

Studies of Visual Double Stars. I

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An initial sample of 66 visual double stars was examined. Fifty of these were judged to have physically associated components. Absolute magnitudes using Δm 's were obtained for 43 companions. For early-type stars, absolute magnitudes on the Petrie (1965) system were also determined from photographic equivalent widths of $H\gamma$. The results are compared with the MK calibrations of Keenan (1963) and Blaauw (1963). Comparison of absolute magnitudes derived in two ways for the same stars indicate mean deviations M_V (Δm 's) minus M_V ($H\gamma$) of -1.0 ± 0.2 (m.d.) for four stars of types O6-O8 and $+1.1 \pm 0.2$ (m.d.) for four stars of types B0-B2 and classes II and III. For ten Be stars, a mean M_V (Δm) minus M_V (MK main sequence) of -1.0 ± 0.2 (m.d.) was obtained in agreement with previous results (Schild 1965, 1966; Schmidt-Kaler 1964).

Average values of $V \sin i$ and probable errors were obtained for each component with apparent rotational velocity greater than 50 km/sec. The new results were combined with those previously obtained by Slettebak (1963). In agreement with Slettebak's earlier result, no significant difference of $\langle V \sin i \rangle$ between single and double stars was found although the total sample was enlarged by some 20%. The combined results (both double and single stars) have been used to derive new $\langle V \rangle$ and $\sigma(V)$ for early-type MK stars.

I. INTRODUCTION

BINARY star systems consist of two or more stars that presumably were formed in the same neighborhood of space at about the same time. In systems having large physical separations, it may be assumed that the components have evolved independently. Wide visual multiple stars, unlike close binaries where disturbing interactions occur continuously, afford an opportunity to test theories of stellar evolution in a manner similar to star clusters. Astrophysical investigations of visual multiple stars have been carried out by Leonard (1923), Johnson (1953), Wallenquist (1954, 1958), Struve and Franklin (1955), Struve, Franklin and Stableford (1955), Opolsky (1956), Bakos and Oke (1957), Bidelman (1958), Bakos (1959), Hopmann (1959), Stephenson (1960), Wallerstein and Westfall (1960), Berger (1962), Slettebak (1963), Cester (1963), Eggen (1963, 1965), Tolbert (1964), Petrie and Batten (1966), and others. In the study reported here, 66 systems were originally investigated in order to obtain rotational velocities, MK spectral types, and where possible, absolute magnitudes. [A master list of some 1200 pairs was compiled by cross-referencing the Index Catalogue of Double Stars 1961.0 (ICDS) of Jeffers, van den Bos, and Greeby (1963), with a number of special lists. It is hoped to publish a revised and extended version of the list at a later date.] Those systems involving O- and B-type stars, supergiants, Be stars, Ap stars, and variable stars constituted the primary groups of interest. Some visual pairs involving eclipsing binaries, spectroscopic binaries, and high-velocity stars were also included on the observing program. On the basis of mutual incompatibility of interstellar line intensities, $H\gamma$ equivalent widths, radial velocities, and proper motions (where available), 16 of the 66 systems

were judged to be optical and rejected for further study. Data on these stars are included since they may have interest for other studies.

For three physical systems, the notation of the *Index Catalogue of Double Stars* (ICDS) is different from that used here. Finder charts have therefore been provided (Fig. 1).

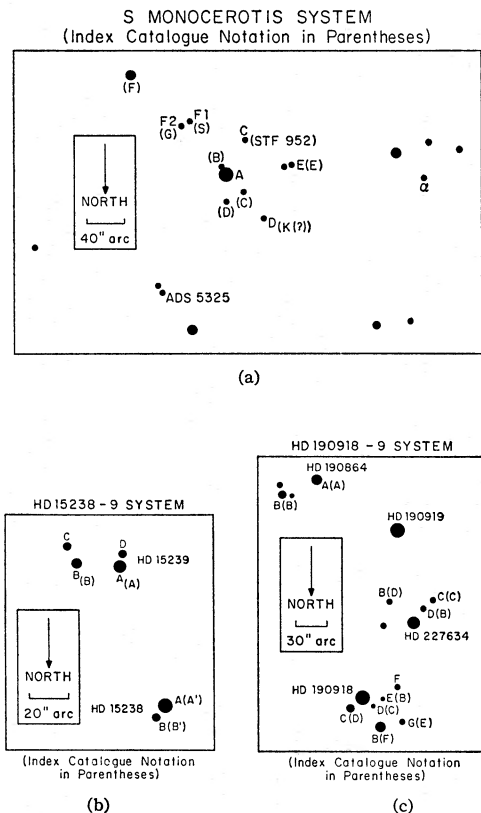


FIG. 1. Finder charts for three physical systems with ICDS notation different from that used in this paper.

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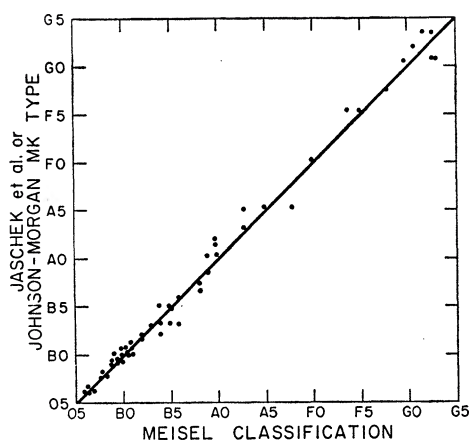


FIG. 2. A comparison of spectral types estimated in this paper with those given by Johnson and Morgan or by Jaschek, Conde, and de Sierra.

II. OBSERVATIONS

Spectrograms used in this study were taken with the 72-inch Perkins telescope of the Ohio State and Ohio Wesleyan Universities at the Lowell Observatory. The 8-in. camera of the Yoder spectrograph was used to obtain plates having a dispersion of 40 Å/mm at $H\gamma$. A range of 3400 to 5000 Å was covered on Kodak IIa-O emulsions baked 27 h at 51°C. MK standard-star spectrograms with 0.5-mm spectrum widths, previously taken by Slettebak, were supplemented with additional spectrograms for spectral types later than F8, where necessary. The spectra of the program stars were taken with the same width when possible, but in a number of cases the spectrum width was reduced to 0.25 mm in order to permit the required exposure time to be decreased.

Photoelectric observations of Δm_v 's for a number of systems were made with the 32-inch telescope at the Fan Mountain Station of the Leander McCormick Observatory, University of Virginia. The photometer is a single-channel device with a temperature-stabilized dc amplifier and integrator (Wood 1965; Berg 1966).

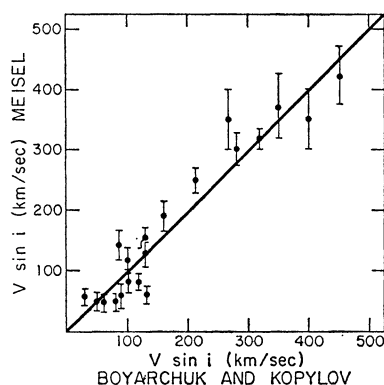


FIG. 3. A comparison of $V \sin i$ values derived in this paper with those listed in the catalogue of Boyarchuk and Kopylov.

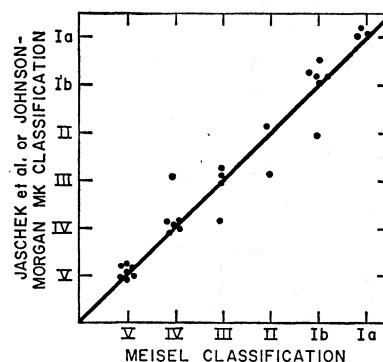


FIG. 4. A comparison of luminosity classes estimated in this paper with those given by Johnson and Morgan or by Jaschek, Conde, and de Sierra.

