J. Astrophys. Astr. (1991) **12,** 213–223

On the Shell Star Pleione (BU Tauri)

D. K. Ojha & S. C. Joshi *Uttar Pradesh State Observatory, Manora Peak, Naini Tal 263129*

Received 1991 January 10; accepted 1991 May 23

Abstract. BU Tauri (Pleione) an interesting star in the Pleiades cluster, has been observed spectrophotometrically. The energy distribution curves of the star have been discussed vis a vis model atmospheres for normal stars in the appropriate range of temperature and effective gravity. The changes in the energy distribution curve noticed during our observations and previous observations taken from the literature have been pointed out. On the basis of the measured Hα emission equivalent width, a rough estimate of the dimensions of the extended envelope of the star has been made.

Key words: Be star—energy distribution

1. Introduction

The shell star Pleione (BU Tauri = HD 23862 = HR 1180) has been an object of several studies ever since its discovery by Pickering in 1889 (Pickering 1890), as a peculiar star having bright Hα line superposed over the broad absorption line. The star is a member of the Pleiades cluster and is associated with the formation and dissipation of a shell around it. To date after its discovery the star has gone into the shell phase twice. The first shell phase lasted during 193–854 and the later one commenced in 1972 and reached a maximum around 1980. In between, during 1955–71, was the Be phase of the star (Doazan 1982). According to Slettebak (1982), the rotational velocity of the star, $v \sin i$ is 320 km s^{-1} and it has a spectral type B8 (V:)e-shell. Hoffleit & Jaschek (1982) have quoted a spectral type B8 Ve for Pleione and a $v \sin i$ value equal to 340 km s^{-1}. Hack & Struve (1970) assigned a spectral type B5 V to the star while Blanco *et al.* (1968) quoted it as B7 p. The emission in the lines in the spectra of the star disappeared in 1905 and through the period 1905–36 the star showed normal spectrum of a rapidly rotating B8 dwarf. The emission in hydrogen lines reappeared in 1938 (McLaughlin 1938) along with faint shell lines of Fe II, Cr II and other ionized metals. The star also became redder in colour (Williams 1939). The shell line intensities increased to a very high level during 1945–47. The Hα emission intensity (ω) of the star ranged between 25–35 Å during the period 1954–65 (Hirata & Kogure 1976), which is the Be phase of the star. In 1972 the star entered a new shell phase (Delplace & Hubert 1973; Morgan, White & Tapscott 1973). The Hα intensity decreased from the pre-shell phase value in 1969 to the early-shell phase value during 1973 and then started to increase in 1974. Gulliver (1977) has studied the spectrum variations during 1935–75 of Pleione. He concludes that the stellar wind model for the star rather than the elliptical ring or binary models agrees with the spectral observations.

On the continuum side, Sharov & Lyuty (1976) found a minimum in the brightness of the star in 1973. During 1974–75 they found a brightening of the *B* and *V* magnitudes. Hopp & Witzigmann (1980) found that during 1977–80 the brightness of the star was still below its normal maximum value, and inferred that the shell outburst responsible for dimming the starlight was still present. Hopp, Witzigmann & Geyer (1982) and Goraya (1984) found that during 1980–82 the star had an unusually large Balmer Jump as compared with stars of the same spectral and luminosity class (B8 V), indicating the presence of a sufficiently dense envelope around the star. Garrison (1987) has reported that Pleione's shell phase was fading rapidly. In order to study the development of the shell, we observed the star during 1988 and 1990.

2. Observations

The observations of BU Tau have been secured on 4 nights (UT 1988 November 19, 1988 December 3,1988 December 7, and 1990 January 9) with the 104-cm reflector of Uttar Pradesh State Observatory, Naini Tal. The spectrum scanner used for these observations has a dispersion of 70 Å mm^{-1} at the exit slit. A thermoelectrically cooled EMI 9658 B photomultiplier and d.c. recording technique have been used. The exit slit was set at 0.7 mm admitting about 50 Å of the spectrum. Data were obtained in a continuous scanning mode.

The standard star γ Gem was observed each night along with the programme star to enable a conversion of the observed energy distribution into absolute units. The mean extinction coefficients collected for the observatory site pertaining to the observing season October–December were applied to the observations to correct them for atmospheric extinction. The extinction corrected magnitudes of Pleione have been converted into absolute values using the standard magnitudes of γ Gem given by (Taylor 1984).

