THE ASTROPHYSICAL JOURNAL, Vol. 154, December 1968

THE EARLY A STARS. III. MODEL-ATMOSPHERE ABUNDANCE ANALYSIS OF FOUR FIELD STARS*

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Received April 11, 1968

ABSTRACT

An abundance analysis of four extremely sharp-lined field A stars has been made. The analysis uses a complete model-atmosphere approach to secure the abundance of each element The results show that γ Gem, θ Vir, and HD 2421 have nearly identical element abundances which are the same as Vega, aside from the element barium. The other star, *o* Peg, has underabundant scandium and overabundant heavy elements, much like Sirius. *o* Peg is like Am stars in its composition. This model-atmosphere analysis confirms that early A stars showing a low ratio of Sc II λ4246 to Sr II λ4215 will also have other Am abundance characteristics.

I. INTRODUCTION

It has been pointed out (Conti 1965; hereinafter referred to as "Paper I"; Deutsch 1967) that among the early A stars in the field there is an excess of stars with relatively small rotational velocities, $V \sin i$. In Paper I it was shown that an appreciable fraction of these sharp-lined early A stars show an anomalously low ratio of the line Sc II λ4246 to Sr II λ4215. It was suggested there that the "low" Sc/Sr stars were the early A analogues of the well-known Am stars, heretofore found only as early as spectral type A4 V.

It was shown by one of us (Conti 1967) that among several sharp-lined Pleiades A stars a few also had a low Sc/Sr ratio. In the previous paper of this series (Conti and Strom 1968; hereinafter referred to as "Paper II") we made an abundance analysis of these Pleiades stars. The result was that those stars (and only those stars) showing a low Sc/Sr ratio also showed other *abundance* anomalies similar to Am stars, as well as high microturbulence. This tended to confirm the suggestion that early Am stars exist and can be identified by a low Sc/Sr ratio.

The question naturally raised at this point is what of an abundance analysis of those *field* A stars with the low ratio? It is the purpose of this paper to answer this question. Among the A stars listed in Paper I with relatively sharp lines, four with the sharpest lines were chosen for further study. These stars are listed in Table 1. One of these stars shows a low Sc/Sr ratio, and another one is a known short-period binary. Although most Am stars are short-period binaries according to Abt (1961), it has not yet been demonstrated conclusively that *all* short-period binaries are Am stars (Abt 1965; Batten 1967). The fact that the short-period binary studied here does not appear to be an Am star leads to no contradictions at present. The other two stars appear to be normal in their spectral appearance.

II. OBSERVATIONS

Spectra of the stars listed in Table 1 were obtained at the coudé focus of the Mount Wilson 100-inch reflector by one of us (P. S. C.). All spectra were obtained using the 32-inch camera and a 900 line mm^{-1} grating in the third order for the ultraviolet and blue,

* *Contributions from the Lick Observatory*, No. 268

and second order for the yellow. The dispersion was 4.5 and 6.7 Å mm^{-1}, respectively. Two well-widened spectra of each wavelength region for each star were obtained. These used the following: ultraviolet region, baked IIaO and a 9863 filter; blue region, baked IIaO and a Wr2B filter; yellow region, baked IIaD and a GG11 filter.

The dispersion was sufficient so that line blending was a negligible problem. It is important to point out that only for γ Gem was any line broadening apparent on the blue or ultraviolet spectra. This suggests the $V \sin i$ of all these stars is of the order of 5 km sec^{-1} or less and for γ Gem, about 7 km sec^{-1}. It should be noted that γ Gem was listed by Slettebak (1954) as having a $V \sin i$ of 48 km sec^{-1}.

Direct-intensity microphotometer tracings of the spectra were made in the usual fashion, and line identifications were prepared from various published lists. The most important of these was Kohl's (1964) list for Sirius. Equivalent widths were found using a derived equivalent width–central depth relation for each spectrum in the manner used in Paper II. For these stars, the equivalent-width probable error (in log W) is about ± 0.07. The list of lines and equivalent widths (in units of log W/λ) is given in Table 2.