Refrigerated 1P21 and unrefrigerated EMI 6256 SA phototubes were used. In order to decrease the possibilities of contamination, all observations were made with either a 10- or 15-sec of arc diaphragm.

Microdensitometer tracings of the Perkins plates were made at Georgetown University Observatory. The density tracings were reduced to digitized intensity data by means of a motorized, one-dimensional micrometer especially suited for measuring chart recordings. The sets of intensity values were then used to construct line profiles from which the equivalent widths and half-intensity widths of particular lines were found. For the $H\gamma$ lines, the profiles were drawn freehand out to 300–400 Å on either side of the line center, and the assumed continuum level drawn in. The enclosed line areas were measured with a polar planimeter. Similar profiles were constructed and measured to obtain the half-intensity widths.

Before the results of the observations are discussed in detail, it is useful to compare them briefly with the data obtained by others. Figure 2 shows the spectral types classified on the MK system obtained from the Perkins plates compared with those given by Johnson and Morgan (1953) or by Jaschek, Conde, and de Sierra (1964). For nonstandard stars, the criteria given by Jaschek *et al.* were used to decide which of the entries in their catalogue provided the "best" basis for comparison. In Fig. 3, $V \sin i$ values from Perkins plates are compared with entries in the Boyarchuk and Kopylov catalogue (1964). Figure 4 shows a comparison between MK luminosity classes. Only stars earlier

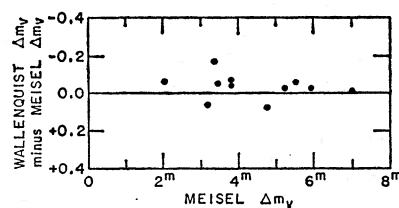


FIG. 5. A comparison of photoelectric Δm_v 's measured in this study with Δm_v 's listed in the general catalogue of Wallenquist.

TABLE I. Photoelectric and photographic data.

A. Stars with Meisel photoelectric Δm 's			B. (con't) Stars with Wallenquist Δm 's (physical pairs) (Meisel values given in parentheses)		
Star	Δm with p.e.	$H\gamma$ with p.e.	Star	Δm with p.e.	$H\gamma$ with p.e.
HD 15239 ^a	A ...	2.9±0.4	...	B 3.58±0.03	...
...	D 2.71±0.04	...	η Per	A (4.65±0.05)	...
...	B 1.43±0.2	8.9±0.4	...	B 4.72±0.13	15.0±0.4
...	C 2.44±0.04	...	HD 23439	A ...	...
HD 15238 ^a	A -0.16±0.01	Shell	...	B 0.55±0.02	...
...	B 2.64±0.03	...	HD 23675	A ...	2.2±0.1
HD 18473	A ...	5.2±0.1	...	B 2.70±0.39	5.0±0.4
...	B 1.62±0.03	...	23 Ori	A (2.19±0.03)	4.1±0.3
IQ Per	A ...	5.1±0.3	...	B 2.12±0.09	5.3±0.3
...	B 1.56±0.03	12.4±0.1	ν Gem	A (3.84±0.04)	6.2±0.2
HD 37330	A ...	6.3±0.1	...	B 3.76±(?)	14.0±0.3
...	B 0.66±0.03	Emission	β Mon	A ...	Emission
S. Mon ^a	A ...	3.8±0.2	...	B 0.46±0.04	6.4±0.2
...	C 4.19±0.03	11.6±0.4	...	C 0.38±0.05	Emission
...	D 5.69±0.4	...	HD 45955	A ...	3.0±0.3
...	E 5.67±0.03	...	...	B 2.88±0.07	4.6±0.2
...	E ₁ -E ₂ -0.27±0.03	8.8±0.1	2 Com	A ...	...
...	F ₁ 4.45±0.03	...	...	B 1.44±(?)	...
...	F ₁ -F ₂ 0.93±0.04	...	h Cen	A ...	6.9±0.2
...	" α " 5.35±0.03	...	...	B 3.71±0.08	7.6±0.3
HD 149632	...	8.0±0.4	HD 159481	A (2.98±0.06)	...
HD 149631	...	21.8±0.3	...	B 3.05±0.15	...
μ Sgr	A ...	2.2±0.2	d Ser	A ...	6.2±0.2 {A0 V spectrum
...	E 5.51±0.02	4.8±0.3	...	B 2.30±0.15	...
...	D 5.96±0.03	...	HD 179957	A ...	...
...	B 5.05±0.04	...	...	B 0.25±0.03	...
HD 187566	A ...	8.2±0.3	HD 184360	A ...	11.4±0.2
...	B 2.11±0.02	...	...	B 1.56±0.09	...
...	C 3.77±0.03	13.3±0.3	HD 191566-7	A ...	2.8±0.2
HD 190918 ^a	A ...	1.1±0.1	...	B 0.90±0.05	3.6±0.3
...	D 4.73±0.03	4.6±0.2	HD 206267	A ...	3.1±0.2
...	F 0.64±0.02	4.3±0.3	...	D 2.37±0.11	...
...	B 4.30±0.04	...	10 Lac	A (5.26±0.06)	3.2±0.2
...	C 3.05±0.03	...	...	B 5.22±0.18	4.2±0.2
HD 190919 ^a	...	3.3±0.2	HD 215812	A ...	...
HD 227634	A ...	3.6±0.1	...	B 0.27±0.05	...
...	D 0.97±0.03	4.0±0.2	HD 203374	A (3.43±0.05)	Emission
...	C 3.96±0.03	...	...	B 3.28±0.29	6.0±0.1
...	B 3.51±0.02	...	59 Cyg	A ...	Emission
α^1 Cap	A ...	...	...	B 4.42±0.08	...
...	B 5.13±0.02	...	C. Optical pairs Meisel photoelectric Δm 's (Wallenquist values in parentheses)		
HD 193322	A ...	3.6±0.4	HD 16429	AB ...	2.2±0.4
...	C 5.22±0.03	6.9±0.3	...	C 3.20±0.03	...
...	D 5.36±0.02	5.3±0.4	HD 26906-7	A ...	Emission
β Cap	A ...	4.0±0.2	...	B 0.95±0.02	9.9±0.3
...	B 2.98±0.03	...	HD 48279	AB ...	2.3±0.3
...	C 5.30±0.03	...	...	C 2.22±0.03	...
V389 Cyg	AB ...	12.4±0.4/14.2±0.1	ξ Gem	A ...	...
...	C 4.67±0.03	...	...	B 5.74±0.03	...
...	D 5.82±0.02	...	η CMa	A ...	3.1±0.2
ϵ Cap	A ...	3.6±0.2 (Shell)	...	B 4.85±0.03	25.6±0.2
...	B 3.98±0.03	...	29 Cyg	A ...	11.9±0.3
12 Lac	A ...	3.7±0.2	...	B 1.69±0.02	...
...	B 5.33±0.04	18.0±0.2	69 Cyg	A ...	2.1±0.1
AR Cas	AB ...	6.6±0.3	...	C 4.49±0.03	...
...	C 2.22±0.03	28.2±0.4	EN Lac	A (3.67±0.04)	4.0±0.2
...	CC' 5.59±0.04	...	...	B 5.85±0.02	...
...	D 6.33±0.04	...	...	C 3.72±0.03	...
...	E 6.16±0.03	...	D. Optical pairs, Wallenquist Δm 's (Meisel values given in parentheses)		
...	F 5.96±0.03	...	σ Dra	A (3.45±0.04)	...
B. Stars with Wallenquist Δm 's (physical pairs) (Meisel values given in parentheses)			...	B 3.42±0.02	...
HD 3266	A ...	...	λ Cyg	A ...	7.6±0.3
...	B 0.80±0.05	...	...	B 5.31±0.30	...
α Cas	A (6.68±0.02)	...	69 Cyg	A ...	2.1±0.1
...	C 6.67±0.03	...	...	B 5.29±0.10	...
HD 9311	A/C ...	3.7±0.2/8.1±0.2			
...	B 2.56±0.20	2.7±0.2			
ι Cas	A ...	12.2±0.3			

