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THE CHEMICAL COMPOSITION OF GAMMA PEGASI

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ABSTRACT

Equivalent-width data for 274 spectral lines (λλ3090–6700), the profiles of Hγ and Hδ, and the continuous flux distribution (λλ1400–8100) of the sharp-lined B2 star γ Peg have been interpreted with the aid of the Princeton ultraviolet line-blanketed model atmospheres and the hydrogen line-broadening theory of Vidal, Cooper, and Smith. New equivalent-width data from 2 Å mm^{-1} coudé plates extend the ground-based observations for γ Peg shortward to λ3094. Seventy-one additional lines have been identified, of which 34 could be analyzed. In addition to new ground-based continuum observations (λλ3300–8100), flux data in the far-ultraviolet (λλ1384–2550) have been obtained with the S2/68 experiment package on board the TD1 satellite.

An interpolated model atmosphere of T_{eff} = 21,500 K, log g = 3.7 predicts the observed continuous energy distribution from λλ2200–7500, the observed profiles of Hγ and Hδ, and the ionization equilibria of Si III/Si IV and S II/S III. With the exception of neon, chlorine, and argon, the derived abundances are within 0.2 dex of the currently accepted solar values. Neon appears to be overabundant because non–LTE effects are large for Ne I; the chlorine and argon anomalies are discussed in the paper. The temperature which was obtained for γ Peg in this investigation is consistent with the one predicted by the angular-diameter calibration of effective temperatures for early B-type stars. The only serious mismatch between the observations and the model atmosphere is shortward of λ2200, where much more line blanketing is observed than was included in the computation of the models.

Subject headings: abundances: stellar — stars: early-type — stars: individual

I. INTRODUCTION

In an attempt to understand the atmospheres of early B-type stars, the line and continuous spectra of γ Peg (B2 IV), ι Her (B3 IV), and τ Sco (B0 V) are repeatedly analyzed. Whereas complete model-atmosphere analyses have been performed for ι Her (Peters and Aller 1970; Kodaira and Scholz 1970; Peters 1976) and τ Sco (Hardorp and Scholz 1970), γ Peg has been overlooked. To provide a new complete model-atmosphere abundance analysis of γ Peg, heretofore unpublished line and continuum data combined with older observations have been interpreted with the aid of the Princeton ultraviolet-line-blanketed model atmospheres and the hydrogen-line-broadening theory of Vidal, Cooper, and Smith (1970, 1971, 1973). Continuum data from λλ1400–8100, equivalent-width data from 274 spectral lines in the interval λλ3090–6700, and the profiles of Hγ and Hδ have been analyzed.

Recently, Mihalas (1973) and Auer and Mihalas (1973) have made non–LTE analyses of the Ca II K line and the lines of Ne I, respectively, in the spectrum of γ Peg and have shown that, while non–LTE effects are small for the K line, they are substantial for the Ne I features. According to Mihalas (1973), the most representative model atmosphere for γ Peg (determined by fitting the observed continuous energy distribution and the Balmer-line profiles to model predictions) was uncertain because the energy scan of Schild, Peterson, and Oke (1971) suggested a much higher effective temperature than the same scan reduced to the Hayes calibration of α Lyr. The former suggested a T_{eff} of 25,000 K compared with 22,500 K for the latter. In order to determine the extent of the deviations from LTE for particular lines (especially if the effects are small), it is essential that one know the effective temperature and surface gravity of the star reasonably well. In view of the uncertainty in the model most representative of γ Peg, it is necessary to assemble a bulk of observational data and select the model which predicts the greatest number of reliably determined observables. Subsequently, transformations can be made between systems of model atmospheres (unblanketed, non–LTE; extensively line-blanketed, LTE; etc.) to enable one to carry out specialized analyses of spectral features (non–LTE analyses, line-profile analyses, etc.).

The rich line spectrum of γ Peg was first analyzed in detail by Miczaika (1948) and Aller (1949). Miczaika used the method of Unsöld (1941) in conjunction with data from prismatic plates of 54 Å mm^{-1} at Hγ. Aller obtained equivalent-width and line-profile data from 3 Å mm^{-1} coudé plates and employed, respectively, Unsöld's method, a modified curve-of-growth procedure, and a model atmosphere to determine the chemical composition of γ Peg. Aller also analyzed the profile of Hδ according to the Holtzmark theory. The spectrum of γ Peg was then reanalyzed by Aller and Jugaku (1959). They employed Pecker's formulation of the method of weighting functions and model atmospheres of Underhill (1957) and Milligan (unpublished). Aller and Jugaku obtained an effective temperature of 24,000 K and a log g of 4.0. The abundances which they obtained for γ Peg are compared with the ones obtained in this investigation in Table 4.

II. GENERAL OBSERVED PROPERTIES OF γ PEG

The spectrum of γ Peg has been classified as B2 IV by Johnson and Morgan (1953) and by Lesh (1968). Photometric data for γ Peg are summarized in Table 1. The adopted V magnitude and UBV colors are means from Iriarte *et al.* (1965), Johnson *et al.* (1966), and Crawford, Barnes, and Golson (1971). $E(B - V)$ was obtained with the aid of the two-color relationship $(U - B, B - V)$ published by Johnson (1966). Also included in Table 1 are *ubvy* and Hβ photometry from Crawford *et al.* (1971).

According to the present investigation, the projected rotational velocity of γ Peg is essentially zero. McNamara and Hansen (1961) also found no evidence of rotational broadening in the spectral lines of γ Peg.

It has been well established that γ Peg is a member of the class of variable stars known as β Cephei (β Canis Majoris) stars. McNamara (1953) was first to show that the radial velocity of γ Peg varied by 7 km s^{-1} with the short period of 3^h38^m. Williams (1954) later reported light variations, ΔV, of 0.015 mag. According to data given in lists of properties of β Cephei stars (Underhill 1966; Hill 1967), γ Peg essentially displays the shortest period and lowest variation of light of the group. Unlike many β Cephei objects, γ Peg does not show variations in the profiles or equivalent widths of its spectral lines (McNamara 1955). Therefore, static model atmospheres which presently exist should represent the star reasonably well.

III. OBSERVATIONAL MATERIAL

New coudé plates of γ Peg were obtained by Dr. L. H. Aller with the 120 inch (3m) telescope at Lick Observatory. The spectrograms were taken at a dispersion of 2 Å mm^{-1} and widened to 2 mm on the plate. The new plates were centered on λ3900 and λ3500, respectively, and each covered about 1200 Å. Not only did the new plate material allow us to check the scale of equivalent widths given by Aller and Jugaku (1959), but it also extended the ground-based data on γ Peg to λ3090 and allowed us to identify 71 additional lines. Thirty-four of these features could be analyzed since values of log gf could be found for them. The new line identifications in the range λλ3093–3632 are given in Table 2. This list is intended to supplement the ones published by Aller (1949) and Aller and Jugaku (1958*a*) which covered the wavelength ranges λλ3530–4430 and λλ3975–4650, respectively. Additional identifications for $\lambda > 4650$ can be found in Aller and Jugaku (1959).

Figure 1 shows a comparison between the new equivalent-width data for γ Peg and the values adopted by Aller and Jugaku (1959). No systematic trend is evident; however, the newer plate material gives slightly lower equivalent widths for the weaker lines. For the present analysis, an unweighted mean was taken between the individual newer equivalent widths and the ones used by Aller and Jugaku.

New data on the profiles of the Balmer lines were also obtained from the plates. In addition, Beaver (1972) supplied a photoelectric profile of Hγ which he obtained with his Digicon.

C. D. Keyes and M. V. Wright of UCLA have obtained a new continuum scan of γ Peg in the range λλ3300–8100 with the Wampler prime focus scanner attached to the 36 inch (91 cm) Crossley reflector at Lick Observatory. This energy distribution is compared with other published scans of γ Peg in § V of this paper.

Flux data for γ Peg in the far-ultraviolet portion of the spectrum have been provided by Dr. L. H. Aller. The observations, which covered the spectral region λλ1384–2550, were made with the S2/68 experiment package on board the TD1 satellite (see Boksenberg *et al.* 1973 for a description of the S2/68 experiment). Since the bandpass for the observations was about 40 Å, the data were effectively "continuum" observations. In total, flux measurements were made at 60 points in the spectrum with an interval of about 20 Å between integrations. The flux distribution obtained with TD1 is given in Table 3 and compared in § V with other observations made in the far-ultraviolet.

IV. METHOD OF ANALYSIS

a) *Choice of Model Atmosphere*

The Princeton ultraviolet-line-blanketed, LTE model atmospheres were chosen to carry out this analysis of γ Peg. The Princeton atmospheres include models by Mihalas and Morton (1965), Adams and Morton (1968), Hickok and Morton (1968), and Van Citters and Morton (1970). Since non–LTE effects in the continuum seem to be negligible for main-sequence stars near spectral type B2 (Auer and Mihalas 1972; Mihalas 1972), the use of LTE models should not

TABLE 1

PHOTOMETRIC DATA FOR GAMMA PEGASI*

V	$B - V$	$U - B$	$E(B - V)$	$b - y$	m_1	c_1	β
2.84	−0.23	−0.86	0.015	−0.106	0.093	0.116	2.629

* See text for references.

