Revista Mexicana de Astronomía y Astrofísica, **35**, 65–83 (1999)

CHEMICAL COMPOSITION AND TEMPERATURE FLUCTUATIONS IN M17

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Received 1999 February 12; accepted 1999 February 24

RESUMEN

Presentamos espectroscopía echelle en dos posiciones de la región H II galáctica M17. Las observaciones cubren el intervalo de 3500 a 10,300 Å y fueron hechas con el telescopio de 2.1-m del Observatorio Astronómico Nacional en San Pedro Mártir, Baja California. Hemos medido las intensidades de 160 líneas de emisión, en particular 36 líneas permitidas de C^+, N^0, N^+, N^{++}, O^0, O^+, Ne^0, Si^0 y Si^+. Hemos determinado temperaturas y densidades electrónicas a partir de cocientes de líneas de emisión. También hemos determinado abundancias para un gran número de iones y elementos a partir de líneas excitadas colisionalmente. Hemos obtenido abundancias de H^+, He^+, C^{++} y O^{++} a partir de líneas de recombinación, abundancias que son prácticamente independientes de la estructura de temperatura de la nebulosa. Hemos determinado valores precisos de t^2 comparando las abundancias de O^{++} determinadas por medio de líneas excitadas colisionalmente y por medio de líneas de recombinación. Comparamos las abundancias solares, las de M17 y las de otras regiones H II galácticas. Determinamos gradientes de composición química como función de la distancia al centro de la Galaxia para He, C, N, O, Ne, S, Cl y Ar. Obtenemos cocientes de abundancias que deben ser ajustados por modelos de evolución química de la Galaxia y que permiten discriminar entre modelos que han sido propuestos recientemente.

ABSTRACT

We present echelle spectroscopy in the 3500 to 10,300 Å range for two positions of the galactic H II region M17. The data have been obtained using the 2.1-m telescope at Observatorio Astronómico Nacional in San Pedro Mártir, Baja California. We measure the intensities of 160 emission lines, in particular 36 permitted lines of C^+, N^0, N^+, N^{++}, O^0, O^+, Ne^0, Si^0, and Si^+. We determine electron temperatures and densities using different line intensity ratios as well as abundances from collisionally excited lines for a large number of ions and elements. We derive the He^+, C^{++} and O^{++} ionic abundances from recombination lines, these nebular values are almost independent of the temperature structure of the nebula. We determine accurate t^2 values by comparing the O^{++} ionic abundance obtained from collisionally excited lines and recombination lines. A comparison of the chemical abundances of the Sun, M17, and other galactic H II regions is made. We present strong observational constraints based on abundance ratios and compare them with recent models of galactic chemical evolution.

Key words: **H II REGIONS — ISM: ABUNDANCES — ISM: INDIVIDUAL (M17) — LINE IDENTIFICATION**

1. INTRODUCTION

Messier 17 (M17), also known as the Omega nebula, NGC 6618, or W28 is one of the brightest H II regions of the Galaxy. The western edge of the optical nebula is bounded by a dense molecular cloud, M17SW (Lada 1976; Thronson & Lada 1983), which is a site of active star formation. Hanson & Conti (1995) have identified a group of O3–O6 stars located in the dark bay. These stars are responsible for most of the nebular ionization. M17 is one of

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the galactic H II regions with the highest degree of ionization.

M17 has been intensely studied in all spectral ranges. A comprehensive review of optical, infrared, and radio observations of this object up to 1975 can be found in Goudis (1976). The chemical composition of the nebula has been studied extensively by Peimbert, Torres-Peimbert, & Ruíz (1992; hereafter PTR) making use of low resolution optical spectrophotometry in different slit positions.

Traditionally, the abundance studies for ionized nebulae have been based on determinations from forbidden lines, which are strongly dependent on temperature variations over the observed volume. Recently, with the increase of sensitivity of spectrographs and detectors, it has been possible to obtain accurate measurements of recombination lines of heavy elements in bright nebulae. It is well known that the intensity of these lines (and specially their ratio relative to H I recombination lines) are almost independent of electron temperature and therefore, of the possible spatial variation of this parameter along the nebula. This fact makes recombination line ratios more precise indicators of the true nebular chemical abundances.

This is the third paper of a series devoted to the analysis of high signal-to-noise, high resolution spectroscopy of the brightest galactic H II regions (the Orion nebula: Esteban et al. 1998, hereafter EPTE; M8: Esteban et al. 1999, hereafter EPTGR). These new data have allowed: a) to obtain accurate line intensities of a large number of permitted lines of heavy elements avoiding the problem of line blending, and b) to compare ionic abundances determined from forbidden collisionally excited lines with those obtained from recombination lines of the same ion. A common result of these previous papers is that the ionic abundances derived from recombination lines are systematically higher than those obtained from collisionally excited lines. In the case of the Orion nebula, EPTE have obtained O^{++}/H^{+} and C^{++}/H^{+} ratios from recombination line intensities which are a factor of 1.5 and 1.75 larger, respectively, than those obtained from forbidden lines. On the other hand, for M8 EPTGR have found differences between the abundances obtained from recombination and collisionally excited lines of 1.25, 2.0, and 2.15 for O^{+}, O^{++} and C^{++}, respectively. These discrepancies can be interpreted in terms of the effect of temperature fluctuations, t^2, of the order of 0.024 for Orion and 0.032 for M8.

There are some previous determinations of t^2 for M17. PTR have obtained values of 0.036 ± 0.020 and 0.045 ± 0.019 for the two slit positions observed in common with this work from the ratio of Balmer lines to the Balmer continuum. On the other hand, Peimbert, Storey, & Torres-Peimbert (1993a) have estimated values of t^2 of 0.031 ± 0.012 and 0.028 ± 0.012 for the same slit positions from the comparison between O^{++} abundances derived from collisionally excited and recombination lines. These last authors make use of the low resolution spectroscopic data obtained by PTR.

2. OBSERVATIONS AND REDUCTIONS

The observations were carried out with the 2.1-m telescope (in its f/7.5 configuration), of the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, México, on 1995 August and 1996 June. High resolution CCD spectra were obtained using the REOSC Echelle Spectrograph (the general characteristics of this instrument are reported by Levine & Chakrabarty 1994). The spectrograph gives a resolution of 0.234 Å pixel^{-1} at Hα using the University College London (UCL) camera and a

TABLE 1

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Zone	Date	$\Delta\lambda$ (Å)	Orders	Exp. Time (s)	Designation
Position 3	1995 Aug. 22	3500–5950	38–63	3600	Blue Range
	1995 Aug. 23	4600–7075	30–46	300, 4800	Red Range
	1996 Jun. 10	6450–9100	25–34	300, 3600	First NIR[a] Range
	1996 Jun. 13	8450–10,300	22–26	1800	Second NIR[a] Range
Position 14	1995 Aug. 24	3500–5950	38–63	3600	Blue Range
	1996 Jun. 11	6450–9100	25–34	300, 2700	First NIR[a] Range
	1996 Jun. 13	8450–10,300	22–26	2100	Second NIR[a] Range

[a] Near-infrared.

CCD-Tek chip of 1024 × 1024 pixels with a 24 μm^2 pixel size. The spectral resolution is of 0.5 Å FWHM and the accuracy in the wavelength determination of emission lines is of 0.1 Å.

We obtained spectra in four (three in the case of Position 14) overlapping wavelength intervals covering a very wide spectral range from 3500 to 10,300 Å. Typically, three or four individual exposures were added to obtain the final spectra in each range.

Slits covering 13.3″ × 2″ in the blue exposures, 26.6″ × 2″ in the red ones and 39.9″ × 2″ in both near-infrared (NIR) exposures were used to avoid overlapping between orders. We used two slit positions on the nebula, which were observed previously by PTR. For consistency, we adopted the same designation as these authors to refer the two slit positions. Position 3 is centered at 250″S and 54″W of the star BD−16°4819 and Position 14 at 300″S and 72″E relative to the same star. The slit orientation was east-west in all cases. A journal of the observations is presented in Table 1.

We used a Th-Ar lamp for wavelength calibration in all spectral ranges and a tungsten bulb for internal flat-field images. The absolute flux calibration of the blue and red spectra was achieved by taking echellograms of the standard stars HR 7596, HR 7950, and HR 8634; for both NIR spectra the standard stars were HR 4963, HR 5501, and HR 7596. All the stars are from the list of Hamuy et al. (1992) which includes bright stars with fluxes sampled at 16 Å steps. An average curve for atmospheric extinction was used (Schuster 1982).

The spectra were reduced using the IRAF[3] echelle reduction package following the standard procedure of bias subtraction, aperture extraction, flatfielding, wavelength calibration and flux calibration.

3. LINE INTENSITIES

Line intensities were measured integrating all the flux in the line between two given limits and over a local continuum estimated by eye. In the cases of line-blending, the line flux of each individual line was derived from a multiple Gaussian profile fit procedure. All these measurements were made with the SPLOT routine of the IRAF package.

In the cases of the red and first NIR spectra, we took additional 300 s exposures to avoid problems of saturation of Hα, the brightest emission line in these spectral ranges. All the line intensities of a given spectrum have been normalized to a particular bright recombination line present in each wavelength interval. For the blue range the reference line was Hβ; for the red range He I λ5876; for the first NIR range He I λ7065; and for the second NIR range H I P13 λ8665. To have a final homogeneous set of line intensity ratios referred to the same line, the relative line intensities of each spectra were re-scaled to Hβ by means of the different flux ratios of those recombination lines measured in consecutive spectral ranges. For Position 14 we do not have the red spectrum and, therefore, there is no overlap between the blue and first NIR spectra; therefore, to refer the line intensity ratios with respect to Hβ, we have assumed the theoretical value of Hα/Hβ for the physical conditions and reddening coefficient determined for this zone (see § 4).