TABLE I (continued)

D. (con't) Optical pairs, Wallenquist Δm 's (Meisel values given in parentheses)			
Star		Δm with p.e.	$H\gamma$ with p.e.
HD 213470-1	A	...	2.7 ± 0.3
...	B	3.83 ± 0.25	...
σ Sco	A	(5.66 ± 0.04)	4.3 ± 0.2
...	B	5.62 ± 0.02	5.1 ± 0.2
E. Physical pairs ICDS Δm 's			
HD 5005	A	...	5.8 ± 0.1
...	D	0.8	4.2 ± 0.2
...	C	1.4	4.2 ± 0.1
HD 46056	A	...	3.0 ± 0.1
...	B	1.4	5.7 ± 0.3
TW Dra	A	...	...
...	B	1.0	...
HD 178001	A	...	20.0 ± 0.3
...	B	0.5	14.3 ± 0.2
HD 189783	A	...	...
...	B	0.2	...
HD 190864	A	...	1.4 ± 0.3
...	B	0.5	6.3 ± 0.4
HD 206267	A	...	3.1 ± 0.2
...	C	2.4	3.5 ± 0.3
HD 193007	A	...	2.7 ± 0.2
...	B	0.5	2.9 ± 0.3
HD 210940	A	...	...
...	B	0.5	...
F. Optical pairs, ICDS Δm 's			
HD 1810	A	...	Peculiar profile
...	B	1.5	...
HD 52504	A	...	2.4 ± 0.3
...	B	0.9	...

* Notation used does not agree with ICDS. See finder charts for notation used here.

than G5 are shown since later types are not frequent enough in this study to make meaningful comparisons. Figure 5 shows the comparison between the photoelectric Δm 's obtained for this study and Δm 's in the Wallenquist general catalogue (1954). When ICDS magnitude differences were compared with the photoelectric Δm 's there was no distinct systematic trend, but the scatter was considerable (averages about $\pm 0^m.8$). Thus ICDS magnitude differences should only be used when other magnitudes are not available or cannot be obtained directly from observation. Ten such cases occur for pairs of very small separation in the present sample.

All Δm 's used in this study are listed in Table I and grouped according to source. From the listed probable errors it can be seen that the accuracy of the photoelectric Δm values is not as high as one might expect from recent work on photoelectric photometry of single stars. There are several reasons for this. No attempt was made to remove the contributions of contamination except by using a small diaphragm (10–15" diameter). As well as cutting down the contamination, the small diaphragms cut down the sky contribution. It was assumed that for the stars measured, the sky contributions would be small. In order to reduce the

observing time, the sky was checked only occasionally during the course of the night. In addition, the problems of using small diaphragms even for single stars are well known. Thus it was decided that if there was satisfactory agreement with the Wallenquist catalogue for stars in common, the accuracy obtained would be satisfactory for the purposes of this study. The mean departure between those obtained and the Wallenquist values was -0.04 ± 0.04 . In view of the uncertainties mentioned above, the agreement is considered to be satisfactory and any systematic effects that might be present are obscured by accidental and random errors.

The equivalent widths of $H\gamma$ obtained from Perkins plates are listed in Table I with their probable errors. The external accuracy of these is hard to estimate directly. Few 40 Å/mm plates were available for stars used by Petrie to establish his absolute magnitude calibration (1965). It was therefore necessary to find an *indirect* transfer into the Petrie system.

First, the equivalent widths for 30 MK standards were found from the Perkins plates. Stars in the Petrie lists which had assigned MK types were then grouped according to spectral type and luminosity. If group had the exact MK type of one of the standard stars, the Petrie equivalent widths were given weight 5.0 in the regression. A few stars had spectrograms taken at both Perkins and Victoria and were given weight 10.0. Several stars did not have corresponding Petrie stars of the same MK type. In these cases, mean equivalent widths were interpolated from smoothed curves relating Petrie equivalent widths and MK spectral types for a given luminosity class. These were given weight 2.0. The least-squares fit of 63 points between the Petrie system and equivalent widths obtained from Perkins plates was found to be a linear regression,

$$H\gamma(\text{Petrie}) = (0.77 \pm 0.03) H\gamma(\text{Meisel}) + (0.1 \pm 0.3)$$

with correlation coefficient of 0.94 ± 0.01 . This regression was used to determine absolute magnitude on the Petrie system. The difference in scale factors may be attributed to the fact that the Petrie profiles have had contributions due to nonhydrogenic elements removed (Petrie 1965) and those obtained from Perkins plates have not. The placement of the assumed continuum also may not have been the same in the two cases. The estimated error in M_v contributed by the transfer alone is $\sim \pm 0.3$.

Spectral classifications and rotational velocities obtained from Perkins plates are listed in Table II with Δm 's rounded to $0^m.1$. The Δm sources are indicated by capital letters in the notes. In certain individual cases, the MK classifications were difficult to estimate by visual inspection. Microdensitometer tracings were made of the entire spectrum from the plates in question and from plates of appropriate MK standard stars. The tabulated MK types were assigned after an independent classification by intercomparison of the