The presence of circumstellar matter around Be stars, their rapid rotation and the inclination of their rotation axes to the line of sight causes anomalies in their colours and spectral types. The mean two-colour relation used in case of B type stars for determining the interstellar reddening is not strictly applicable to Be stars. Methods based on the distance modulus (Goraya 1986) or the strength of the interstellar absorption band at 2200 Å (Beeckmans & Hubert-Delplace 1980) have been proposed for determining the reddening corrections for Be stars. In case of Pleione, however, we have a fortunate situation in that it belongs to a well-known cluster, the reddening of which is known. We have therefore adopted a value of $E(B-V)=0^m.04$ (Lang 1974) which is the average reddening value for the Pleiades cluster, and used it as the interstellar reddening value for the star. The standardized magnitudes take care of instrumental sensitivity variations, if any. The interstellar absorption at different wavelengths has then been calculated with the help of the curve given by Nandy *et al.* (1975). After applying these corrections, we obtained the reddening free monochromatic magnitudes ($-2.5 \log F_\nu + C$), which are given in Table 1 after normalizing at 5000 Å.

The accuracy of the observations have been estimated by determining the standard deviations of several observations on each night at a given wavelength of the standard star. It was found that below 4000 Å the accuracy of the observations is $\pm 0^m.05$ and beyond 4000 Å it is $\pm 0^m.03$.

Table 1. Mean dereddened monochromatic magnitudes of BU Tau.

(Å)	$\frac{1}{\lambda}$ (μm^{-1})	1980 Dec. 27, 30	1988 Nov. 19	1988 Dec. 03	1988 Dec. 07	1990 Jan. 09
3400	2.94	+1.567	+0.537	+0.699	+0.686	—
3500	2.86	1.456	0.517	0.695	0.655	+0.700
3600	2.78	1.122	0.518	0.677	0.739	0.698
3700	2.70	0.852	0.520	0.539	0.657	0.619
3800	2.63	0.577	+0.179	+0.212	+0.259	+0.298
3900	2.56	+0.261	−0.215	−0.198	−0.157	−0.082
4000	2.50	−0.087	0.296	0.316	0.294	0.256
4100	2.44	0.186	0.212	0.239	0.242	0.228
4200	2.38	0.164	0.203	0.205	0.210	0.194
4300	2.33	0.149	0.197	0.202	0.192	0.166
4400	2.27	0.137	0.180	0.189	0.178	0.152
4500	2.22	0.108	0.157	0.157	0.148	0.127
4600	2.17	0.087	0.117	0.119	0.118	0.098
4700	2.13	0.063	0.087	0.099	0.097	0.082
4800	2.08	0.047	0.061	0.075	0.070	0.057
4900	2.04	−0.016	−0.005	−0.018	−0.017	−0.009
5000	2.00	0.000	0.000	0.000	0.000	0.000
5100	1.96	+0.033	+0.008	+0.002	+0.031	+0.028
5200	1.92	0.067	0.037	0.048	0.054	0.052
5300	1.89	0.078	0.034	0.061	0.072	0.037
5400	1.85	0.096	0.065	0.068	0.085	0.095
5500	1.82	0.129	0.096	0.081	0.101	0.124
5600	1.79	0.137	0.086	0.105	0.123	0.148
5700	1.75	0.164	0.099	0.125	0.148	0.141
5800	1.72	0.183	0.134	0.182	0.180	0.157
5900	1.69	0.216	0.136	0.208	0.199	0.188
6000	1.67	0.221	0.130	0.229	0.234	0.217
6100	1.64	0.244	0.149	0.231	0.255	0.234
6200	1.61	+0.264	+0.126	+0.236	+0.268	+0.222
		(Mean values)				

3. Results

3.1 *Continuum*

The reddening corrected normalized monochromatic magnitudes of BU Tau have been displayed in Fig. 1. In the same figure we have plotted similar data from Goraya (1985) and the normalized model atmosphere fluxes taken from Kurucz (1979) for a model with T_e = 12,000, log g = 4.0, and solar composition.

