The Astrophysical Journal, 393:666–673, 1992 July 10

SPECTROSCOPIC BINARIES IN THE α PERSEI CLUSTER

Nidia Morrell[1] and Helmut A. Abt
Kitt Peak National Observatory, National Optical Astronomy Observatories,[2] Box 26732, Tucson, AZ 85726
Received 1991 August 20; accepted 1992 January 21

ABSTRACT

We have obtained an average of 16 radial velocity measures for each of the 28 brightest (B3–A2) cluster members and found four binaries. The resulting binary frequency of 14% is, like the previous 20% for the B6–A1 stars in the Pleiades, unusually low compared with a typical 30% for early-type field stars or with 30% or more in other open clusters. These two clusters are the only known ones with unusually high mean rotational velocities. We suspect that the mean rotational velocities are high either because these clusters lack short-period binaries ($P < 20^d$; none in α Persei, only three in the Pleiades) or are not old enough for synchronization of rotational and orbital velocities to have occurred.

The four α Persei binaries are all relatively wide ones ($P > 20^d$) and with small mass ratios (0.1–0.5). The same results apply to the young Orion Nebula cluster. We can explain these results in terms of the formation of binaries by capture in that during the first free-fall time, capture will produce wide binaries with small mass ratios, as in the Orion Nebula and α Persei clusters, but repeated captures and disruptions will produce more closely spaced binaries with many mass ratios near 1.0, as in IC 4665.

Subject headings: binaries: spectroscopic — open clusters and associations: individual (α Persei) — stars: statistics

1. INTRODUCTION

Turbulence, which is usually in the range of 1–20 km s^{-1} (e.g., Dickman 1985) in interstellar clouds tends to impart high rotational velocities to the early-type stars that form from the clouds. One effective way to reduce those rotational velocities is by tidal braking in short-period binaries. Of course, that mechanism requires time to occur (Levato 1976) and depends on the stellar masses, ages, and binary separations. Therefore clusters with large mean rotational velocities may, or may not, have few binaries. This was the starting point for a series of projects to explore binary frequencies in open clusters. As we will see, the results and interpretation developed far beyond that initial idea.

Centered on the bright F5 Ib star α Persei is a set of at least 100 stars that share its proper motion. The cluster was discovered independently by Boss (1910), Eddington (1910), and Kapteyn (1910). It has a distance of about 165 pc (Crawford & Barnes 1974) and a diameter of at least 3° or 9 pc. The earliest main-sequence member is a B3 V star (Roman & Morgan 1950) implying an age of about 10^7 yr; Prosser (1992) obtains 8×10^7 yr from a comparison of new infrared photometry and the current evolutionary models by VandenBerg. The cluster has identifications by Heckman & Lübeck (1958); proper motions by Heckmann, Dieckvoss, & Kox (1956); *UBV* photometry by Harris (1956); four-color and Hβ photometry by Crawford & Barnes (1974) and Trullols et al. (1989); spectral types by Morgan, Hiltner, & Garrison (1971) and Abt (1978); rotational velocities by Kraft (1967); and radial velocities by Petrie & Heard (1969).

One interesting characteristic of this cluster is its high mean stellar rotational velocity for its B stars. This cluster plus the Pleiades seem to have the highest mean rotational velocities for any open clusters studied (Abt & Hunter 1962). The second interesting characteristic is its apparent paucity of spectroscopic binaries: Heard & Petrie (1967) found only two definite spectroscopic binaries out of 64 stars measured, compared with a control sample of field stars observed similarly that yielded 25% binaries.[3]

The Petrie & Heard (1969) study was incomplete in that it included an average of only 10 measures per star for the B3–A1 members, and often only four or five, and those were obtained with moderate dispersions of 30–66 Å mm^{-1}. No orbital elements were obtained.

We decided to complete the Heard-Petrie study of the 28 brightest members, using the advantages of a higher disperion, a CCD detector with spectra analyzed impartially with a cross-correlation analysis, and more observations.

This is a part of a series of studies of binary frequencies in open clusters of various ages and mean rotational velocities. Originally we contemplated a comparison with the cluster IC 4665 (Morrell & Abt 1991) of similar age but normal rotational velocities, but our discovery rate of binaries is so low in both clusters that most conclusions are subject to the reservation of small-number statistics.

