WAVE LENGTHS IN A TYPE STARS

By W. E. Harper

THE determination of the velocity of a star towards us or away from us is based upon the shift of the stellar lines from their normal positions in the spectrum. If the star is approaching, its light waves are in effect shorter than normal and the resulting spectral lines are shifted to the violet by an amount proportional to the velocity of the star towards us. If the star is receding the shift is to the redward end of the spectrum.

To measure these shifts it becomes necessary to have a suitable comparison spectrum impressed on the plate on either side of the star spectrum. The particular one used at Victoria is the iron arc which gives numerous lines throughout the length of the spectrum suitable for standards from which we can measure the shifts of the stellar lines. If a star at rest with respect to ourselves should happen to have an atmosphere in which iron vapour is present then a set of lines will be found in its spectrum coincident in position with the iron-comparison lines, that is, they will join on to and make one continuous line with the broken ends of the comparison lines. If, however, the star should be approaching or receding there will not be this continuity but a displacement of the stellar with respect to the comparison lines.

All the lines, however, should show the same shift when expressed in terms of velocity. And this is true not only for the lines of the element which happens to match the comparison used but for all the lines due to any element whatsoever in the star's atmosphere. This presupposes that we know the normal wavelength of every line occurring in the spectrum if we are to use it in determining the velocity from the line shift. In the case of the hotter stars, technically known as the O and B types, which have simple spectra with relatively few lines due to hydrogen, helium, oxygen, nitrogen, silicon and a few other elements there is not much uncertainty. We can adopt the laboratory wavelengths for these lines with a reasonable degree of assurance as they are in general isolated in the spectrum. In the case of solar and later type stars (G-K-M), where the lines are numerous and closely crowded together, blending is bound to occur and trouble arises in arriving at the normal wave-lengths of these composite lines. The practice very often is to match spectra of this type directly against a similar one whose velocity is known and in this way a knowledge of the normal blended wave-length is unnecessary.

In between these two groups lie the A-F stars in which there is an increasing number of spectral lines as we proceed from A to F. It is with the spectral lines in the A type (the hydrogen stars so-called because in them hydrogen reaches its maximum intensity) that this article particularly deals although the results obtained are in large measure applicable to the F-stars, at least those in the earlier subdivisions.

The A type stars are characterized by the strong Balmer series of hydrogen. In some stars these are the only lines found. The ionized lines of calcium, H and K, are usually present, the former being in general blended with Hϵ of Hydrogen. The increasing strength of K as we proceed from A to F is a partial basis of classification on the Harvard system. In other stars again in addition to the foregoing lines we have an increasing number of metallic lines, mostly of iron and titanium and many of these are due to the ionized atoms. Both the arc and enhanced lines of other elements are also present, such as the well known enhanced line of magnesium λ4481.

In the simplest spectra of this type where only a few lines occur laboratory values suffice. Where the spectra become rich in lines with consequent blending it is desirable to have some knowledge of the components entering into a blend and their relative intensities. The practice in early days was to use Rowland's Table of Solar Wave-Lengths as a guide and to compute a blended value based upon the intensities as given in that work. Only the lines due to elements suspected to be present in the star were so incorporated. In course of time certain of these complex lines were seen to give results systematically different from the mean of that for the plate in general. Such systematic differences could be used to deduce a normal value for the wave-length concerned more in keeping with the observed trend of the residuals. Such empirical values of the blended wave-lengths were determined by the writer at Ottawa in the case of the star 14 Aurigae and some of these values were adopted by R. K. Young, who compiled the list of wave-lengths first used in the Victoria radial velocity work. For the remainder of the list Young used the best determined laboratory values at that time.

This table has been used throughout by the writer not only in the original radial velocity programme where the director and the other three members of the staff co-operated but since then in an extended programme of A type stars. It was early noted that a few wave-lengths might be improved but the values have been used consistently throughout. As these were on the Rowland System they were transferred to the International System a couple of years ago in conformity with the recommendations of the Union. In the case of the stellar lines the wave-lengths were adjusted by the corrections given in Revised Rowland, page VII.

