_2. This group and the omnipresent and always strong λ 3883 0, 0 sequence of *CN* bands are the most outstanding of the emissions and are of approximately the same total intensity. The usually very strong λ 4737 1, 0 sequence of the Swan system of C_2 is less intense than either the *CN* or the CH_2 bands. The λ 4315 band of *CH* is faint but definitely measurable. These exceptional intensity ratios are doubtless a consequence of the considerable heliocentric distance of the comet, $r = 1.4$ astronomical units. At such a distance the breakdown of "parent" polyatomic molecules to form *CN*, *CH*, C_2, etc., by photodissociation under the influence of sunlight, has not proceeded to such an extent as at closer approach of the comet to the sun. Therefore, as pointed out previously,[3] the emission bands due to polyatomic molecules should be, and apparently are actually found to be, more intense with respect to those of diatomic molecules at the greater heliocentric distances. Much the same general observations as above and similar conclusions are contained in a brief note by Swings and Struve[4] on the spectrum of Comet 1942g.

THE BANDS OF *CN*

On every plate the λ 3883 0, 0 *CN* band exhibited the complex structure which has been the subject of study over the last few years.[5,6] This is evident from the measurements given in Table 2. One spectrogram, that of March 1, taken with projected slit width at λ 3880 of only 0.5 angstrom, showed unusually fine definition. The appearance of the band is shown in Plate V. On this plate the rotational structure of the *R* branch (nonhead-forming branch) of the λ 3883 band is just barely resolved. Reference to Table 2 will show that nearly all the individual lines from the short-wave-length extremity at the line *R*(12) up to the band origin have been measured. The intervals between successive lines are about 0.7–0.8 angstrom unit. In so far as the writer is aware, such resolution has not been obtained up to the present on the *CN* bands in the spectrum of any comet. Use will be made of this plate in a spectrophotometric study to determine the rotational distribution of the cometary *CN* molecules.

It will be noted in Table 2 that for the sharp lines in the *CN* band from *R*(12) to *R*(1), while the agreement between the accurate laboratory and the cometary wave lengths, determined mainly from one low-dispersion plate, is fairly good, there appears to be a small but definitely systematic difference between them. The mean difference for ten lines is λ (comet) − λ (lab.) = +0.09 angstrom unit. Unfortunately, there are no other spectral features with well-determined laboratory wave lengths and sharp enough in the

[3] See, e.g., P. Swings, *Rev. Mod. Phys.*, **14**, 190, 1942; G. Herzberg, *Rev. Mod. Phys.*, **14**, 195, 1942.

[4] P. Swings and O. Struve, *Pub. A.S.P.*, **55**, 150, 1943.

[5] P. Swings, *Lick Obs. Bull.*, **19**, 131, 1941.

[6] A. McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942.

cometary spectrum to test the reality of this difference, except, perhaps, the λ 4300 and λ 4304 lines of *CH*. The measurements of these are not definitive enough to permit a decision on this point. Under the circumstances of observation the existence of a systematic error of this amount cannot be excluded. If, however, the shift of wave length can be attributed to a physical cause which may be referred to the comet, the only obvious explanation would appear to be an average motion of recession (toward the tail of the comet), the line-of-sight component amounting to some 7 km/sec. While no definite conclusion can be drawn from the present observations, the matter is of sufficient interest to warrant further attention in the future when greater spectrographic power is available for studies of this kind.

The matters of the over-all wave-length range of the *CN* band and its general intensity distribution are worthy of note. In the present case the short-wave-length limit of the band is at λ 3866.2, the $R(12)$ line, and the long-wave-length limit at λ 3881.5, the $P(15)$ line. Thus the band appears to be developed to such an extent that lines originating from the rotational levels up to $K' = 14$ appear. The maximum of intensity in the P (head-forming) branch occurs at λ 3880.16, between the lines $P(10)$ and $P(11)$. For comet Cunningham (1940c), it was found[6] that, for the heliocentric distances $r = 0.92$ and $r = 0.54$, lines from levels up to about $K' = 25$ were present and the P-branch maximum occurred at $P(13)$ for $r = 0.92$ and $P(20)$ for $r = 0.54$. Dufay[7] had earlier found from examination of spectra of several comets that the K'' corresponding to the *CN* band maximum advanced from $K'' = 6$ to $K'' = 14$ as r decreased from 1.8 to 0.5 astronomical units. The general intensity profile of the *CN* band in the spectrum of Comet 1942g is thus in conformity with these recent suggestions regarding the increase in "rotational temperature" (the term "temperature" being used only in the sense referring to the relative populations of the molecular rotational states) with decreasing heliocentric distance. Also, it yields another point in establishing the quantitative relationship between r and the K'' corresponding to maximum intensity. The role in the determination of this intensity maximum played by the radial velocity of the comet with respect to the sun and discussed in references 5 and 6, must not be ignored.