TABLE II. Assigned spectral classifications and rotational velocities.^a

	Star		MK type	$V \sin i$	Δm	Notes ^b
A. Physical pairs						
1	HD 3266	A	F5IV	<50		
		B	A9V	<50	0.8	W
2	α Cas	A	K2II	<50		
		B	K2IV-V	<50	6.7	W
3	HD 5005	A	O6	110 $\pm$ 20		e, n
		D	O8	220 $\pm$ 10	0.8	I
		C	O9.5V	70 $\pm$ 10	1.4	I
4	HD 9311	A	B5Iab:	<50		n
		B	B3IV: p	170 $\pm$ 20	2.6	W, i
		C	B3IV: ne	320 $\pm$ 30	3.6	I
5	ϵ Cas	A	A5p(Sr)	<60:		n
		C	G7V	<50	3.6	W
6	HD 15239	A	B4IV: sh	280 $\pm$ 10		n, i
		B	B6V	80 $\pm$ 10	1.4	M
	HD 15238		B3V: pnnsh	400 $\pm$ 30	-0.2	M, n
7	η Per	A	K3Ib	<50		n
		B	A0Vn	160 $\pm$ 10	4.7	W
8	HD 18473	A	A0p(Si)	60 $\pm$ 10		n
		B	A8V:	90 $\pm$ 10	1.6	M
9	HD 23439	A	G8V	<50		
		B	K3V	<50	0.6	W
10	HD 23675	A	B0.5II:	<50		n
		B	B3V	120 $\pm$ 10	2.7	W
11	IQ Per	A	B8Vp:	100:		n
		B	A0Vnp:	200 $\pm$ 20	1.6	M
12	HD 37330	A	B5V	150 $\pm$ 20		n
		B	B8V: (e)nn	300 $\pm$ 30	0.7	M
13	23 Ori	A	B1IVnn	350 $\pm$ 50		n
		B	B3Vnn	370 $\pm$ 10	2.1	W
14	ν Gem	A	B6IV: (e)p	250 $\pm$ 20		n, i
		B	A1V	150 $\pm$ 10	3.8	W
15	β Mon	A	B4IV: nne	350 $\pm$ 50		n, i
		B	B2V	130 $\pm$ 10	0.5	W
		C	B4IV: nne	370 $\pm$ 50	0.4	W, i
16	HD 45995	A	B3IV: nne	320 $\pm$ 20		n, i
		B	B8Ve:	220 $\pm$ 10	2.9	W, f
17	HD 46056	A	O8	190 $\pm$ 20		
		B	B2III	70:	1.4	I
18	S Mon	A	O7p	60:		n
		C	B8V	150 $\pm$ 20	4.2	M
		D	A6III	120:	5.7	M
19	S Mon	E ₂	A0V	140 $\pm$ 10	5.4	M
20	HD 50123	A	B6Vnpe	300:		n
		B	B9V:	170 $\pm$ 20	2.6	I, f
21	2 Com	A	F0IV: p::	<50		n
		B	A9V	<50:	1.4	W
22	h Cen	A	B4IV	<50:		n
		B	A0-A6-A7	70 $\pm$ 10	3.7	W
23	TW Dra	A	A9V	<50		n
		B	F7V	<50	1.0	I
24	HD 149632		A1Vp::	70 $\pm$ 20		n
	HD 149631		A2V	80:	0.1	M
25	HD 159481	A	F7V	<50		
		B	K3V:	<50	3.7	W
	HD 159482		F9Vp:	<50	0.7	I
26	μ Sgr	A	B8Iap	<50		n
		E	B2V	200 $\pm$ 10	5.5	M
27	d Ser	A	A0Vn+G0	300 $\pm$ 10, 80:		n
		B	F5V	<50	2.3	W, f
28	HD 178001	A	A2V+Ap	70:		n
		B	A0-A1-F6	80:	0.5	I
29	HD 179957-8	A	G3V	<50		
		B	G4V	<50	0.3	W
30	HD 184360	A	A3p(Sr)	<50		n
		B	F3V	<50	1.6	W
31	HD 187566	A	A0p(si)	70 $\pm$ 20		n
		C	B8pe	400:	2.1	M, b, f
32	HD 189783	A	F5V	<50		n
		B	F7V	<50	0.2	I
33	HD 190864	A	O6	120 $\pm$ 20		n
		B	B0.5Vp:	60 $\pm$ 20	0.5	I
34	HD 190918	A	O9.5Ia+WN5	130 $\pm$ 20, 320:		n
		D	B3V	280 $\pm$ 20	4.7	M
		F	B1Ia	50 $\pm$ 20	0.6	M
	HD 190919		B1Ib	70:		

TABLE II (*continued*)

Star		MK type	$V \sin i$	Δm	Notes ^b
A. Physical pairs					
35	HD 227634	A	B0II-III:	80 ± 10	n
		D	B1V	400 ± 20	M
	HD 190918	A	O9.5Ia+WN5	$130 \pm 20, 320:$	M
36	HD 191566-7	A	B0IVp	140 ± 30	n
		B	B1V	140 ± 30	W
37	α^1 Cap	A	G3Ib	≤ 50	
		B	K5III	≤ 50	M
38	HD 193007	A	B1II	120 ± 10	n
		B	B0IVp	50 ± 10	I
39	HD 193322	A	O8	130 ± 20	n
		C	B7Vp: (e)	380 ± 20	M
		D	B8Vp:	310 ± 20	M
40	β Cap	A	A0V: +G5III+	$120 \pm 30, 50 \pm 20$	
		B	A2V	100 ± 10	M
41	59 Cyg	A	B1IV: nne	420 ± 50	n, i
		B	A8III	100 ± 30	W, f
42	V 389 Cyg	A	B8Vp:	≤ 50	n
		B	A0V	80 ± 30	W
		C	K1III	≤ 50	M, d
43	HD 203374	A	B0.5IVnne	$400:$	n
		B	B2V+	180 ± 20	W
44	ϵ Cap	A	B5V: nmesh	370 ± 30	n
		B	K1III-IV:	≤ 50	M
45	HD 206267	A	O6P	130 ± 10	f
		D	B2V+	300 ± 20	W
		C	B1.5: IV	80 ± 10	I
46	HD 210940	A	M0III+	≤ 50	n, f
		B	K3III	≤ 50	BD, f
47	10 Lac	A	O9V	60 ± 20	n
		B	A6III, IV	150 ± 20	W
48	12 Lac	A	B2III	≤ 50	n
		B	A3V	90 ± 20	M
49	HD 215812	A	G2V	≤ 50	n
		B	G3V	≤ 50	W
50	AR Cas	A	B3V	160 ± 20	n
		C	A0Vn	230 ± 20	M
B. Optical pairs for all components studied					
0-1	HD 1810	A	B0IVp	200 ± 10	n
		B	A9V	150 ± 20	I
0-2	HD 16429	A	O9.5III	140 ± 10	
		B	F4V	≤ 50	M
0-3	HD 26906-7	A	B2III: nnep	290 ± 30	n, i
		B	A2-A2-A7	≤ 50	M
0-4	HD 48279	A	O8	60 ± 30	
		B	F2V	≤ 50	M
0-5	HD 52504	A	B1V: nnp	350 ± 30	n
		B	K0III-IVp	≤ 50	I
0-6	ζ Gem	A	G3Ib:	≤ 50	
		B	G1V	≤ 50	M
0-7	η CMa	A	B5Ia	≤ 50	
		B	A0V	≤ 50	M
0-8	σ Sco	A	B1III	≤ 50	n
		B	B8Vp	≤ 50	W, c, f
0-9	$\circ$ Dra	A	G9IIp	≤ 50	n
		B	K3IIIp	≤ 50	W
0-10	RY Cap	B	F0V	≤ 50	I
0-11	29 Cyg	A	A0p (λ Boo)	30 ± 20	
		B	K1III	≤ 50	M, f
0-12	U Cyg	B	G8IV	≤ 50	I
0-13	λ Cyg	A	B5V	130 ± 20	
		C	K2III-IV	≤ 50	W
0-14	69 Cyg	A	B0Ib	90 ± 10	
		B	F7V	≤ 50	W
0-15	HD 213470-1	A	A3Ia	≤ 50	n
		B	K0IIIp	≤ 50	W
0-16	EN Lac	A	B2III:	≤ 50	n
		C	F5V	≤ 50	M
C. Other optical components					
	S Mon	E ₁	B5V	280 ± 10	M
	HD 187566	B	K2V	≤ 50	M
	V389 Cyg	C	K1III	≤ 50	M