TABLE 1

SPECTROPHOTOMETRIC CHARACTERISTICS OF STARS DISCUSSED IN THIS PAPER

Star	$B-V$	$V-I$	Sp.	Duplicity	Sc/Sr*
θ Vir.. .	−0 01	0 04	A1 V	ADS 8801	1
o Peg...	− .01	.04	A1 V	.. ..	<1
HD 2421....	+ .04	.. . .	A2	SB1, 3.9 days	1
γ Gem........	0 00	0 06	A0 IV	SB1, 12.5 yr†	1

* Notation of Paper I. † Beardsley (1967).

All log W/λ entries of less than -5.70 should be considered upper limits. Entries followed by the letter A were measured on one plate only. For entries followed by the letter B the two plates disagreed by more than 0.2 in the logarithm to the base 10 (0.2 dex). Those lines were given lower weight in the analysis.

III. MODEL PARAMETERS

For a model-atmosphere analysis of these stars it is necessary to specify the effective temperature and the surface gravity. As can be seen from Table 1, these stars all have about the same $B - V$ and $V - I$ colors, those of standard A0 V–A1 V type stars according to Johnson (1966). The spectral types and these colors suggest a temperature of about 9500° K and normal dwarf-star gravities. Accordingly, models were constructed with effective temperatures of 9000°, 9500°, and 10000° K and surface gravities (log g) of 4.0 and 3.5. The details of construction of these models have been specified elsewhere (Strom and Avrett 1965).

After a model atmosphere had been chosen, the following method was followed: (1) Line profiles and equivalent widths were computed from the model and the atomic parameters for a range of abundances, A, and microturbulent velocities, ξ. (2) A plot was made of deduced abundance against observed equivalent width for each value of ξ by using the Fe I lines. The condition that this slope be zero led to the best value for ξ. (3) The observed equivalent width and data from steps 1 and 2 gave an abundance for each line. (4) A plot of A against χ, the lower excitation potential for the observed Fe I lines, permitted an estimate of the effective temperature; the condition was that this slope be zero. This is analogous to a curve-of growth method for choosing an "excitation temperature" but makes full use of the model atmosphere. (5) Another estimate of the