The 0,1 sequence of the violet *CN* system at λ 4216 appeared on the plates with moderate intensity. In view of the smaller spectrographic dispersion compared with λ 3880 and the lower intensity of this sequence, nothing worth while is gained by a detailed discussion of it.

THE λ 4050 GROUP OF CH_2 BANDS

On the spectrogram of March 1, 1943, the resolution in the region of the λ 4050 group of bands was also very good. Plate V includes a reproduction of the group from this spectrogram. The projected slit width at λ 4050 was 0.60 angstrom. These bands have recently been shown by Herzberg[8] to be due to the triatomic molecule CH_2. A comprehensive résumé, including previous summaries of the wave lengths of this group of bands in the spectra of many comets, is given by Swings, Elvey, and Babcock.[9]

Measurements on the present plates have revealed certain structure not previously noted. Of perhaps most interest is the duplicity of the strongest emission feature at λ 4051. On four of the eight plates it has been found to be double, with components at λ 4050.43 and λ 4051.75, the component of longer wave length being perhaps a little over twice as intense as the other. On the plate of March 1, the region from λ 4013 to λ 4020 appears to contain four intensity maxima. Also, the duplicity of the emission at λ 4068, heretofore suspected, is confirmed, components being measured at λ 4066.17 and λ 4069.99.

7 J. Dufay, *C.R.*, **206**, 1948, 1938.

8 *Loc. cit.*; and *Ap. J.*, **96**, 314, 1942.

9 P. Swings, C. T. Elvey, and H. W. Babcock, *Ap. J.*, **94**, 342, 1941.

According to current ideas on the resonance or fluorescence origin of cometary emission bands, the observed intensity distributions over these bands would be expected to show certain definite differences from those encountered in laboratory studies. These differences would be a consequence of the intensity distribution over the region of the solar spectrum absorbed in the course of the production of the bands. In the case of the CH_2 bands, the three very strong *Fe* absorption lines at λλ 4045, 4063, and 4072 in the solar spectrum would doubtless have considerable effect in this way. They would cause intensity minima in the CH_2 bands at these three wave lengths and possibly other wave lengths, depending on the as yet unknown detailed band structure. The CH_2 bands shown in Plate V appear to exhibit this effect, particularly for λ 4072, where the emission centered at λ 4074 seems to be cut off sharply on its violet edge. The effect mentioned has, of course, to do only with the cometary *emissions*, not with that part of the cometary spectrum which is simply reflected or scattered solar radiation and which exhibits the normal Fraunhofer lines.

Unfortunately, the laboratory investigation and analysis of the λ 4050 group of CH_2 bands, from high-dispersion spectrograms, at present being conducted by Dr. Herzberg, is not yet completed. While it could be suggested that the main sharp maxima are probably *Q* branches, yet the detailed interpretation of the structural features of the band discussed above and of the intensity profile to be expected under cometary conditions of excitation cannot profitably be undertaken now. The band structure should be re-examined, however, when the complete laboratory data on the system become available.

THE SWAN BANDS OF C_2

As already noted, the Swan bands of C_2 appeared with somewhat lower intensity than usual. On the ordinary plates the 1, 0 sequence, λ 4737, was readily measured, and a trace of the 2, 0 sequence (the 4, 2 band) was found to be present. On the panchromatic plates the 0, 0 sequence, λ 5165, and the 0, 1 sequence, λ 5635, occurred.

One point of interest may be noted, namely, that on the two best plates a sharp emission feature was measured near λ 4752. This is the wave length of the head of the 1, 0 Swan band due to $C^{13}C^{13}$, the diatomic carbon molecule made up of two atoms of the carbon isotope of atomic weight 13. This band is the analogue of the λ 4737 Swan band due to ordinary $C^{12}C^{12}$.