From the plots in Fig. 1 the Balmer Jump (BJ) and the slope between 4000 and 5000 Å were determined. Since the circumstellar envelope emits extra radiation in the ultraviolet and infrared regions, the ultraviolet excess radiation affects the Balmer continuum shortward of 4000 Å and the infrared excess radiation affects the Paschen continuum longward of 5000 Å appreciably. The part of the Paschen continuum between 4000 Å and 5000 Å is least disturbed by these excess emissions. So this range in wavelength for the slope has been chosen for the temperature determination. The

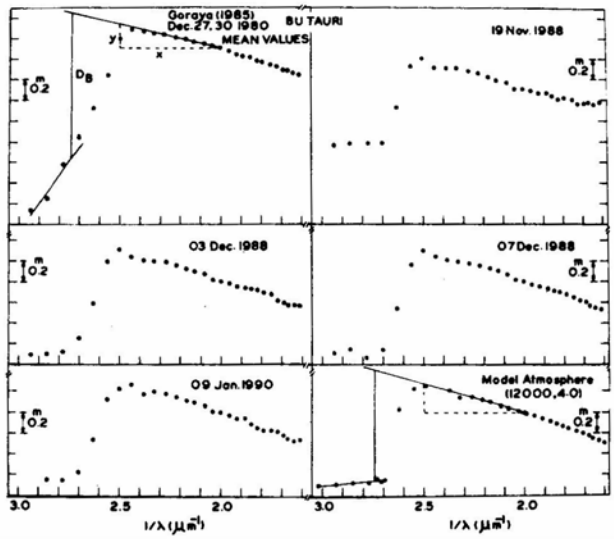

Figure 1. The standard monochromatic magnitudes of BU Tau normalized at 5000 Å. The first panel shows the observations of the star taken during Dec. 1980 by Goraya. The last Panel shows the normalized monochromatic magnitudes of a normal stellar atmosphere taken from the grid of model atmospheres by Kurucz (1979). The Balmer Jump D_B and the slope (y/x) of the energy distribution curve between 4000-5000 Å as used in this paper have been indicated in panels 1 and 6.

Table 2. Parameters for the envelope.

	1980 Dec. 27, 30	1988 Nov. 19	1988 Dec. 03	1988 Dec. 07	1990 Jan. 09
Balmer Jump (D_B)	1.40	0.99	1.15	1.10	1.06
ΔD_B w.r.t. Dec. 1980	—	0.41	0.25	0.30	0.34
Slope (400–500 nm.)	0.46	0.64	0.66	0.58	0.60
m_λ (5500 Å)	—	5.12	5.08	5.04	5.08
Hα equivalent width (ω in Å)	—	21.5	20.8	26.1	18.6
Balmer Emission measure (ε_{UV})	—	1.287E36	0.726E36	0.893E36	1.031E36
VN_3	—	0.604E45	0.585E45	0.734E45	0.523E45
V (from Hα) $\chi=14$	—	1.107E36	1.072E36	1.345E36	0.959E36
Outer radius in terms of R_* (a) $\chi=14$	—	4.244	4.182	4.657	4.120

definitions of the Bahner Jump (BJ) and the slopes have been shown in Fig. 1. Table 2 gives these quantities along with the *V* magnitude of the star.

In the shell phase in 1979 the star had a significant decrease in the Balmer continuum (Hirata & Kogure 1984) as compared to its pre-shell phase in 1966. Also the *V* magnitude of the star in the shell phase was 5.29 in 1974. This decrease in the continuum has been attributed to the bound-free absorption in the Balmer continuum. Goraya's (1985) observations also show a BJ (Balmer Jump) for the star which is considerably larger than that obtained during 1988–90 by us. Likewise the slope between 4000–5000 Å has shown an increase reflecting an increase in the temperature of the star. The *V* magnitudes from our observations also show a brightening of the star as compared to its 1974 value, indicating a decrease in the density of the envelope.