The different spectral orders covered have overlapping regions at the edges. In these regions the optical sensitivity drops, the line intensities are not accurate and, therefore, they have not been considered. For the lines in common in two consecutive orders with good flux measurement, i.e., not detected at the edge of the order, the line intensity was calculated as the average of the values obtained in both orders. We estimate that the accuracy of the relative flux calibration achieved among the different orders is about 3–5 per cent from the comparison of pairs of well measured fluxes of the same line and their underlying continua. In addition, each consecutive pair of spectral intervals covered have a common region where it is possible to measure the same lines. The differences between the relative fluxes of a given line (with respect to the same reference line) obtained in the spectra of two consecutive spectral ranges do not present any systematic trend that could be related to anomalies in the relative flux calibration. The final intensity of a given line in the overlapping regions was the average of the values obtained in the different consecutive spectra. The final list of observed wavelengths and line intensities relative to Hβ for both slit positions is presented in Table 2. The observational errors associated with the line flux intensities (including all the possible sources of uncertainties in line intensity measurement and flux calibration) are estimated to be 2–5 per cent (0.01–0.02 dex), if the ratio $F(\lambda)/F(\mathrm{H}\beta) \geq 0.1$; about 10 per cent (0.04 dex) when $0.01 < F(\lambda)/F(\mathrm{H}\beta) < 0.1$, and about 20 per cent (0.08 dex) when $0.001 < F(\lambda)/F(\mathrm{H}\beta) < 0.01$. For lines weaker than $0.001 \times F(\beta)$, the uncertainty could be ≤ 30 per cent (0.12 dex); colons indicate uncertainties ≤ 40 per cent (0.16 dex).

For a given line, the observed wavelength (referred to the heliocentric reference frame; fourth and seventh columns of Table 2) is determined by the centroid of a Gaussian fit (performed for every emission line even for single ones). For a line observed in different spectra and orders, we have adopted the average wavelength of the different measurements.

The identification and adopted laboratory wavelengths (first column of Table 2) of the lines were obtained following previous identifications in the Orion nebula made by EPTE and Osterbrock,

[3] IRAF is distributed by NOAO, which is operated by AURA, under cooperative agreement with NSF.

TABLE 2

OBSERVED AND REDDENING-CORRECTED LINE RATIOS AND IDENTIFICATIONS

λ_0 (Å)	Ion	Multiplet	Position 3 λ (Å)	Position 3 $F(\lambda)$	Position 3 $I(\lambda)$	Position 14 λ (Å)	Position 14 $F(\lambda)$	Position 14 $I(\lambda)$
3691.56	H I	H18	3691.43	0.293:	0.838:	...	...	...
3697.15	H I	H17	...	...	...	3697.16	0.608	1.23
3703.86	H I	H16	3703.87	0.206:	0.601:	3703.86	0.540	1.11
3705.04	He I	(25)	...	...	...	3705.04	0.362	0.742
3711.97	H I	H15	3712.06	0.246	0.709	3711.96	0.840	1.71
3721.83 3721.94	[S III] H I	(2F) H14	3721.89	0.912	2.61	3721.83	1.26	2.57
3726.03	[O II]	(1F)	3726.09	8.65	24.7	3726.02	21.8	44.1
3728.82	[O II]	(1F)	3728.83	7.51	21.3	3728.76	21.8	44.0
3734.37	H I	H13	3734.39	0.534	1.50	3724.33	1.18	2.38
3750.15	H I	H12	3750.08	0.727	2.02	3750.08	1.61	3.19
3770.63	H I	H11	3770.65	1.18	3.20	3770.60	1.75	3.43
3797.90	H I	H10	3797.85	1.47	3.89	3797.83	3.04	5.84
3819.61	He I	(22)	...	...	...	3819.56	0.642	1.22
3835.39	H I	H9	3835.36	2.20	5.59	3835.37	3.51	6.58
3853.66	Si II	(1)	3853.92	0.224:	0.558:	...	...	...
3856.02	Si II	(1)	...	...	...	3855.89	0.173	0.319
3864.45	O II	(12)	3864.69	0.357	0.797	...	...	...
3868.75	[Ne III]	(1F)	3868.71	7.13	17.5	3868.66	9.78	17.9
3888.65 3889.05	He I H I	(2) H8	3888.92	4.89	11.8	3888.86	9.59	17.3
3964.73	He I	(5)	3964.69	0.357	0.797	3964.67	0.563	0.966
3967.46	[Ne III]	(1F)	3967.42	2.55	5.68	3967.42	3.18	5.46
3970.07	H I	Hϵ	3970.01	5.64	12.5	3970.07	9.01	15.4
4026.19	He I	(18)	4026.16	1.01	2.13	4026.16	1.20	1.98
4068.60	[S II]	(1 F)	...	...	...	4068.68	0.295	0.475
4101.74	H I	Hδ	4101.71	11.0	21.7	4101.69	16.5	26.0
4267.26	C II	(6)	4267.14	0.229	0.399	4267.12	0.356	0.517
4340.47	H I	Hγ	4340.43	28.3	46.9	4340.42	34.7	48.8
4363.21	[O III]	(2F)	4363.26	0.709	1.16	4363.16	0.746	1.04
4368.25	O I	(5)	4368.12	0.121:	0.196:	...	...	...
4369.28[a]	O II	(26)	4368.96	0.144:	0.233:	...	...	...
4387.93	He I	(51)	...	...	...	4387.90	0.428	0.583
4437.55	He I	(50)	4437.58	0.083:	0.125:	...	...	...
4471.48	He I	(14)	4471.49	3.15	4.58	4471.48	3.85	4.96
4638.85	O II	(1)	4638.82	0.065:	0.080:	4638.76	0.113	0.130
4640.64	N III	(2)	...	...	...	4640.63	0.054:	0.062:
4641.81	O II	(1)	4641.78	0.141	0.174	4641.80	0.124	0.143
4643.09	N II	(5)	...	...	...	4643.19	0.087	0.100
4649.14	O II	(1)	4649.16	0.103	0.126	4649.33	0.099	0.113
4650.84	O II	(1)	4650.98	0.100:	0.122:	4650.88	0.089	0.102
4658.10	[Fe III]	(3F)	4658.16	0.221	0.267	4658.12	0.266	0.302
4661.64	O II	(1)	4661.61	0.105	0.127	4661.65	0.110	0.125
4701.62	[Fe III]	(3F)	...	...	...	4701.56	0.107	0.119

TABLE 2 (CONTINUED)

λ_0 (Å)	Ion	Multiplet	Position 3 λ (Å)	Position 3 $F(\lambda)$	Position 3 $I(\lambda)$	Position 14 λ (Å)	Position 14 $F(\lambda)$	Position 14 $I(\lambda)$
4711.34	[Ar IV]	(1F)	4711.58	0.065	0.075	...	...	...
4713.14	He I	(12)	4713.17	0.507	0.584	4713.12	0.444	0.488
4740.20	[Ar IV]	(1F)	4740.20	0.057	0.064	...	...	...
4754.70	[Fe III]	(3F)	4754.71	0.054:	0.060:	...	...	...
4861.33	H I	Hβ	4861.34	100	100	4861.30	100	100
4881.00	[Fe III]	(2F)	4881.13	0.072	0.071	4880.98	0.080	0.079
4921.93	He I	(48)	4921.88	1.42	1.34	4921.91	1.37	1.32
4924.50	[Fe III]	(2F)	4924.48	0.069	0.065	...	...	...
4958.91	[O III]	(1F)	4958.97	145	133	4958.91	121	114
4985.90	[Fe III]	(2F)	...	...	...	4985.74	0.064	0.059
5006.84	[O III]	(1F)	5006.90	453	397	5006.82	369	337
5015.68	He I	(4)	5015.66	2.78	2.41	5015.63	2.65	2.41
5041.03	Si II	(5)	5041.02	0.171	0.145	5040.96	0.137	0.123
5047.74	He I	(47)	5047.72	0.220	0.186	5047.72	0.192	0.171
5055.98 5056.31	Si II Si II	(5) (5) }	5056.05	0.194	0.163	5056.11	0.136	0.121
5191.82	[Ar III]	(3F)	5191.70	0.067	0.050	5191.83	0.055	0.045
5197.90	[N I]	(1F)	5197.82	0.114	0.085	5198.05	0.082	0.067
5200.26	[N I]	(1F)	5200.19	0.081	0.061	5200.42	0.071	0.058
5270.40	[Fe III]	(1F)	5270.55	0.185	0.131	5270.47	0.173	0.137
5342.40	C II	17.06	5342.30	0.039	0.026	5342.30	0.048	0.036
5517.71	[Cl III]	(1F)	5517.80	0.865	0.500	5517.73	0.674	0.466
5537.88	[Cl III]	(1F)	5537.93	0.773	0.440	5537.84	0.553	0.379
5666.64	N II	(3)	5666.77	0.104	0.053	...	...	...
5679.56	N II	(3)	5679.68	0.175	0.088	5679.52	0.065	0.041
5754.64	[N II]	(3F)	5754.70	0.447	0.211	5754.61	0.445	0.268
5875.67	He I	(11)	5875.70	34.2	14.6	5875.64	24.8	14.0
5931.79[a]	N II	(28)	5932.32	0.322	0.132	...	...	...
5941.65	N II	(28)	5941.58	0.050:	0.020:	...	...	...
5952.39[a]	N II	(28)	5952.92	0.287	0.116	...	...	...
5978.93	Si II	(4)	5979.11	0.106	0.042	...	...	...
6300.30	[O I]	(1F)	6299.92	1.99	0.648	...	...	...
6312.10	[S III]	(3F)	6312.20	4.22	1.33	...	...	...
6347.09	Si II	(2)	6347.39	0.594	0.189	...	...	...
6363.78	[O I]	(1F)	6363.31	0.680	0.213	...	...	...
6371.36	Si II	(2)	6371.44	0.371	0.116	...	...	...
6401.50 6402.25	[Ni III] Ne I	(2F) (1) }	6401.77	0.123	0.038	...	...	...
6461.95	C II	(17.04)	6461.93	0.202	0.060	...	...	...
6548.03	[N II]	(1F)	6548.32	19.7	5.55	6548.18	18.3	7.84
6562.82	H I	Hα	6562.86	1075	301	6562.83	640	272
6578.05	C II	(2)	6578.09	3.365	0.943	6578.02	0.678	0.287
6583.41	[N II]	(1F)	6583.65	190	18.0	6583.48	58.4	24.6
6666.94	O II	(85)	6666.97	0.067:	0.018:	...	...	...
6678.15	He I	(46)	6678.28	16.4	4.34	6678.37	9.35	3.82
6716.47	[S II]	(2F)	6716.71	11.0	2.84	6716.65	10.7	4.31
6730.85	[S II]	(2F)	6731.10	12.4	3.19	6730.99	10.5	4.21