The relative abundance of C^{12} to C^{13} has been reliably measured[10] in terrestrial samples of carbon as about 100 to 1. Also, a spectrographic analysis of some meteoritic samples[11] has indicated that the relative abundance of C^{13} in these is not sensibly greater than this value. If the abundance ratio C^{12} to C^{13} is a, the relative abundances of the isotopic molecular species $C^{12}C^{12}:C^{12}C^{13}:C^{13}C^{13}$ are as $a^2:2a:1$, that is, for terrestrial or meteoritic carbon, approximately 10,000:200:1.

Bobrovnikoff[12] and later Swings,[13] on the basis of their own measurements on the spectra of Comets Halley (1910) and Brooks (1911) and also Wright's measurements on the spectrum of Comet Brooks, concluded that the isotopic bands of $C^{12}C^{13}$ and $C^{13}C^{13}$ at λ 4745 and λ 4752 were present, hence that the carbon isotope, C^{13}, was a constituent of the heads of these comets. While this result is not specifically questioned, yet in the case of Comet 1942g the relatively low intensity of the main, $C^{12}C^{12}$, Swan system and also the absence of the $C^{12}C^{13}$ band head at λ 4745 lead us to conclude that the feature measured at λ 4752 is not due to the isotopic carbon molecule $C^{13}C^{13}$. Perhaps one would think that the fact that $C^{12}C^{13}$ is not a strictly homonuclear molecule and so probably has a different

[10] F. A. Jenkins and L. S. Ornstein, *Kon. Akad. v. Wetensch., Amsterdam*, **35**, 1212, 1932; A. O. Nier and E. A. Gulbransen, *J. Amer. Chem. Soc.*, **61**, 697, 1939.

[11] F. A. Jenkins and A. S. King, *Pub. A.S.P.*, **48**, 323, 1936.

[12] N. T. Bobrovnikoff, *Pub. A.S.P.*, **42**, 117, 1930; and *Pub. Lick Obs.*, **17**, 441, 1930.

[13] P. Swings, *Ap. J.*, **95**, 270, 1941; and *M.N.*, **103**, 86, 1943.

rotational distribution of molecules than $C^{12}C^{12}$ and $C^{13}C^{13}$ could be invoked to explain, partially at least, the absence of λ 4745. But the origin of this band is at about λ 4738, the band head occurs at about $K'' = 17$, and the rotational constant $B'' = 1.6$, so this argument is not strong. In any case, the matter of relative abundances inclines us to the view that in the present instance the emission at λ 4752 is due to some as yet unidentified emitter. Swings[13] has pointed out that for Comet Cunningham (1940c), on spectrograms on which the very intense Swan bands were strongly overexposed, there was no trace of the isotopic bands. He advances the suggestion that the relative abundance of C^{12} and C^{13} may be different in various comets. If our present view should be erroneous and the λ 4752 emission in the spectrum of Comet 1942g should actually be due to $C^{13}C^{13}$, this fact, together with the data on Comet Cunningham, would provide very strong evidence in favor of Swings's suggestion.

An additional point regarding the measured wave lengths of the heads of the 1,0, 2,1, and 3,2 bands of C_2 is evident from Table 2. These wave lengths are consistently about 1 angstrom unit greater than the laboratory values. Since, as was earlier stated, care was taken to correct the measured wave lengths by an amount equal to one-half the projected slit width, this cannot be the cause. No reason for this difference is apparent.

THE *CH* BANDS

While relatively weak, the λ 4315 0, 0 band of the $^2\Delta$, $^2\Pi$ transition was definitely present. The *Q*-branch maximum at λ 4313 and the sharp lines of the *R* branches at λ 4304 and λ 4300 were measured. No trace of the less intense band due to the $^2\Sigma$, $^2\Pi$ transition, with heads at λ 3872 and λ 3889, was detected.

OTHER EMISSIONS

Certain emission features occurring between the 0,1 *CN* band at λ 4216 and the *CH* band near λ 4300 may now be dealt with. Swings[13] has recently identified three of these at λλ 4231, 4238.5, and 4254.4 as the $R(0) + R(1)$, the $Q(1) + Q(2)$, and the $P(3)$ lines of the 0, 0 band of the violet CH^+ system. Incidentally, the first of these, suspected by Swings to be double on one of his plates, has been found to be so for Comet 1942g.