3.2 *Balmer Excess*

The combined spectrum (star + shell) during the 1980 observations corresponds in Balmer Jump and slope to a model atmosphere with T_e = 10,000, log g = 4.0. If we assume that the decrease in Balmer Jump (BJ) and the increase in the slope are due to the emission in the shell, we can calculate the emission measure, using the procedure given by Garrison (1978), who explains the small Balmer Jump by free-bound emission and establishes a means of computing the "Balmer Excess" for an optically thin model. The change in BJ is given by,

$$\Delta D_B = -2.5 \log \frac{4\pi R_*^2 \pi F_\nu}{4\pi R_*^2 \pi F_\nu + 4\pi \int_V j_{\nu bf}\, dv}, \tag{1}$$

where F_ν is the flux from the star shortward of $1/\lambda = 2.7 \mu m^{-1}$, $j_{\nu bf}$ is the volume emission coefficient for the free-bound hydrogen transitions (ergs cm^{-3} s^{-1} sr^{-1}), V is the volume of the emitting region, and R_* is the radius of the star. But

$$j_\nu = 1.88 \times \text{EXP}\,(-34)\, T_S^{-3/2} N_e N_i \text{ cgs}, \tag{2}$$

where T_S is the shell temperature. Then the shell emission called" emission measure" is defined as

$$\varepsilon_{\text{UV}} = \frac{\int_V N_e N_i\, dv}{R_*^2}. \tag{3}$$

From Equation (1)

$$\int_V j_{\nu bf}\, dv = \pi F_\nu R_*^2 [\text{dex}(0.4\, \Delta D_B) - 1]$$

Hence from Equations (1) and (2) we get,

$$1.88\ \text{EXP}(-34)\, T_S^{-3/2} \int_V N_e N_i\, dv = R_*^2 \pi F_\nu [\text{dex}(0.4 \Delta D_B) - 1]$$

or,

$$\varepsilon_{\text{UV}} = 1.67\ \text{EXP}\,(34)\, T_S^{3/2} F_\text{v} [\text{dex}\,(0.4\, \Delta D_B) - 1]. \tag{4}$$

For this calculation we have determined the change in BJ with respect to the 1980 observations of the star by Goraya (1985). To evaluate F_v and T_S we have to have a knowledge of the effective temperature of the star and a shell temperature. During 1905–36 when the star showed a normal behaviour, its spectral type was that of a rapidly rotating B8 dwarf. The effective temperature of a normal B8 V star is given to be 11,900 K (Schmidt-Kaler 1982; Underhill *et al* 1979). As the presence of circumstellar matter in shell stars distorts the observed energy distribution of the stars by way of showing excess emission, a variety of Balmer Jumps and flux deficiencies and/or flux excesses in the ultraviolet, the observed energy distribution curves cannot be directly compared to the model atmospheres for normal stars. Nevertheless during the normal phase of a B-Be-Be-shell star, we can assume that the envelope is absent, or is optically quite thin and a comparison with that of a normal star or the model atmospheres can be made. There is another effect due to rapid rotation of these stars, which produces gravity darkening, and broadening of spectral lines resulting in ambiguities in determining their spectral types. The net flux from the star would, however, correspond to an average temperature of the underlying star.

For our purpose we have taken this temperature to be 12,000 called it T_e and have assumed log g = 4.0 for the star. For T_{Shell} we have adopted a value given by $T_{\mathrm{disc}} = 0.8\ T_{\mathrm{eff}}$ = 9600 K (Lamers 1986). F_v was taken from a model atmosphere for T_e = 12,000, log g = 4.0 and solar composition (Kurucz 1979). The radius of the star has been calculated using the standard luminosity-effective temperature relation. For this we have used $L_*/L_\odot$= 180 corresponding to the calibration for a B8 V star given by Schmidt-Kaler (1982). A value of $R_* = 3.12\ R_\odot \simeq 2.18 \times 10^{11}$ cm is thus obtained for the star. The emission measures thus calculated from Equation 4 taking the case of an optically thin envelope are given in Table 2.

During 1980 the Balmer Jump (BJ) and the slope were nearer to a model (10,000, 4.0). The same parameters approached values appropriate for models 12,000–13,000 K log g =4.0 during 1988–90. The brightening of the star to a mean value 5.08 as compared to its value 5.29 in 1974 (See Hirata & Kogure 1976) and 5.18 given in the HD catalogue might lead one to suggest that the circumstellar envelope now has become optically thin in the continuum.