TABLE 2

LINE IDENTIFICATIONS FOR GAMMA PEGASI λλ3093–3632

λ	Identification	Multiplet Number	Equivalent Width
3093.42...	Si III	1	0.051
3093.61...	Si III	1	0.049
3096.79...	Si III	1	0.049
3104.71...	Mg II	6	0.053
3104.81...	Mg II	6	...
3107.95...	Fe III	29	0.011
3122.62...	O II	14	0.013
3129.44...	O II	14	0.010
3134.82...	O II	14	0.019
3136.55...	Ar II	uncl	0.021
3158.87...	Ca II	4	0.012
3165.51...	C II	9	0.005
3167.95...	C II	9	0.006
3174.09...	Fe III	38	0.006
3176.00...	Fe III	38	0.016
3178.03...	Fe III	38	0.011
3179.33...	Ca II	4	0.015
3181.28...	Ca II	4	0.006
3185.16...	Si III	8	0.009
3187.74...	He I	3	0.145
3193.81...	Fe II	6	0.007
3196.50...	Si III	8.02	0.007
3198.81...	Fe III	6	0.007
3204.76...	Fe III	6	0.008
3210.52...	Si III	8.02	0.009
3213.31...	Fe II	6	0.008
3215.60...	Fe III	6	0.010
3227.73...	Fe III bl	6	0.010
3230.50...	Si III	6	0.009
3233.95...	Si III	6	0.011
3241.62...	Si III	6	0.019
3266.88...	Fe III	7	0.026
3276.08...	Fe III	7	0.020
3288.81...	Fe III	7	0.024
3305.22...	Fe III	7	0.014
3324.01...	S III	2	0.003
3324.87...	S III	2	0.012
3328.79...	N II	22	0.008
3330.30...	N II	22	0.009
3331.32...	N II	22	0.005
3339.36...	Fe III	7	0.012
3347.70...	Fe III	18	0.008
3354.55...	He I	8	0.045
3367.18...	S III	2	0.011
3370.38...	S III	2	0.006
3377.20...	O II	9	0.008
3387.13...	S III	2	0.008
3390.25...	O II	9	0.013
3396.71...	Fe III	18	0.007
3437.16...	N II	13	0.014
3447.59...	He I	7	0.071
3486.91...	Si III	8.06	0.009
3497.34...	S III	uncl	0.016
3499.57...	Fe III	26	0.009
3501.75...	Fe III	26	0.006
3512.51...	He I	38	0.122
3530.49...	He I	36	0.096
3554.5....	He I	34	0.134
3586.05...	C II, Fe II bl	...	...
3587.25...	He I	31	0.209
3590.47...	Si III	7	0.028
3593.15...	Fe III	36	0.007
3595.99...	S II	4	0.008
3599.30...	He I	30	0.020
3600.93...	Fe III	36	0.017
3601.62...	Al III	1	0.038
3601.92...	Al III	1	0.011
3603.89...	Fe III, Ar II bl	...	0.016
3612.35...	Al III	1	0.027
3613.64...	He I	6	0.107
3632.02...	S III	1	0.010

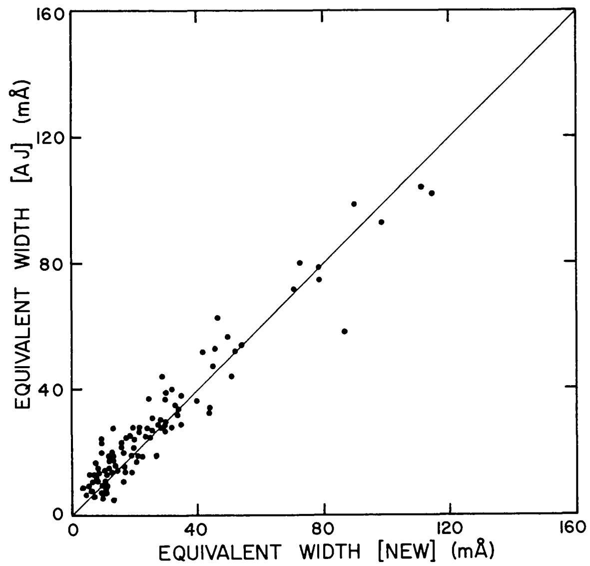

FIG. 1.—Comparison between new equivalent-width data for γ Peg and those of Aller and Jugaku (1959).

present a serious problem. However, non–LTE effects in the lines could be large (as shown by Auer and Mihalas for Ne I). Alternatively, non–LTE effects could be small or absent (i.e., Ca II K line). Therefore, some degree of caution must be taken when one interprets abundance results from LTE treatments.

The following procedure was used to choose a representative model for γ Peg: (1) An approximate T_{eff} was obtained from the intrinsic $(U - B)$ color with the aid of the scale of effective temperatures given by angular diameter data (Webb 1971). (2) Upon adopting a T_{eff}, an approximate log g was determined by comparing the observed profiles of Hγ and Hδ with those computed according to the Vidal-Cooper-Smith theory of hydrogen line broadening. (3) The observed continuous energy distribution and ionization balance (ionization equilibria) of Si III/Si IV and S II/S III were then considered to refine the initial estimates of T_{eff} and log g. (4) The model which was adopted best represented the observed energy scan and the profiles of Hγ and Hδ, and gave ionization balance for the above-mentioned ion pairs.

b) *Computation of the Abundances*

The elemental abundances were determined with the aid of the UCLA spectrum-synthesis program (Ross and Aller 1968) used in the iterative abundance mode. From a set of input parameters which include the equivalent width of the line, its wavelength, lower excitation potential, log gf, the radiation and Stark damping parameters, and an estimate of the abundance of the element in question, a theoretical equivalent width is computed with the aid of an adopted model atmosphere, He/H ratio, and microturbulent parameter, ξ_t. An iteration procedure is then followed by adjusting the elemental abundance until observed and computed equivalent widths agree. Usually the procedure converges in three steps.

TABLE 3

ULTRAVIOLET FLUX DISTRIBUTION OF γ PEGASI(1)

λλ 1384 - 2550

λ	$F_\nu(10^{-21})$	$M_{1/\lambda} - M_{1/V}^{(2)}$	λ	$F_\nu(10^{-21})$	$M_{1/\lambda} - M_{1/V}^{(2)}$
1384.1	4.803	-0.71	1977.2	4.421	-0.63
1403.6	4.409	-0.61	1996.7	4.546	-0.66
1423.0	4.720	-0.69	2016.1	4.531	-0.66
1442.4	5.137	-0.78	2035.5	4.519	-0.66
1461.8	5.194	-0.79	2054.9	4.385	-0.63
1481.2	5.020	-0.76	2074.3	4.430	-0.64
1500.6	4.923	-0.73	2093.7	4.395	-0.64
1520.0	4.580	-0.66	2113.1	4.427	-0.65
1539.4	4.348	-0.59	2132.5	4.549	-0.68
1558.8	4.392	-0.60	2151.9	4.765	-0.73
1578.2	4.850	-0.71	2181.1	4.703	-0.71
1597.7	4.801	-0.70	2200.6	4.723	-0.72
1617.1	4.872	-0.71	2220.0	4.782	-0.73
1636.5	5.087	-0.76	2239.4	4.714	-0.72
1655.9	5.549	-0.85	2258.8	4.772	-0.73
1675.3	5.557	-0.86	2278.2	4.756	-0.72
1694.7	5.465	-0.85	2297.6	4.728	-0.71
1714.1	5.210	-0.81	2317.0	4.726	-0.71
1733.5	4.822	-0.71	2336.4	4.585	-0.67
1752.9	4.347	-0.60	2355.8	4.525	-0.65
1783.1	4.807	-0.71	2375.2	4.470	-0.64
1802.6	4.965	-0.74	2394.7	4.441	-0.62
1822.0	4.877	-0.72	2414.1	4.439	-0.62
1841.4	4.703	-0.78	2433.5	4.493	-0.64
1860.8	4.527	-0.64	2452.9	4.450	-0.62
1880.2	4.553	-0.66	2472.3	4.474	-0.63
1899.6	4.393	-0.62	2491.7	4.356	-0.59
1919.0	4.327	-0.60	2511.1	4.382	-0.60
1938.4	4.271	-0.61	2530.5	4.216	-0.56
1957.8	4.356	-0.61	2549.9	4.166	-0.54

(1) Observed with S2/68 experiment package on board the TD1 satellite.

(2) Corrected for reddening; E(B - V) = $0^m.015$.

A microturbulent parameter of 3 km s^{-1} was chosen to remove trends of increasing abundance with increasing line strength which were observed for C II, N II, and O II when ξ_t was taken to be zero. The same value of ξ_t removed the observed trend for each of the above elements.

Radiative damping parameters which include the effects of stimulated emission and upward transitions were computed for all multiplets which contained at least one line stronger than 70 mÅ in the spectrum of γ Peg. Transition probabilities and statistical weights needed for the computations were obtained from Wiese, Smith, and Glennon (1966) and Wiese, Smith, and Miles (1969). Quadratic Stark interaction constants, C_4, were computed from electron impact half-widths and ion-broadening parameters published by Griem (1964). In most cases, however, the value of the radiative damping parameter, Γ_{RAD}, was greater than 10 times Γ_{STARK} in the line-forming region of the stellar atmosphere.

V. THE CONTINUUM

Various observations of the continuous energy distribution of γ Peg in the ground-based spectral region are compared with each other, and with model-atmosphere predictions, in Figure 2. The individual monochromatic magnitudes for each scan have been corrected for interstellar reddening and line blanketing.