The same procedure might logically have been followed in the case of the comparison lines. However, there was in existence at the Observatory at that time a table of comparison wave-lengths which were based largely on Burns, as his determinations were seemingly the most reliable when the table had been prepared some years previously for the B-type stars. It was noted that the wave-lengths of the iron arc as recommended by the Union were slightly different to these and systematically so, the difference in the sense Victoria (Burns) minus I.A.U. for 23 comparison lines most frequently used being +.0034 angstroms. Two lines are given as a sample of the differences concerned. The first column shows the wave-length as adopted in the tables first used at this observatory. The second column shows the corrections necessary according to Revised Rowland to reduce to the International System. The third column shows this revised value while the other two columns give Burns' determination (as then in use here) and the value recommended by the Union.

Original	Correction	Revised	Burns	I.A.U.
4325.932	−.158	.774	.770	.765
4337.214	−.160	.054	.052	.049

If the I.A.U. values had been adopted instead of those in the table referred to (Burns) it would have meant that future measures would be more positive to the extent of 0.2 km. per sec. On the other hand if revised values had been adopted for the comparison lines by applying similar corrections to them as to the stellar lines then velocities 0.3 km. per sec. more negative on the average would have resulted. Probably the best course to have pursued at that time of change would have been to have adopted the wave-lengths recommended by the I.A.U. for the iron arc comparison lines and applied a systematic correction of +0.5 km. to the velocities of the earlier plates. In talking over the matter, however, with the director it seemed best for the sake of uniformity within the Observatory to adopt the comparison wave-lengths as then in use, since they were about midway between the two others, in which case only a small systematic difference would exist between the two systems. Thus, to sum up this phase of the question, stellar wave-lengths were transferred to the International System by the corrections given in Revised Rowland but Burns' determinations on the International scale were used for the comparison lines.

Although the winter section of the A-programme is, owing to wretchedly poor weather during the past two or three winter seasons, not yet wholly completed its approaching completion has led to some provisional investigations of the results. Many of the brighter stars were purposely included so that we might have their spectra and while radial velocity results for these had previously been obtained at other observatories nevertheless it was deemed worth while to measure those plates secured at Victoria. An intercomparison of the results for all A type stars in common with other observatories showed that the writer was consistently negative with the best determined values at other places to the extent of about 1 km. per sec. In a paper presented to the Royal Society of Canada last year various possible causes were studied and it was concluded that the curvature correction used at Victoria of −1.00 km. per sec. would account for 0.3 km. of the difference as a better determination of that constant for the region of spectrum used is −0.70 km. per sec.

The question of the wave-lengths of the stellar lines used was left open for further study. It seemed worth while to study anew the residuals given by each line from the mean of the plate. It is generally recognized that slight differences of wave-length will be found for certain lines as we proceed from one type to another. The assumption, moreover, that stellar wave-lengths are the same as those for the corresponding elements in the laboratory cannot be accepted without question. Jewell, in 1896, found a slight difference between arc and solar wave-lengths and this has been further studied by St. John and Adams at Mount Wilson and their conclusion that the solar wave-lengths are roughly .007 angstroms to the red with respect to the corresponding arc lines is accepted. Moreover minor differences have been found in the resulting velocities depending upon whether the arc or enhanced lines of the elements are used.

It was felt that while these minor differences would persist, yet a working value of the wave-lengths concerned would be obtained by studying a number of spectra of all types from A0 to F0. Accordingly 200 were selected in which no fewer than 10 lines on each had been measured. While a lower average deviation, taken without regard to sign, would doubtless have been secured had spectra been chosen with sharp lines only, yet a better cross-section of the type is secured by choosing spectra having lines of diffuse as well as of sharp character.