TABLE 2

EQUIVALENT WIDTHS

LAMBDA	EXCIT	MULT	GAMMA GEM	HD 2421	THETA VIR	OMI PEG
			LOG W/LAMBDA			
	O1					
5329.57	10.69	12	5.50	5.78	5.71	5.64B
5330.64	10.69	12	5.30	5.64	5.47	5.52
6155.97	10.69	10	5.35	5.51A	5.47	5.49
6156.76	10.69	10	5.14	5.31A	5.35	5.29
6158.17	10.69	10	5.02	5.14	5.22	5.23
	NA1					
5889.93	0.	1	4.61	4.70	4.60	4.49
5895.90	0.	1	4.72	4.80	4.74	4.65
	MG1					
4703.96	4.33	11	5.01	5.07	5.17	5.06
5167.30	2.70	2	4.62	4.82	4.78	4.55
5172.66	2.70	2	4.57	4.70	4.64	4.51
5183.58	2.70	2	4.52	4.62	4.60	4.49
5528.37	4.33	9	5.07	5.18	5.39	5.23
	MG2					
4384.62	9.94	10	5.21	5.03	5.12	5.04
4390.57	9.95	10	4.99	4.95	5.01	4.92
4428.00	9.95	9	5.39	5.46	5.50	5.52B
4433.97	9.96	9	5.31	5.20	5.26	5.24
4481.11	8.85	4	4.47	4.57	4.55	4.34B
	SI2					
5957.59	10.02	4	5.28	5.31	5.62B	5.23
5978.95	10.03	4	5.26	5.21	5.13	5.04
	P2					
5588.25	13.09	27	5.65	5.63	5.89	5.76
	CA1					
4226.71	0.	2	4.74	4.81	4.80	4.79
4302.51	1.89	5	5.33	5.51	5.64B	5.54B
5270.25	2.51	22	5.17	5.37A	5.66B	5.27
	SC2					
3567.68	0.	3	5.34	5.75	5.62B	5.82
3630.72	0.01	2	5.17	5.17	5.20	5.26
3642.77	0.	2	5.23	5.26	5.22	5.47
4246.81	0.31	7	4.80	4.75	4.73	4.84
4325.00	0.59	15	5.31	5.32	5.19	5.47B
4374.44	0.62	14	5.23	5.26	5.18	5.60
4400.34	0.60	14	5.31	5.24	5.28	5.79
4415.54	0.59	14	5.42	5.51B	5.41	5.79
5526.79	1.76	31	5.46	5.34	5.67B	5.85
	TI2					
3287.64	1.88	89			4.68A	4.55A
3308.79	0.13	7			4.72A	4.71A
3318.00	0.12	7			4.64	4.69A
3321.68	1.23	65		4.84A	4.56	4.75A
3343.75	0.15	7	4.78A	4.75A	4.69	4.73A
3346.70	0.13	7	4.76A	4.63A	4.73	4.66A
3352.05	1.22	54	5.03A	5.08A	4.92	5.02A
3372.78	0.01	1	4.52	4.59A	4.45	4.47
3409.79	0.03	1	5.30	5.10A	5.24	5.04
3416.94	1.23	53	5.63	5.40A	5.79	5.16B
3452.45	2.04	99	5.58	5.59A	5.28	5.09
3456.37	2.05	99	5.15	5.21	4.91	4.92
3477.16	0.12	6	4.91	4.98	4.85	4.85
	TI2 CONTINUED					
3489.72	0.13	6	5.40	5.38	5.42	5.30
3491.03	0.11	6	4.96	5.17	4.84	4.90
3510.82	1.88	88	4.89	4.79	4.83	4.80
3596.03	0.60	15	5.10	5.19	4.98	5.17
3641.31	1.23	52	5.03	5.15	5.04	5.06
3662.22	1.56	75	5.18	5.22	5.18	5.14
4171.88	2.59	105	4.85	4.86	4.79	4.77
4174.07	2.59	105	5.69	5.68	5.59B	5.63
4290.20	1.16	41	4.72	4.77	4.65	4.67
4301.91	1.16	41	4.85	4.87	4.76	4.77
4312.84	1.18	41	4.82	4.86	4.77	4.74
4316.79	2.04	94	5.63	5.35	5.43	5.63
4386.84	2.59	104	5.24	5.11	5.08	5.25
4394.04	1.22	51	5.20	5.20	5.02	5.15
4395.01	1.08	19	4.63	4.61	4.56	4.54
4395.83	1.24	61	5.25	5.27	5.22	5.26
4399.75	1.23	51	4.90	4.81	4.94	4.78
4411.06	3.08	115	5.09	5.17	5.12	5.30
4417.70	1.16	40	4.93	4.83	4.77	4.79
4418.32	1.23	51	5.42	5.29	5.27	5.52
4443.78	1.08	19	4.70	4.66	4.61	4.63
4450.47	1.08	19	4.99	4.98	4.90	4.92
4464.44	1.16	40	5.17	5.21	5.06	5.14
4468.47	1.13	31	4.71	4.64	4.61	4.59
4470.84	1.16	40	5.55	5.38	5.35	5.28
4488.30	3.11	115	5.20	5.13	5.17B	5.15
4501.25	1.11	31	4.71	4.68	4.63	4.64
4529.45	1.56	82	5.03B	5.31	5.18	5.27
4563.75	1.22	50	4.78	4.71	4.67	4.66
4571.95	1.56	82	4.66	4.65	4.62	4.56
4805.09	2.05	92	5.00	5.22	5.04	4.88A
5336.79	1.57	69	5.17	5.38	5.25	5.30
5418.78	1.57	69	5.55	5.69	5.69	5.84
5490.63	1.56	68	5.82	5.63	5.89	5.65B
	V2					
3530.75	1.07	5	5.56	5.52A	5.12	5.21
3592.00	1.09	4	5.26	5.23A	5.11	5.07
4183.42	2.04	37	5.69	5.40	5.59	5.69
	CR1					
4254.33	0.	1	5.11	5.32	5.27	5.18
4274.78	0.	1	5.20	5.41	5.37	5.55
4289.70	0.	1	5.21	5.43	5.61B	5.36
4379.76	3.00	130	5.71	5.67	5.81	5.40
5206.02	0.94	7	5.29	5.59	5.64B	5.29
	CR2					
3328.33	2.41	4	4.91A	5.06A	4.79B	4.79A
3342.50	2.44	4	4.67A	4.64A	4.66	4.56A
3353.10	2.47	4	5.13	5.01A	4.94	4.96A
3361.75	3.09	21	5.07	4.90A	4.81	4.81
3363.69	2.42	3	5.54B	5.33A	5.16B	4.77
3367.40	4.39	79	5.26	5.39A	5.09	5.06
3368.03	2.47	4	4.62	4.56A	4.47	4.51
3378.32	3.09	21	4.99B	5.20A	4.83B	4.74