3.3 *Hα Emission*

The spectrophotometric tracings of the star BU Tau showed quite a strong Hα line in emission on all four nights. Specimen tracings obtained on the night of 1988 November 19, 1988 December 3 & 7 and 1990 January 9, have been shown in Fig. 2. The ratio I_λ/I_c on the tracings read at 20 Å interval were plotted against $\Delta\lambda$ where I_c is the intensity of the assumed stellar continuum. The area of the resulting curve was measured to give the intensity of the Hα emission line in equivalent angstroms. Due to the low resolution of the scans, the curve obtained above does not represent the profile of the line, however, an estimate of the line strength can be obtained. To check on this point we have measured the equivalent widths of the Hα absorption line in γ Gem on two nights in a similar manner. For the Hα line in γ Gem we obtained ω(Hα) = 12.6 ± 1.5 Å. The star γ Gem has spectral type AO IV. The effective temperature and log g for an AO IV star are taken as 9500 K and 4.0. The Hα equivalent width for a model with T_e = 9500 K and log g = 4.0 and of solar composition is 13.5 Å (Kurucz 1979).

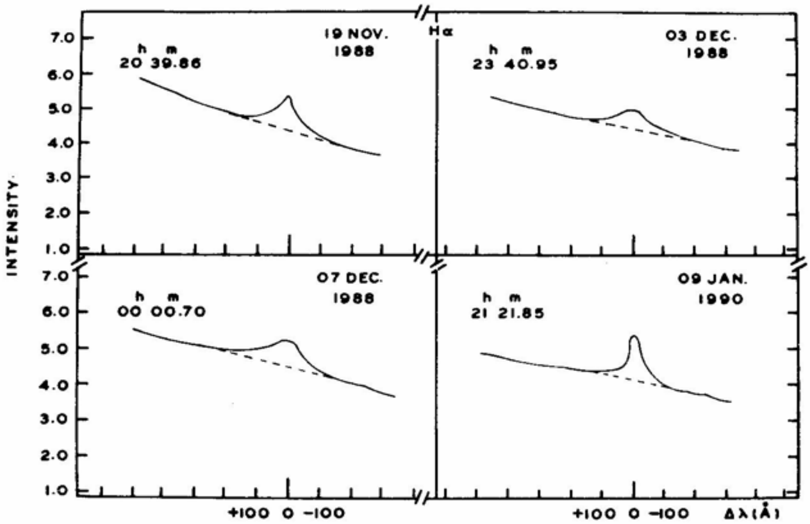

Figure 2. Original spectrophotometric scans of Pleione, showing the Hα line in emission. Ordinates represent the intensity in arbitrary units.

Taking this value as the equivalent width for γ Gem we find that the measured equivalent width is within the estimated error. We have also observed the B8 V star HR 1051 on 1990 January 9, which, although it has a $v \sin i$ value equal to 334 km s^{-1} (Hoffleit & Jaschek 1982), does not show emission at Hα The absorption Hα equivalent width of this star comes out to be 7.2 Å, whereas a model T_e= 12,000, log g = 4.0 taken to correspond to the star has an Hα equivalent width of 8.9 Å. Thus we feel that the error in the equivalent width measurement is $\simeq$ 2.0 Å although part of the difference in the later case may be due to the partial filling-in of the line due to possible emission. The measured equivalent widths are affected by the central absorption in the envelope, which have high values of line optical depths and are seen more or less equator-on. An estimate of this absorption was made using the Hα profile taken from Hirata & Kogure (1976) taken in a pre-shell phase. The central absorption has been estimated to be 10 per cent of the total unresolved emission. Thus due to unresolved absorption in our measurements an overestimate by 10 per cent in the equivalent with could be made.

In addition to the above, the underlying Hα absorption due to the photospheric Hα line would lead to an underestimation of the Hα emission equivalent width. In the subsequent analysis, we have however, not applied these corrections to the measured equivalent width of the Hα emission line, due to the low resolution of our scans.

3.4 *Size of Emitting Region*

To study the physical character and dimensions of the emitting region of the star, we have calculated the total emission in frequency (Hα) from an emitting volume V, assuming that the emission per cubic centimeter is constant throughout the emitting region. The energy emitted in the Hα line can be written as (Burbidge & Burbidge 1953),

$$VN_3 = 8\pi^2 CR_*^2 \frac{\omega}{\lambda^{3/4} A_{32}(e^{h\nu/kT} - 1)} \tag{5}$$

where N_3 is the number of neutral hydrogen atoms per cubic centimeter in level 3. ω is the measured equivalent width of the emission line in equivalent angstroms. R_* is the radius of the star, V the emitting volume and A_{32} is the downward transition probability of hydrogen atoms for a transition from level 3 to level 2.