The individual observations are quite discordant, especially shortward of the Balmer discontinuity. Certainly, a reliable effective temperature could not be determined from a single observed energy scan. The major discrepancies between the scans are not a result of the individual observers' adopting different systems of absolute calibration. The scans of Wolff, Kuhi, and Hayes (1968), Watson (1972), and Keyes and Wright (unpublished) were reduced using the Hayes (1970) system of absolute calibrations. Schild, Peterson, and Oke (1971) adopted the Oke-Schild calibration for α Lyr. Keyes and Wright used the same equipment as Wolff, Kuhi, and Hayes. Although their scans agree rather well longward of λ4400, Keyes and Wright obtain significantly lower fluxes shortward of the Balmer discontinuity. According to Keyes and Wright, even though the night visibly seemed photometric, the ultraviolet extinction may have been anomalous on the evening of their observations.

Watson's magnitudes in the near-infrared predict a temperature which is much too low (15,000 K). Alternatively, the slopes of the Paschen continuum given by the energy distributions of Schild, Peterson, and Oke and Watson suggest unreasonably high temperatures (in excess of 25,000 K). The scan of Schild, Peterson, and Oke cannot be made to agree with the one of Wolff, Kuhi, and Hayes by transforming it to the Hayes calibration system. The slope of the Paschen continuum changes only slightly and the points shortward of the Balmer discontinuity still fall 0.03 mag above Wolff, Kuhi, and Hayes's. Since the Schild, Peterson, and Oke scan appeared to be anomalous, it was placed on the Hayes's system of absolute calibration and then given low weight in

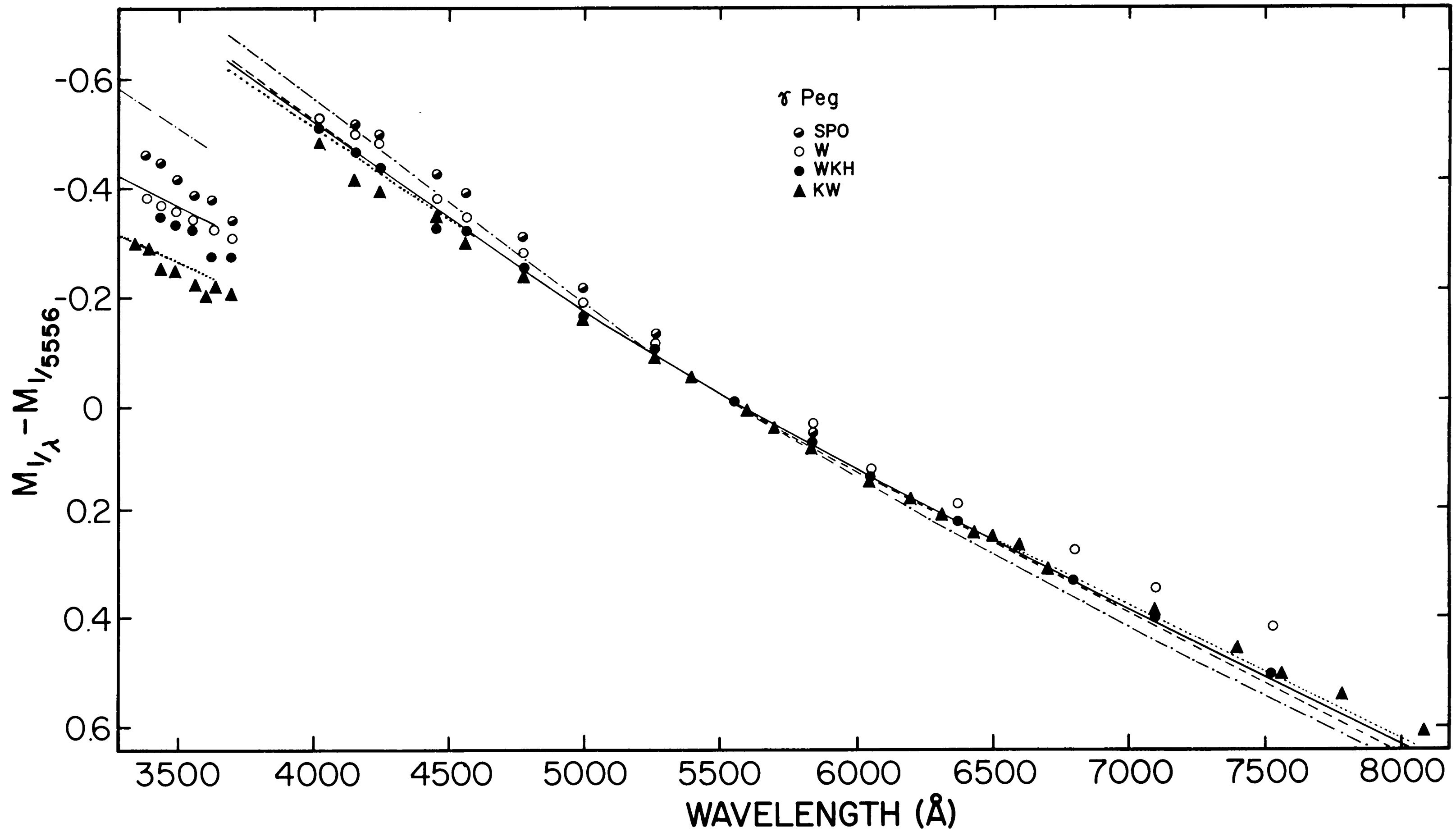

FIG. 2.—The continuous flux distribution of γ Peg in the ground-based portion of the spectrum compared with the predictions of the Princeton model atmospheres. The observed scans are from Schild, Peterson, and Oke (1971; SPO), Watson (1972; W), Wolff, Kuhi, and Hayes (1968; WKH), and Keyes and Wright (KW). Models are denoted by: (———), 21,500 K, $\log g = 3.7$, interpolated, and 21,910 K, $\log g = 4$, $\lambda < 3650$; (– – –) 21,910 K, $\log g = 4$, $\lambda > 3650$; (—·—) 25,200 K, $\log g = 4$; and (···) 20,200 K, $\log g = 4$.

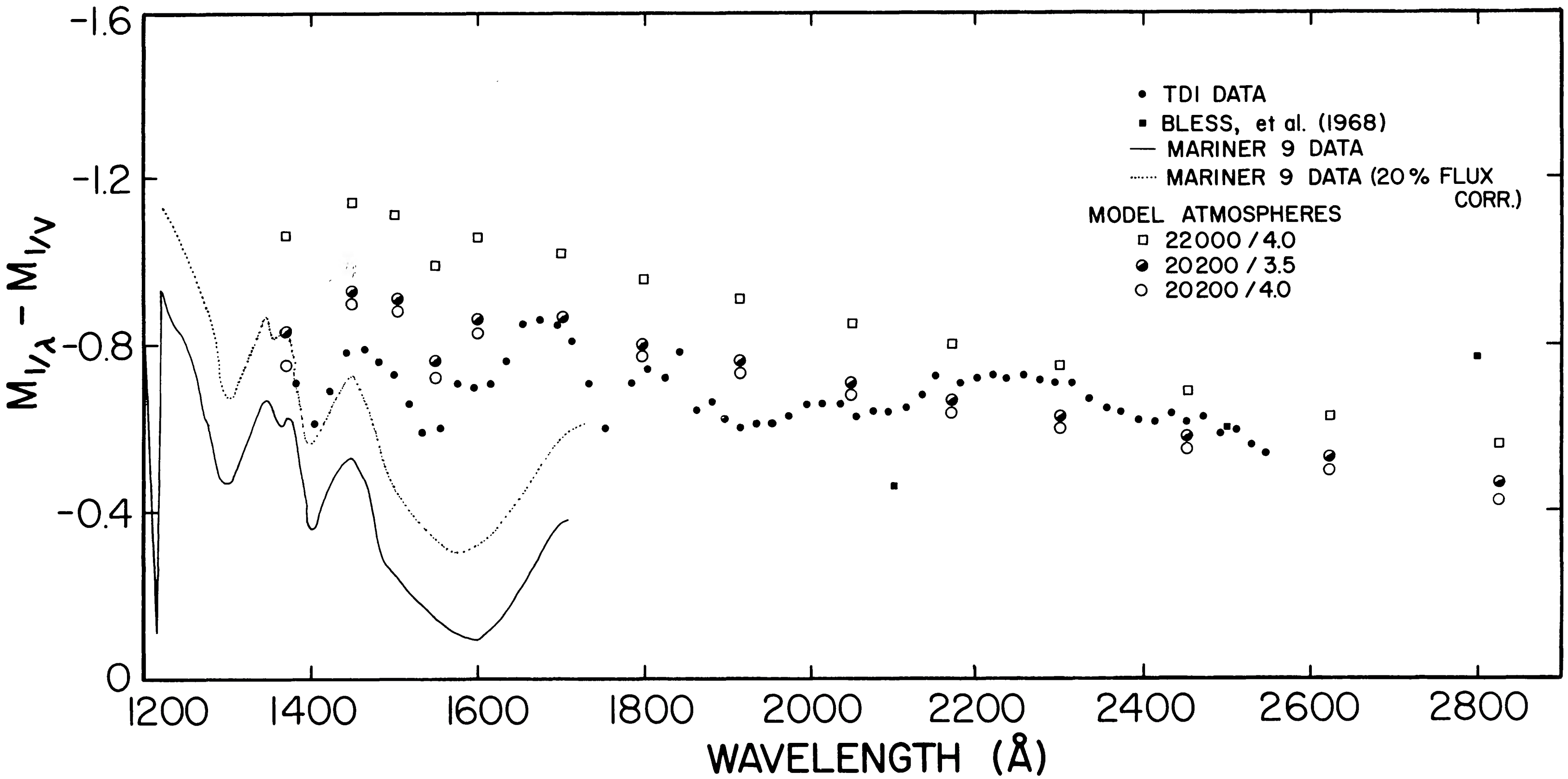

FIG. 3.—The ultraviolet continuum of γ Peg compared to flux predictions from the Princeton model atmospheres. Flux points from model atmospheres have been convolved with instrumental profile for the S2/68 equipment.

adopting a mean energy distribution for γ Peg. The recent recalibration of the energy distribution of α Lyr by Hayes and Latham (1975) reveals that the latter procedure was reasonable.