TABLE 2 (continued)

LAMBDA	EXCIT	MULT	GAMMA GEM	HD 2421	THETA VIR	OMI PEG
			LOG W/LAMBDA			
CR2 CONTINUED						
3379.35	3.09	21	4.95	4.93A	4.91	4.81
3393.84	3.09	21	5.00	4.93A	4.96	4.75
3394.30	3.09	21	5.01	5.10A	4.90	4.74
3421.18	2.41	3	4.70	4.76	4.79	4.61
3454.96	4.92	136	5.81	5.53B	5.39	5.33
3472.05	4.90	135	5.76	5.35	5.64	5.62
3475.11	2.42	2	5.52B	5.25	5.33	5.09
3511.82	2.47	2	5.11	5.25	5.14	5.08
4179.41	3.81	26	5.18	5.39	5.29	5.16
4224.83	5.31	162	5.41	5.21B	5.49B	5.39
4242.36	3.85	31	4.70B	4.99	4.88	4.83
4252.60	3.84	31	5.36	5.40	5.33	5.33
4261.90	3.85	31	5.04	5.03	4.98	4.90
4269.27	3.84	31	5.55	5.47	5.48	5.60
4275.55	3.84	31	5.20	5.25	5.17	5.05
4284.19	3.84	31	5.27	5.40	5.23	5.22
4555.00	4.05	44	5.12	5.11	5.03	4.94
4558.64	4.06	44	4.74	4.74	4.71	4.60
4588.20	4.05	44	4.85	4.76	4.93B	4.67
4616.52	4.05	44	5.13	5.16	5.07	4.91
4618.81	4.06	44	4.92	4.87	4.88	4.72
4634.09	4.05	44	5.01	5.03	4.87	4.77
4824.11	3.85	30	4.90	4.97	4.86	4.72A
5305.83	3.81	24	5.53	5.79	5.87	5.36
5308.42	4.05	43	5.28	5.79	5.62B	5.27
5313.57	4.06	43	5.16	5.63	5.20	5.02
5334.86	4.05	43	5.24	5.58	5.42	5.24
5478.33	4.16	50	5.59	5.60	5.51	5.42
5502.03	4.15	50	5.60	5.65	5.85	5.66B
5503.16	4.13	50	5.63	5.80	5.71	5.66
5508.58	4.14	50	5.63	5.80	5.74	5.63B
5510.66	3.81	23	5.79	5.57	5.64	5.37
MN2						
3438.96	1.17	1	5.18	5.06	5.06	4.85
3460.29	1.80	3	4.70	4.69	4.66	4.64
3482.89	1.82	3	4.78	4.80	4.71	4.69
3488.66	1.84	3	4.84	4.81	4.78	4.67
3497.52	1.84	3	5.02	5.07	4.96	4.76
4292.25	5.36	6	5.70	5.69	5.80	5.77
FE1						
3387.39	2.75	306	5.80	5.42A	5.63	5.04B
3427.10	2.17	81	5.50	5.33	5.45	5.25
3440.59	0.	6	5.18	5.12	4.98	4.93
3440.97	0.05	6	5.22	5.12	5.16	5.00
3443.86	0.09	6	5.38	5.43A	5.09	5.13
3475.43	0.09	6	5.46B	5.32	5.31	5.22
3476.68	0.12	6	5.54B	5.36	5.47B	5.15
3490.56	0.05	6	5.30	5.62B	5.28	5.14
3497.82	0.11	6	5.46	5.81	5.41	5.49
3521.25	0.91	24	5.72	5.49	5.81	5.44
3536.54	2.86	326	5.82	5.64	5.61B	5.59B
3541.06	2.84	326	5.82	5.64	5.81	5.41B
3542.06	2.85	326	5.76	5.64	5.63	5.66