For a solution of Equation 5 we have used $A_{32} = 4.415 \times 10^7$ s^{-1} (Wiese, Smith & Glennon 1966), ω is the measured value of equivalent width (see Table 2) and T = 12,000 K where this value represents the effective temperature of the B8 star. With the above values we obtained VN_3 for the Hα line in Table 2.

We next applied the Saha ionization equation to assess the degree of ionization in the emitting volume. For this we write,

$$\log\left(\frac{N_{\mathrm{H}^+}}{N_{\mathrm{H}}}\right) = -13.54\theta + 2.5\log T_{\mathrm{disc}} - 0.48 - \log p_e. \tag{6}$$

In using this equation for the envelope we have adopted T_{disc} = 0.8 T_{eff} (Lamers 1986), $p_e = n_e kT$ and $\theta = 5040/T$.

Struve & Swings (1941) have observed the hydrogen lines up to H 31 during 1940–41. According to the Inglis-Teller formula, this gives an electron density of 1.2 × 10^{12} cm^{-3}. Underhill (1949) has derived values of $n_e \sim 10^{12} - 10^{13}$ cm^{-3} in the shell based upon the curve of growth method. Higurashi & Hirata (1978) derive n_e ~ 7.5 × 10^{10} cm^{-3} and 4.7 × 10^{10} cm^{-3}. Dachs, Poetzel & Kaizer (1989) have derived typical electron densities for circumstellar envelopes around Be stars which are approximately 1.2 × 10^{12} cm^{-3}, assuming a geometrical thickness of the envelope equal to one stellar radius and a mean inclination i of 60°. The continuum energy distribution curves of the star during our period of observations nearly match with model atmospheres for normal stars although showing strong Hα emission. We adopt the typical value of 1.2 × 10^{12} cm^{-3} for the electron density in Pleione's envelope.

In Equation 6 assuming $n_e = N_{\mathrm{H}+}$ we get,

$$N_{\mathrm{H}} = 8.184 \times 10^9$$

Now for the emitting region $\sum_{n=1}^{\infty} N_n = N_{\mathrm{H}}$,

let us put

$$\left[\sum_{n=1,2} N_n + \sum_{n=4} N_n\right] = \chi N_3.$$

But

$$\chi N_3 + N_3 = N_{\mathrm{H}}$$

or,

$$(1+\chi)N_3 = N_{\mathrm{H}}. \tag{7}$$

Multiplying both sides of Equation (7) by V, we get,

$$VN_3\,(1+\chi) = VN_{\mathrm{H}}. \tag{8}$$

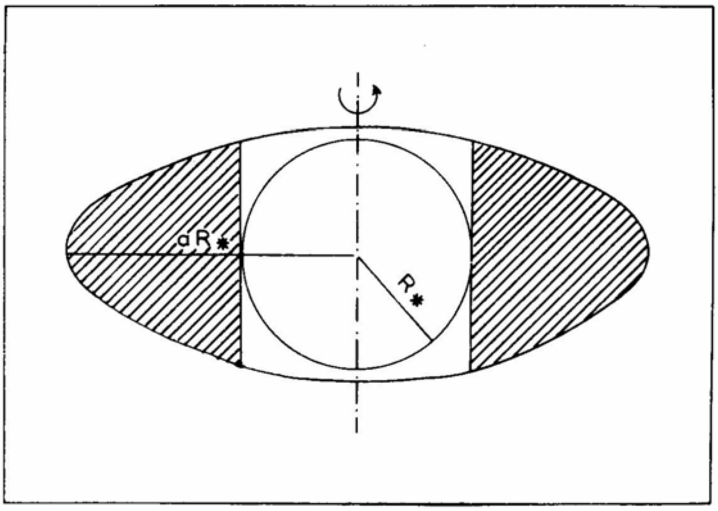

Figure 3. Ellipsoidal model for the emitting region of BU Tau.

Here χ is an unknown factor and depends on the total of all the populations in the remaining levels of the H-atoms.