NOTES FOR TABLE II

- ^a Based on Perkins plates only.
^b E₁-E₂ form close optical pair.
^c Helium deficient star.
^d Companion may be composite.
^e Component optical.
^f H β peculiar.
^g Assigned spectral type and luminosity class confirmed by microdensitometer tracing comparisons.
^h ICDS Δm .
ⁱ Meisel Δm .
^j Wallenquist Δm .
^k Bonner Durchmusterung Δm .
^l Luminosity higher than class V indicated by 3995/4009, 3995/4026 ratios.
^m See additional notes for further description of spectrum.
- HD 5005**—The derived H γ equivalent widths are not consistent with assigned spectral types.
HD 9311—Absolute magnitudes of all three components are uncertain. Since the companion absolute magnitudes are completely unknown, the B5Iab absolute magnitude was used for calibration. The C companion may be as luminous as III, but no standards were available at this type, so IV was assigned. H β and H γ show emission. The λ 3995 (N II) line is peculiar (due to luminosity?). The B component had a number of suspected peculiarities, but an unidentified feature near 4460 [O II-Fe III(?)] is the most obvious.
HD 15089 (*u Cas*). The primary is an A5p strontium star with Cr and Eu present.
HD 15238-9—There are at least four other members of this system, only one of which is listed in the ICDS. In the brightest component, HD 15239, shell lines were noted down to H ϵ . No emission was visible. In HD 15238, all hydrogen lines down to the Balmer limit appear to have shell cores. O II at 4349 also appears narrow.
HD 17506 (*q Per*)—The primary is an MK standard. This pair has been studied using UVB photometry by Tolbert (1964).
HD 18473—The primary is an A0p silicon star with 4077 (Cr II-Sr II) faint, Ca II abnormally faint, and Mg II 4481 faint. Balmer lines fairly weak. Plate of companion is fogged and has some flaws, but microphotometry comparisons confirm the assigned type.
HD 23675—According to the Morgan-Code-Whitford catalogue (1955), the primary is of type B0.5 III, but 4089 (Si IV) is much too strong compared to 4072 (O II), 4120 (Si IV, He I). Hence luminosity class II was assigned here.
IQ Per—The H γ equivalent width indicates primary luminosity is higher than class V. The primary is an eclipsing variable, but only single lines are visible on the Perkins plates, although the Balmer lines have broad wings and the Ca II lines are diffuse.
HD 37330—H δ of secondary may be in emission.
HD 35149 (23 Ori)—System previously studied by Slettebak (1963).
HD 45542 (*v Gem*)—Only H β shows emission (weak). The other Balmer lines down to H ϵ have deep cores probably due to a thin shell. Several weak lines around H δ are abnormally faint compared to ratios in the standards.
HD 45725 (*\beta Mon*)—The A component of this system has been extensively studied by McLaughlin (1961, 1951). This system is listed in the Merrill and Burwell catalogues (1933, 1943, 1949) with two components given as Be, but the Yale Bright Star Catalogue lists all as Be. The Cowleys (1966) have pointed out that the B component did not have emission on plates taken by them. The placement of the components makes it very difficult to obtain uncontaminated spectra. On Perkins plates taken in 1965, the B component is comparatively slowly rotating with an estimated $V \sin i$ near 130 km/sec. No emission was detected. It is interesting to note that the faintest component is the most rapidly rotating. The A and C components were assigned the same spectral type and luminosity class although there are subtle differences between them other than shell and emission features. In the A component, H β shows single broad emission; H γ shows narrow double emission; H δ shows faint single emission. The Balmer lines become increasingly narrow shortward of H γ . In the component, H δ shows double emission with the blue line component stronger than the red; H γ shows single emission; H ϵ shows only a faint shell line. Emission is visible at 4650 (Fe II), 4580 (Fe II), and on the blue edge of 4387 (Fe II).
HD 45995—The spectrogram of the secondary was fogged, unfortunately. However, an intercomparison of microphotometric tracings of the unknown and standard stars verified the assigned type. H β appears to be in emission on the tracing so B8V: (e) might be more appropriate. The primary shows H β in double emission and H γ with faint single emission.
HD 47839 (*S Mon*)—The E₁ component is the brighter component of a close pair which is Walker No. 179 in NGC 2264. It appears to be a B5V star and therefore is considered optical. The C component has a weak H β line suggestive of emission. Other Balmer lines are normal. All companions earlier than A0 show Ca II interstellar lines, but A shows only very weak Ca II lines. Yet there is little doubt that the stars, except E₁, are physically connected. Although Morgan, Code, and Whitford (1955) give O6e for the A component, no emission is present on the Perkins plate. On the basis of the strength of the He I-He II lines, an O7 classification seems appropriate.
HD 50123—This star is not listed in a recent survey of southern Be stars (Jaschek, Jaschek, and Kuciewicz 1964), but is given by Merrill and Burwell (1933). Because of the great southern declination of this object, the spectrogram obtained of the companion was very faint. A microphotometer tracing verifies a type of B9V:, with Mg II faint compared to Ca II. The excellent Perkins plates of the primary taken by Slettebak show complicated shell and emission structure; H β shows emission; H γ shows an absorption core. There are numerous lines that are not present in any of the available standards 4530 and 4650 and near H γ . Also Mg II 4481=He I 4471; emission was noted at 4950 (Fe II), 4923 (Fe II), 4894 (Fe II), 4887 (Fe II), 4520 (Fe II), 4351 (Fe II); the 4481 (Mg II) line has emission on the red edge. The 4236 line is flanked by two absorption cores.
HD 104827—Enhanced 4172 (Fe I) relative to 4226 (Ca I) and numerous lines between 4270 and 4330 indicate luminosity higher than class V, but no standards were available at class III, hence class IV was selected.
HD 120955 (*h Cen*)—The primary is a spectroscopic binary, although only single lines were noted. The companion, however, is an Am star (A0-A6-A7) of 63 Tauri type. If a coeval hypothesis is assumed for the pair, then the Am star is still contracting toward the main sequence.
TW Dra—This eclipsing binary was previously studied by Roman (1950),