The flux distribution given by the model atmosphere of Mihalas and Morton (1965), $T_{\rm eff} = 21{,}910$ K, $\log g = 4$, matches the mean of the observed energy scans reasonably well. An interpolated model of 21,500 K, $\log g = 3.7$ gives the slope of the Paschen continuum observed by Wolff, Kuhi, and Hayes and Keyes and Wright ($\lambda\lambda$4400–7500). The latter model also agrees well with the mean of the scans of Wolff, Kuhi, and Hayes, Schild, Peterson, and Oke, and Watson for points shortward of the Balmer discontinuity.

The flux distribution for γ Peg in the far-ultraviolet portion of the spectrum is compared with the model predictions in Figure 3. Ultraviolet flux measurements which are considered include those of Bless *et al.* (1968), data from *Mariner 9* (Lillie, Bohlin, and Molnar 1972), and our data from the TD1 satellite.

Bless *et al.* made flux measurements at $\lambda\lambda$2100, 2500, and 2800 with filter photometers flown in an Aerobee rocket. Later, γ Peg was observed in the region $\lambda\lambda$1200–1700 with the ultraviolet spectrometer flown aboard *Mariner 9*. The flux calibration for the *Mariner 9* data was supplied by Molnar (1972).

All ultraviolet flux measurements were corrected for interstellar reddening using the extinction curve of Bless and Savage (1972). Conversion to monochromatic magnitudes relative to the V magnitude was achieved by adopting the flux for $V = 0.0$ given by Oke and Schild (1970).

The ultraviolet flux distribution for γ Peg as measured with the S2/68 experiment package on board the TD1 satellite is given in Table 3. Flux points from the model atmospheres considered in Figure 3 have been convolved with the instrumental profile for the S2/68 equipment (Boksenberg *et al.* 1973) in order to make a more meaningful comparison between the S2/68 observations and the models.

Longward of λ2200, where line blanketing is minimal, the observed flux is consistent with that predicted by an interpolated model of 21,500 K, $\log g = 4.0$. Shortward of λ2200, however, the observed flux measurements fall significantly below those given by models pertinent to B2 stars. Line blanketing in this spectral region is far more extensive than that considered by the Princeton group in their computations. The energy distribution obtained from *Mariner 9* (7.5 Å resolution) also falls below the model predictions. According to Lillie *et al.* (1972), the flux data from *Mariner 9* are 20 percent below those from OAO-2. Even when a 20 percent correction is applied, the observed flux falls below the model predictions (see Fig. 3).

The broad absorption features centered at $\lambda\lambda$1920 and 2070 which were observed by Thompson, Humphries, and Nandy (1974) in TD1 scans of other early B type stars are also seen in γ Peg. The suggestion made by Thompson, Humphries, and Nandy that the depressions are due primarily to Fe III absorption features seems reasonable in view of the numerous Fe III lines seen in the ground-based portion of the spectrum.

VI. THE PROFILES OF Hγ AND Hδ

Theoretical profiles were computed for Hγ and Hδ using the Princeton model atmospheres and the hydrogen-line-broadening theory of Vidal, Cooper, and Smith (1970, 1971, 1973; VCS). Since profiles computed from the Stark broadening functions given by the VCS theory are broader than those computed from theories of Griem (1967), Kepple and Griem (1968), and Edmonds, Schluter, and Wells (1967; ESW), lower values of log g are obtained for a given $T_{\rm eff}$.

Observed profiles of Hγ and Hδ are compared with the computed profiles in Figure 4. The Hγ profile published by Aller and Jugaku (1958*b*), from 3 Å mm^{-1} plates, agrees well with the one Norris (1971) obtained from 7 Å mm^{-1} plates. Beaver's profile, however, is shallower due to the lower resolution (about 2.5 Å) of the Digicon data. Except for a discrepancy in the line center, there is good agreement between Norris's Hδ profile and the one obtained from the new coudé plates. For purposes of comparing theory and observation, we will adopt the mean of Aller and Jugaku and Norris for Hγ, and the mean of Norris and the new data for Hδ.

Except at the line centers, where non-LTE effects appear (Mihalas 1972), the mean observed profiles

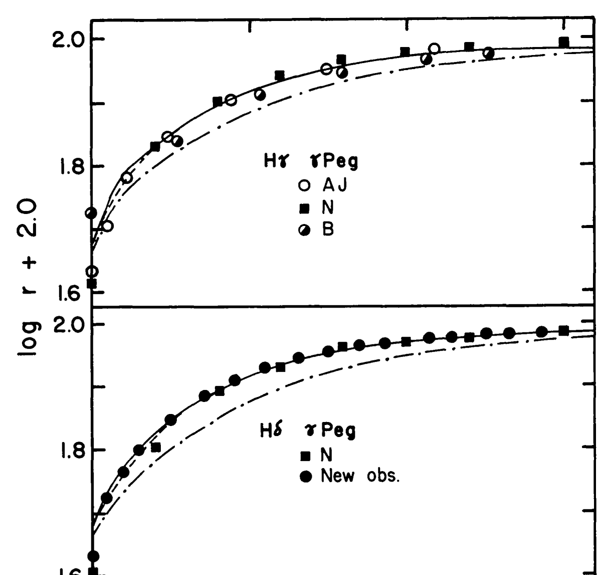

FIG. 4.—Comparison between observed and computed profiles of Hγ and Hδ. Observed profiles are from Aller and Jugaku (1958*b*; AJ), Norris (1971; N), Beaver (1972; B), and new observations. Computed profiles are from the following models: (———) 21,500 K, $\log g = 3.7$, interpolated; (– – – –) 20,200 K, $\log g = 3.5$; and (— · —) 20,200 K, $\log g = 4.0$.

TABLE 4

THE CHEMICAL COMPOSITION OF GAMMA PEGASI[1]

Ion	Number of Lines	log N[2]	log N_{AJ}[3]	log$N_{\mathrm{Sun}(W)}$[4]	log $N_{\mathrm{Sun}(A)}$[5]
He I..........	6	10.96 ± 0.09	11.17		10.9 ± 0.1
C II..........	29	8.45 ± 0.31	8.58	8.57	8.62 ± 0.04
N II..........	39	7.82 ± 0.24	8.01	8.06	7.94 ± 0.11
O II..........	77	8.66 ± 0.36	8.63	8.83	8.84 ± 0.03
Ne I..........	11	8.54 ± 0.16	8.73	7.45	7.57 ± 0.10
Mg II..........	5	7.45 ± 0.08	7.95	7.54	7.55 ± 0.05
Al III..........	9	6.45 ± 0.17	5.76	6.40	6.56 ± 0.09
Si II..........	8	7.07 ± 0.26			
Si III..........	14	7.53 ± 0.24	7.03	7.55	7.55 ± 0.05
Si IV..........	2	7.56 ± 0.05			
P III..........	5	5.20 ± 0.23	5.50	5.43	5.59 ± 0.15
S II..........	37	7.20 ± 0.23	7.80	7.21	7.20 ± 0.05
S III..........	7	7.26 ± 0.44			
Cl II..........	5	6.70 ± 0.47	6.21	5.65	5.35 ± 0.3
Ar II..........	8	6.70 ± 0.36	6.90	6.75	6.0 ± 0.5
Ca II..........	4	6.21 ± 0.22		6.33	6.39 ± 0.08
Fe III..........	8	7.44 ± 0.09		7.40	7.45 ± 0.15

NOTES.—(1) $T_{\mathrm{eff}} = 21{,}500$ K, log $g = 3.7$; $\xi_t = 3$ km s^{-1}; (2) log $N_{\mathrm{H}} = 12.0$; (3) Aller and Jugaku 1959 and Aller 1960; (4) Withbroe 1971; (5) Aller 1975.

of Hγ and Hδ fit theoretical profiles computed from the $T_{\mathrm{eff}} = 20{,}200$ K, log $g = 3.5$ model. However, an effective temperature of 21,500 K is suggested by the intrinsic $U - B$ color of γ Peg and the angular-diameter calibration of effective temperatures. If the latter temperature is adopted for γ Peg, then a reasonably good fit to the observations is achieved with log $g = 3.7$. The values of log g obtained from the Griem and ESW theories, 3.9 and 4.1, respectively, are inconsistent with the spectral type of γ Peg.