Now we consider the elliptical disc model for the emitting region of the star following Doazan (1986) as shown in Fig. 3. Here the shaded portion represents the emitting region. The volume of this region has been approximated to a thick hollow cylinder with inner radius equal to R_* and outer radius equal to aR_*. Then

$$V = (a^2 - 1)2\pi R_*^3 \tag{9}$$

So from Equations (8) and (9), we get values of *a*.

To get an estimate of the outer radius of the envelope, we take account of the population in various levels of hydrogen at the temperature of the envelope, we get for χ a value of about 14 for the first 13 levels. The populations of the various levels of hydrogen have been determined using the Boltzman equation taking departures from LTE into consideration. For this we used the departure factor *b* given by Baker & Menzel (1938). The calculated values of the outer radius have been shown in Table 2.A mean value of 4.3 R_* for the outer radius of the emitting volume is thus obtained. This outer radius is quite sensitive to the electron density adopted for the calculation. Adopting a value equal to 4.0×10^{11} cm $^{-3}$ based upon the Inglis-Teller relation (Hirata & Kogure 1978) leads to a value of the outer radius equal to 12.45 R_*.

4. Discussion

Several Be stars have shown phase changes B-Be-Be shell. Kogure (1990) has displayed the phase behaviour of a few well studied stars including Pleione. Another star 88 Her showing similar behaviour has been discussed by Doazan, Thomas & Barylak (1986). The time scales for the phase changes are of the order of months, years and decades for different stars. Kogure (1990) has also discussed the possible geometries of the envelopes of stars in the Be and shell phases based on an equator-on view of the envelope and assuming rotational broadening of shell absorption lines. For Pleione in the Be phase (1969) he has quoted a value of 17.6 R_* for the equatorial radius of the emitting volume. The new shell episode which began in 1972 has been characterized by a new thick disc of material appearing at the equatorial plane and expanding both horizontally and vertically. The Hα emitting volume also expands which is the cooler outer region of the envelope.

The dimensions of the envelopes of Be stars have been determined using different methods by various authors. They range from 3 R_* to 10 or 15 R_* (Doazan 1982).

The formation and clearing time scales of these envelopes are orders of magnitude shorter than the nuclear time scales (Marlborough 1986). It seems appropriate to think that changes in the nuclear reactions in the deep interior are not responsible for the changes in the circumstellar envelopes. Radiation-driven winds coupled with rotation, non-radial pulsations and perhaps magnetic fields (Underhill 1986) are responsible for the changes in the mass ejection mechanism from these stars.

5. Conclusions

(i) Emission measure (ε_{UV}) from the change in the Balmer Jump has been calculated,

(ii) The energy distribution curves show that matter in the circumstellar envelope has decreased from its value in December 1980.

(iii) The envelope is optically thick in the Hα line. The present values of Hα emission equivalent width are of the same order as they were in the period 1954–65, when the star was in Be phase.

(iv) On the basis of an assumed electron density and an elliptical model for the envelope, an estimate of the extension of the disc equal to 4.3 R_* has been made.

Acknowledgements

The authors are thankful for the comments and criticism of an anonymous referee. The authors thank Dr. B. S. Rautela for helpful discussion. One of the authors (DKO) is thankful to UPSO, Naini Tal for providing necessary facilities and to C.S.I.R., India for financial support.

References

Baker, J. G., Menzel, D. H. 1938, *Astrophys. J.*, **88,** 52

Beeckmans, F., Hubert-Delplace, A.M. 1980, *Astr. Astrophys.*, **86,** 72

Blanco, V. M., Demers, S., Douglass, G. G., FitzGerald, M. P. 1968, *Photoelectric Catalogue*, Publ. US Naval Obs. Vol. 21, Washington.

Burbidge, G. R., Burbidge, E M. 1953, *Astrophys. J.*, **117**, 407.

Dachs, J., Poetzel, R., Kaiser, D. 1989, *Astr. Astrophys. Suppl.*, **78,** 487.

Delplace, A. M., Hubert, H. 1973, *Compt. Rend. Acad. Sci.*, Paris, Ser.B. **277**, 575.

Doazan, V. 1982, *B Stars With and Without Emission Lines*, Eds A. Underhill & V. Doazan.

Doazan, V. 1986, in *IAU Coll. 92: Physics of Be Stars*, Eds A. Slettebak & T. P. Snow, Cambridge Univ. Press, p. 384.

