The greatest difference in velocity dark minus bright, is shortly before maximum light when the emission lines make their first appearance. The relative displacement of the bright lines becomes definitely less with time in any cycle. They first appear with a velocity-difference of 16 km./sec. which slows to 7 km./sec. 160 days after maximum. At minimum, the bright and dark lines have little relative motion.

For the hydrogen emission lines, which have been shown to originate in a lower stratum than the absorption lines of the reversing layer, the motions seem more irregular than those of the neutral metallic emission lines, but this effect may be due to less accurate measurement of the hydrogen lines which are often wide, overexposed, and broken up by overlying absorption. At maximum, the hydrogen emission layers seem to be rising at slower speed with respect to the reversing layer than the neutral metallic strata, but at phase +30 days they meet the neutral-line velocity curve and during later phases partake of the same motion.

16. SPECTROPHOTOMETRY OF χ CYGNI

By Yoshio Fujita. (*Presented by* Z. Suemoto)

Spectrograms of χ Cygni have been obtained with the Mills Spectrograph of the Lick Observatory. For the purpose of spectrophotometry, the intensity spots have been given to all the plates using the Mills sensitometer. These spectrograms have been traced by the photo-electric microphotometer at the Yerkes Observatory, and equivalent widths of nearly 215 atomic and molecular lines have been derived.

The curve of growth was constructed by two methods. One is to make use of the observed values of the transition probabilities. The other is to make use of the theoretical values assuming LS coupling. Although Wright has used both values for constructing a single curve of growth, we have used them separately.

(I) *Observed* gf *values*

In this case it is not possible to make a very well-defined curve of growth, because the number of lines available for this method is not very great. As the *gf* values of Ti, Fe and Cr have been derived from laboratory experiments we have tried to make use of these values. Assuming temperatures of 1800°, 2000°, 2200°, 2500°, 2800° we plotted $\log \frac{W}{\lambda}$ against $\log gf\lambda - \frac{5040}{T}\chi$. And by superposing the plots of each element, we got the best fit for a temperature of 2200°

To fix the origin we must compare these plots with some theoretical curve of growth. For that purpose, we have used the theoretical curve of growth calculated by Menzel using the Schuster-Schwarzschild model. It is given by the following equation:

$$\log \frac{W}{\lambda} = \log X_0 \frac{v\sqrt{\pi}}{c} - \tfrac{1}{2}\log(1+X_0) - \frac{\tfrac{1}{2}\log 4\sqrt{\pi}\,\frac{v}{c}\frac{\nu}{\Gamma}}{1+15e^{-2\log X_0}}, \tag{1}$$

where the optical depth at the centre of a line, X_0, is given by

$$X_0 = \frac{N\varpi}{b(T)}\, 10^{-\frac{5040}{T}\chi}\, \frac{\pi e^2}{mc}\, \frac{c}{\sqrt{\pi}\,\nu_0 v} f, \tag{2}$$

and

$$\varpi f = \frac{\nu}{3R}\,\phi\,\frac{S_s}{\Sigma_s}. \tag{3}$$

Recently, Wright has applied the theoretical curve of growth that Wrubel calculated following Chandrasekhar's method. However, as we have no exact knowledge about the

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contribution of the negative hydrogen ion and the molecular absorption to the opacity of such a low-temperature star as χ Cygni, in our case the real meaning of applying the exact solution by a Milne-Eddington model might be lost.

The final results from the theoretical curve are shown in Fig. 1, and the diagrams of each element are shown in Fig. 2.

(II) *LS coupling*

We have selected the following transition arrays of Ti, V and Cr.

Ti: $3d^3(^4F)\ 4s-3d^3(^4F)\ 4p$, $3d^3(^4P)\ 4s-3d^3(^4P)\ 4p$.
V: $3d^34s^2-3d^34s(^5F)\ 4p$, $3d^4(^5D)\ 4s-3d^4(^5D)\ 4p$.
Cr: $3d^44s^2-3d^44s(^6D)\ 4p$.