TABLE 2 (CONTINUED)

λ_0 (Å)	Ion	Multiplet	Position 3 λ (Å)	Position 3 $F(\lambda)$	Position 3 $I(\lambda)$	Position 14 λ (Å)	Position 14 $F(\lambda)$	Position 14 $I(\lambda)$
?			6863.36	0.483	0.117	...	...	...
7065.28	He I	(10)	7065.87	20.8	4.68	7065.10	9.56	3.47
7135.78	[Ar III]	(1F)	7135.93	61.5	13.2	7135.88	36.1	12.8
?			7160.64	0.108	0.023	7160.63	0.045	0.017
7231.12	C II	(3)	7231.38	0.669	0.138	7231.37	0.352	0.122
7236.19	C II	(3)	7236.61	1.131	0.233	7236.55	0.771	0.267
7281.35	He I	(45)	7281.27	3.32	0.670	7281.27	1.69	0.577
7319.65	[O II]	(2F)	7320.43	4.85	0.964	7320.36	3.29	1.11
7330.16	[O II]	(2F)	7330.56	4.40	0.871	7330.49	3.23	1.05
7499.82	He I		7499.89	0.195	0.036	7499.75	0.123	0.040
7751.12	[Ar III]	(1F)	7751.14	21.7	3.68	7751.08	11.7	3.55
7771.96	O I	(1)	7772.11	0.094:	0.016:	7771.76	0.068:	0.020:
7774.18[a]	O I	(1)	7773.67	0.242	0.041	7773.79	0.181	0.054
7816.16	He I	(69)	...	...	...	7815.89	0.181	0.054
7889.9	[Ni III]	(1F)	7890.27	0.782	0.126	7890.09	0.556	0.163
8046.00	[Cl IV]	(1F)	8045.80	0.172	0.026	...	...	...
8094.06	He I		8093.77	0.199	0.030	...	...	...
8242.34	N I	(2)	...	...	...	8242.18	0.118	0.032
8245.64	H I	P42	8245.85	0.127	0.018	8245.85	0.120	0.033
8247.73	H I	P41	8248.00	0.165	0.024	8247.93	0.151	0.041
8249.97	H I	P40	8250.22	0.216	0.031	8250.04	0.115	0.031
8252.40	H I	P39	8252.57	0.237	0.034	8252.53	0.166	0.045
8255.02	H I	P38	8255.28	0.380	0.054	8255.18	0.176	0.048
8257.86	H I	P37	8258.09	0.408	0.058	8257.91	0.198	0.053
8260.94	H I	P38	8261.13	0.450	0.064	8261.04	0.213	0.057
8264.29	H I	P35	8264.64	0.622	0.089	8265.03	0.296	0.080
8267.94	H I	P34	8268.11	0.455	0.065	8268.03	0.282	0.076
8271.93	H I	P33	8271.93	0.593	0.084	8271.99	0.244	0.066
8276.31	H I	P32	8276.35	0.463	0.066	8276.46	0.273	0.073
8281.12	H I	P31	8281.47	0.987	0.140	8281.47	0.695	0.187
8286.43	H I	P30	8286.55	0.820	0.116	8286.48	0.443	0.119
8292.31	H I	P29	8292.39	0.730	0.103	8292.32	0.350	0.094
8298.84[a]	H I	P28	8299.01	1.83	0.258	8298.87	1.19	0.319
8306.22	H I	P27	8305.95	0.753	0.106	8306.10	0.384	0.103
8314.26	H I	P26	8314.30	0.937	0.132	8314.25	0.452	0.121
8323.43	H I	P25	8323.43	1.03	0.145	8323.32	0.529	0.141
8333.78	H I	P24	8333.76	1.12	0.157	8333.68	0.603	0.160
8345.55[a]	H I	P23	8344.78	3.86	0.534	8344.54	2.80	0.741
8359.01	H I	P22	8358.91	1.532	0.211	8358.89	0.772	0.203
8361.77	He I	(68)	8361.60	0.822	0.113	8361.51	0.382	0.100
8374.48	H I	P21	8374.40	1.63	0.221	8374.35	0.835	0.218
8392.40	H I	P20	8392.32	2.04	0.275	8392.26	0.997	0.259
8413.32	H I	P19	8413.50	2.13	0.284	8413.43	1.16	0.300
8438.64	H I	P18	8438.12	2.46	0.323	...	...	...
8444.48	Si I	(46)	8444.67	0.252	0.033	...	...	...
8446.48	O I	(4)	8447.17	0.378	0.049	8446.88	0.485	0.123
8467.26	H I	P17	8467.64	3.10	0.399	8467.61	1.56	0.392

TABLE 2 (CONTINUED)

			Position 3			Position 14		
λ_0 (Å)	Ion	Multiplet	λ (Å)	$F(\lambda)$	$I(\lambda)$	λ (Å)	$F(\lambda)$	$I(\lambda)$
?			8486.64	0.151	0.019	8486.56	0.083	0.021
8502.49	H I	P16	8502.83	3.52	0.444	8502.79	1.80	0.450
8528.99	He I		8529.25	0.164	0.020	8529.26	0.114	0.028
8545.38	H I	P15	8545.54	4.28	0.527	8545.50	2.18	0.534
8578.70	[Cl II]	(1F)	8578.88	0.273	0.033	8578.75	0.252	0.060
8582.54	He I		8582.25	0.493	0.060	8582.26	0.237	0.057
8598.39	H I	P14	8598.23	5.68	0.678	8598.18	2.94	0.704
8665.02	H I	P13	8664.58	7.87	0.902	8664.53	4.43	1.01
8776.77	He I		8776.51	1.10	0.117	8776.37	0.596	0.132
8845.38	He I		8845.55	0.475	0.049	8845.43	0.265	0.057
8848.05	He I		8848.05	0.203	0.021	···	···	···
8862.79	H I	P11	8862.74	12.1	1.25	8862.71	6.10	1.32
8914.74	He I		8914.25	0.266	0.027	···	···	···
8996.99	He I		8995.76	0.457	0.045	8995.73	0.287	0.060
9014.91	H I	P10	9013.62	18.4	1.75	9013.59	8.51	1.75
9068.9	[S III]	(1F)	9067.98	194	17.9	9068.06	113	22.7
9210.28	He I	(83)	9210.71	1.05	0.094	9210.75	0.359	0.071
9229.02	H I	P9	9229.25	24.3	2.18	9229.42	11.4	2.25
9463.57	He I	(67)	9463.12	1.33	0.117	9463.53	0.567	0.111
9545.97	H I	P8	9545.47	28.9	2.52	9545.59	13.2	2.56
9603.50	He I	(71)	9602.19	0.365	0.032	···	···	···
9850.24	[C I]	(1F)	9849.27	1.30	0.111	9849.44	0.974	0.185

[a] Dubious identification.

Tran, & Veilleux (1992) and in M8 by EPTGR; we also used the compilations of atomic data by Moore (1945, 1993) and Wiese, Smith, & Glennon (1966). Sky emission lines were not included in the list. Three emission lines could not be identified in any of the available references but two of them have been reported previously in other objects. The line at λ6863.36 has been observed in M8 (λ6863.45, EPTGR). The line observed at λ7160.64 has been reported in M8 (λ7160.62, EPTGR), IC 4997 (λ7160.62, Hyung, Aller, & Feibelman 1994) and NGC 6567 (λ7160.60, Hyung, Aller, & Feibelman 1993). The intensity of these lines, relative to Hβ, is very similar in all the objects, despite the large differences in excitation conditions of the nebulae, a fact that suggests a nebular origin and that recombination is their most likely production mechanism.

The reddening coefficient, $C(\mathrm{H}\beta)$, was determined by fitting iteratively the observed Balmer decrement to the theoretical one computed by Storey & Hummer (1995) for the physical conditions determined for each slit position (see § 4) and assuming the extinction law of Seaton (1979). The final $C(\mathrm{H}\beta)$ for each slit position was the average of the values obtained from the Hα/Hβ, Hγ/Hβ and Hδ/Hβ ratios. The final adopted values of $C(\mathrm{H}\beta)$ are 1.71 ± 0.05 and 1.05 ± 0.05 for positions 3 and 14, respectively. These values are in good agreement with the $C(\mathrm{H}\beta)$ obtained by PTR for the same slit positions (1.72 and 1.20, respectively). The reddening corrected Hβ surface brightness from the blue exposure spectra is 1.38×10^{-12} and 0.35×10^{-12} erg cm^{-2} s^{-1} arcsec^{-2} for positions 3 and 14, respectively.