While examining wave-length material on the spectra of polyatomic molecules in connection with the spectrum of Comet 1942g, it was noted that the strongest bands of a system tentatively ascribed to SiO_2[14] occurred in this same region. Furthermore, it appeared that very good wave-length coincidences occurred between the most intense SiO_2(?) bands and certain of the cometary emissions. The state of affairs in this respect is presented in Table 3, which gives five columns containing data on the spectra of comets, followed by columns giving the laboratory wave lengths of CH^+ band lines and of SiO_2(?) band heads and intensity maxima. The letters "V," "R," and "M" following the wave length in the last column indicate the heads of bands degraded to the violet, those degraded to the red, and headless bands, respectively. All the numbers in parentheses give relative intensity estimates except in the CH^+ column, where, of course, they refer to the rotational quantum numbers used to designate the band line. When considering the wave-length region covered in Table 3, it should be called to mind that the two molecules responsible for all the emission bands known in the spectra of cometary tails have bands in this region. There are CO^+ band heads at λλ 4248.9, 4252.4, 4272.0, and 4274.3; and there are N_2^+ band heads at λ 4236.5 and λ 4278.1.

Strangely, the wave lengths of the CH^+ band lines and the SiO_2(?) bands are very similar, and the general agreement between cometary and laboratory values for the two molecular spectra is about the same. Favoring the conclusion that some of the cometary

[14] R. C. Pankhurst, *Proc. Phys. Soc.* (London), **52**, 707, 1940; R. W. B. Pearse and A. G. Gaydon, *The Identification of Molecular Spectra*, pp. 179–80, London: Chapman & Hall, Ltd., 1941; L. H. Woods, *Phys. Rev.*, **63**, 426, 1943.

emissions may be due to SiO_2(?) are (1) the close wave-length coincidences and (2) the fact that the bands occur in the comet spectrum at the heliocentric distance $r = 1.4$. Opposing this conclusion is the following greater number of points: (1) The lines at λ 4228 and λ 4232 are definitely sharp and so are more likely to be the single lines of the CH^+ band. (2) SiO_2 (quartz) in solid form is a most refractory compound and, if present in molecular form, must have been formed by dissociation of some parent polyatomic molecule. No obvious parent comes to mind. In this connection carbon is also very nonvolatile, and yet C_2 bands appear in the coolest hydrocarbon flames and in cometary spectra,

TABLE 3

COMETARY EMISSION BANDS IN THE λλ 4230–4280 REGION

Comet Whipple-Fedtké-Tevzadze (1942g) r=1.4 A.U.	Comet Cunningham (1940c)* $r\sim0.6$	Comet Brooks (1911c)† $r\sim0.5$	Comet Halley (1910)‡ $r\sim0.7$	Unidentified Nuclear Emissions, Summary by Baldet (1926)§	Wave Lengths of Lines of the 0,0 CH^+ Band‖	Wave Lengths of Bands Due to SiO_2(?)¶
....	....	....	......	....	4225.26 } $R(4)$ line	....
....	....	....	......	....	4225.69 } $R(3)$	....
....	....	....	......	....	4225.80 } $R(5)$	....
....	....	....	......	....	4227.06 $R(2)$	....
4228.4(0+s)	4229.1(1)	....	......	....	4229.34 $R(1)$	4228.5V(9)
....	....	4230(0)(long line tail)	......	4230(1)	....	....
4231.9(0+s)	4231.8(1)	....	4231.2	....	4232.54 $R(0)$	....
4235.6(0)	....	....	......	....	4237.56 $Q(1)$	4235.5V(10)
4239.4(0)	4240.4(1−2n)	4238.5(0)(long line, tail)	......	4238(1)	4239.37 $Q(2)$	4240 M(10)
....	....	....	......	....	4242.11 $Q(3)$	....
....	....	....	......	....	4247.57 $P(2)$	....
....	....	....	......	....	....	4252.4V(6)
....	4254.3(1n)	4254.5(0+)(long line, tail)	......	4255.8(2)	4254.38 $P(3)$	4254.4R(7)
4257.7(0)	....	....	......	....	....	4256.6R(8)
4263.7(0)	....	4265(0)	4264.5	4264.2(2)	4262.13 $P(4)$	4262.8R(6)
....	....	....	......	....	....	4269.6R(4)
....	....	4277.2(long line, CO^+?)	......	....	....	4274.5R(4)
....		....	4283.0	....	....	4283 M(9)

* P. Swings, *Ap. J.*, **95**, 270, 1942; *Contr. Lick Obs.*, Ser. II, No. 3.