who finds the secondary of the eclipsing system to be subluminoous. On the Perkins plates of the visual system, no trace of the subluminoous companion could be found, although one plate was taken at the end of total eclipse.
HD 149631-2—The brighter component is a spectroscopic binary. The mean type is A1V, but the double Ca II and Mg II lines indicate unequal component brightness.
HD 166937 (*\mu Sgr*)—This star is a spectroscopic binary, but only a single set of lines was available and a type of B8Iap was assigned to the primary. The complete absence of 4009 (He I) and the very weak (He I) are the most obvious peculiarities at 40 Å/mm, indicating perhaps that the star is of class B8Ia+. H β may be in emission, but the focus was poor in that region.
d Ser (59 Ser)—The primary is a known spectroscopic binary and variable star, but it has not been shown to be eclipsing. The visual companion is only 4' away so contamination is very possible. The system was previously investigated by Tilley (1943), who assigned the type A0 to the faint companion. A third spectroscopic component was postulated to explain short-period variations in the K-line velocity. Since it is not clear to which member of the spectroscopic binary the third component belongs, the configuration of the system cannot be specified. It is possible that this third member is responsible for the K-line anomaly and the light variations, but more observations are necessary. The Perkins plate shows a composite spectrum of A0V plus G0. For the visual companion, the Perkins plate shows an F5V star under the dominating A0V spectrum. Since this A0 spectrum matches that of the primary, contamination is certainly responsible. The underlying spectrum, however, is too early for G0 and so is considered real and not due to contamination.
HD 178001—The primary of this interesting system is listed in the Pennsylvania eclipsing binary catalogue (Koch, Sobieski, and Wood 1963) but it does not have an official IAU designation. The visual system consists of an A2p (V) and an A0-A1-F6 metallic line star. For calibration purposes the primary was treated as an ordinary A2V star. From its spectrum, however, it is evident that it is peculiar. H β is weak and appears to be asymmetrical or double; H γ appears asymmetrical with the wings of equal extent, but a displaced core. H δ may be double. The K line also is double. A group of lines between 4170 and 4180 for which no plausible identifications could be made are more prominent than any other features between H γ and H δ . The Fe II, Fe II-Ti II (4172) doublet is particularly strong. Since the Am visual companion is probably physical, this pair merits considerable future study.
HD 184360—High-velocity stars.
HD 187566—The B component is considered optical. The C component is very peculiar. No features other than Balmer lines are definitely present. The 4881 (Mg II) line is so faint and broad that even half-width measurements could not be applied with certainty. The microphotometer shows H β with emission. Ca II and the Balmer lines indicate B8V, but He I is totally absent. The dish-shaped Balmer and Ca II contours indicate rapid rotation possibly in excess of 500 km/sec. If the line broadening is indeed due to rotation, this star may have one of the largest $V \sin i$ values yet found.
HD 189783—The brighter component is a close visual binary.
HD 190864—The fainter component of the system may be peculiar since some features suggested higher luminosity than class V, but 3995 (N II) was absent so V was chosen. The O II line at 4416 was particularly anomalous, being too strong for the assigned type.
HD 190918-9—The bright components belonging to the P Cygni association have been studied by Roman (1951).
HD 190918 A is a spectroscopic binary. It consists of a Wolf-Rayet star and an O9 supergiant. Kuhl (1966) lists the O star as an O9.5III star. The Perkins plate indicates a classification of O9.5Ia plus a WN5.5, which agrees well with an independent classification by Hiltner and Schild (1966). The plate shows faint emissions flanking H γ ; emission redward of H δ ; broad emissions (± 12 Å) flanking 4600 (N II), 4615 (N II), and blueward of 4650 (C III); extremely broad emission features flanking a faint line 4686 (He II). It is not possible to determine which star is fainter, but a Δm less than one magnitude seems indicated. The F component is subluminoous for type B1Ia compared to HD 190919 which is B1Ib. The luminosity inversion between Ia and Ib postulated by Weaver and Ebert (1964) is not confirmed, however.
HD 227634—The brighter component was classified as B0.5III by Morgan, Code and Whitford (1955), but the Perkins plate indicated B0II, although B0II-III is possible.
HD 191566—In the primary, H γ and He I 4471 are double. The O II lines around H γ are faint, but visible. The red edge of the Balmer lines, particularly H β and H γ are sharp. All Balmer lines show shading and asymmetry on the blue edges.
HD 193007—The primary is not sharp-lined at 40 Å/mm. The companion is peculiar, although if it is treated as a normal star, the calibration is not inconsistent. In particular, a line at 4550 (Fe II) which appears to be luminosity sensitive in the standards is much too strong relative to 4552 (Si II). On the other hand, O II 4318 is too faint for the assigned type.
HD 193322—The rotational velocities of the two fainter components are large (380 and 310 km/sec). Intercomparison of microphotometric tracings of standards star spectrograms with tracings of these stars confirmed the assigned MK types, but certain peculiarities were evident. In the D component, the 4471-4481 (He I-Mg II) lines are too weak and the silicon lines are too strong compared to the stellar Ca II lines. In the C component, the helium lines are weak and silicon lines are too strong. It is possible that both stars are helium and magnesium deficient, similar to the companion to HD 187566.
HD 200120 (59 Cyg)—The primary of this system is a Be star that is variable in both spectrum and light. Its rotational velocity is very high. H β shows double emission; H γ has single emission; H δ single emission asymmetrically placed with respect to the core, He shows a single faint emission.
V 389 Cyg—The B component is considered optical. The primary is a known spectroscopic binary and variable star, but eclipses have not been established. The spectrum resembles IQ Per with extensive wings on the Balmer lines. The stellar Ca II lines indicate type B8V, but the Mg II 4481 is much too strong for B8. Only a single set of lines was present. The luminosity calibration and H γ equivalent widths indicate luminosity brighter than V. Hence the notation p: was applied to the classification.
HD 203374—The primary has H β with single emission; H γ with double emission; and H δ , He, H ϵ with single emission. O II around H γ is faint but definitely in emission. Also Fe II emissions at 4556 and 4577 are plain.

HD 205637 (ϵ Cap)—Luminosity criteria for the companion conflict. The assigned type of K1III–IV is considered a compromise. Some of the line ratios indicate luminosity higher than III, but the plate is too faint to confirm this with a sufficient number of line pairs.

50°2485–8—These stars share common proper motion, although the separation is wide, 1 min of arc.

HD 214680 (10 Lac)—The primary is an MK standard. Although the fainter companion has well-developed Balmer lines, other criteria indicate a luminosity brighter than V, hence III, IV was assigned.

HD 214993 (12 Lac)—This star is a β CMA star and MK standard. It is virtually identical with σ Sco.

AR Cas—The primary is an eclipsing binary, but only a single set of lines was noted. The C component, if not optical, is subluminal.

HD 1810—The brighter component shows line asymmetry and strong interstellar Ca II.

HD 26906—The brighter star shows H β with double emission; H γ is sharp, but with no emission; emission occurs on the red edges of 4144 (He I), 4387 (He I). Luminosity of III is definitely indicated. The fainter optical component is an A3m (A2–A2–A7) with 4130 (Si II) absent.

HD 147165 (σ Sco)—The primary is a β CMA variable and MK standard. Although the secondary is considered optical, it is of considerable interest.

The mean type B6V was assigned, but a number of peculiarities are noted. Some of the anomalies might be explained if B5V plus B8V is assumed, but a number of lines between 4840–4860 are found in either of the assumed types.

σ Dra—The primary is a spectroscopic binary. Low relative radial velocities are coincidental.

HD 213470—The CN break of the fainter component is anomalous.

EN Lac—The primary is a β CMA variable.

HD 52504—The primary does not show emission, in spite of its high rotation rate. The most obvious peculiarity is a strong unidentified line near the interstellar K line.

tracings. Where this procedure was necessary, it is indicated in the notes.

The luminosity classifications of the MK system of the Be stars are very uncertain. In the stars studied here, the line ratios 3995 (N II)/4009 (He I) and 3995 (N II)/4026 (He I) were the only ones that indicated luminosity differences, but these were very subtle. Therefore, the assignment of class IV: or III: may be marginal and must be treated with caution. Except in the star HD 26906–7A, no standard luminosity ratios other than 3995/4009 indicated luminosity higher than class V. However, at 40 Å/mm a spectral type indicator, the 4009/4026 ratio, itself appears to be luminosity sensitive between classes V and III.

As shown in Fig. 3, the correlation of $V \sin i$ with values obtained from higher-dispersion spectrograms is very poor between 100 km/sec and the resolution limit of 40 km/sec. This is not considered serious for statistical purposes since the appropriate corrections for observational errors can be applied in a straightforward manner. Every tabulated $V \sin i$ value was obtained by taking a weighted average of five *independent* visual estimates and the mean obtained from half-width measurements of selected stellar lines. Mean calibrations between the half-intensity width for a specific line and rotational velocity were obtained from microphotometer tracings of standard star spectrograms. Then for each double star component, a mean rotational velocity was derived from several different lines on each spectrogram. Although a number of the probable errors of the mean $V \sin i$ for each star are less than ± 20 km/sec, external errors, even in the most favorable cases, may exceed ± 30 km/sec.

Detailed descriptions of individual spectrograms are given in additional notes to Table II. Three Be stars studied here (HD 26906–7A, HD 203374 and 59 Cyg) were included in a recent study by Crampton (1967).