4. PHYSICAL CONDITIONS

The large number of collisionally excited emission lines identified and measured in the spectra allows the derivation of physical conditions using line ratios of different ions. The values of n_e and T_e given in Table 3 have been obtained using the five-level program for the analysis of emission-line nebulae of Shaw & Dufour (1995).

The values of n_e obtained for the different ions available in each slit position are very similar. Average values of 860 and 520 cm^{-3} have been adopted as

TABLE 3

PHYSICAL CONDITIONS

Parameter	Line	Position 3	Position 14
n_e (cm^{-3})	[O II]	790 ± 250	480 ± 200
	[S II]	940^{+950}_{-500}	550^{+600}_{-370}
	[N I]	5270:	1560:
	[Cl III]	1400^{+3000}_{-1400}	880^{+2600}_{-880}
	[Ar IV]	1550:	...
T_e (K)	[O III]	8120 ± 250	8210 ± 250
	[O II]	$11,980 \pm 1300$	9880 ± 850
	[N II]	8990 ± 850	8770 ± 800
	[Ar III]	8210 ± 750	8040 ± 700
	[S III]	8320 ± 600	...

representative for Positions 3 and 14 respectively, in good agreement with the densities obtained by PTR for the same zones.

Electron temperatures from forbidden lines have been derived from [O II], [O III], [N II], [Ar III], and [S III] line ratios. The T_e values obtained from different ions are similar within the uncertainties, except in the case of the T([O II]) derived for Position 3, which is significantly higher (see § 5 for further discussion). Similar values of T([O III]) for both slit positions and T([N II]) for Position 14 were obtained by PTR. In contrast, those authors find T([II]) = 11,600 ± 550 K for Position 3, a value much higher than the value we obtain for the same zone.

5. H I AND He I RECOMBINATION SPECTRA

The H I Balmer and Paschen spectra can be detected up to H18 and P42 respectively, in our data. In Table 4, we present the comparison between the observed relative intensities of the H I Balmer and Paschen lines with respect to the predicted ones using the machine-readable line-ratio tables by Storey & Hummer (1995). The theoretical line ratios have been evaluated for $T_e = 8300$ K and $n_e = 860$ cm^{-3} in the case of Position 3 and $T_e = 8280$ K, and $n_e = 520$ cm^{-3} for Position 14. The adopted value of T_e corresponds to the mean of the electron temperatures weighted by their relative uncertainties. In any case, the H I line ratios are almost independent of the adopted temperatures and densities. The comparison between observed and predicted line ratios stops at H25 and P25 because this is the limit of the calculations of Storey & Hummer (1995). In the optical range, H8 and H14 have not been included in Table 4 because they are blended with He I λ3888.65 and [S III] λ3721.83, respectively. In the NIR ranges, P23 and P12 have not been included in Table 5; because P23 is severely affected by strong sky emission lines and P12 is at a wavelength not covered between

TABLE 4

OBSERVED OVER PREDICTED H I BALMER AND PASCHEN EMISSION LINE RATIOS

Line	Position 3	Position 14	Line	Position 3	Position 14
H18	0.91:	...	P25	1.16	1.15
H17	...	1.14	P24	1.12	1.16
H16	0.47	0.86	P22	1.18	1.15
H15	0.45	1.10	P21	1.08	1.07
H13	0.63	0.99	P20	1.17	1.10
H12	0.67	1.05	P19	1.04	1.10
H11	0.81	0.87	P18	1.01	...
H10	0.74	1.11	P17	1.05	1.03
H9	0.77	0.91	P16	0.98	0.99
Hϵ	0.79	0.99	P15	0.96	0.97
Hδ	0.84	1.01	P14	1.00	1.04
Hγ	1.01	1.05	P13	1.07	1.19
Hβ	1.00	1.00	P11	0.89	0.94
Hα	1.04	0.94	P10	0.94	0.94
...	...	...	P9	0.84	0.87
...	...	...	P8	0.68	0.69

two consecutive spectral NIR orders. Columns 2 and 3 of Table 4 give the ratio of the observed to the predicted intensities. The differences between theoretical and observed line ratios are typically of the order of 10–15 per cent for the Balmer and Paschen lines except P8, which is just at the edge of a spectral order, and the spectral zone shortwards of Hδ for Position 3, where the differences between observed and predicted intensity ratios become larger with decreasing wavelength. This behaviour can be explained either by: a) the effect of strong underlying absorption of the Balmer lines by dust-scattered stellar continuum; or b) a systematic error in the flux calibration in this spectral zone and slit position.

The possibility of strong underlying stellar absorption appears unlikely due to the low contribution of the nebular and dust-scattered stellar continuum in the blue spectral zone, as well as the absence of any appreciable degree of absorption in the brightest Balmer lines. On the other hand, the effect of a flux calibration problem can be checked because it should also affect other emission line intensities in this spectral zone. The only two He I lines in this wavelength range (at λ3964.73 and λ4026.19) show a contradictory behaviour (see Table 5), but are rather weak and their relatively high uncertainty makes them useless for this analysis. However, there are several bright collisionally excited lines that can be used for the analysis, as the [O II] doublet in the blue ($\lambda\lambda$3726.03, 3728.82) and the [Ne III] lines at λ3868.75 and λ3967.46. We have compared the intensity ratios of these lines in our spectra with the ones measured by PTR, finding that they are less intense in our spectrum of Position 3 (but not for Position 14) by factors similar to the departures from theoretical intensities that show the nearest Balmer lines (a factor of 30 percent for the [O II] lines and between 10 to 15 percent in the case of the [Ne III] lines). The effect of a possible underestimation of the line intensities shortwards of Hδ could also explain the high T([O II]) value found in Position 3. The fact that the blue spectra of both slit positions were taken in different nights (see Table 1) and that this problem does not appear for Position 14, also suggests a possible flux calibration problem.

There are 30 He I emission lines identified in our spectra. These lines arise mainly by recombination, although they may have contributions due to collisional and self-absorption effects. In Table 5, we present the comparison between the observed line intensity ratios and those predicted by Smits (1996). The theoretical line ratios have been evaluated for case B for singlets and triplets assuming the same physical conditions as in the case of the H I spectrum. The ratio between observed and predicted line intensity ratios for both slit positions are shown in columns 3 and 4. As in the case of the H I Balmer spectrum, the observed ratios compare well in general with the predicted ones, taking into account that uncertainties of the order of 10–20 per cent are expected due to the relative faintness of most of the He I lines as well as some contribution of collisional

TABLE 5

OBSERVED OVER PREDICTED He I EMISSION LINE RATIOS

λ (Å)	Transition	I_{obs}/I_{pred} Pos. 3	Pos. 14	λ (Å)	Transition	I_{obs}/I_{pred} Pos. 3	Pos. 14
5015.68	$2^1S - 3^1P$	0.97	0.90	5875.67	$2^3P - 3^3D$	1.14	1.01
3964.73	$2^1S - 4^1P$	0.81	0.90	4471.48	$2^3P - 4^3D$	1.00	1.00
...	...	...	...	4026.19	$2^3P - 5^3D$	1.00	0.86
7281.35	$2^1P - 3^1S$	1.09	0.87	3819.61	$2^3P - 6^3D$	...	0.97
5047.74	$2^1P - 4^1S$	1.11	0.92	3705.04	$2^3P - 7^3D$	...	0.97
4437.55	$2^1P - 5^1S$	1.65:	...	...	...	...	...
...	...	...	...	9463.57	$3^3S - 5^3P$	1.18	1.00
6678.15	$2^1P - 3^1D$	1.19	0.96	8361.70	$3^3S - 6^3P$	1.67	1.33
4921.93	$2^1P - 4^1D$	1.09	0.99	7816.16	$3^3S - 7^3P$	...	2.75
4387.93	$2^1P - 5^1D$	...	0.98	7499.82	$3^3S - 8^3P$	1.60	1.60
9603.50	$3^1S - 6^1P$	1.75	...	9210.28	$3^3D - 9^3F$	0.95	0.67
8914.74	$3^1S - 7^1P$	1.20	...	8996.99	$3^3D - 10^3F$	0.67	0.80
...	...	...	...	8845.38	$3^3D - 11^3F$	1.00	1.00
7065.28	$2^3P - 3^3S$	2.41	1.65	8582.54	$3^3D - 14^3F$	2.17	1.83
4713.14	$2^3P - 4^3S$	1.38	1.05	8528.99	$3^3D - 15^3F$	1.00	1.50

effects from the metastable 2^3S level (see Kingdon & Ferland 1996). An apparent trend is detected in the $2^3P - n^3S$ and $3^3S - n^3P$ lines, the observed intensities of these lines are systematically brighter than the predicted ones. This discrepancy can be explained by self-absorption effects from the metastable 2^3S level. On the other hand, the ratios presented in Table 5 indicate the absence of significant line-transfer effects in the helium singlet spectrum (e.g., Robbins & Bernat 1973).