Assuming the same temperature range, we have calculated $\log \frac{S_s}{\Sigma_s}-\frac{5040}{T}\chi$ and plotted $\log \frac{W}{\lambda}$ against this value for each element. The best fit is again obtained with the same temperature 2200° The results are shown in Fig. 3. Fig. 4 shows the diagrams for each element.

It is very remarkable that the coincidence between the two methods is satisfactory and we can see that the theoretical curve of growth is quite the same in both diagrams. Now, from the vertical shift of the curve of growth, we are able to derive $\log (c/v)$ which has the numerical value 4·68, and from the damping portion of the curve of growth, we obtain the numerical value of $\Gamma/\nu=3{\cdot}8\times 10^{-7}$ $\log c/v=4{\cdot}68$ means $v=6{\cdot}3$ km./sec. If we assume $T=2200°$, then the velocity due to thermal motion is 0·85 km./sec., taking

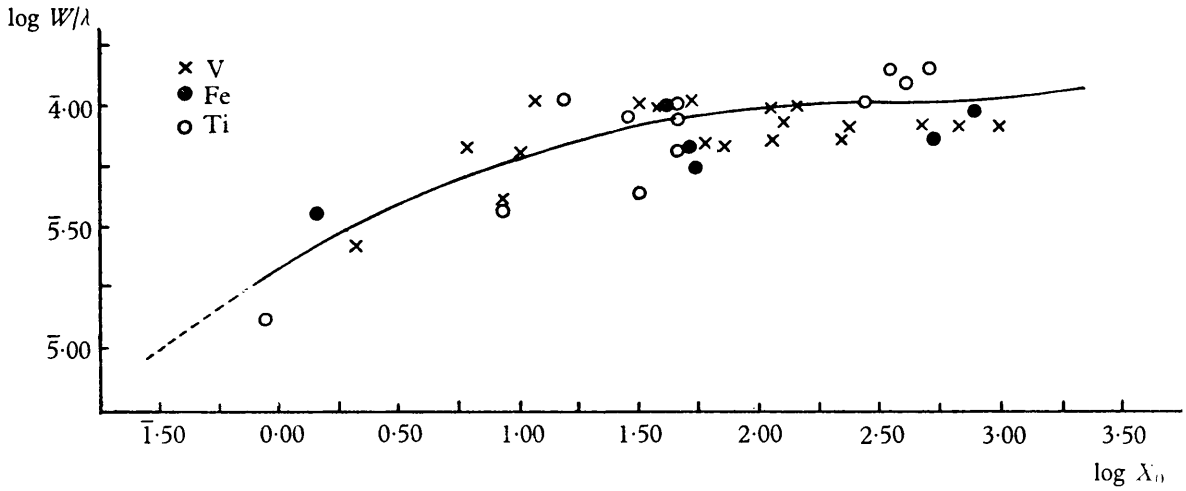

Fig. 1. Curve of growth for χ Cygni (I). The line is the theoretical curve.

the mean atomic weight 50. It is thus seen that the turbulent motion in this star is very large. This is not surprising because we have some stars which show a large turbulent motion. On the other hand, the small value of Γ/ν shows that this physical characteristic of this star also resembles that of a super-giant star.

Now, we may consider the chemical composition of this star. The number of atoms or molecules can be written in the following way

$$\log N=17{\cdot}82+L-\log\frac{c}{v}+\log b(T)-\log\phi, \tag{4}$$

where

$$L=\log X_0-\log\frac{S_s}{\Sigma_s}+\frac{5040}{T}\chi \tag{5}$$

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and $b(T)$ is the partition function. We take, here, $\phi = 1$. In case of atoms, we are able to calculate $b(T)$ easily. However, in such a molecule as TiO, the exact calculation of $b(T)$ seems to be impossible. With the assumption that the nuclear spin of Ti is approximated by O, we can give an approximate value for it and we use, here, $b(T = 2200°) = 4{\cdot}95$ for TiO. This value may not be far from the true value. The greatest difficulty exists rather in the transition probabilities for the molecules. We assume here $\log f$ for every