The plates used had all been secured with single prism dispersion with the camera of medium focal length (IM). As the prism has been refigured once and the system changed from Rowland to International, three different tables have been used in the reductions and care has been necessary so as not to confuse one line with another. The residuals of each line from the mean were taken and averaged both without regard to sign and with regard to sign. The results showed some lines with considerable systematic residuals and it was felt that before accepting such as definite more of the data at hand should be drawn upon. Consequently 200 additional spectra of similar type and character to the first batch were selected and the residuals tabulated in the same way. Almost identical results were secured in the two cases so that while much more material could have been used it was not deemed necessary to do so. The combined results are given in two tables, the first one being the Main List, the second a Supplementary List of wave-lengths. Column 1 gives the wave-lengths on the International System as heretofore used; column 2 the number of times the line was measured on the 400 plates selected; column 3 gives the numerical value of the residual, *i.e.*, taken without regard to sign; column 4 gives the algebraic residual; column 5 the correction necessary to the wave-length to make this residual vanish; column 6 gives the revision of λ suggested while the last column deals very briefly with identifications of the elements concerned in the line.

Some of the values of the wave-lengths in column 6 are starred as indicating that so much uncertainty exists in the blends that it seemed better to accept the empirical value which satisfied the line residuals. The elements given in the last column are not necessarily all that occur but are deemed the principal ones. The presence of other elements in A type spectra has been conclusively established by different investigators but the intensities of such are generally weak and the effective wave-lengths would not be materially changed, it is thought, by their inclusion. Nevertheless, by reason of this very uncertainty some might prefer to accept the definite corrections (column 5) which the residuals call for. The wave-lengths recommended in almost every case tend to improve matters and in most cases are nearly in agreement with what the residuals call for. They are formed from the components indicated in the last column in which the intensities shown have been based upon results from the laboratory, from the sun as indicated in Revised Rowland, from Dunham's high dispersion spectra of α Persei, from Albrecht's study of three-prism spectra of γ Geminorum and to a lesser degree from three-prism plates of our own. Additional studies of high dispersion spectra of typical stars will further increase our knowledge of these blends and will be a worthwhile contribution to the subject.

WAVE-LENGTHS FOR CLASS A STARS

MAIN LIST

λ	n	|Δ|	Δ km	Δ λ	λ Recom-mended	Identification and Remarks
3933.667	160	8.1	+2.10	−.026	3.664	Ca+
4005.263	135	8.9	−5.25	+.070	5.333*	Fe .246 blended with others
4030.695	45	7.4	+5.12	−.069	0.610	Fe .504 (3), Ti .514 (6), Mn .760 (6)
4045.790	327	8.4	+3.42	−.046	5.739	Fe .132 (1), Fe .815 (8)
4063.567	266	8.8	+4.19	−.057	3.539	Fe .292 (2), Fe .601 (8)
4071.739	164	9.4	+3.84	−.052	1.687*	Fe .743 probably violet component
4077.721	233	11.0	+7.36	−.100	7.644	La+ .35 (1), Y .38 (1), Sr+ .714 (8)
4101.740	197	8.8	−0.77	+.011	1.738	Hδ
4118.678	58	8.6	+0.94	−.013	8.650	Fe .549 (5), Fe .901 (2)
4128.059	39	8.7	−4.69	+.065	8.053	Si+ .053 though possibly V .101 and others
4130.892	27	7.6	−1.57	+.022	0.884	Si+ .884
4143.686	224	10.8	+1.54	−.021	0.682	Fe .417 (5), Fe .871 (7)
4198.511	210	10.7	−6.23	+.087	8.605	Fe .239 (4), .331 (4), .632 (3), 9.100 (5)
4202.024	74	8.2	−3.63	+.051	2.031	Fe .031 main, probably blended with Fe .752
4215.578	254	8.5	−3.51	+.049	5.636	Fe .416 (2), Sr+ .515 (10), Fe 6.186 (3)
4226.953	245	10.0	+3.02	−.042	6.911	Fe .426, Ca .735, Fe 7.435 blended
4233.270	290	8.1	−1.75	+.024	3.275	Fe 2.729 (2), Fe+ 3.164 (8), Fe 3.606 (6)
4235.846	40	8.2	−3.95	+.056	5.902*	Fe .950 main, probably blended with Y+ .70
4250.464	124	8.2	−4.02	+.057	0.481	Fe .131 (7), Fe .788 (8)
4260.405	87	7.3	−2.67	+.038	0.425	Fe 9.985 (1), Fe 0.132 (1)' Fe 0.486 (12)
4271.524	234	8.6	−3.43	+.049	1.548	Fe .170 (4), Fe .764 (7)
4289.946	270	9.7	+0.17	−.002	9.933	Cr 9.725 (5), Ti+ 0.230 (2), Fe 0.380 (1)
4307.824	45	8.1	−4.87	+.070	7.892	Ti+ .880 (8), Fe .906 (7)