6. IONIC ABUNDANCES FROM FORBIDDEN LINES

Ionic abundances of N^+, O^+, O^{++}, Ne^{++}, S^+, S^{++}, Cl^+, Cl^{++}, Cl^{3+}, Ar^{++}, and Ar^{3+} have been obtained from collisionally excited lines, using the five-level atom program of Shaw & Dufour (1995) and the atomic parameters referenced in it. Additionally, we have determined the ionic abundances of Fe^{++} and Ni^{++} with the methods and data that will be discussed below. For the low ionization potential ions N^+, O^+, S^+, Cl^+, Fe^{++}, and Ni^{++} we have taken T([N II]) as the representative electron temperature. We select T([N II]) instead of T([O II]) due to its lower dependence on the assumed reddening and, in the case of Position 3, because T([O II]) can be affected by possible flux calibration problems shortwards of Hδ in the blue spectrum, as has been discussed in § 5. On the other hand, we have adopted T([O III]) for the high ionization potential ions O^{++}, Ne^{++}, S^{++}, Cl^{++}, Cl^{3+}, Ar^{++} and Ar^{3+}. The density assumed is 860 and 520 cm^{-3} for Positions 3 and 14, respectively. Ionic abundances are listed in Table 6 and correspond to the mean value of the abundances derived from all the individual lines of each ion observed. The values obtained are consistent with those derived by PTR for the ions in common. The O^+/H^+ and Ne^{++}/H^+ ratios could have been underestimated due to the possible flux calibration problem of the bluest part of the spectrum of Position 3 as was discussed in § 5. We estimate that the correction in the ionic abundances due to this effect should be of the order of +0.11 dex for O^+/H^+ and about +0.05 dex for Ne^{++}/H^+.

We have measured seven [Fe III] lines of multiplets (1F), (2F), and (3F) in M17. The presence of some [Fe III] lines in the spectrum of this object was previously reported by PTR and Rodríguez (1996). We have used the Fe III level population tables and line emissivities computed by Keenan et al. (1992) to obtain the Fe^{++} abundance. The adopted average Fe^{++} abundance (obtained from those lines not affected by line-blending) is included in Table 6. Our values of the Fe^{++}/H^+ are highly consistent with previous determinations by Rodríguez (1996) and PTR, but in the latter case there is a discrepancy by a factor of about 0.4 dex in the Fe^{++}/H^+ derived for Position 14. This large difference could be due to the larger intensity of [Fe III] λ4658 line reported by those authors for this slit position.

TABLE 6

IONIC ABUNDANCES FROM FORBIDDEN LINES[a]

	Position 3		Position 14	
	t^2		t^2	
X^m	0.000	0.033	0.000	0.044
N^+	6.66 ± 0.12	6.73	6.85 ± 0.12	6.99
O^+	7.51 ± 0.20	7.58	7.82 ± 0.19	7.98
O^{++}	8.49 ± 0.06	8.75	8.40 ± 0.06	8.77
Ne^{++}	7.56 ± 0.12	7.84	7.53 ± 0.11	7.93
S^+	5.30 ± 0.16	5.37	5.45 ± 0.15	5.58
S^{++}	6.83 ± 0.08	7.12	6.91 ± 0.08	7.33
Cl^+	3.59 ± 0.22	3.71	3.86 ± 0.22	4.01
Cl^{++}	5.09 ± 0.14	5.35	5.02 ± 0.14	5.37
Cl^{3+}	3.61 ± 0.22	3.81	...	...
Ar^{++}	6.36 ± 0.08	6.57	6.32 ± 0.08	6.62
Ar^{3+}	4.39 ± 0.15	4.61	...	...
Fe^{++}	5.36 ± 0.16	5.43	5.47 ± 0.14	5.60
Ni^{++}	5.22 ± 0.18	5.33	5.36 ± 0.16	5.51

[a] In units of 12+log(X^m/H$^+$).

Two [Ni III] lines have been measured in our spectra. It is possible that λ6401.5 is blended with a Ne I line and its intensity might be overestimated. Unfortunately, there are no calculations of the level populations of this ion because no published collision strengths are available for [Ni III]. Osterbrock et al. (1992) estimate these atomic parameters from available calculations for [Fe VII], with analogous electron ground configuration. We have calculated the Ni^{++}/H^+ from the brightest line at λ7890, following the procedure outlined by Osterbrock et al. (1992) that uses the collision strengths estimated by these authors and the transition probabilities obtained by Garstang (1958). The abundances derived for each slit position are shown in Table 6.

7. He^+ ABUNDANCES

The intensity of He I lines can be affected mainly by two physical processes: self-absorption and collisions. The comparison between observed and predicted He I emission lines shown in Table 5 indicates that lines coming from $2^3P - n^3S$ and $3^3S - n^3P$ transitions could suffer substantial self-absorption and, therefore, that they are not suitable for deriving an accurate He^+/H^+ ratio. On the other hand, collisional effects may affect all the measured lines, but unfortunately, we have collision-to-recombination factors (C/R) for only 7 of the lines available. In Table 7, we show the He^+ abundance for

TABLE 7

He^+/H^+ ABUNDANCE RATIO[a]

λ (Å)	Position 3 Uncorrected	C/R	Corrected	Position 14 Uncorrected	C/R	Corrected
4026	0.0952	0.0042	0.0948	0.0885	0.0028	0.0882
4388	...	...	...	0.1010	0.0018	0.1008
4471	0.0952	0.0065	0.0946	0.1081	0.0043	0.1076
5876	0.1084	0.0162	0.1067	0.1039	0.0107	0.1028
6678	0.1133	0.0081	0.1124	0.0996	0.0053	0.0991
7065[a]	0.2328	0.1716	0.1987	0.1718	0.1136	0.1543
7282	0.1039	0.0640	0.0976	0.0900	0.0424	0.0863
Mean	0.1032	...	0.1012	0.0985	...	0.0975
	± 0.0071	...	± 0.0070	± 0.0060	...	± 0.0066

[a] Not included in the derivation of the the mean He^+/H^+.

these 7 lines —uncorrected and corrected by the collisional contribution— as well as their corresponding C/R factors. The uncorrected He^+/H^+ ratios have been obtained using the predicted line emissivities calculated by Smits (1996) and assuming the same physical conditions as in § 5. The C/R factors have been obtained from the calculations by Kingdon & Ferland (1995). The average values of He^+/H^+ have been derived excluding He I λ7065 (the line that suffers the largest self-absorption effects) and are given in Table 7. The He^+/H^+ ratios obtained (for both corrected and uncorrected cases) are consistent with the values derived by PTR for the lines in common.

8. PERMITTED HEAVY ELEMENT LINES

We have measured 36 permitted lines of heavy element ions such as C II, N I, N II, N III, O I, O II, Ne I, Si I, and Si II, most of them detected for the first time in M17.

All the permitted lines of heavy elements observed in M17 have been observed also in the spectrum of other galactic H II regions such as the Orion nebula (EPTE) or M8 (EPTGR). In these two papers, the authors carried out a detailed discussion of the excitation mechanisms that produce those lines, being in most cases line and/or continuum resonance fluorescence except in the cases of C II λ4267.26, the lines of multiplet 1 of O I, and the lines of O II which are produced largely by recombination.

Let $I(\lambda)$ be the intensity of a recombination line of an element i times ionized at wavelength λ, then the abundance of the ionization state $i+1$ of element X is given by

$$\frac{N(X^{i+1})}{N(H^+)} = \frac{\lambda(\text{Å})}{4861}\frac{\alpha_{eff}(H\beta)}{\alpha_{eff}(\lambda)}\frac{I(\lambda)}{I(H\beta)}\,, \qquad (1)$$

where α_{eff} represents the effective recombination coefficient.

Most calculations of α_{eff} use term-averaged transition probabilities, which give rates for total intensities of multiplets. However, our echelle observations can resolve several lines of some multiplets. The measurement of several lines of the same multiplet of a given ion permits the comparison of their relative intensities with those expected in an appropriate angular momentum coupling. If we assume that the relative populations of levels within a term are approximately proportional to their statistical weights, g_j, the intensities of the lines of a multiplet will be proportional to the gf values, $g_j f_{ji} = g_i f_{ij}$, which are proportional to the line strength, s_{ij}. The results of this comparison are shown in Table 8. In this table we include those multiplets with more than one emission line measured. Columns 1 to 3 indicate the ion, multiplet number and laboratory wavelength corresponding to each line. Column 4 gives J values of the lower and upper levels of the transitions. Columns 5 and 7 give the observed intensity of each line relative to the strength of the expected brightest line of the multiplet. Columns 6 and 8 include the ratio of the observed and the predicted relative intensities.

In Table 8, we show that the relative intensities between the two observed lines of multiplet 3 of C II and N II and multiplet 2 of Si II are in very good agreement with the predictions of LS-coupling. In contrast, there is no good agreement for the O II lines observed (all belonging to multiplet 1) and perhaps for multiplet 5 of Si II. For the Orion nebula, EPTE find that all these lines follow closely the LS-coupling predictions behaviour which, in contrast, is not followed in the case of M8. EPTGR find that multiplet 3 of N II and multiplet 1 of O II (among others) do not fit the LS-coupling predictions for M8. In this

TABLE 8

OBSERVED OVER PREDICTED INTENSITY RATIOS OF PERMITTED LINES OF HEAVY ELEMENTS

Ion	Mult.	λ (Å)	J–J′	Position 3 I_{obs}	Position 3 I_{obs}/I_{pred}	Position 14 I_{obs}	Position 14 I_{obs}/I_{pred}
C II	3	7236.19	3/2–5/2	1	1	1	1
		7231.12	1/2–3/2	0.59	1.05	0.46	0.82
N II	3	5679.56	2–3	1	1	...	...
		5666.64	1–2	0.60	1.12	...	...
O II	1	4641.81	3/2–5/2	1	1	1	1
		4649.14	5/2–7/2	0.72	0.41	0.91	0.44
		4638.85	1/2–3/2	0.45:	1.30:	1.15	2.60
		4661.64	3/2–3/2	0.80	1.67	0.87	1.99
		4650.84	1/2–1/2	0.70:	2.00:	0.71	2.02
Si II	2	6347.09	1/2–3/2	1	1	...	...
		6371.36	1/2–1/2	0.61	1.22	...	...
	5	5055.98 5056.31	3/2–5/2 3/2–3/2	1	1	1	1
		5041.03	1/2–3/2	0.89	1.78	0.98	1.96

sense, the similar behaviour of the departures found for the lines of multiplet 1 of O II in M8 and M17 is striking. The lines of multiplet 1 of O I have not been included in Table 8 because one of the lines, λ7774.18, suffers from severe contamination by sky emission.