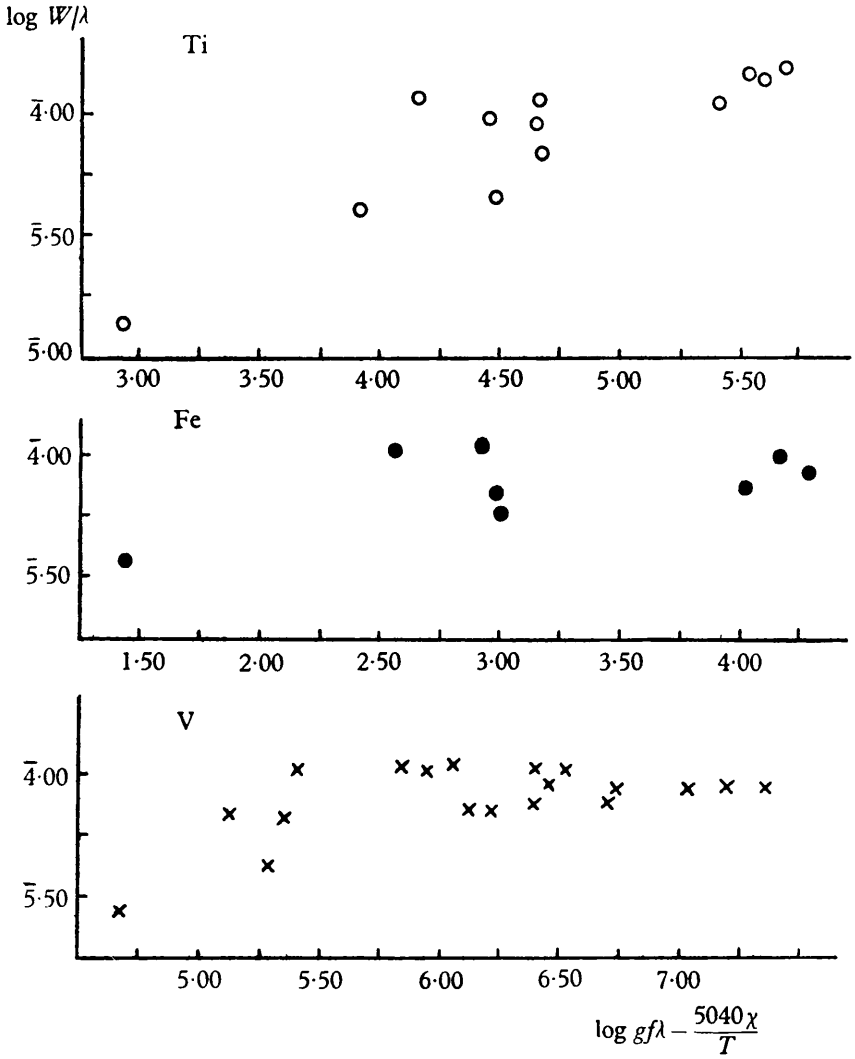

Fig. 2. Intensity plots for lines of Ti, Fe and V in the spectrum of χ Cygni (I).

rotational line of TiO to be $\bar{3}{\cdot}50$. To derive the molecular abundance, it seems reasonable to select rotational lines which are not located in the neighbourhood of strong band heads. Because most of the rotational lines of ZrO are blended with other lines and only some band heads have been measured, we will treat only the case of TiO. Thus we have calculated $\log N$ for Ti, Fe, V, Cr, Zr and TiO. Next, we derive a general idea of the oxygen abundance in the following way. The electron pressure P (dynes/cm.^{2}) can be written

$$\log P = \tfrac{5}{2} \log T - \log \frac{N_1}{N_0} + \log \frac{2b_1}{b_0} - \frac{5040}{T} \chi_0 - 0{\cdot}48. \qquad (6)$$

We adopt an approximate value of $\log P$ for a super-giant star and put $\log P = \bar{4}{\cdot}00$. Then the number of ionized atoms can easily be calculated by equation (6).