VII. THE CHEMICAL COMPOSITION

A preliminary abundance analysis carried through with $T_{\mathrm{eff}} = 21{,}500$ K, log $g = 3.7$ showed ionization balance for Si III/Si IV and S II/S III. Since the latter model also predicted the observed profiles of Hγ and Hδ, matched the continuum data reasonably well, and gave silicon and sulfur abundances within 0.1 dex of the solar values, it was deemed representative of the star.

The chemical composition of γ Peg which was determined in this analysis is given in Table 4. For comparison, the abundances that Aller and Jugaku (1959) obtained for γ Peg and the solar composition are listed. Two recent compilations of solar abundances are presented, Aller (1975) and Withbroe (1971). It is important to keep in mind that the solar abundances also have uncertainties associated with them when they are compared with the stellar results. Uncertainties in some solar values can be as high as 0.5 dex (e.g. argon), and the means given by Aller can typically differ from Withbroe by 0.1 dex. The degree of scatter (standard deviation) in the individual values of log N for γ Peg, which result from uncertainties in the line strengths, f-values, damping parameters, etc., are also given in Table 4. Note that in most cases the standard deviation is comparable with the uncertainties in the solar abundances.

The data used for this analysis of γ Peg, including the values of log gf, their sources, and the radiative-damping parameters ($\Gamma_{\mathrm{RAD}}/\gamma_{\mathrm{classical}}$), are presented in Table 5. Also given are the individual values of log N obtained from the various spectral lines. A detailed discussion of each elemental abundance is presented below.

a) *Helium*

The helium abundance was determined from six weak lines of He I which gave a mean value of 10.96 or 9 percent. According to Aller (1975), recent data on the solar corona, solar chromosphere, and solar wind give a mean solar helium abundance of 10.9. Individual values for the various lines of He I in γ Peg ranged from 10.83 (7%) to 11.08 (12%). Leckrone (1971) obtained a mean He/H ratio of 10.4 ± 2.1 from the profiles and equivalent widths of 10 strong to moderately strong He I lines. The interpolated Princeton model which Leckrone adopted for his analysis of the helium lines in γ Peg (21,900 K, log $g = 4.1$) is slightly high in temperature and excessively high in gravity. However, Leckrone points out that, since γ Peg happens to fall in the temperature domain where the helium lines reach maximum strength, the abundance deduced for helium is not very sensitive to the model parameters. Leckrone's individual values show the same range of abundances as do the ones obtained in this investigation. The individual abundances obtained from the four He I lines which were common to both investigations, $\lambda\lambda$4121, 4438, 4713, and 5016, agreed within 0.05 dex.

b) *Carbon, Nitrogen, and Oxygen*

Twenty-nine lines of C II were used to obtain the mean carbon abundance of 8.45. The resulting value is 0.15 dex below the solar abundance of carbon.

TABLE 5

PHYSICAL DATA, EQUIVALENT WIDTHS, AND VALUES OF LOG N FOR LINES OBSERVED IN THE SPECTRUM OF γ PEGASI

ION	λ	MULT. NO.	E.P.	EQUIV. WIDTH	LOG gf	ref	γ	LOG N
He I	3447.59	7	20.53	0.071	-1.894	1	0.6	10.83
	3613.64	6	20.53	0.093	-1.656	1	1.0	10.94
	4168.97	52	21.13	0.097	-2.338	1	15.3	11.00
	4437.55	50	21.13	0.125	-2.034	1	17.3	10.99
	4713.20	12	20.87	0.240	-0.973	1	1.1	10.89
	5015.68	4	20.53	0.290	-0.820	1	7.5	11.08
C II	3876.05	33	24.17	0.085	0.489	1	10.0	9.45
	3876.19	33	24.17	0.032	0.860	1	10.0	8.12
	3876.41	33	24.17	0.034	0.740	1	10.0	8.28
	3876.67	33	24.17	0.027	0.620	1	10.0	8.24
	3878.22	33	24.17	0.020	-0.307	1	10.0	8.98
	3879.60	33	24.17	0.007	-0.187	1	10.0	8.31
	3880.59	33	24.17	0.008	-0.307	1	10.0	8.49
	3918.98	4	16.26	0.079	-0.540	1	2.7	8.16
	3920.68	4	16.26	0.097	-0.242	1	2.7	8.15
	3952.08	32	24.17	0.012	-0.199	3	10.0	8.60
	4074.53	36	24.27	0.029	0.590	1	10.0	8.39
	4074.89	36	24.27	0.021	0.203	3	10.0	8.57
	4267.02	6	17.97	0.108	0.580	1	21.3	8.00
	4267.27	6	17.97	0.108	0.730	1	21.3	7.85
	4411.19	39	24.50	0.018	0.540	1	10.0	8.27
	4411.52	39	24.50	0.017	0.690	1	10.0	8.09
	5132.96	16	20.61	0.037	-0.244	1	10.0	8.59
	5133.28	16	20.61	0.031	-0.210	1	10.0	8.43
	5137.26	16	20.61	0.013	-0.940	1	10.0	8.65
	5143.48	16	20.61	0.035	-0.246	1	10.0	8.55
	5145.16	16	20.62	0.064	0.157	1	10.0	8.68
	5151.07	16	20.62	0.039	-0.213	1	10.0	8.62
	5640.50	15	20.61	0.023	-0.680	1	10.0	8.79
	5648.07	15	20.61	0.027	-0.381	1	10.0	8.59
	5662.51	15	20.62	0.031	-0.205	1	10.0	8.51
	5889.96	5	17.97	0.060	-0.201	1	10.0	8.31
	5891.64	5	17.97	0.058	-0.455	1	10.0	8.53
	6578.03	2	14.39	0.167	0.096	1	28.2	8.51
	6582.85	2	14.39	0.130	-0.206	1	28.2	8.40
N II	3328.79	22	20.58	0.008	-0.110	1	10.0	7.76
	3330.30	22	20.56	0.009	-0.730	1	10.0	8.44
	3331.32	22	20.56	0.005	-0.382	1	10.0	7.79
	3437.16	13	18.42	0.014	-0.371	1	10.0	7.79
N II	3847.38	30	21.06	0.010	-0.940	1	10.0	8.08
	3995.00	12	18.42	0.077	0.276	1	17.0	7.74
	4035.09	39	23.02	0.028	0.609	3	4.1	7.70
	4043.54	39	23.03	0.024	0.728	3	4.1	7.48
	4044.75	39	23.03	0.011	-0.448	3	4.1	8.18
	4179.67	50	23.15	0.012	-0.197	3	10.0	8.04
	4227.75	33	21.51	0.022	-0.068	1	10.0	7.86
	4236.93	48	23.14	0.016	0.396	3	33.0	7.63
	4237.05	48	23.14	0.017	0.568	3	33.0	7.49
	4241.78	48	23.14	0.034	0.727	3	10.0	7.82
	4427.96	55	23.32	0.007	-0.168	1	10.0	7.84
	4432.73	55	23.31	0.017	0.580	1	10.0	7.58
	4442.00	55	23.32	0.009	0.309	1	10.0	7.49
	4447.03	15	20.32	0.047	0.285	1	15.0	7.83
	4530.39	59	23.37	0.019	0.670	1	10.0	7.60
	4601.48	5	18.39	0.031	-0.368	1	15.2	7.64
	4607.14	5	18.39	0.032	-0.488	1	15.2	7.79
	4613.87	5	18.39	0.027	-0.730	1	15.2	7.91
	4621.39	5	18.39	0.022	-0.540	1	15.2	7.59
	4630.53	5	18.40	0.053	0.129	1	15.2	7.60
	4643.09	5	18.40	0.037	-0.345	1	15.2	7.76
	4987.37	24	20.85	0.019	-0.630	1	10.0	7.33
	4994.35	24	20.85	0.030	-0.082	1	10.0	8.09
	5002.69	4	19.38	0.023	-1.021	1	10.0	8.44
	5007.32	24	20.85	0.023	0.161	1	10.0	7.66
	5010.62	4	18.39	0.029	-0.520	1	10.0	7.83
	5025.67	19	20.58	0.014	-0.451	1	10.0	7.90
	5045.10	4	18.40	0.041	-0.328	1	10.0	7.91
	5666.64	3	18.39	0.049	0.008	1	10.0	7.84
	5676.02	3	18.38	0.040	-0.347	1	10.0	8.02
	5679.55	3	18.40	0.065	0.278	1	10.0	7.87
	5686.21	3	18.39	0.027	-0.473	1	10.0	7.86
	5710.76	3	18.40	0.025	-0.475	1	10.0	7.81
	5927.82	28	21.06	0.016	-0.303	1	10.0	8.13
	6482.07	8	18.42	0.036	-0.162	1	10.0	7.89
O II	3122.62	14	25.54	0.013	-0.610	1	10.0	9.29
	3129.44	14	25.53	0.010	-0.540	1	10.0	9.04
	3134.82	14	25.55	0.019	0.036	1	10.0	8.96
	3377.20	9	25.18	0.008	-0.193	1	10.0	8.61
	3390.25	9	25.18	0.013	0.108	1	10.0	8.65
	3851.47	13	25.55	0.006	-1.402	1	10.0	8.72
	3857.18	13	25.54	0.013	-1.222	1	10.0	8.98
	3863.50	12	25.54	0.006	-0.830	1	10.0	8.15
	3864.13	11	25.52	0.006	-1.840	1	3.6	9.16
	3864.45	12	25.54	0.015	-0.348	1	3.6	8.20
	3864.68	12	25.54	0.012	-0.740	1	3.6	8.45
	3882.20	12	25.55	0.021	-0.050	1	3.6	8.16