LAMBDA	EXCIT	MULT	GAMMA GEM	HD 2421	THETA VIR	OMI PEG
			LOG W/LAMBDA			
FE1 CONTINUED						
3554.90	2.82	326	5.49	5.81	5.39	5.34
3606.66	2.68	294	5.62	5.33	5.44	5.38
3622.00	2.75	295	5.65	5.82	5.82	5.65
3640.37	2.72	295	5.83	5.80	5.82	5.66
3647.82	0.91	23	5.16	5.17	5.27	5.07
3649.28	0.	5	5.83	5.82	5.82	5.65
4175.62	2.84	354	5.58	5.64	5.79	5.62
4176.55	3.37	695	5.63	5.69	5.79	5.61
4181.75	2.83	354	5.22	5.37	5.29	5.11
4187.02	2.45	152	5.14	5.44	5.33	5.13
4187.78	2.42	152	5.09	5.21	5.02	4.84
4191.42	2.47	152	5.23	5.57B	5.42	5.32
4199.08	3.05	552	5.05	5.02	5.08	4.94
4202.01	1.48	42	5.04	5.05	4.96	4.85
4203.95	3.63	850	5.61	5.81	5.79	5.59B
4210.33	2.48	152	5.38	5.53	5.79	5.54
4219.34	3.57	800	5.30	5.46	5.29	5.32
4224.16	3.37	689	5.69	5.82	5.33	5.76
4227.41	3.33	693	5.02	5.05	5.04	4.97
4233.59	2.48	152	5.28	5.35	5.34	5.27
4235.92	2.42	152	5.09	5.19	5.14	4.99
4247.41	3.37	693	5.51	5.46	5.64B	5.34
4250.11	2.47	152	5.13	5.30	5.13	5.12
4250.77	1.56	42	5.04	5.10	5.02	4.91
4271.14	2.45	152	5.13	5.13	5.08	5.11
4271.75	1.48	42	4.73	4.81	4.77	4.68
4282.39	2.18	71	5.24	5.46	5.34	5.29
4299.22	2.42	152	5.16	5.21	5.21	5.09
4325.75	1.61	42	4.78	4.89	4.77	4.69
4383.53	1.48	41	4.67	4.67	4.65	4.60
4404.75	1.56	41	4.81	4.78	4.75	4.66
4415.11	1.61	41	4.99	4.96	4.91	4.84
4466.53	2.83	350	5.40	5.39	5.60	5.37
4494.55	2.20	68	5.56	5.44	5.47	5.42
5168.88	0.05	1	4.48	4.60	4.48	4.44
5192.33	2.99	383	5.33	5.55	5.59B	5.36B
5227.17	1.55	37	5.07	5.46B	5.19	5.00
5269.52	0.86	15	5.05	5.31A	5.17	5.07
5324.17	3.20	553	5.25	5.43	5.47	5.26
5328.02	0.91	15	5.09	5.63	5.36	5.36
5364.85	4.43	1146	5.45	5.61	5.88	5.80
5367.45	4.40	1146	5.26	5.64B	5.65B	5.51
5369.95	4.35	1146	5.33	5.59	5.50	5.39
5383.35	4.29	1146	5.21	5.57	5.43	5.18
5404.12	4.42	1165	5.18	5.32	5.41	5.19
5405.76	0.99	15	5.44	5.80	5.74	5.69
5410.89	4.45	1165	5.34	5.80	5.74	5.81
5415.18	4.37	1165	5.27	5.33A	5.44	5.40
5424.05	4.30	1146	5.19	5.35	5.62B	5.29
5429.68	0.95	15	5.34	5.71	5.86	5.43
5487.75	4.12	1025	5.67	5.80	5.71	5.45
5586.75	3.35	686	5.43	5.69	5.65	5.27
5615.63	3.32	686	5.27	5.54	5.64B	5.23

TABLE 2 (continued)