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The total pressure p can be expressed in the following way

$$p=\frac{1+\theta}{\theta}P, \tag{7}$$

where

$$\theta=\sum_i(\theta_i x_i), \tag{8}$$

and i refers to all atoms considered, θ_i the relative abundance of each element (expressed per unit volume) and x_i means the ionized fraction. Then we have $\theta=1{\cdot}70\times10^{-3}$ and $\log p=\bar{2}{\cdot}77$ (dynes/cm.^{2}). If the abundance of Fe increases and takes nearly the same value as Ti, then we have a little higher value of p, namely $\log p=\bar{2}{\cdot}93$. This means no serious change in the forthcoming calculation. On the other hand, the value of $\log P$ assumed has also no serious effect upon $\log p$. Even if we take $\log P=\bar{4}{\cdot}50$, we have $\log p=\bar{2}{\cdot}78$. It is of course true that some other elements, the abundances of which have not been deduced here, are in existence in this star. The existence of such elements will, however, not change the general feature of the calculation.

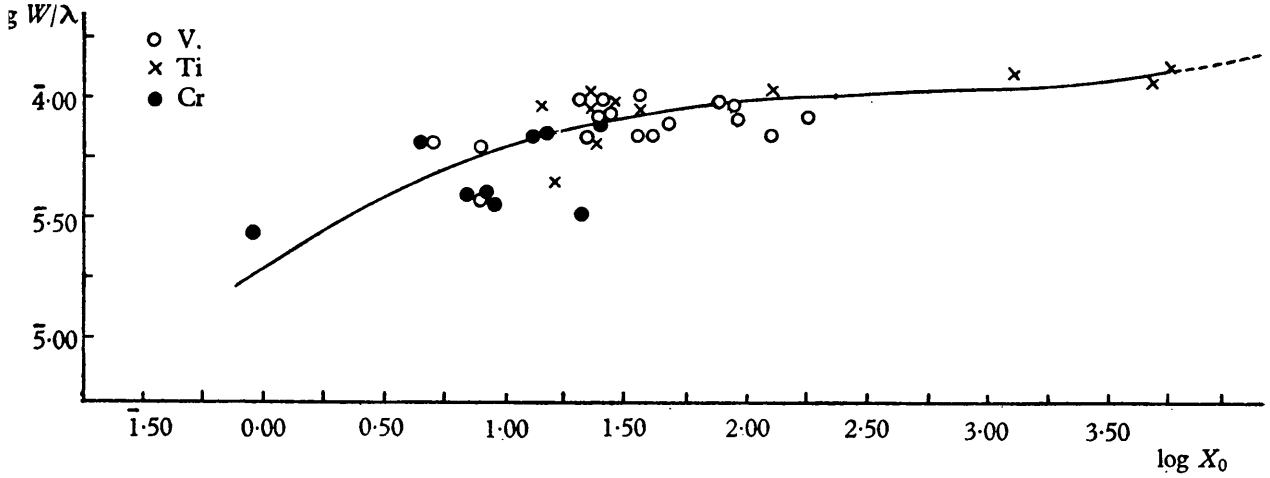

Fig. 3. Curve of growth for χ Cygni (II). The line is the theoretical curve.

Consider the dissociative equilibrium of a molecule AB. Thus we have $AB\rightleftarrows A+B$. The dissociation coefficient K_{AB} can be written in the following equation

$$K_{AB}=\frac{p_A p_B}{p_{AB}}, \tag{9}$$

and partial pressure p_A, p_B and p_{AB} can be written

$$p_A=\theta_A p=\frac{N_A}{\sum_i N}p, \quad p_B=\theta_B p=\frac{N_B}{\sum_i N}p, \tag{10}$$

$$p_{AB}=\theta_{AB}p=\frac{N_{AB}}{\sum_i N}p.$$

Combining (9) and (10) we have

$$\log K_{AB}=\log N_A+\log N_B-\log N_{AB}+\log p-\log\sum_i N. \tag{11}$$

K_{AB} can be calculated as a function of temperature. And in our case we obtain $\log K_{TiO}=\bar{10}{\cdot}42$, using a dissociation energy of 6·9 electron volts. Then in equation (11) $\log N_{TiO}$, $\log N_{Ti}$ and $\log p$ are known and we obtain the following numerical value: $\log N_O=20{\cdot}7$. However, it must be taken into consideration that the above estimation

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depends upon the value of the partition function and of the transition probability of TiO. These values directly affect the numerical values of the abundances.

