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THE ABUNDANCES OF BORON, BERYLLIUM, AND LITHIUM IN THE PECULIAR A STAR KAPPA CANCRI

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ABSTRACT

A weak feature in the spectrum of κ Cnc is attributed to B II, and the abundance B/H is found to be $\sim 2 \times 10^{-7}$. The abundance of Be is determined to be Be/H $\sim 2.5 \times 10^{-9}$. Wavelength measurements indicate that there is little, if any, ^{7}Be or ^{10}Be. An upper limit of Li/H $< 4.5 \times 10^{-7}$ has been determined. The galactic-cosmic-ray origin of the light elements is insufficient to account for the Be and B abundances by 2 to 3 orders of magnitude and for the B/Be ratio of 75. It is suggested that a nearby supernova explosion or spallation reactions on the surface of this Mn-Hg Ap star could account for the observed abundance ratios.

Subject headings: abundances, stellar — peculiar A stars

I. INTRODUCTION

Kappa Cancri (= HR 3623) is a sharp-lined peculiar A star of the Mn-Hg type; it is a single-line spectroscopic binary of spectral class B8. Sargent and Jugaku (1962) have reported that it is overabundant in Be. We ascribe to B II a feature in the spectrum of κ Cnc which agrees well with the wavelength of $\lambda 3451.291 \pm 0.010$ for the $^1P_1$–$^1D_2$ transition obtained by Ölme (1970) for the strongest B II line accessible from ground-based observations. We have done an abundance analysis of B and Be in κ Cnc, and obtained an upper limit on the abundance of Li in this star.

II. OBSERVATIONS AND WAVELENGTH MEASUREMENTS

Four well-widened (0.75 mm), ultraviolet spectrograms of κ Cnc were obtained at a dispersion of 6.8 Å mm^{-1} between 1973 February 9 and 1973 April 10 with the coudé spectrograph of the 224-cm telescope of the Mauna Kea Observatory. A red-sensitive spectrogram at 10.1 Å mm^{-1} widened to 0.75 mm was obtained 1973 May 21. Spectrograms of the sharp-lined normal A stars π Cet (B7 V) and ν Cap (B9 V) were taken for comparison. Visual inspection on a spectral comparator revealed that neither of these stars shows a feature at either the position of the Be II doublet or the B II line.

Wavelength measurements were made twice on each of the four ultraviolet spectrograms of κ Cnc. The measured positions of the Be II and B II lines were corrected by the appropriate $\Delta\lambda$ corresponding to the average radial velocity as found from 30 stellar lines. The results of these measurements are given in table 1. These data confirm the identification of the measured features with Be II and B II. The B II line is considerably weaker than any of the other features measured, and consequently the internal agreement is not quite as good.

Figure 1 shows a composite profile of the B II feature. It is broader than expected from the turbulent and thermal velocities, even when compared with the similarly thermally broadened Be II feature. We conclude that weak Mn II features at $\lambda 3451.123$ and $\lambda 3451.549$ (Iglesias and Velasco 1964) are blended with the B II line. The intensities of these two Mn lines (30 and 10, respectively) are consistent with their relative contributions to this blend and with the intensities of the nearby strong Mn II lines at 3442.0 ($I = 3000$) and 3460.3 ($I = 2000$). Assuming Gaussian profiles, we have calculated the resultant blended profile and find a good fit by using these three lines. It

TABLE 1

WAVELENGTH MEASUREMENTS

Plate No.	Velocity (km s^{-1})	p.e. (km/sec)	Be II 3130 +	Be II 3131 +	Be II 3451 +
787	−22.32	±0.75	0.429	0.083	0.322
890	82.14	±0.63	0.426	0.064	0.298
891	82.19	±0.72	0.430	0.064	0.313
900	8.16	±0.78	0.428	0.060	0.267
Mean	...	±0.36*	0.429	0.068	0.300 ± 0.02
Lab λ	...	...	0.416	0.064	0.291
$\lambda_{meas} - \lambda_{lab}$	...	...	0.012	0.004	0.009

* A velocity of ±0.36 km s^{-1} corresponds to ~ ±0.004 Å.

is not possible to reproduce any reasonable approximation to this profile without including a feature at 3451.29.