III. RESULTS AND DISCUSSION

A. Calibration of Absolute Magnitudes

Both Blaauw (1963) and Keenan (1963) have given revised absolute-magnitude calibrations for the MK system of spectral classification. Petrie (1965) has calibrated the equivalent width of H γ with absolute magnitude. Intercomparison of different calibrations shows some discrepancies. Blaauw has shown that cluster stars and field stars of class V give somewhat different calibrations. Petrie was not able to satisfactorily reconcile his results with those of Blaauw, although both used cluster stars in their calibrations.

With the Δm 's from Table II and the mean absolute magnitudes given by Keenan (1963) [and Blaauw (1963) for O-type stars] corresponding to the MK types of the companions assumed to have "normal" spectra, the absolute magnitudes of the other components in 43 systems were evaluated. The results are given in Table III. In certain instances, both companions were ill-suited for use as calibrators. Selection of the star to be calibrated was therefore made somewhat arbitrarily. These are indicated in the table with a semicolon. For comparison with the double-star calibration, the Blaauw or Keenan (M_v) most nearly corresponding to the individual MK type is also given. Possible luminosity significance of suffixes in the assigned MK type were ignored in the choice of the appropriate (M_v).

Absolute magnitudes obtained from equivalent widths of H γ and subsequently transferred to the Petrie system are also included in Table III.

It is of interest to intercompare the present calibration using Δm 's and spectral types of companions, $M_v(\Delta m)$, or H γ equivalent widths on the Petrie system, $M_v(H\gamma)$, with previous results of Keenan (1963) [or Blaauw (1963) for calibration O-type stars]. Table IV gives the mean differences of several groups of stars. In comparisons involving the $M_v(H\gamma)$, all stars (including companions used in the Δm calibration) which appeared to have normal profiles on the Perkins plates have been included. With the exception of HD 9311 B [$M_v(\Delta m) = -3.7$ and $M_v(H\gamma) = -2.3$], stars between type O6 and B3 with "p" designations and *normal* hydrogen profiles do not appear to give results significantly different from stars of the same type but without the "p". The effects of composite spectra are quite drastic even when the profiles do not show the duplicity. Thus undetected multiplicity can lead to serious errors in $M_v(H\gamma)$. Although the number of objects in each grouping is relatively small, the results are considered significant. In particular, it should be noted that:

(1) Relative to class V stars, Be field stars are over-luminous by 1 mag, in agreement with previous results (Schild 1965, 1966; Schmidt-Kaler 1964).

(2) Relative to the Keenan calibration for giants and supergiants, the double-star calibration indicates

TABLE III. Absolute-magnitude calibration.

Star		MK type	M_V using Δm 's	Mean M_V (Keenan or Blaauw)	M_V using H_γ Eq. W. (Petrie calibration)
HD 5005	A	O6	-5.9	-5.5	-2.8 ^a
HD 5005	D	O8	-5.1	-5.2	-4.5
HD 46056	A	O8	-5.0	-5.2	-5.0
S Mon	A	O7p	-4.1	-5.3	-3.7
			-5.1		
			-4.8		
HD 193322	A ^o	O8	-5.8:	-5.2	-4.6
			-5.6:		
HD 306267	A	O6p	-4.9	-5.5	-4.5
			-5.9		
10 Lac	A ^o	O9V	-4.5:	-4.7	-5.2
HD 15239	A	B4IV: sh	-2.5	-1.9	-5.8 ^b
HD 15238		B3V: pnnsh	-2.8	-1.7	
HD 37330	B	B8V: (e)nn	-0.4	+0.1	
ν Gem	A	B6IV: (e)p	-2.6	-1.4	-3.5 ^a
β Mon	A	B4IV: nne	-3.0	-1.9	
β Mon	C	B4V: nne	-2.6	-1.4	
HD 203374	A	B0.5IVnne	-5.8	-4.6	
ϵ Cap	A	B5V: nnesh	-2.3	-1.0	
HD 50123	A	B6Vnpe	-2.6	-0.7	-3.0 ^b
HD 45995	A	B3IV: nne	-3.1	-2.5	-5.7 ^b
HD 9311	C ^o	B3IVne	-2.9:	-2.5	-5.6 ^b
59 Cyg	A ^o	B1V: nne	-4.3:	-3.6	
HD 190864	B	B0.5Vp	-4.4	-4.0	-5.0
HD 191566	A	B0IVp	-4.4	-4.8	-4.3
HD 9311	B ^o	B3IV: p	-3.7:	-2.5	-2.3
HD 18473	A ^o	A0p(Si)	+0.8:		+3.7
HD 184360	A	A3p(Sr)	+1.6		+1.1
2 Com	A	F0IVp:	+1.6		
h Cen	B	A0-A6-A7	+1.7		-2.3
ι Cas	A	A5p(Sr)	-0.4		
HD 23675	A	B0.5II:	-4.4	-5.2	-5.5
HD 227634	A	B0II-III:	-4.5	-5.2	-5.5
HD 193007	A	B1II	-5.1	-5.0	-5.6
12 Lac	A	B2III	-3.7	-3.6	-5.2
HD 190918	A	{ O9.5Ia	{ -6.3		
		{ +	{ -7.6	-8.1:	-6.4
		{ WN5	{ -7.0		
μ Sgr	A	B8Iap	-7.3	-8.2	-7.3
AR Cas	A	B3V	-1.6	-1.7	-3.1
23 Ori	A	B1IVnn	-3.8	-4.1	-4.5
α^1 Cap	A	G3Ib	-5.5	-4.5	
α Cas	A	K2II	-2.2	-2.0	
η Per	A	K3Ib	-4.1	-4.4	
HD 210940	A	M0III+	-0.7	-0.4	
β Cap	A	A0V+G5	-1.5	+0.6(A0)	-0.3
IQ Per	A	B8Vp:	-1.0	+0.1	-4.2
V 389 Cyg	A	B8Vp:	-1.7	+0.1	+1.0
d Ser	A	A0V+G0	+1.1	+0.6(A0)	-3.5
Hydrogen-line data					
Star		M_V (Petrie calibration)	Star		M_V (Petrie calibration)
HD 5005	C	-4.2	HD 227634	D	-4.5
HD 9311	A	-5.8	HD 191566-7	B	-4.3
HD 15239	B	-1.8	HD 193007	C	-5.0
η Per	B	+1.6	HD 193322	C	-3.1
HD 23655	B	-5.5		D	-4.0
IQ Per	B	-4.2	V 389 Cyg	B	+1.0
HD 37330	A	-3.5	HD 203374	B	-3.3
23 Ori	B	-4.2	HD 206267	D	-4.9
ν Gem	B	+1.7		C	-4.3
β Mon	B	-3.1	12 Lac	B	+2.1
HD 45995	B	-5.2	AR Cas	C	+1.7
HD 46056	B	-3.1	HD 16429	A	-5.5
S Mon	C	+1.2	HD 26906-7	B	-1.2
S Mon	E ₂	-1.5	HD 48279	A	-5.5
h Cen	A	-2.9	HD 52504	A	-5.6
HD 149631		-2.3	η CMa	A	-6.2
μ Sgr	D	-4.1		B	+1.7
HD 178001	A	+2.0	σ Sco	A	-4.5
	B	+1.9		B	-4.4
HD 187566	C	+2.1	29 Cyg	A	+1.2
HD 190864	A	-5.0	λ Cyg	A	-2.8
HD 190918	D	-4.5	69 Cyg	A	-5.5
	F	-4.5	HD 213470-1	A	-8.5
HD 190919		-5.0	EN Lac	A	-5.3

^a Absorption cores on spectrogram.^b Emission or shell present on spectrogram.^c Mean absolute magnitude for calibrating companion is not well established. Determination of M_V is therefore of lower weight.

an average underluminosity of $+0^m.6$, while the Petrie calibration is in good agreement.