LAMBDA	EXCIT	MULT	GAMMA GEM	HD 2421	THETA VIR	OMI PEG
			LOG W/LAMBDA			
FE2						
3295.79	1.07	1			4.75A	4.62A
3297.87	3.93	91			5.02A	4.90A
3302.84	1.04	1			4.77A	4.75A
3303.45	1.09	1			4.86A	4.82A
3425.56	1.66	5	5.38	5.40	5.22	5.10
3436.09	3.95	91	5.39	5.29	5.35	5.04
3456.91	3.89	76	5.66	5.51A	5.28	5.21
3468.66	4.14	114	5.22	5.20	5.03	4.91
3487.97	1.69	4	5.77	5.56	5.52B	5.31
3507.37	2.33	16	5.71	5.44	5.81	5.56B
3508.19	1.72	4	5.81	5.77	5.83	5.81
3564.52	4.13	113	5.82	5.68	5.56	5.44
4178.84	2.57	28	4.80	4.77	4.67	4.62
4273.30	2.57	27	5.09	5.06	5.00	4.93
4296.55	2.69	28	4.91	4.94	4.83	4.73
4303.15	2.69	27	4.76	4.81	4.71	4.64
4369.38	2.77	28	5.35	5.33	5.30	5.20
4384.31	2.65	32	5.22	5.08	5.14	5.05
4385.36	2.77	27	4.84	4.71	4.70	4.64
4413.58	2.66	32	5.71	5.84	5.63B	5.61
4416.80	2.77	27	4.84	4.70	4.72	4.64
4472.90	2.83	37	5.21	5.29	5.21	5.20
4489.17	2.82	37	4.92	4.95	4.84	4.75
4491.38	2.84	37	4.91	4.83	4.80	4.74
4508.26	2.84	38	4.78	4.76	4.71	4.61
4515.32	2.83	37	4.82	4.77	4.73	4.68
4520.21	2.79	37	4.86	4.80	4.75	4.65
4522.61	2.83	38	4.75	4.71	4.67	4.54
4541.50	2.84	38	4.99	4.93	4.88	4.78
4555.88	2.82	37	4.82	4.71	4.74	4.60
4576.31	2.83	38	5.02	4.92	4.91	4.81
4582.82	2.83	37	5.11	5.12	5.02	4.89
4583.81	2.79	38	4.63	4.63	4.62	4.50
4620.50	2.82	38	5.14	5.08	5.15	4.86
4629.32	2.79	37	4.80	4.79	4.72	4.62
4635.31	5.93	186	5.15	5.13	5.08	4.81
4656.95	2.88	43	5.32	5.36	5.42	5.16
4666.75	2.82	37	5.18	5.18	5.16	4.93
4731.42	2.88	43	5.06	5.07	4.98	4.84
5234.60	3.21	49	4.76	4.80	4.74	4.61
5264.78	3.22	48	5.07	5.16	5.08	5.01
5272.39	5.93	185	5.42	5.31	5.71	5.19
5325.54	3.21	49	5.14	5.29	5.27	5.12
5414.07	3.21	48	5.40	5.72	5.73	5.50
5425.25	3.19	49	5.24	5.44	5.27	5.35
5534.84	3.23	55	4.98	5.12	4.94	4.85
5991.36	3.14	46	5.54	5.46	5.56	5.44
6147.72	3.87	74	5.27	5.67B	5.24	5.10
6149.22	3.87	74	5.34	5.31A	5.35	5.13
6238.36	3.87	74	5.35	5.33	5.24	4.92
6247.54	3.87	74	5.06	5.06	5.10	4.73
NI1						
3414.75	0.03	19	4.99	5.11	4.90	4.70
NI1 CONTINUED						
3437.26	0.	3	5.80	5.51A	5.54B	5.28
3452.87	0.11	17	5.69	5.61B	5.54B	5.08
3458.45	0.21	19	5.41	5.51B	5.16	4.83
3472.53	0.11	20	5.74	5.49B	5.40	5.13
3492.94	0.11	18	5.14	5.28	5.14	4.97
3500.83	0.16	6	5.66	5.81	5.63	5.44B
3510.32	0.21	18	5.59	5.51	5.25	5.15
3515.03	0.11	19	5.30	5.27	5.08	4.97
3597.69	0.21	18	5.67	5.82	5.73	5.39
3619.37	0.42	35	5.31	5.35	5.24	4.98
4714.40	3.37	98	5.74	5.87	5.50	5.35
NI2						
3350.40	2.94	1	5.22A	5.00A	5.01	4.93A
3373.96	2.85	1	5.39	4.83A	4.80	4.69
3401.75	3.06	4	5.59B	5.35A	5.42B	5.08B
3454.14	2.94	1	5.42	5.28	5.07	4.87
3471.33	3.07	4	5.31	5.36	5.01	4.81
4192.05	4.01	10	5.69	5.82	5.60	5.30
4244.78	4.01	9	5.70	5.83	5.74	5.51
4362.08	4.01	9	5.71	5.68	5.25	5.21
SR2						
4215.50	0.	1	4.88	4.81	4.71	4.59
Y2						
3327.87	0.41	18	5.80A	5.08A	5.04B	5.29A
3600.72	0.18	9	5.82	5.73	5.42	5.27
3601.91	0.10	9	5.82	5.81	5.71	5.62B
3611.04	0.13	9	5.83	5.82	5.77	5.63
4374.92	0.41	13	5.19	5.28	5.01	4.92
ZR2						
3391.94	0.16	1	5.34	5.16A	4.93	4.72
3410.25	0.41	11	5.80	5.40A	5.55B	5.15
3438.21	0.09	1	5.28	5.19	5.03	4.81
3479.37	0.71	46	5.81	5.80	5.46	5.22
3505.65	0.16	1	5.81	5.66	5.44	5.47
3551.92	0.09	1	5.82	5.81	5.51	5.42
4179.79	1.66	99	5.69	5.82	5.79	5.76
4211.86	0.52	15	5.69	5.75	5.79	5.77
BA2						
4554.01	0.	1	5.09	5.17	4.81	4.65
6141.70	0.70	2	5.45	5.70	5.35	5.18