TABLE 5—*Continued*

ION	λ	MULT. NO.	E.P.	EQUIV. WIDTH	LOG gf	ref	γ	LOG N
O II	3907.45	11	25.54	0.011	-1.810	1	5.0	9.48
	3911.96	17	25.55	0.050	0.066	1	22.7	8.86
	3919.29	17	25.55	0.029	-0.192	1	22.7	8.57
	3954.37	6	23.32	0.048	-0.353	1	21.6	8.65
	3982.72	6	23.34	0.030	-0.670	1	21.6	8.53
	4048.22	50	28.57	0.008	-0.369	3	10.0	8.64
	4054.10	50	28.57	0.005	-1.122	3	10.0	9.14
	4060.58	97	31.01	0.012	0.727	3	10.0	8.39
	4060.98	97	31.01	0.013	0.614	3	10.0	8.56
	4062.90	50	28.58	0.015	-0.190	3	10.0	8.87
	4069.64	10	25.52	0.045	0.140	1	4.0	8.74
	4069.90	10	25.53	0.054	0.346	1	4.0	8.75
	4072.16	10	25.54	0.071	0.530	1	4.0	8.94
	4078.86	10	25.53	0.026	-0.259	1	4.0	8.61
	4084.66	21	25.74	0.013	-0.890	1	10.0	8.78
	4085.12	10	25.54	0.031	-0.144	1	4.0	8.66
	4087.16	48	28.55	0.017	0.530	1	10.0	8.25
	4089.30	48	28.58	0.039	0.900	1	10.0	8.64
	4112.03	21	25.74	0.019	-0.780	1	10.0	8.95
	4129.34	19	25.73	0.011	-1.116	1	35.4	8.91
	4132.80	19	25.72	0.039	-0.066	1	35.4	8.84
	4153.30	19	25.73	0.038	0.076	1	35.4	8.68
	4156.51	19	25.74	0.015	-0.790	1	4.3	8.81
	4185.46	36	28.24	0.032	0.710	1	10.0	8.57
	4192.50	42	28.39	0.010	-0.334	3	10.0	8.75
	4275.52	67	28.73	0.025	0.760	3	4.9	8.46
	4277.90	67	28.73	0.010	-0.179	3	4.9	8.71
	4281.40	54	28.70	0.006	-0.006	1	10.0	8.23
	4282.98	54	28.73	0.014	0.417	1	4.9	8.35
	4283.75	67	28.73	0.011	-0.187	1	10.0	8.79
	4288.82	54	28.71	0.010	-0.039	1	10.0	8.57
	4294.82	54	28.71	0.017	0.362	1	10.0	8.54
	4303.82	54	28.70	0.029	0.640	1	10.0	8.72
	4308.95	64	28.73	0.007	-0.978	3	10.0	9.31
	4312.10	79	28.76	0.009	-0.238	3	10.0	8.73
	4317.14	2	22.87	0.054	-0.325	1	9.7	8.77
	4319.62	2	22.88	0.050	-0.321	1	9.7	8.68
	4325.77	2	22.87	0.025	-1.060	1	10.0	8.77
	4327.48	41	28.39	0.012	0.208	3	10.0	8.38
	4328.62	61	28.71	0.005	-0.168	1	10.0	8.32
	4366.89	2	22.90	0.048	-0.239	1	9.7	8.58
	4369.28	26	26.11	0.012	-0.349	1	21.2	8.39
	4378.46	102	31.24	0.007	0.576	3	10.0	8.40
	4395.95	26	26.14	0.016	-0.161	1	10.0	8.41
	4414.91	5	23.34	0.075	0.305	1	26.4	8.69
	4416.98	5	23.32	0.063	0.044	1	27.4	8.72
	4443.05	35	28.24	0.013	0.002	1	10.0	8.66
	4448.21	35	28.24	0.017	0.131	1	27.4	8.72
O II	4452.37	5	23.34	0.024	-0.740	1	26.4	8.59
	4489.48	86	28.83	0.010	0.262	1	10.0	8.39
	4491.25	86	28.82	0.018	0.520	1	35.4	8.54
	4590.96	15	25.55	0.043	0.447	1	21.3	8.57
	4596.17	15	25.55	0.042	0.290	1	21.3	8.70
	4602.10	93	28.94	0.014	0.510	1	10.0	8.44
	4609.42	93	28.94	0.024	0.670	1	10.0	8.70
	4638.85	1	22.87	0.049	-0.264	1	11.0	8.70
	4631.80	1	22.88	0.057	0.183	1	11.0	8.43
	4649.14	1	22.90	0.083	0.429	1	11.0	8.70
	4650.84	1	22.87	0.044	-0.277	1	11.0	8.60
	4661.64	1	22.88	0.053	0.169	1	11.0	8.37
	4673.75	1	22.88	0.020	-1.067	1	11.0	8.73
	4676.23	1	22.90	0.045	-0.296	1	11.0	8.66
	4699.21	25	26.11	0.042	0.408	1	29.7	8.78
	4703.18	40	28.39	0.018	0.215	1	10.0	8.82
	4705.35	25	26.14	0.039	0.560	1	29.7	8.54
Ne I	5852.48	6	16.78	0.012	-0.433	1	10.0	8.33
	5881.89	1	16.55	0.012	-0.701	1	10.0	8.54
	6074.34	3	16.60	0.018	-0.467	1	10.0	8.56
	6143.05	1	16.55	0.038	-0.214	1	10.0	8.79
	6163.59	5	16.64	0.008	-0.563	1	10.0	8.26
	6266.48	5	16.64	0.016	-0.405	1	10.0	8.46
	6334.43	1	16.55	0.028	-0.388	1	10.0	8.77
	6382.98	3	16.60	0.022	-0.291	1	10.0	8.53
	6402.25	1	16.55	0.054	0.270	1	10.0	8.67
	6506.53	3	16.60	0.028	-0.133	1	10.0	8.54
	6598.94	6	16.78	0.016	-0.308	1	10.0	8.44
Mg II	4384.64	10	9.95	0.007	-0.780	2	10.0	7.42
	4390.59	10	9.96	0.014	-0.530	2	10.0	7.52
	4433.98	9	9.96	0.006	-0.928	3	10.0	7.50
	4481.12	4	8.83	0.080	0.594	3	8.1	7.47
	4481.32	4	8.83	0.080	0.750	3	8.1	7.33
Aℓ III	3601.62	1	14.31	0.038	0.020	2	10.0	6.46
	3601.92	1	14.31	0.011	-0.930	2	10.0	6.46
	3612.35	1	14.31	0.027	-0.236	2	10.0	6.39
	4149.76	5	20.47	0.023	0.632	3	5.1	6.32
	4150.14	5	20.47	0.021	0.477	3	5.1	6.42
	4512.53	3	17.73	0.033	0.407	3	7.9	6.14
	4529.18	3	17.74	0.061	0.662	3	7.9	6.51
	5696.46	2	15.57	0.070	0.227	3	10.0	6.69
	5722.64	2	15.57	0.056	-0.069	3	10.0	6.70
Si II	3853.66	1	6.83	0.012	-1.320	4	10.0	7.25
	3862.02	1	6.83	0.034	-0.340	4	10.0	6.85