We have used the C II α_{eff} values obtained by Péquignot, Petitjean, & Boisson (1991) to derive the C^{++} abundances from the C II λ4267.26 line. The physical conditions assumed are T_e = 8120 K and n_e = 860 cm^{-3} for Position 3, and T_e = 8210 K and n_e = 520 cm^{-3} for Position 14. The C^{++}/H^+ ratios obtained are 5.8 × 10^{-4} and 7.5 × 10^{-4} for Positions 3 and 14, respectively [12+log(C^{++}/H^+) = 8.76 and 8.88, respectively].

The O^+ abundance can be derived from the lines of multiplet 1 of O I which is the only one probably produced by pure recombination. However, the line at λ7774.18 is affected by sky emission and the line at 7771.96 Å has a very low signal-to-noise ratio and can be affected also by the neighboring sky emission. Therefore, a high uncertainty is associated with this line. In any case, taking into account this line and the α_{eff} of Péquignot et al. (1991) we obtain an O^+/H^+ ratio of 1.6 and 2.0 × 10^{-4} for Positions 3 and 14, respectively [12+log(O^+/H^+) = 8.21 and 8.31, respectively]. For this calculation, we have assumed T_e = 8990 K and n_e = 860 cm $^{-3}$ for Position 3, and T_e = 8770 K and n_e = 520 cm $^{-3}$ for Position 14. Although these values are highly uncertain, they are clearly higher than the O^+/H^+ ratios obtained from collisionally excited lines. This behaviour is similar to that reported for M8 by EPTGR.

Storey (1994) has computed the O II α_{eff} for Cases A, B, and C. We have used these coefficients to derive the O^{++} abundances listed in Table 9. The physical conditions assumed are the same as for the C II calculations. We have determined the ionic abundances from individual lines of O II multiplying the α_{eff} of the multiplet by a factor that takes into account the relative intensity of each line within the multiplet

$$\frac{s_{ij}}{\sum_{\text{all } i,j} s_{ij}} , \qquad (2)$$

where the sum runs over all the components of the multiplet. The O^{++} abundances obtained from the different lines of multiplet 1 observed show significant dispersion, mainly because we have assumed that the relative line intensities within a multiplet follow those predicted in LS-coupling. The abundances determined for this ion are almost independent of the case assumed. Additionally, we have determined the average of the ionic abundances obtained from all the lines of a given multiplet (labeled as "Mean" in Table 9).

An alternative approach is to estimate the total intensity of the multiplet by multiplying the sum of intensities of the observed lines by the multiplet correction factor which introduces the contribution of all —observed and unobserved— lines

$$m_{cf} = \frac{\sum_{\text{all } i,j} s_{ij}}{\sum_{\text{obs } i,j} s_{ij}} ; \qquad (3)$$

TABLE 9

O^{++}/H^+ RATIO FROM O II LINES

Mult.	λ (Å)	Position 3 $I(\lambda)/I(H\beta)$ [$I(H\beta)$=100]	O^{++}/H^+ ($\times 10^{-5}$) Case A	Case B	Position 14 $I(\lambda)/I(H\beta)$ [$I(H\beta)$=100]	O^{++}/H^+ ($\times 10^{-5}$) Case A	Case B
1	4638.85	0.080:	83	80	0.130	135	130
	4641.81	0.174	63	61	0.143	52	50
	4649.14	0.126	26	25	0.113	23	22
	4650.84	0.122:	128	123	0.102	107	103
	4661.64	0.127	107	103	0.125	105	101
	Mean	...	81	78	...	84	82
	m_{cf}	1.10	...	...	1.10	...	...
	Sum	0.629	59	57	0.613	57	55

where the upper sum runs over *all* the components of the multiplet, and the lower sum runs over the *observed* components of the multiplet. The abundances obtained from the estimated total intensity of a multiplet is labeled as "Sum" in Table 9 along with its m_{cf} in LS-coupling. The abundance deduced from this last method is preferred over the average abundance because observational errors and the effects of departures from LS-coupling are minimized.

9. TEMPERATURE FLUCTUATIONS IN M17

Ionic abundances from forbidden lines often differ significantly from those derived from recombination lines (e.g., Peimbert et al. 1993a; Liu et al. 1995; EPTE; EPTGR), probably because both abundance determinations have a different dependence on the temperature structure of the nebula. In Table 10 we show the comparison between the abundances of O^{++} determined from collisionally excited lines and from recombination lines. The O^{++}/H^+ ratio from recombination lines has been taken from the "Sum" value for Case B of Table 9. As it was found also for the Orion nebula (EPTE) and M8 (EPTGR) and the previous study for M17 by Peimbert et al. (1993a), the ionic abundances determined from collisionally excited lines are always somewhat lower than those obtained from recombination lines, and their comparison can provide an estimate of the spatial temperature fluctuations. The presence of these fluctuations, t^2, in gaseous nebulae was first proposed by Peimbert (1967, 1971). We have derived the t^2 value that produces the agreement between the O^{++} abundance obtained from both recombination lines and forbidden lines, for each slit position. The values of t^2 are shown in Table 10 and are consistent with the previous determination of Peimbert et al. (1993a) based on low resolution spectroscopy. Values of t^2 ranging from 0.00 to 0.09 have been found for planetary nebulae, with a typical value around 0.04 (Peimbert 1971; Dinerstein, Lester, & Werner 1985; Liu & Danziger 1993; Liu et al. 1995; Kingsburgh, López, & Peimbert 1996). For other galactic H II regions, EPTE find $t^2 = 0.020$ and 0.028 for two slit positions in the Orion nebula and, in the case of M8, EPTGR obtain a value of 0.032. As it can be seen, these values obtained for PNe nebulae and H II are very similar and higher than those derived from photoionized models which predict values not larger than 0.01 (i.e., Baldwin et al. 1991). Very recently, Liu (1998) has obtained a difference of a factor of $\sim$ 15 between collisional and recom-

TABLE 10

COMPARISON OF O^{++}/H^+ RATIOS[a] AND t^2 PARAMETER

Position 3 Forbidden lines ($t^2 = 0.00$)	Recombination lines	t^2(R/C)	Position 14 Forbidden lines ($t^2 = 0.00$)	Recombination lines	t^2(R/C)
8.49 ± 0.06	8.75 ± 0.13	0.033 ± 0.015	8.40 ± 0.06	8.74 ± 0.13	0.044 ± 0.015

[a] In units of 12+log (O^{++}/H^+).

TABLE 11

M17 GASEOUS ABUNDANCES[a]

	This Work				
	Position 3		Position 14		PTR[b]
Element	t^2=0.00	t^2=0.033	t^2=0.00	t^2=0.044	t^2=0.035
He	11.02 ± 0.04	11.01	11.00 ± 0.04	10.99	11.00
C	8.77 ± 0.10	8.76	8.89 ± 0.10	8.88	8.73
N	7.80 ± 0.12	7.87	7.65 ± 0.12	7.79	7.97
O	8.53 ± 0.10[c]	8.78[c]	8.50 ± 0.10[c]	8.84[c]	8.77
Ne	7.60 ± 0.12	7.88	7.63 ± 0.11	8.03	8.09
S	6.94 ± 0.09	7.23	7.02 ± 0.09	7.44	7.28
Cl	5.12 ± 0.14	5.38	5.05 ± 0.14	5.40	5.44
Ar	6.36 ± 0.09	6.57	6.36 ± 0.09	6.62	6.60
Fe	6.50 ± 0.16	6.57	6.27 ± 0.14	6.40	6.90

[a] In units of 12+log (X/H).
[b] Average value for M17 by Peimbert, Torres-Peimbert, & Ruíz (1992).
[c] O^+/H^+ from collisionally excited lines and O^{++}/H^+ from recombination lines.

bination C^{++}/H^+ ionic abundance in the planetary nebula NGC 4361. Liu interprets that this large difference cannot be accounted for with temperature fluctuations and could be related to uncertainties in the effective recombination coefficients. In the case of the results for the Orion nebula (EPTE) and M8 (EPTGR) the agreement of the t^2 values obtained for different ions (C^{++}, O^+, and O^{++} in the case of M8 and C^{++} and O^{++} in the case of the Orion nebula) strongly suggests that these differences are not related to uncertainties in the effective recombination coefficients and are more likely due to external physical reasons.

10. TOTAL ABUNDANCES

To derive the total gaseous abundances we need to adopt a t^2 value and to correct for the unseen ionization stages by using ionization correction factors, i_{cf}. The abundances derived from collisionally excited lines have been computed assuming t^2 values of 0.00 and 0.033 for Position 3 and 0.00 and 0.044 for Position 14; they can be used to interpolate or extrapolate for other t^2 values. The total abundances adopted for each element are presented in Table 11.