effective temperature and effective gravity was given by the Fe I/Fe II ionization equilibria.

The adopted parameters are given in Table 3. The accuracy of our model parameters is estimated to be ± 250 in T_{eff}, ± 0.5 in $\log g$, and ± 0.5 km sec^{-1} in ξ.

IV. ABUNDANCE RESULTS

The results of this investigation, using model parameters of Table 3 and the equivalent widths of Table 2, are given in Table 4. Abundances have been averaged for all four

TABLE 3

ADOPTED ATMOSPHERE PARAMETERS

Star	T_{eff}	$\log g$	ξ (km sec^{-1})
θ Vir	9500	4 0	3
o Peg	9500	4 0	3
HD 2421	9500	4 0	3
γ Gem ..	9500	3 7	2 5

TABLE 4

ABUNDANCE RESULTS*

	θ Vir	o Peg	HD 2421	γ Gem	Mean
Fe I, II	6 6	6 8	6 5	6 6	6 6
O I	8 6	8 6	8 6	8 8	8 6
Na I	6 6	7 1†	6 2‡	6 8	6 7
Mg I, II	7 2	7 7†	7 2	7 6	7 4
Si II	7 6	8 0	7 8	7 7	7 8
Ca I .	5 6	5 8	5 8	6 2†	5 8
Sc II	2 9	2 5‡	2 9	2 9	2 8
Ti II	4 9	4 8	4 6	4 6	4 7
V II	3 7	3 6	3 4	3 3	3 5
Cr I, II	5 3	5 5	5 2	5 5	5 4
Mn II	5 2	5 5†	5 0	5 1	5 2
Ni I	5 9	6 4†	5 7	5 8	6 0
Ni II	5 3	5 6†	5 0	4 8‡	5 2
Sr II .	3 3	3 7†	3 1	3 0‡	3 3
Y II	2 7	2 7	2 5	2 2†	2 5
Zr II ..	3 1	3 4†	2 9	2 8	3 0
Ba II	3 2	3 6†	2 7‡	3 0	3 1

* Entries are log A on scale log H = 12 0.
† 0 3 dex higher than mean.
‡ 0.3 dex lower than mean.

stars in the last column of Table 4. This mean value for each element can be considered an estimate of the "normal" A-star abundances. These *could* differ from other analyses of other A stars by systematic differences in equivalent width, transition probabilities, or the differences in models used here. The advantage of using a mean for the "normal" abundances is to avoid any possible systematic errors of this type.

For all stars the Ni II entry does not agree with that for Ni I. This is the *only* case where those elements appearing in two stages of ionization give decidedly different results. The difference of about 0.7 dex for three of the stars probably reflects a systematic error in the transition-probability scale for Ni.