† W. H. Wright, *Lick Obs. Bull.*, **7**, 8, 1912.

‡ N. T. Bobrovnikoff, *Lick Obs. Pub.*, **17**, 445, 1931.

§ F. Baldet, *Ann. obs. Astr. phys. Paris*, **7**, 58, 1926.

‖ A. E. Douglas and G. Herzberg, *Canad. J. Research*, **20**, 71, 1942.

¶ R. C. Pankhurst, *Proc. Phys. Soc.* (London), **52**, 707, 1940; R. W. B. Pearse and A. G. Gaydon, *The Identification of Molecular Spectra*, pp. 179–80, Chapman & Hall, Ltd., 1941; L. H. Woods, *Phys. Rev.*, **63**, 426, 1943.

where, of course, the molecular carbon results from dissociation. Also, Bobrovnikoff states[15] that for Comet 1882 I at $r = 0.87$ before perihelion and for Comet 1914 V at $r = 1.21$, the sodium D lines were observed in emission, despite the fact that the boiling-point of sodium is 877° C and, at $r = 1$, the temperature of a black body is only around 0° C. (3) If SiO_2 were present, one might expect to find bands due to SiH and SiN and perhaps CO_2 in the spectrum of the same comet. A careful search in the present case has not revealed these bands. (4) We do not know whether or not the bands produced in the laboratory and ascribed to SiO_2(?) arise from the ground state of the molecule, a condi-

[15] N. T. Bobrovnikoff, *Rev. Mod. Phys.*, **14**, 171, 1942.

tion necessary for their appearance by resonance and virtually necessary for appearance by fluorescence under cometary conditions.

It must be remembered that the emissions we have been considering in this section are among the weaker ones occurring in cometary spectra. In view of this and also the evidence against the significance of the possible SiO_2(?) origin of the bands, as opposed to the less weighty favorable evidence, the writer is inclined to the belief that the SiO_2(?) bands are probably not present. Nevertheless, it was thought worth while to discuss the matter as we have done, for it cannot be said to be settled with certainty. Two future developments—first, better observational data on bright comets and, second, further laboratory work on the SiO_2(?) bands, clarifying their molecular origin and including their detailed vibrational and rotational analysis—should enable a definite conclusion to be reached on the matter.

There still remain in Table 2 about a dozen unidentified emission features. Study of all available laboratory data on molecular spectra has failed to reveal any reasonable identification for them. The recent studies resulting in evidence for the occurrence of CH_2 bands and probably NH_2 bands in cometary spectra would seem to enhance the possibility that an appreciable portion of these unidentified features may subsequently be found to arise from polyatomic rather than from diatomic molecules.

In conclusion, the need for and the value of good future spectrographic observations of comets should be emphasized. In the dicussion of the measurements which are the basis of the present paper there have arisen several problems, including possibly significant wave-length shifts of the sharp CN band lines, the identification of the weak λ 4752 emission with the $C^{13}C^{13}$ band, and the identification of emissions in the λλ 4230–4280 region, which cannot be settled with the data now at hand. Only by the study of better cometary spectrograms—and there is no substitute for these—can conclusive answers to the above questions be advanced. When the occurrence of a bright comet makes it possible, slit spectrograms secured with the highest practicable combination of dispersion and spectral purity should be obtained. Relatively few observatories have the telescopic and spectrographic equipment necessary for obtaining such spectra, and, when such factors as the transitory nature of comets and the diffuseness of even their nuclei are considered, it is understandable why so few high-purity cometary spectrograms have been secured. In urging that steps be taken to remedy this deficiency, by those who may be in a position to do so when a new bright comet should appear, we may state with certainty that such cometary spectrograms, when obtained, will be of great value. Not only will they help us to arrive at decisions on the above-mentioned matters, but also they will doubtless bring forward, and aid in the solution of, other and important problems in cometary physics.