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TABLE 5—*Continued*

ION	λ	MULT. NO.	E.P.	EQUIV. WIDTH	LOG gf	ref	γ	LOG N
Si II	4128.05	3	9.79	0.036	0.375	4	26.0	7.04
	4130.87	3	9.80	0.039	0.580	4	26.0	6.90
	5041.05	5	10.02	0.019	0.290	4	10.0	6.87
	5056.02	5	10.03	0.029	-0.590	4	10.0	6.83
	6347.09	2	8.09	0.065	0.180	4	10.0	7.56
	6371.35	2	8.09	0.038	-0.065	4	10.0	7.25
Si III	3093.42	1	17.63	0.051	-0.268	3	10.0	7.53
	3093.61	1	17.64	0.049	-0.747	3	10.0	7.96
	3096.79	1	17.64	0.049	-0.621	3	10.0	7.84
	3185.16	8	21.79	0.009	-0.240	2	10.0	7.17
	3230.50	6	21.62	0.009	-0.680	2	10.0	7.59
	3233.95	6	21.62	0.011	-0.200	2	10.0	7.24
	3241.62	6	21.63	0.019	0.030	2	10.0	7.43
	3486.91	8.06	24.99	0.009	0.830	2	10.0	7.15
	3590.46	7	21.79	0.028	0.574	3	10.0	7.46
	3806.56	5	21.63	0.094	0.715	3	6.1	7.68
	4552.64	2	18.92	0.114	0.316	3	28.0	7.65
	4567.87	2	18.92	0.095	0.093	3	28.0	7.61
	4574.78	2	18.92	0.059	-0.383	3	28.0	7.43
	5739.75	4	19.64	0.066	0.040	3	10.0	7.66
Si IV	4088.86	1	23.95	0.019	0.188	3	31.0	7.59
	4116.10	1	23.95	0.013	-0.117	3	31.0	7.52
P III	4057.39	1	14.43	0.004	-1.000	2	10.0	5.53
	4059.27	1	14.43	0.009	-0.050	2	10.0	4.97
	4080.04	1	14.43	0.006	-0.310	2	10.0	5.03
	4222.14	3	14.55	0.022	0.190	2	10.0	5.33
	4246.68	3	14.55	0.010	-0.110	2	10.0	5.16
S II	3923.48	55	16.13	0.019	0.440	2	10.0	7.07
	3933.29	55	16.20	0.019	0.580	2	10.0	6.95
	3939.49	45	15.83	0.006	-0.840	2	10.0	7.69
	3950.42	45	15.83	0.006	-0.700	2	10.0	7.55
	3990.94	45	15.83	0.007	-0.302	2	10.0	7.23
	3998.79	59	16.18	0.008	0.057	2	10.0	7.03
	4032.81	59	16.18	0.010	0.236	2	10.0	6.96
	4153.10	44	15.83	0.029	0.620	2	10.0	7.09
	4162.80	44	15.88	0.029	0.781	2	10.0	6.93
	4168.41	44	15.80	0.012	-0.160	2	10.0	7.36
	4217.23	44	15.88	0.009	-0.153	2	10.0	7.23
	4257.42	66	17.38	0.008	0.360	2	10.0	7.08
	4267.80	49	16.03	0.015	0.280	2	10.0	7.11
	4282.62	49	16.03	0.008	-0.010	2	10.0	7.07
	4294.43	49	16.07	0.015	0.345	5	10.0	7.06
	4318.68	49	16.07	0.005	-0.080	2	10.0	6.95
	4391.84	43	15.83	0.005	-0.560	2	10.0	7.37
S II	4463.57	43	15.88	0.016	0.123	5	10.0	7.27
	4483.42	43	15.80	0.004	-0.430	2	10.0	7.13
	4486.66	43	15.80	0.003	-0.265	5	10.0	6.85
	4991.94	7	13.56	0.022	-0.363	5	10.0	7.33
	5014.03	15	14.01	0.044	0.036	5	10.0	7.56
	5032.41	7	13.61	0.041	0.196	5	10.0	7.22
	5320.69	38	15.00	0.015	0.552	5	10.0	7.64
	5345.67	38	15.00	0.030	0.459	5	10.0	7.16
	5428.64	6	13.53	0.020	-0.054	5	10.0	6.99
	5432.77	6	13.56	0.050	0.348	5	10.0	7.28
	5453.80	6	13.61	0.045	0.578	5	10.0	6.96
	5473.59	6	13.53	0.033	-0.001	5	10.0	7.27
	5564.94	6	13.61	0.027	-0.193	5	10.0	7.35
	5606.10	11	13.67	0.022	0.156	5	10.0	6.90
	5616.62	11	13.62	0.003	-0.810	2	10.0	6.87
	5639.96	14	14.01	0.052	0.235	7	10.0	7.59
	5646.98	14	13.94	0.037	0.085	7	10.0	7.41
	5659.94	11	13.62	0.021	-0.063	5	10.0	7.08
	5664.73	11	13.62	0.020	-0.301	5	10.0	7.41
	5819.21	14	14.01	0.012	-0.651	5	10.0	7.48
S III	3324.01	2	17.67	0.003	-1.180	2	10.0	7.28
	3324.87	2	17.67	0.012	-0.710	2	10.0	7.62
	3370.38	2	17.67	0.006	-1.180	2	10.0	7.68
	3983.77	8	18.23	0.015	-0.440	2	10.0	6.76
	4284.99	4	18.11	0.030	0.087	2	27.6	6.83
	4354.56	7	18.23	0.010	-1.610	2	10.0	7.79
	4361.53	4	18.17	0.016	-0.395	2	27.6	6.86
Cℓ II	3913.92	68	18.17	0.014	0.230	2	10.0	7.28
	3916.70	68	18.16	0.005	0.070	2	10.0	6.94
	3917.57	68	18.15	0.002	-0.050	2	10.0	6.66
	4132.48	29	15.93	0.004	0.320	2	10.0	6.01
	4572.12	35	16.27	0.005	-0.060	2	10.0	6.63
Ar II	4042.91	33	18.35	0.005	0.130	2	10.0	6.30
	4131.73	32	18.35	0.018	-0.140	2	10.0	7.23
	4266.53	7	16.57	0.009	-0.590	2	10.0	6.83
	4400.09	1	16.37	0.010	-0.720	2	10.0	6.97
	4401.02	1	16.34	0.009	-0.612	3	10.0	6.80
	4426.01	7	16.68	0.009	0.164	3	10.0	6.13
	4430.18	7	16.74	0.009	-0.232	3	10.0	6.54
	4545.07	15	17.07	0.010	-0.291	2	10.0	6.76
Ca II	3158.87	4	3.11	0.012	0.260	2	10.0	6.09
	3179.33	4	3.14	0.015	0.520	2	10.0	5.97
	3181.28	4	3.14	0.006	-0.439	2	10.0	6.44
	3933.66	1	0.0	0.077	0.140	2	2.0	6.33

TABLE 5—*Continued*

ION	λ	MULT. NO.	E.P.	EQUIV. WIDTH	LOG gf	ref	γ	LOG N
Fe III	4053.10	119	20.52	0.015	0.180	6	10.0	7.52
	4081.01	119	20.54	0.016	0.301	6	10.0	7.47
	4122.06	118	20.51	0.015	0.398	6	10.0	7.34
	4122.98	118	20.51	0.016	0.362	6	10.0	7.42
	4137.76	118	20.52	0.022	0.624	6	10.0	7.40
	4139.35	118	20.52	0.021	0.518	6	10.0	7.47
	4164.73	118	20.54	0.036	0.920	6	10.0	7.56
	4166.84	118	20.54	0.014	0.398	6	10.0	7.31

References for values of log gf:

(1) Wiese, Smith, and Glennon (1966)

(2) Wiese, Smith, and Miles (1969)

(3) Griem (1964)

(4) Schulz-Gulde (1969)

(5) Miller (1968)

(6) Warner (1965)

(7) Coulomb approximation computation made at UCLA

The nitrogen abundance was determined from 39 lines of N II which gave a mean value of 7.82. The abundances from the four lines shortward of the Balmer discontinuity were consistent with the mean from the other lines of N II. The mean nitrogen abundance is 0.1–0.2 dex below the solar value.

Oxygen, also, appears to be slightly underabundant in γ Peg. The mean from 77 lines of O II is 8.66, compared with the solar value of 8.84. As in the case of N II, the O II lines shortward of λ3400 gave abundances which agreed well with those from the other O II features.

Although their mean values suggest that C, N, and O are slightly underabundant in γ Peg, the differences from the solar abundances are less than the scatter in the individual abundances. Also, the ratios of N/C and N/O are within 0.1 dex of the solar ratios. Therefore, it appears that the abundances of C, N, and O are not significantly different from the solar values.

c) *Neon*

The neon abundance, obtained from 11 lines of Ne I, is 0.55 dex above the usually quoted cosmic abundance of 8.0 and over 10 times higher than the values given by the solar coronal features. However, Auer and Mihalas (1973) predict that non–LTE effects in Ne I will operate in such a way as to cause LTE abundances to be too high by 0.7 dex. Therefore, the present LTE results are in agreement with the computations of the latter authors.

d) *Magnesium*

The mean magnesium abundance was determined from five lines of Mg II which gave a mean value of 7.45. The mean abundance is 0.1 dex below the solar value. There was very good agreement between the individual values. The Mg II line at λ3104 was originally included in the analysis but rejected in the end because it gave an unreasonably high abundance (8.0).

e) *Aluminum*

Nine lines of Al III gave a mean aluminum abundance of 6.45. The latter value is in excellent agreement with the solar abundance.

f) *Silicon*

The silicon abundance for γ Peg was determined from the lines of Si III and Si IV. The mean value of 7.55 is identical with the currently accepted solar value.

Although it was possible to achieve ionization balance for Si III/Si IV, the eight lines of Si II gave a silicon abundance which was 0.5 dex lower than the values from the higher ionization features. The individual values from Si II range from 6.8 to 7.6. The failure of the Si II lines to give abundances which agreed with those from Si III and Si IV could be a result of non–LTE, incorrect *f*-values, or an incorrect model atmosphere. The importance of non–LTE can only be assessed when the equations of statistical equilibrium and radiative transfer are solved. Possibly a scale error could exist between the *f*-values for Si II and the other ions of silicon. The Si II *f*-values were determined experimentally (Schulz-Gulde 1969), while the *f*-values for the other ions were obtained from the Coulomb approximation. If Coulomb-approximation *f*-values had been used for Si II, the mean silicon abundance from Si II would be 0.2 dex lower! Since the lines of Si II are formed in the uppermost layers of the stellar atmosphere, if the true temperatures in these layers are higher than the Princeton models indicate, then the discrepancy could be due primarily to a faulty model. Similar problems with the lines of Si II also exist for ι Her (Peters and Aller 1970; Peters 1976). Aller and Jugaku (1959) could predict the observed strengths of the lines of Si II and Si IV with a 24,000 K model and a silicon abundance of 7.03; however, the lines of Si III were stronger than the computed values.