Doazan, V., Thomas, R. N., Barylak, M. 1986, *Astr. Astrophys.*, **159,** 75.

Garrison Jr., M. L. 1978, *Astrophys. J.*, **224,** 535.

Garrison, R. F. 1987, *Bull. am. astr. Soc.*, **19,** 704.

Goraya, P. S. 1984, *Inf. Bull. Var. Stars*., No. 2493.

Goraya, P. S. 1985, *PhD Thesis*, Punjabi University, Patiala, India.

Goraya, P. S. 1986, *Mon. Not. R. astr. Soc.*, **222,** 121.

Gulliver, A. F. 1977, *Astrophys. J. Suppl*., **35**, 441.

Hack, M., Struve, O.1970, in *Stellar Spectroscopy: Peculiar Stars*, Osservatorio Astronomico Di Trieste, p. 39.

Higurashi, T., Hirata, R. 1978, *Publ. astr. Soc. Japan*, **30,** 615.

Hirata, R., Kogure, T. 1976, *Publ astr. Soc. Japan*, **28,** 509.

Hirata, R., Kogure, T. 1978, *Publ. astr. Soc. Japan*, **30,** 601.

Hirata, R., Kogure, T. 1984, *Bull. astr. Soc. India*, **12,** 109.

Hoffleit, D., Jaschek, C. 1982, *The Bright Star Catalogue*, 4th rev. edn., Yale University Obs., New Haven, USA.

Hopp, U., Witzigmann, S. 1980, *Inf. Bull. Var. Stars,* No. 1782.

Hopp, U., Witzigmann, S., Geyer, E. H. 1982, *Inf. Bull. Var Stars,* No. 2148.

Kogure, T. 1990, *Astrophys. Sp. Sci*., **163,** 7.

Kurucz, R. L. 1979, *Astrophys. J. Suppl*., **40,** 1.

Lamers, H. J. G. L. M. 1986, in *IAU Coli 92: Physics of Be Stars*, Eds A. Slettebak & T. P. Snow, Cambridge Univ. Press, p. 219.

Lang, K. R. 1974, in *Astrophysical Formulae*, Springer Verlag, Berlin, p. 513.

Marlborough, J. M. 1986, in *IAU Coll 92: Physics of Be Stars*, Eds A. Slettebak & T. P. Snow, Cambridge Univ. Press, p. 316.

McLaughlin, D. B. 1938, *Astrophys. J.*, **88,** 622.

Morgan, W. W., White, R. A., Tapscott, J. W. 1973, *Astr. J*., **78,** 302.

Nandy, K., Thompson, G. I., Jamer, C., Monfils, A., Wilson, R. 1975, *Astr. Astrophys*., **44,** 195.

Pickering, E. C. 1890, *Astr. Nachr.,* **123,** 95.

Schmidt-Kaler, Th. 1982, *Zahlenwerte und Funktionen aus Naturwissenschaft und Technik/ Landolt-Bornstein*, New Series, Ed. K.-H., Hellwege, Vol. VI/2b, (Springer, Berlin).

Sharov, A. S., Lyuty, V. M. 1976, in *IAU Symp. No. 70*, *Be and Shell Stars,* Ed. A. Slettebak, D. Reidel, Dordrecht, p. 105.

Slettebak, A. 1982, *Astrophys. J. Suppl*., **50,** 55.

Struve, O., Swings, P. 1941, *Astrophys. J*., **93,** 446.

Taylor, B. J. 1984, *Astrophys. J. Suppl.*, **54,** 259.

Underhill, A. B. 1949, *Astrophys. J.*, **110,** 166.

Underhill, A. B. 1986, in *IAU Coli. 92: Physics of Be Stars*, Eds A. Slettebak & T. P. Snow, Cambridge Univ. Press, p. 411.

Underhill, A. B., Divan, L., Prevot-Burnichon, M.-L., Doazon, V. 1979, *Mon. Not. P., astr. Soc*., **189,** 601.

Wiese, W. L., Smith, W. L., Glennon, B. M. 1966, *Atomic Transition Probabilities*, U.S. Dept. of Commerce, Vol. I, NBS4, Washington D.C.

Williams, E. G. 1939, *Observatory*, **62,** 301.