The above results indicate an oxygen abundance of the order of 100 times that of titanium.

Now, applying the numerical value of log N_O which has been calculated from log N_{Zr} we are able to derive the value of log N_{ZrO}. The value of log K_{ZrO} is $\bar{1}2{\cdot}47$, using a dissociation energy of 7·8 electron volts. Then the results show that from log $N_O = 20{\cdot}7$ we have log $N_{ZrO} = 20{\cdot}16$. This means that the abundance of ZrO is about four times less than that of TiO.

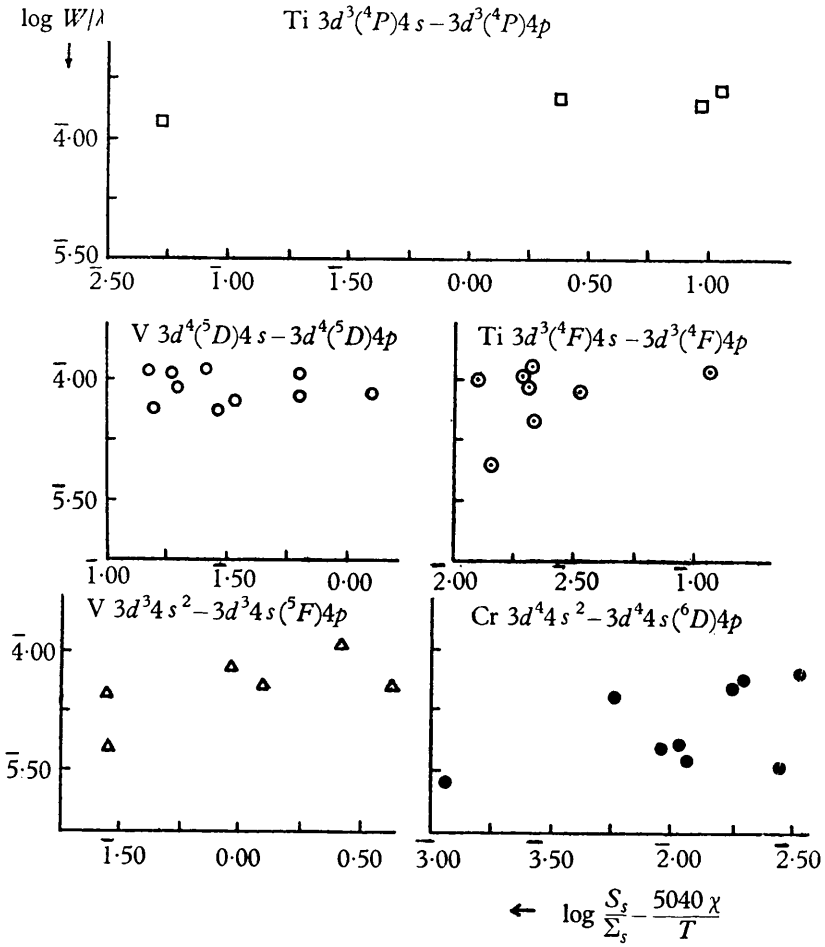

Fig. 4. Intensity plots for lines of Ti, V and Cr in the spectrum of χ Cygni (II).

17. TECHNETIUM IN S-TYPE STARS

By Paul W Merrill. (*Presented by* I. S. Bowen)

Element number 43, now called technetium, has had a curious history. As a hypothetical element, when the implications of the periodic table were first realized, it was called eka-manganese after its chemical homologue. In 1925 three German chemists announced its detection by means of lines in the X-ray spectrum, and gave it the name masurium; but their discovery has not been confirmed and is now considered erroneous, although their parallel discovery of rhenium, element number 75, was valid.

Element number 43 was identified in 1937 by Perrier and Segre in a piece of molybdenum that had been bombarded with neutrons in the cyclotron at Berkeley. It was named technetium because it was the first element to be prepared artificially. In 1939

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