An abundance entry for a star that differs from the mean by at least a factor 0.3 dex is considered to be discrepant. Out of fifteen discrepant individual abundance entries, nine are in the star *o* Peg, which indicates that this star is anomalous in its element content. It should be noted that, aside from normal calcium, the pattern of other Am abundance characteristics is present: low scandium and enhanced heavy elements.[1] Moreover, the Fe/H ratio appears marginally enhanced in accordance with the pattern found in Paper II. As suggested in Paper I, it appears that this star is indeed an early A analogue of Am stars.

For the other stars, the abundance anomalies show no pattern. The Ni II discrepancy for γ Gem is probably not significant, since it disagrees by more than 0.7 dex with Ni I. The other discrepancies for this star are just at the limit of significance, although (with the exception of Sr II) for a wide range of assumed log g and $T_{\rm eff}$ values these marginal anomalies persist. The anomalies for HD 2421 are considered real, especially for the Ba II lines which by inspection on lower-dispersion spectra were noted to be weak with respect to the other A stars included in our study. In this, HD 2421 is similar to Vega where the Ba II lines were not seen at the high dispersion used by Hunger (1955). The Na I discrepancy is a little less certain as the D-lines are slightly stronger than the Fe I lines used to define the parameter ξ.

V. DISCUSSION

What, then, is a *normal* A star? If we consider Vega as the prototype, then HD 2421, which has almost identical abundances (cf. Table 4 of Paper II), is "normal." Aside from Ba II, the metal abundances for these two stars also agree very well with the value obtained for five other A stars, analyzed in Paper II, which have Sc/Sr ratios within a factor of 2 of unity. The abundances of HD 2421 are the same as θ Vir and nearly the same as γ Gem, again except for barium. It is unfortunate that elements heavier than barium are not easily studied in A stars from presently accessible spectral regions. Rocket ultraviolet spectra may help to provide the data necessary to obtain the heavy-element abundances and their variations among the early A stars (Maran *et al.* 1968).

We have also demonstrated that another A star, *o* Peg, which is anomalous in its Sc/Sr line ratio, shows Am abundance characteristics. This high-dispersion–model-atmosphere evidence, coupled with that of the Pleiades in Paper II, strongly supports the assertion of Paper I that a class of early Am stars exists; the boundary of this class is at least as early as spectral type A0. It is not likely that evidence for additional members of this class of even higher $T_{\rm eff}$ can be obtained owing to the general weakness of metallic lines in late B-type stars.

On the other hand, *o* Peg does not show particularly high turbulence, nor is it a known spectroscopic binary. It might be argued for these reasons that *o* Peg should not be considered an Am star in the strict, classical sense. However, we feel that rather than create a *new* class of objects which have abundance anomalies nearly identical with those of Am stars, it is preferable to consider the source of their spectroscopic anomaly as a similar unsolved problem.

With this point in mind we return to the question of the "excess" number of sharp-lined stars near A0 outlined in Paper I and by Deutsch (1967). From the Sc/Sr line ratio, which indicates Am abundance anomalies, nearly half of the sharp-lined A stars in Paper I are Am. If we use the statistics of Deutsch (1967), combined with our definition of early Am stars, we find that thirteen out of Deutsch's twenty-four sharp-lined early A stars are definitely spectroscopically peculiar (one classical Am star, five Ap stars, and seven early Am stars). Deutsch considers that about eighteen of these twenty-four stars are the "excess" slow rotators. Since few of the eleven "normal" A stars have been subjected

[1] Normal calcium and underabundant scandium are also found among classical later-type Am stars; e.g., 15 Vul (Miczaika *et al.* 1956).

to a model-atmosphere analysis, it is still possible that some members of this group may prove to be in some ways spectroscopically peculiar. Therefore, there exists a group, consisting of at least thirteen *peculiar* stars, which could then be identified as the "excess" slow rotators. This seems a more natural interpretation than the opposite conclusion advanced by Deutsch, who did not allow for the existence of a class of early Am stars. However, in view of the presently available rotation and classification statistics, this suggestion should be regarded as a tentative one.

A portion of this work was performed while one of us (P. S. C.) was at the Mount Wilson and Palomar Observatories, California Institute of Technology. Support there was under U.S. Air Force contract AF 49(638)-1323. The other (S. E. S.) gratefully acknowledges the support of grant NGR22-024-001 from NASA. Assistance with equivalent-width reductions was provided by Eric Jones and Robert Milton.

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