λ	n	|Δ|	Δ km	Δ	Recom-mended	Identification and Remarks
4325.761	249	10.6	+6.03	−.087	5.674*	Fe .765 main, but Sc+ 5.000 affects blend
4340.474	350	8.2	−0.64	+.009	0.466	Hγ
4351.841	233	9.0	−0.21	+.003	1.839	Cr Fe+ .762 (5), Mg .916 (5)
4374.931	174	10.4	+1.21	−.016	4.915*	Sc+ .46 (1), Y+ .96 (5) adjusted
4395.130	106	10.8	+4.96	−.073	5.044	Ti+
4404.723	86	7.7	−1.33	+.020	4.752	Fe .752
4415.136	37	7.1	−1.10	+.016	5.125	Fe .125, possibly blended with Sc+ .55
4481.238	361	8.4	−4.85	+.072	1.310*	Mg+ .13, Ti .26, Mg+ .33, latter component apparently strongest
4501.284	47	11.5	+1.45	−.022	1.270	Ti+ .270
4508.290	24	8.2	−0.67	+.010	8.290	Fe+ .290
4515.343	23	5.6	−1.90	+.029	5.340	Fe+ .340
4522.703	27	9.4	0.00	.000	2.701	Fe+ .633 (3), Ti .802 (2)
4533.972	107	10.1	−5.52	+.083	4.055*	Ti+ 3.97 main but Fe+ 4.17 contributes
4549.530	305	8.5	−1.67	+.025	9.550	Fe+ .48, Ti+ .62 assumed equal intensity
4571.986	34	8.2	−1.40	+.021	1.980	Ti+ .980
4583.848	45	12.1	+9.59	−.147	3.701*	Fe+ .841 main but Ti+ .45 contributes
4861.343	36	15.0	−4.12	+.067	1.326	Hβ

Supplementary List

λ	n	|Δ|	Δ km	Δ λ	λ Recommended	Identification and Remarks
3968.488	2	4.7	− 4.70	+.062	8.465	Ca+
4033.083	15	11.1	+11.13	−.150	2.933*	Fe 2.458, Fe 2.636, Mn 3.070, Fe 3.183
4132.083	29	10.7	− 6.39	+.088	2.141	V 1.952 (2), Fe 2.062 (10), −2.533 (3)
4246.844	49	11.1	− 7.01	+.099	6.943*	Sc+ 6.84, Fe 7.44
4282.682	13	13.4	+ 4.26	−.061	2.621*	Fe .41, Ti .70
4300.056	11	15.4	+ 9.81	−.141	9.885	Ti 9.640 (2), Ti+ 0.048 (3)
4315.022	18	19.1	+16.40	−.236	4.786*	Sc+ 4.09, Ti 4.32, Ti .81, Ti+ .98, Fe 5.10
4416.962	11	13.2	+ 0.03	.000	6.937	Fe+ 6.822 (3), Ti 7.282 (1)
4443.817	13	18.8	+16.46	−.244	3.578	Fe .196 (3), Ti+ .807 (5)
4468.502	16	11.6	− 9.48	+.141	8.643*	Ti+ 8.495 main, but Ti+ 9.149 contributes
4528.631	6	11.8	−10.35	+.156	8.619	Fe .619, possibly components to red
4563.769	9	6.8	+ 2.43	−.037	3.767	Ti+ .767