The absence of He II emission lines in the spectra (He II $\lambda 4686/H\beta \leq 0.0006$ for Position 3 and ≤ 0.0003 for Position 14), and the similarity between the ionization potentials of He^+ and O^{++}, implies the absence of measurable O^{3+} in the observed zones of M17. Therefore, to obtain the total oxygen abundance we can simply assume that

$$\frac{N(\mathrm{O})}{N(\mathrm{H})} = \frac{N(\mathrm{O}^+ + \mathrm{O}^{++})}{N(\mathrm{H}^+)} \quad . \tag{4}$$

To derive the total nitrogen abundance, the usual i_{cf} based on the similarity between the ionization potential of N^+ and O^+ (Peimbert & Costero 1969) is not a good approximation for ionized nebulae with high degree of ionization. Instead, following PTR, we have used the set of i_{cf}s obtained by Mathis & Rosa (1991). In the case of nitrogen, we have adopted the average of the cool and hot atmosphere results of these authors, which is 0.12 dex higher than the i_{cf} determined using the standard relation for both slit positions.

The only measurable collisionally excited lines of Ne in the optical region are those of Ne^{++}. The ionization potential of this ion is very high (63.4 eV) and we do not expect a significant fraction of Ne^{3+} in M17. In contrast, we expect to find a large amount of Ne^+. In our case, we adopt the usual $i_{cf}(Ne^{++})$ for nebulae of high degree of ionization (e.g., Peimbert & Costero 1969)

$$\frac{N(\mathrm{Ne})}{N(\mathrm{H})} = i_{cf}(\mathrm{Ne}^{++}) \times \frac{N(\mathrm{Ne}^{++})}{N(\mathrm{H}^+)} = \frac{N(\mathrm{O}^+ + \mathrm{O}^{++})}{N(\mathrm{O}^{++})} \times \frac{N(\mathrm{Ne}^{++})}{N(\mathrm{H}^+)} \quad . \tag{5}$$

We have measured forbidden lines from two ionization stages of S, giving $S^+/S^{++} = 0.03$ and 0.04 for Positions 3 and 14, respectively. Taking into account the high ionization degree of M17, an ionization correction factor, $i_{cf}(S^+ + S^{++})$, for the presence of S^{3+} has to be considered. PTR present the S^{++}/H^+ versus O^+/O^{++} distribution for all the slit positions they observed in M17, finding that this diagram (their Figure 11) does not indicate the presence of appreciable amounts of S^{3+} even for the regions with the highest degree of ionization. These authors adopt the average value of $(S^{+}+S^{++})/H^{+}$ for the regions with the lowest degree of ionization as representative of the total S/H value. In our case, we adopt an $i_{cf}(S^{+}+S^{++}) = 1.26$ for our two slit positions from the difference between S/H and $(S^{+}+S^{++})/H^{+}$ adopted or calculated by PTR for each slit position.

For Cl we have measurements of Cl^{+}, Cl^{++}, and Cl^{3+} lines for Position 3 (all the possible ionization stages of this element) and Cl^{+} and Cl^{++} for Position 14. The Cl/H ratio for Position 3 has been derived adding the three ionic abundance determinations available for this element. In the case of Position 14, the Cl abundance has been assumed simply as the sum of Cl^{+}/H^{+} and Cl^{++}/H^{+} ratios. This assumption seems reasonable taking into account the small Cl^{3+}/H^{+} ratio found for Position 3 and the lower ionization degree of this zone of the nebula.

For Ar we have determinations of Ar^{++}/H^{+} and Ar^{3+}/H^{+} for Position 3 and only of Ar^{++}/H^{+} for Position 14. We obtain $Ar^{3+}/Ar^{++} = 0.011$ for Position 3, indicating that most Ar should be in the form of Ar^{++}. However, some contribution for Ar^{+} is expected. To minimize the contribution of Ar^{+}, PTR adopt the average value of $(Ar^{++}+Ar^{3+})/H^{+}$ for the regions of the highest ionization degree (Position 3 among them) as representative of the Ar/H ratio. In our case, we adopt the uncertain assumption that $Ar/H = (Ar^{++}+Ar^{3+})/H^{+}$.

We measure lines of only one stage of ionization of iron; Fe^{++}; however, the contribution for the presence of Fe^{3+} is expected to be important. Taking into account the similarity of N^{+} and Fe^{++} ionization potentials PTR propose the following $i_{cf}(Fe^{++})$

$$\frac{N(\mathrm{Fe})}{N(\mathrm{H})} = i_{cf}(\mathrm{Fe}^{++}) \times \frac{N(\mathrm{Fe}^{++})}{N(\mathrm{H}^{+})} = \frac{N(\mathrm{N})}{N(\mathrm{N}^{+})} \times \frac{N(\mathrm{Fe}^{++})}{N(\mathrm{H}^{+})}. \quad (6)$$

Helium has to be corrected for the presence of He^{0}. Following PTR we will assume that He is neutral in the regions where S is once ionized, therefore

$$\frac{N(\mathrm{He})}{N(\mathrm{H})} = i_{cf}(\mathrm{He}^{+}) \times \frac{N(\mathrm{He}^{+})}{N(\mathrm{H}^{+})} = \left[1 + \frac{N(\mathrm{S}^{+})}{N(\mathrm{S}) - N(\mathrm{S}^{+})}\right] \times \frac{N(\mathrm{He}^{+})}{N(\mathrm{H}^{+})}. \quad (7)$$

From the mean values of He^{+}/H^{+} given in Table 7 and equation (7), we obtain He/H ratios of 0.104 and 0.101 for Positions 3 and 14, respectively. These values are consistent with the He/H ratios obtained by PTR for the same zones, which are 0.106 and 0.103 for Positions 3 and 14, respectively.

For C we only have direct determinations of C^{++}. Taking into account the similarity between the ionization potentials of C^{++} and Ar^{++} and the low Ar^{3+}/Ar^{++} ratios obtained, the expected C^{3+}/C^{++} ratio is very small. On the other hand, the ionization potential of C^{+} (24.4 eV) is intermediate between those of S^{+} (23.3 eV) and He^{0} (24.6 eV); therefore, we expect $S^{+}/S \leq C^{+}/C \leq He^{0}/He$. Moreover, to obtain the total He/H ratio we have assumed that $S^{+}/S = He^{0}/H$. Therefore, following PTR we will assume that $S^{+}/S = C^{+}/C$.

In Table 11 we present the gaseous abundances of the two slit positions of M17, derived for $t^2 = 0.000$ and $t^2 = 0.033$ in the case of Position 3, and $t^2 = 0.000$ and $t^2 = 0.044$ in the case of Position 14. We also present the average abundances obtained by PTR for $t^2 = 0.035$, which is the mean value of t^2 derived by PTR from Balmer continuum measurements, and by Peimbert et al. (1993a) from comparing O^{++}/H^{+} ratios from recombination and forbidden lines.

11. DISCUSSION

We will discuss the abundances derived in this paper together with those derived in the two previous papers of this series on the Orion nebula (EPTE), and M8 (EPTGR). Reviews on the chemical composition of galactic H II regions, on galactic abundance gradients derived from H II regions and on the implications of these observations for models of galactic chemical evolution have been presented elsewhere (Peimbert 1993, 1999; Tosi 1996; Esteban & Peimbert 1996; Matteucci & Chiappini 1999).

11.1. *Comparison with other H II Regions and the Sun*

In Table 12 we compare the gaseous abundances of M17 with those obtained for the Orion nebula (EPTE), ⟨M8⟩ (the mean of the values derived by Peimbert, Torres-Peimbert, & Dufour 1993b, and EPTGR), and for the Sun (Grevesse & Sauval 1998). We have defined an average value of the chemical abundances of M17, ⟨M17⟩, which is the mean of the values obtained for each slit position (columns 3 and 5 of Table 11) and of PTR (column 6 of Table 11). It must be noted that the effects of the possible flux calibration problems at the bluest part of the spectrum of Position 3 (see § 5), which could affect the O^{+}/H^{+} and Ne^{++}/H^{+} ratios for this zone, are in fact very diluted at this point. Due to the small contribution of O^{+} to the total O abundance, this calibration effect could increase the O/H of Position 3 by about 0.01 dex and does not affect the average O/H value adopted for ⟨M17⟩. For Ne/H the effect could be

TABLE 12

M17[a], ORION[a], M8[a], AND SOLAR ABUNDANCES[b]

Element	Sun[c]	⟨M17⟩	⟨M17⟩−Orion	⟨M17⟩− ⟨M8⟩	⟨M17⟩−Sun
He	10.99 ± 0.035	11.00	+0.01	0.00	+0.01
C	8.52 ± 0.06	8.77	+0.38	+0.25	+0.25
N	7.92 ± 0.06	7.90	+0.12	+0.11	−0.02
O	8.83 ± 0.06	8.79	+0.15	+0.12	−0.04
Ne	8.08 ± 0.06	8.02	+0.15	+0.09	−0.06
S	7.33 ± 0.11	7.31	+0.14	+0.04	−0.02
Cl	5.50 ± 0.30	5.42	+0.09	+0.06	−0.08
Ar	6.40 ± 0.06	6.60	+0.11[d]	−0.16:	+0.20
Fe	7.50 ± 0.05	6.69	+0.28	+0.39	−0.81

[a] Gaseous values.
[b] In units of 12+log (X/H).
[c] Grevesse & Sauval (1998).
[d] Orion value from Peimbert (1993) for $t^2 = 0.024$.

slightly larger. Taking into account a correction of +0.05 dex estimated in § 6 for the Ne^{++}/H^+ ratio of Position 3, the average Ne/H for ⟨M17⟩ should be increased by +0.03 dex.

The most remarkable fact of Table 12 is the small dispersion in the differences among ⟨M17⟩ and the other objects for N, O, Ne, S, and Cl which implies that the evolution of the abundance ratios involving these elements is small. For C the difference is higher relative to all the other objects indicating that M17 is C rich and that the evolution of C is different to that of the other elements. For Ar, the large difference between M17 and M8 could be due to the uncertain i_{cf} used as as result of the absence of Ar^+ lines in the optical and the significant contribution of this ionization stage expected for the typical conditions prevailing in M8. For Fe we also have the problem of the uncertainty of the applied i_{cf} as well as the fact that most of the Fe is expected to be locked into dust grains EPTE estimate a dust depletion of Fe of 1.37 dex (in the Orion nebula, from the comparison of nebular and stellar abundances).