(3) Relative to the Blaauw calibration for O-type stars, the double star calibration shows good agreement

while the Petrie calibration is underluminous by nearly one full magnitude.

(4) Relative to the Keenan calibration for non-emission B-type stars of classes III, IV, or V, the Petrie calibration applied to field stars is overluminous by nearly $0^m.8$.

The difficulties expressed in (3) can be explained if it is assumed that the spectral-type correction for O-type stars suggested by Petrie is not necessary for Perkins plates and leads to inconsistent results if applied.

The conclusions expressed in (2) and (4) are more difficult to explain. The earlier results obtained by Slettebak (1963) on double stars indicate that the Keenan calibration for the early B-type main-sequence stars may be somewhat underluminous compared to class V stars of later spectral types. Since companions in the B0-B5V range were used for the majority of the Δm calibrations of supergiants, an assumption of underluminosity averaging $\sim 0^m.5$ between B1V and B5V is consistent with both (2) and (4). By implication, the cluster main-sequence calibrations of Petrie and Blaauw would also be somewhat underluminous for the range of B1V to B5V relative to field stars of the same type. This might account for some of the difficulties mentioned in (4). It should be noted that the MK recalibration given by Weaver and Ebert (1964) does not resolve these problems.

Slettebak's previous results and the difficulties mentioned above, suggest that the main sequence for field stars later than spectral type B0 is overluminous relative to the cluster calibration by as much as $0^m.5$. This conclusion is independent of any revision of the Hyades distance modulus and its consequences. More work on early-type visual binaries is needed to obtain estimates of the calibration differences.

B. Rotational Velocities of Early-Type Stars

The rotational velocities given in Table II have been merged with those of Slettebak (1963, 1966a, 1966b) and those listed by Boyarchuk and Kopylov (1964). The combined results have been grouped to obtain $V \sin i$ means for double stars, single stars, and double and single stars together. The means and standard deviations approximately corrected for observational error and rounded to the 10 km/sec are listed in Table V. In agreement with previous results (Slettebak 1963), it is concluded that there are no significant differences between the means for double stars and those found for single stars. Although the double-star sample is small, this result appears to apply to Be stars as well. If all stars, whether single or double, are combined, a total sample of nearly 500 stars is obtained, with 15 stars forming the smallest group.

The moments of the rotational velocity distribution from the formulas given by Chandrasekhar and

TABLE IV.

Group	Luminosity class of comparison object	Mean deviations of M_v (Meisel-Keenan) using double-star calibration	No. of stars	Mean deviation of M_v (Meisel-Keenan) using $H\gamma$ equivalent widths and Petrie calibration	No. of stars
Be stars	V	-1.0 ± 0.2 (m.d.)	10	...	...
Early-type giants and supergiants	Same as assigned MK class	$+0.6 \pm 0.2$ (m.d.)	6	$+0.0 \pm 0.6$ (m.d.)	6
O6-O9	V	$+0.0 \pm 0.2$ (m.d.)	7	$+0.9 \pm 0.5$ (m.d.)	7
Nonemission A and B stars	Same as assigned MK class	...		-0.8 ± 0.5 (m.d.)	35
		Mean deviation Δm calibration minus $H\gamma$ calibration	No. of stars		
Group					
O6-O8		-1.0 ± 0.2 (m.d.)	4		
B0-B2					
Classes II and III		$+1.1 \pm 0.2$ (m.d.)	4		

TABLE V. Mean rotational velocities for all available stars with MK types.

Group	Double stars			Single stars			All stars		
	$\langle V \sin i \rangle$ km/sec	σ km/sec	n	$\langle V \sin i \rangle$ km/sec	σ km/sec	n	$\langle V \sin i \rangle$ km/sec	σ km/sec	n
B1-3 V	200	70	20	150	60	54	180	60	74
B5-7 V	160	60	17	210	70	30	190	60	47
B8-2 V	170	60	53	150	60	70	160	60	123
A3-7 V	150	50	17	140	60	32	140	60	49
B1-3 III, IV	120	50	9	100	40	17	110	50	26
B5-7 III, IV	130	50	3	130	50	28	130	50	31
B8-2 III, IV	60	50	3	80	40	20	80	50	23
A3-7 III, IV	160	50	10	170	50	20	170	50	30
B1-B4e	350	80	7	280	70	41	290	70	48
B5-B7e	320	70	4	300	60	29	300	70	33
B8-A0e	310	60	4	260	60	11	270	60	15

Münch (1950):

$$\langle V \rangle = \frac{4}{\pi} \langle V \sin i \rangle,$$

$$\sigma^2 \langle V \rangle = 1.5 \sigma^2 \langle V \sin i \rangle - \left(\frac{16}{\pi^2} - \frac{3}{2} \right) (\langle V \sin i \rangle)^2.$$

The results for the eleven groups considered here are given in Table VI. Third moments were not calculated. In the case of the emission-line stars in the B1-B7 spectral range, correction of $\sigma^2 \langle V \sin i \rangle$ for observational error and rounding produces a small *negative* variance for $\langle V \rangle$. Therefore, the values given for these stars are upper limits estimated from the rounding error of the $V \sin i$ means and variances. The ratio of the mean to $\sqrt{2}$ times the standard deviation for each group as determined empirically is also given. Roughly, this quantity indicates, in multiples of the variance, how far the zero-velocity point is from the mean. Statistical interpretations of this quantity in terms of specific distribution functions can be found in the literature and are not discussed here (see, for example, Chandrasekhar and Münch 1950).

Excluding the Be stars which obviously do not have the same statistical characteristics as the other stars, an average value for the ratio of the mean to $\sqrt{2}$ times the variance is 3 ± 1 . For the Be stars, the ratio is greater than 12. It is concluded that observational errors tend to mask the true variance for Be stars. In agreement with previous results these stars do form a rather narrowly bounded velocity group although the

TABLE VI. Mean equatorial velocities for early-type stars.

Group	$\langle V \rangle$	$\sigma \langle V \rangle$	Ratio of $\langle V \rangle$ to $\sqrt{2} \sigma \langle V \rangle$
B1-3 V	230 km/sec	± 50 km/sec	3.2
B5-7 V	240	± 40	4.2
B8-2 V	200	± 50	2.8
A3-7 V	180	± 60	2.1
B1-3 III, IV	140	± 50	2.0
B5-7 III, IV	170	± 20	6.0
B8-2 III, IV	100	± 60	1.1
A3-7 III, IV	220	± 30	5.4
B1-B4e	370	$< (\pm 30)$	> 12
B5-B7e	380	$< (\pm 30)$	> 12
B8-A0e	340	$< (\pm 30)$	> 11

mean is considerably lower than the theoretical breakup velocity (Slettebak 1966). At the present time, it is not clear what causes this discrepancy. Suggested mechanisms include differential rotation and neglect of gravity darkening. It is felt, however, that the quantitative understanding of these proposed mechanisms is too poor to attempt any correction of the moments obtained. Such corrections would, of course, have to be applied if mean *angular momentum* is to be inferred from the observations.

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