2. METHOD AND RADIAL VELOCITIES

We used the Kitt Peak 1 m coudé feed telescope and spectrograph with a camera (No. 5) and grating (KPC7A) combination that yielded a dispersion of 15 Å mm^{-1} and resolution of 0.22 Å or 15 km s^{-1} per pixel. We employed a Texas Instruments 800 × 800 CCD, so that Hγ, λ4471 He I, and λ4481 Mg II were included in each frame. For the broader lined spectra, we measured only the former line, and for the moderate- and narrow-lined spectra we measured the latter two lines. Because of the broad lines it was necessary to use an

[1] Member of the Consejo National de Investigaciones Cientificas y Técnicas (CONICET) of the Argentine Republic; CONICET Fellow at KPNO, on leave from the Facultad de Ciencias Astronomicas y Geofisicas de la Universidad Nacional de La Plata, Argentina, which is her current address.

[2] Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[3] Their later paper (Heard & Petrie 1969) gave five variables at the 1% confidence level out of 77 stars.

TABLE 1

OBSERVATIONS OF EARLY-TYPE RADIAL VELOCITY STANDARDS

HR	HD	MK TYPE	n	ρ (km s^{-1})	σ (km s^{-1})	FEKEL ρ (km s^{-1})	FEKEL n
153.........	3360	B2 IV	59	+2.2	±1.7	...	1
811.........	17081	B7 V	61	+16.6 var	±2.4	+15.4 var	12
1389.........	27962	A2 IV	17	+40.8	±1.2	+38.8	32
1810.........	35708	B2.5 IV	25	+17.7	±2.2	+18.4	5
2010.........	38899	B9 IV	30	+19.8	±2.1	+20.9	6
6031.........	145570	A2 V	21	−4.9	±1.3	−7.6	7
6035.........	145647	A0 V	19	−12.5	±1.6	−13.4	4
6092.........	147394	B5 IV	15	−16.4 SB2	±3.4	−17.8	11
6787.........	166182	B2 V	39	−15.7	±1.9	−14.3	6
7287.........	179761	B8 III	27	−5.7	±1.0	−4.9	7
7426.........	184171	B3 IV	34	−20.3	±1.6	...	2
7512.........	186568	B8 III	32	−8.0	±1.4	...	2
8641.........	214994	A1 IV	5	+4.6	±0.5	+8.4	26

S/N = 100–300, which is unusually high for radial velocity measures; for late-type stars that have many narrow lines in a CCD frame, an S/N as low as 5 gives good results (Latham 1985). The cross-correlation analysis was done in original data pixel space. Because the spectral range of the CCD chip was only 150 Å, the effect of nonlinearity of the dispersion amounts to, at most, ± 0.02 km s^{-1} at the ends of this range for velocities as great as ± 100 km s^{-1}.

We observed various radial velocity standards to match the spectral types of the cluster stars. They were reduced relative to a thorium-argon comparison spectrum. The selection was taken from the preliminary list of standards by Fekel (1985). In Table 1 we list the standards by HR and HD numbers, types from the Bright Star Catalogue (Hoffleit & Jaschek 1982), number of measures, mean radial velocity (ρ), and dispersion (σ) per measure. We used these mean velocities in reducing our cluster-star velocities. From the dispersions we see that most of the stars have constant velocities during the two years of our observing, but not HR 811 and HR 6092, which were dropped as possible standards.

A comparison is given in Table 1 with preliminary results by F. C. Fekel (private communication). A weighted mean difference indicates that our measures are 0.6 km s^{-1} higher than his. A comparison with eight stars in common with Morse, Mathieu, & Levine (1991) shows our mean to be 1.5 km s^{-1} higher than theirs, but that is mostly due to a discrepancy for HR 153.

The coudé radial velocities of 26 cluster members and four nonmembers are listed in Table 2, which gives for each star the heliocentric Julian Date and heliocentric radial velocities (ρ) uncorrected for any differences in velocity system. The measures for four nearby stars which are nonmembers, according to Roman & Morgan (1950), are also included. Because we cross-correlated the profiles of all one to three lines together, no internal error estimates were derived.