In Table 12 we also compare the M17 gaseous abundances with the solar ones presented by Grevesse & Sauval (1998). The Fe difference implies that dust is present inside M17, and by adopting the results for the Orion nebula by EPTE it follows that to obtain the gas plus dust abundances of C and O their values should be increased by 0.10 dex and 0.08 dex, respectively. The adopted solar helium abundance is the one with which the Sun was formed and not the present atmospheric value, that is smaller probably due to helium diffusion. The dust-corrected C abundance is 0.35 dex higher due to two effects, the presence of an abundance gradient and the chemical evolution of the Galaxy since the Sun was formed. On the other hand, the dust-corrected O abundance is 0.04 dex higher while the average value of O, Ne, and S is 0.03 dex smaller than the solar values.

11.2. *Abundance Gradients*

The differences on the chemical abundances shown in Table 12 indicate the presence of abundance gradients. The distance determinations for M17, M8, and Orion (see PTR, Peimbert et al. 1993b, and references therein) indicate that they are located at 5.9, 6.5, and 8.4 kpc from the galactic center, respectively. In Table 13 we show the computed radial abundance gradients derived from the data of the three H II regions included in Table 12 for $t^2 > 0.00$ and $t^2 = 0.00$, where for Ar the M8 value was not taken into account. The N, O, Ne, S, Cl, and Ar gradients are very similar for $t^2 > 0.00$ and their average value amounts to −0.045 dex kpc^{-1}. As can be seen in Table 13, the dispersion of the radial gradients computed for N, O, Ne, S, and Cl increases and their average value becomes negligible when the effects of t^2 are not considered: these two arguments also support the idea that $t^2 > 0.00$.

In Table 13 we also present H II region abundance gradients derived elsewhere. The galactic gradients presented in this table correspond to the solar vicinity. The C and O gradients derived in this paper, the C gradient derived by PTR, and the He/H gradients are based only on recombination lines, while the other entries in Table 13 are based on ratios of collisionally excited lines to recombination lines. Our O/H value is intermediate between those derived by

TABLE 13

GALACTIC ABUNDANCE GRADIENTS FROM H II REGIONS

Gradient (dex kpc^{-1})	(M17[a], M8[b], Orion[c]) t^2 >0.00	t^2=0.00	Shaver et al. (1983)	Simpson et al. (1995)	Others	Adopted
He/H	−0.004	−0.004	−0.001	...	...	-0.004 ± 0.005
C/H	−0.133	−0.133	...	...	−0.080[d]	-0.110 ± 0.030
N/H	−0.048	−0.033	−0.090	−0.100	...	-0.080 ± 0.020
O/H	−0.049	−0.032	−0.070	...	−0.040[e]	-0.055 ± 0.015
Ne/H	−0.045	+0.031	...	−0.080	...	-0.062 ± 0.020
S/H	−0.055	+0.006	−0.010	−0.070	...	-0.062 ± 0.020
Cl/H	−0.031	+0.021	...	...	...	-0.031 ± 0.030
Ar/H	−0.044	−0.004	...	...	...	-0.044 ± 0.030

[a] This work.
[b] Esteban et al. (1999; EPTGR).
[c] Esteban et al. (1998; EPT).
[d] Peimbert et al. (1992; PTR).
[e] Deharveng et al. (1999).

Deharveng et al. (1999) and Shaver et al. (1983). Deharveng et al. and Shaver et al. use a two temperature scheme for the abundance determinations, with $T(O^{++})$ for the regions of high degree of ionization and a different temperature for the regions of low degree of ionization, but without temperature fluctuations in each region. In the last column of Table 13, we present the adopted abundance gradients for the solar vicinity and their estimated errors. These values are recommended for comparisons with models of galactic chemical evolution.

One of the most important results of this paper is the determination of a galactic C/O gradient which provides a very strong constraint for models of chemical evolution of the Galaxy. Garnett et al. (1999) based on UV observations of H II regions in M101 and NGC 2403 have determined the presence of galactic C/O gradients for the first time.

11.3. *Galactic Chemical Evolution*

There are at least six observational parameters derived from galactic H II region abundances that have been used to constrain models of galactic chemical evolution: C/H and O/H values in the solar vicinity, the C/H and O/H gradients, $\Delta Y/\Delta Z$, and $\Delta Y/\Delta O$ (where ΔY, ΔZ, and ΔO are given by mass).

In Table 14 we present the $\Delta Y/\Delta Z$ values derived from Orion, ⟨M8⟩, and ⟨M17⟩ (EPTE; Peimbert et al. 1993b; EPTGR; PTR; and Table 12), where we have assumed that C+N+O+Ne amounts to 79% of the Z value (Grevesse & Sauval 1998). To estimate ΔY we have adopted a primordial helium abundance by mass of 0.240 ± 0.005, based on the results by Izotov & Thuan (1998), and Fields & Olive (1998) that amount to $0.245 + 0.002$ and 0.235 ± 0.002, respectively. A more precise constraint is provided by the $\Delta Y/\Delta O$ ratio because no correction for the rest of the elements is needed. The errors for the M17 values are smaller because, contrary to Orion and M8, practically all the helium is ionized inside the H II region and no correction for the presence of neutral helium is needed.

The models by Carigi (1996,1999) for the chemical evolution of the solar neighborhood show a good agreement with the observed O/H and C/H gradients

TABLE 14

HELIUM TO HEAVY ELEMENTS ABUNDANCE RATIOS[a]

t^2	$\Delta Y/\Delta Z$ Orion	M8	M17	$\Delta Y/\Delta Z$ Orion	M8	M17
0.00	3.85 ± 1.3	3.94 ± 1.4	3.34 ± 0.9	9.44 ± 2.4	9.69 ± 2.7	11.76 ± 2.2
> 0.00	2.87 ± 1.0	2.81 ± 1.0	1.87 ± 0.5	6.27 ± 1.6	6.55 ± 1.8	4.78 ± 0.9

[a] Where a value of $Y_p = 0.240 \pm 0.005$ was adopted.

presented in Table 13 as well as with the increase of the C/O ratio since the Sun was formed. From the 1996 model the O/H and C/H gradients amount to -0.058 dex kpc^{-1} and -0.118 dex kpc^{-1}, respectively. Alternatively, a recent model of the solar neighborhood by Carigi (Allen, Carigi, & Peimbert 1998; Carigi 1998, private communication) predicts a decrease of 0.01 dex in the C/O ratio since the Sun was formed and a C/O gradient of $+0.01$ dex kpc^{-1}, in clear disagreement with the values in Tables 12 and 13. The difference between the models is due to the yields for stars with masses of more than 8 $M_{\odot}$; the 1996 and 1999 models are based on the yields by Maeder (1992) while the 1998 model is based on the yields by Woosley & Weaver (1995).

Recent models predict $\Delta Y/\Delta Z$ values in the 1.6 to 1.7 range (Chiappini, Matteucci, & Gratton 1997; Allen et al. 1998; Carigi 1999) in good agreement with the M17 values presented in Table 14, but smaller than the values derived from M8 and the Orion nebula.

12. SUMMARY

We present echelle spectroscopy in the 3500 to 10,300 Å range for two slit positions of the galactic H II region M17. We have measured the intensities of 160 emission lines, 36 of them being permitted lines of heavy elements.

We have determined physical conditions of M17 and its chemical composition. We derive the He^{+}, C^{++}, and O^{++} ionic abundances based on recombination lines. These abundances do not depend on the temperature structure of the nebula, and are therefore, more reliable than those derived from collisionally excited lines.

We have obtained $t^2 = 0.033 \pm 0.015$ and 0.044 ± 0.015 for the two slit positions observed in the nebula, from the comparison of the O^{++} abundances obtained making use of both collisionally excited lines and recombination lines. These t^2 values have been used to determine chemical abundances from forbidden lines.

The chemical abundances of He, C, N, O, Ne, S, and Cl in M17 are higher than those of the Orion nebula and M8, which is consistent with the presence of a composition gradient. The radial gradients computed for N, O, Ne, S, Cl, and Ar are remarkably similar and give an average value of -0.045 dex kpc^{-1}. This similarity of the computed gradients is lost when the effects of t^2 are not considered; moreover, the average gradient for $t^2 = 0.00$ amounts to -0.002 dex kpc^{-1} in complete disagreement with all modern determinations.

Based on the C abundances of M17, M8, and Orion we obtained three important constraints for models of galactic chemical evolution: the C/O values are in the 0.00 to -0.23 dex range, the C/O values are considerably higher than in the Sun, and the C/O gradient amounts to -0.08 ± 0.03 dex kpc^{-1}. These constraints are in agreement with models of galactic chemical evolution based on the yields computed by Maeder (1992) and do not agree with the predictions made by models based on the yields by Woosley & Weaver (1995).

We present $\Delta Y/\Delta Z$, and $\Delta Y/\Delta O$ values for M17 that are in agreement with recent models of galactic chemical evolution.

CE would like to thank all the members of the Instituto de Astronomía, UNAM, for their warm hospitality during his stays in México. We would like to acknowledge many fruitful discussions with L. Carigi and M. Peña. This research was partially funded through grant PB94-1108 from the Dirección General de Investigación Científica y Técnica of the Spanish Ministerio de Educación y Ciencia and grants DGAPA-UNAM IN109696 and CONACyT 25451-E (México).

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