The identification of B II rests primarily on the fact that the measured wavelength agrees well with the laboratory study and there are no other compelling indentifications. Nearby Fe II lines of multiplets 207 and 208 are ruled out since the other line of comparable intensity in each multiplet is not present. An unclassified Fe II line at λ3451.318 is considered unlikely since it does not appear in the normal B stars ν Cap and π Cet. Hg II, strong in κ Cnc, has a nearby line at λ3451.69, which is far outside our probable error. In addition there is circumstantial evidence provided by the presence of the strong Be II lines in κ Cnc, while the comparison stars ν Cap and π Cet show lines of neither Be II nor B II. A study at higher dispersion would make the identification more secure, as would a successful search for a weaker B II line at λ4121. If our identification is not confirmed, the B abundance given here can be considered an upper limit.

The isotopic wavelength shifts for Be calculated by Warner (1968) show that a line of pure ^{10}Be (half-life = 2.7 × 10^6 years) is at λ3131.002 and pure ^{7}Be (half-life = 54 days) is at λ3131.219, while ^{9}Be is formed at λ3131.064. Since our average mea-

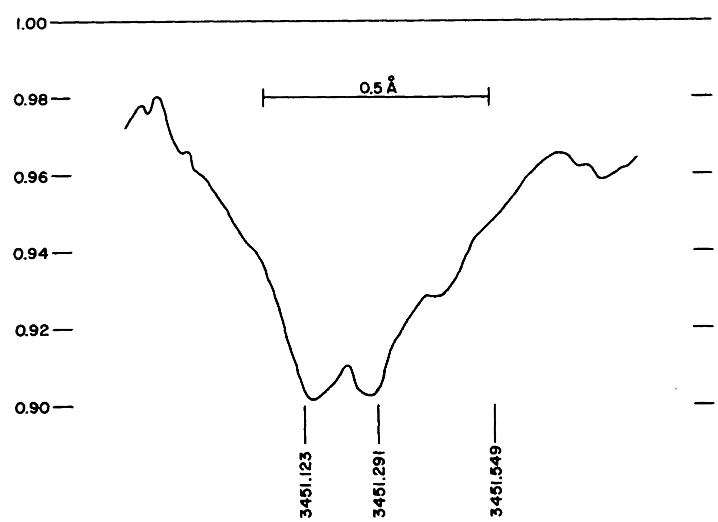

FIG. 1.—The composite profile of the B feature in κ Cnc. It is the average from four spectrograms. The B II line at λ3451.291 is apparently blended with weak Mn II lines at λ3451.123 and λ3451.549.

sured wavelength is 3131.068 ± 0.004, we conclude that neither short-lived isotope is present in substantial quantities.

III. ABUNDANCES

The abundances of Li, Be, and B were determined using a combination of Wrubel's (1949) theoretical curve of growth and the model atmosphere for κ Cnc given by Aller (1970). Mean values of the equivalent widths for the B and Be lines from the four spectrograms and the upper limit for the Li line are listed in table 2. The equivalent width given for B II takes into account the probable blending due to the Mn II features, but should be considered an upper limit since other weak lines, notably Fe II, may contribute.

The value adopted for θ_{eff} is 0.36 from Aller's model, which is in good agreement with $\theta_{\mathrm{eff}} = 0.35 \pm 0.01$ found for κ Cnc by Mihalas and Henshaw (1966). Searle, Lungershausen, and Sargent (1966) found a microturbulent velocity $\xi = 1.6$ km^{-1} s for κ Cnc. The adopted value of the temperature parameter is $\theta_{\mathrm{exc}} = \theta_{\mathrm{ion}} = 0.43$, which corresponds to the line-forming region of Aller's model, log $\tau_{5000} = -0.60$ and log $P_e = 2.22$. It is in good agreement with the value $\theta_{\mathrm{exc}} = \theta_{\mathrm{ion}} = 0.45$ found by Aller and Bidelman (1964) for 53 Tau, a similar Mn peculiar A star, and with the value $\theta_{\mathrm{ion}} = 0.39$ adopted for κ Cnc by Searle and Sargent (1964). Table 2 lists the results for log N_r, the ionization correction found from the Saha equation, and the final log N on a scale where log $N(\mathrm{H}) = 12.00$. Since κ Cnc is deficient in both He and C, H comprises 0.792 of the stellar material by weight, or log $N(\mathrm{H}) = 23.68$. We estimate that the error in the Be abundance is about a factor of 2, but the B abundance may be in error by a factor of 3 to 5, since it is strongly affected by uncertainties in θ. [An error of θ_{exc} of ± 0.02 changes log $N(\mathrm{B})$ by ± 0.27.]