The mean abundance from the nine lines of Si III shortward of the Balmer discontinuity agreed very well with the values given by the other Si III features. In particular, the silicon abundance suggested by multiplet 2 of Si III agrees with the values from other lines. For a 25,000 K atmosphere, Kamp (1973) predicted that non–LTE populations for multiplet 2 would be 3.5 times higher than ones in LTE. These non–LTE effects are not apparent in γ Peg; however, we must consider the possibility that other levels may show overpopulations due to non–LTE to the same degree that Kamp predicts for multiplet 2.

g) *Phosphorous*

Phosphorous appears to be slightly underabundant in γ Peg. Five lines of P III gave a mean phosphorous abundance of 5.20. The latter value is 0.2–0.4 dex below the solar abundance; however, the individual values ranged from 5.0–5.5.

h) *Sulfur*

The mean values of the sulfur abundance from S II and S III are within 0.1 dex of each other, and the resulting abundance agrees with the solar value of 7.2. Whereas the scatter in the individual values from S II was relatively small, the lines of S III suggested a wide range of abundances (6.7–8.0). The fact that multiplets 2 and 7 suggested higher abundances than did multiplets 4 and 8 could be a result of incorrect *f*-values or non–LTE.

i) *Chlorine*

Gamma Pegasi happens to be one of the few early B-type stars whose spectrum contains measurable lines of Cl II. Since the cosmic chlorine abundance is uncertain by at least an order of magnitude, the analysis of the Cl II lines in γ Peg is of considerable interest.

The mean chlorine abundance, determined from five lines, is 6.7; however, the scatter in the individual values is 0.5. To date, knowledge of the solar chlorine abundance rests upon the analysis of one line of Cl I and several lines of HCl observed in the infrared sunspot spectrum. Since the Cl I feature, λ8376, is located in the portion of the spectrum where telluric water-vapor absorption is extensive, some researchers have doubted the identification of the line (Lambert, Mallia, and Brault 1971). Lambert and Mallia (1968) obtained a solar chlorine abundance of 5.65 from the strength of the depression in the combined solar and telluric spectrum which they identified as the Cl I line. Aller and Ross (1973) analyzed the above weak feature using the UCLA spectrum-synthesis program and concluded that the solar chlorine abundance was lower than 5.3 unless there were departures from LTE. From their analyses of the strengths of several lines of HCl observed in sunspot regions, Hall and Noyes (1972) obtained a solar chlorine abundance of 5.4 $\pm$ 0.3. Therefore, all researchers to date conclude that the solar chlorine abundance is less than 5.7, an order of magnitude lower than the value obtained for γ Peg.

The chlorine abundance in planetary nebulae is quite uncertain. Aller and Czyzak (1973) quote values which range from 5.0 to 6.9. Aller (1972) gives a value of 4.9 for the chlorine abundance in the Orion Nebula.

One Cl III line, λ4608, observed in the spectrum of HR 1886 gave a chlorine abundance of 6.7 (Peters 1976). This value is identical to the mean from the five Cl II lines in the spectrum of γ Peg. The order-of-magnitude discrepancy between the chlorine abundances obtained from solar and B-star data suggests the possibility of a non–LTE situation. Detailed non–LTE computations and analyses of additional line-intensity data in the far-ultraviolet portion of the spectrum may resolve the chlorine problem.

j) *Argon*

The mean argon abundance from eight lines of Ar II is 6.7. Withbroe (1971) quotes a representative solar abundance (from coronal data) of 6.7, while Aller (1975) feels that 6.0 $\pm$ 0.5 is a more representative value. Aller and Czyzak (1973) give values which range from 6.0 to 7.0 for planetary nebulae. In view of the uncertainties in the argon abundance both in the Sun and in planetary nebulae, it appears reasonable to state that the argon abundance is normal in γ Peg.

k) *Calcium*

The abundance of calcium was determined from three lines of Ca II near λ3180 (multiplet 4) and the K line. From high-resolution scans of the K line in γ Peg, Hobbs (1973) concluded that the K line is entirely stellar in origin. The equivalent width adopted for this analysis of the K line (77 mÅ) was 2 mÅ lower than the value quoted by Hobbs in order to allow for minor interstellar contribution.

The mean abundance of calcium from the four lines is 6.21, compared with the solar value of 6.4. The abundances from the three lines shortward of the Balmer discontinuity are in agreement with that given by the K line. The K line itself gives a calcium abundance of 6.33, a value identical to the solar abundance as quoted by Withbroe.

Mihalas (1973) investigated the degree of departures from LTE for the K line. He found that non–LTE effects are small for main-sequence stars near spectral type B2, and that calcium abundances determined from the K line will be at most 0.3 dex too high when an LTE analysis is performed. Specifically, upon adopting an effective temperature of 22,500 K and log g of 4.0 for γ Peg and using 85 mÅ for the equivalent width of the K line, Mihalas obtained a solar calcium abundance and a microturbulent parameter of 2.1 km s^{-1}. He claims that a microturbulent parameter of 2.6 km s^{-1} would have to be adopted to obtain a solar calcium abundance from an LTE treatment. Considering the differences between the present analysis and that of Mihalas, our results appear to be in fair agreement. The microturbulent parameter was independently determined from the lines of C, N, and O in this investigation. If ξ_t had been taken to be 2 km s^{-1} instead of 3 km s^{-1}, the calcium abundance deduced from the K line would be 0.2 dex above the solar value. It appears that if non–LTE effects are present in the K line, they are small enough to be neglected entirely.

l) *Iron*

Eight lines of Fe III gave a mean iron abundance of 7.44. The latter value is in agreement with the currently accepted solar abundance of 7.4. The individual values showed very low scatter. Snijders (1969) analyzed many of the same Fe III lines in γ Peg that were considered in this investigation. Using Underhill's (1962) model atmospheres, Warner's *f*-values, and larger measured equivalent widths, he obtained an iron abundance of 6.9.

VIII. SUMMARY AND DISCUSSION

With the possible exception of chlorine, the elemental abundances in γ Peg appear to be very close to those obtained for the Sun. An interpolated Princeton model atmosphere of 21,500 K, log g = 3.7 gives abundances which are (except for neon) within 0.2 dex of the solar values. Where deviations from solar abundances do occur, they are usually less than the scatter in the values from individual lines. It must also be kept in mind that the solar abundances are in most cases uncertain by 0.2 dex. Since the above-mentioned model also predicts the observed profiles of Hγ and Hδ, is consistent with the continuum observations in the near-ultraviolet and the somewhat discordant ground-based continuum observations, and gives ionization balance for Si III/Si IV and S II/S III, it is concluded that the Princeton model atmosphere adequately represents the star. In addition, the angular diameter calibration of effective temperatures (Webb 1971) suggests a 21,500 K temperature for γ Peg (Peters 1976). However, spectral scans in the far-ultraviolet portion of the spectrum show that there is considerably more line blanketing in the region $\lambda\lambda$1200–2200 than the Princeton group included in their computations.

The temperature and gravity determined for γ Peg in this investigation are in excellent agreement with the values given by Lesh and Aizenman (1973, 1974) in their papers on β Cephei-type pulsation. The latter authors obtain $T_{\rm eff}$ = 21,400 K, log g = 3.75. How meaningful, though, is this agreement? The latter authors obtained their temperature from a scale of effective temperatures based upon the continuum observations of Schild, Peterson, and Oke (1971). Since the latter temperature scale agrees with the angular diameter scale in the domain of the B2 stars, the result is expected. However, Lesh and Aizenman determined the mass and radius of γ Peg from, respectively, the position of the star in the theoretical H-R diagram and the value of the luminosity which they obtained with the aid of Crawford's (1970) calibration of β index versus M_V and the bolometric correction given by Van Citters and Morton (1970). Thus two additional calibrations suggest the same values of $T_{\rm eff}$ and log g for γ Peg that were obtained in the present investigation.

Watson (1971, 1972) also considered γ Peg in his study of β Cephei objects. Compared with this investigation, his temperature appears low and his gravity high. He obtained an effective temperature of 20,800 K from scans reduced with the Hayes system of absolute calibrations and a log g of 3.88 from Hγ and Hδ profiles compared with those computed according to the ESW theory. Watson's abundances relative to oxygen, which were obtained from a curve-of-growth analysis of data from 7 Å mm^{-1} plates, are on the average 0.3 dex higher than the values determined in this study.

Auer and Norris (1974) recently analyzed a few selected lines of He I, C II, N II, O II, Mg II, and Si III in γ Peg in order to compare the elemental abundances with those in Barnard 29 in M13. They used the Vidal-Cooper-Smith hydrogen-line-broadening theory, non–LTE, unblanketed model atmospheres, and the Oke-Schild calibration for α Lyr. Although the log g which the above authors obtained is very close to the one determined in this investigation, their temperature of 24,500 K appears to be excessively high. However, the 3000 K discrepancy can be explained by their choice of model atmospheres and calibration system. The abundances which they obtained for the above-mentioned elements range from 0.05 to 0.5 dex higher than the values, from the same spectral features, presented in this paper.

The far-ultraviolet portion of the spectrum of γ Peg offers considerable opportunity for future work. There are at least 3 times as many lines between λ1000 and λ3100 as the number analyzed in this investigation. Data in this spectral region may potentially resolve the problem with the chlorine abundance, provide abundances for elements whose lines do not show up in the ground-based portion of the spectrum, and give additional information on the structure of the atmosphere.

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