IV. DISCUSSION

Sargent and Jugaku (1962) have estimated that the Be abundance in four Mn peculiar A stars (including κ Cnc) is about two orders of magnitude more than in the Sun. Our result, log $N(\mathrm{Be}) = 3.4$, for κ Cnc is consistent with their estimate. The most recent value for solar Be is log $N(\mathrm{Be}) = 1.1$ (Aller and Ross 1973). In chondritic meteorites log $N(\mathrm{Be}) \sim 1.3$ (Sill and Willis 1962). An upper limit for the Sun of log $N_{\odot}(\mathrm{B}) < 2.5$ has been quoted by Engvold (1970) from a search for BH in sunspots. The meteoritic abundance of log $N(\mathrm{B}) = 4.0$ has been reported by Cameron for proto–solar-system boron (Audouze and Truran 1973). Thus κ Cnc with log $N(\mathrm{B}) = 5.3$ is overabundant in B compared to the solar-system values. Whereas the B/Be ratio of 75 in κ Cnc is larger than the solar ratio of B/Be < 25, it is smaller than the probable meteoritic ratio of B/Be $\sim$ 500.

TABLE 2

ABUNDANCE DATA

Ion	λ(Å)	W(mÅ)	log η_0	log N_r	Ion.Corr.*	log N†
Be II	3130	140	1.33	14.89		
	3131	105	0.96	14.96		
	Mean			14.93	+0.15	3.40
B II	3451	22	−0.26	16.97	0.00	5.29
Li I	6707	< 23	< −0.57	< 12.51	4.83	< 5.66

* Ion Corr. = logarithmic value to be added to log N_r to give log N.

† Logarithmic abundance by number on a scale where log $N(\mathrm{H}) = 12.00$.

TABLE 3

LIGHT-ELEMENT RATIOS

Ratio	Observed κ Cnc	GCR	SN*$_1$(30 MeV) +GCR	SN*$_2$(30 MeV) +GCR	Spallation ^{12}C (peak)
Li/H	$< 4.5 \times 10^{-7}$	2×10^{-10}	1.2×10^{-8}	2.5×10^{-7}	...
Be/H	2.5×10^{-9}	2×10^{-11}	3.6×10^{-10}	3.6×10^{-9}	...
B/H	1.9×10^{-7}	3×10^{-11}	7.3×10^{-8}	8.8×10^{-8}	...
Li/Be	< 180	10	34	70	40
B/Be	75	15	202	24	60
B/Li	> 0.4	1.4	6	0.3	3

* SN_1 = Equal total energy per particle. SN_2 = Equal energy per nucleon.

Table 3 compares the observed abundance ratios in κ Cnc with those predicted by several major theories. Reeves *et al.* (1973) conclude that both Be and B are formed almost exclusively by spallation produced by galactic cosmic rays (GCR), whereas only about 20 percent of the Li is formed this way. It is clear that the initial GCR abundances calculated by Meneguzzi, Audouze, and Reeves (1971) have been modified in κ Cnc, since this model is unable to account for the observed high abundances of B and Be or for the B/Be ratio. Audouze and Truran (1973) suggest that B and ^{7}Li will be produced by spallation reactions from particles of energies greater than 10 MeV accelerated by shock waves in supernovae. In table 3 are results from their calculations for 30-MeV particles accelerated with equal total energy for protons and alpha particles (SN_1) and with equal energy per nucleon (SN_2). A supernova erupting in the vicinity of κ Cnc at the time of its formation could account for its enrichment in light elements and perhaps for some of its other abundance anomalies.

The original GCR component of κ Cnc could be enhanced by surface spallation reactions in this Ap star. Bernas *et al.* (1967) present the relevant cross-sections and energies for spallation reactions on C, N, *O*, and Ne. Spallation on ^{12}C with particles of energies near the peak of the cross-section versus energy curves ($\sim$ 100 Mev) gives the best fit to the observations and are presented in table 3. In this regard Preston, Stępień, and Wolff (1969) have reported a variable magnetic field in κ Cnc from +250 to −150 gauss with a period of 5.0035 days. The magnetic activity may provide the mechanism to accelerate particles to the energies required to produce spallation reactions on ^{12}C.

Either a nearby supernova explosion or surface spallation reactions can account for the observed abundances. A more complete report of light-element abundances in this and other Mn Ap stars is in preparation.

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