Our observing list included all the cluster members brighter than $B = 8.0$ or $M_V = 1.5$ mag, except that HD 21375 and 21481 were overlooked. The list of stars is in Table 3, where the four apparent nonmembers are listed at the end. The table gives the Heckmann-Lübeck numbers (HL), Henry Draper numbers (HD), spectral types by Abt (1978), rotational velocities ($V \sin i$) with sources indicated in the table notes, number of measures (n), mean radial velocities ($\langle\rho\rangle$), and velocity dispersion (σ). For the binaries with orbital elements listed below, we give the γ-velocities.

The mean cluster velocity is $+1.3 \pm 2.3$ (dispersion per star) or $+0.6 \pm 1.8$ km s^{-1} if the binaries are excluded. The dispersion is probably more instrumental than intrinsic to the stars. Heard & Petrie derived -1.6 ± 4.0 km s^{-1} for 64 cluster members, including variables. Most of the uncertainty in our value is in the zero point of our velocity system. Morse et al. (1991) derived a mean of 0.0 ± 6.8 km s^{-1}, where the large scatter is due mostly to their having too few measures (average of 2.9 per star) to derive realistic mean velocities for the variables.

We also have a set of photographic Cassegrain spectra that had not been measured or published. They are of a dispersion of 39 Å mm^{-1}, width of 0.6 mm, and resolution of 1.0 Å. They generally do not contribute to the strength of our results, and only one star among them gives orbital elements that are convincing. But we will quote the results on HD 21375 and HD 21481, the two stars inadvertently left out of the coudé program. The radial velocities are listed in Table 4. HD 21375 is a spectroscopic binary (SB1), and HD 21481 has a velocity scatter that is typical of constant-velocity stars of that line broadening, measured with that dispersion.

The velocity dispersion from the coudé spectra are plotted in Figure 1 against rotational velocities. We see a sloped band between $\sigma = 2$ and 5 km s^{-1}, probably representing the constant-velocity stars. A least-squares solution yields $\sigma = 2.9 + 0.0039(V \sin i)$ km s^{-1}, which is similar to the $\sigma = 2.1 + 0.0057(V \sin i)$ derived for stars in IC 4665 (Morrell & Abt 1991). In each cluster there is a shell star (HD 22192 and HD 161261) below the band that has a high value of $V \sin i$ but low dispersion because the shell absorption in the Balmer-line cores yield accurate velocities. Prosser (1992) finds HD 22192 to be a nonmember because of its proper motion.

Above the band in Figure 1 are three nonmembers and seven cluster members. The top star (HD 2298) is a double-lined (SB2) nonmember for which we were unable to derive orbital elements. The second highest star (HD 24760) is another SB2 nonmember; its orbital elements are given in Table 5 (*bottom*) and its velocity curve is shown in Figure 2. However, this interpretation of the spectra of HD 24760 as a SB2 is in contradiction with the recent study by Harmanec (1989) showing evidence of traveling waves crossing the line profiles with a

TABLE 2

COUDÉ RADIAL VELOCITIES OF α PERSEI STARS

Helio. JD 2440000+	ρ (km s^{-1})
HD 20315	
7510.655	+ 0.8
7511.618	- 0.8
7581.605	- 3.1
7583.608	- 2.1
7584.611	+ 1.8
7852.651	- 8.9
7896.655	+22.2
7897.622	+24.7
7898.881	+27.2
7899.881	+28.3
8179.708	-14.5
8237.669	- 4.8
8268.579	+15.3
8269.569	+15.0
8270.576	+15.5
8271.568	+18.9
HD 20365	
7510.661	- 2.1
7511.624	- 5.5
7581.610	+ 1.2
7583.612	+ 2.9
7584.615	+ 1.5
7849.615	+ 0.5
7852.657	- 0.3
7896.673	+ 1.1
7896.630	+ 1.3
7898.624	- 0.6
7899.615	+ 1.3
8127.886	- 1.0
8177.732	- 0.3
8178.718	- 2.2
8179.712	- 1.1
8237.673	+ 1.8
8268.584	- 0.5
8269.572	+ 3.1
8270.580	+ 1.0
8271.672	+ 4.7
HD 20418	
7510.665	- 7.4
7511.630	- 1.8
7581.614	+ 4.4
7583.615	+ 5.0
7584.618	+ 2.3
7849.629	- 1.8
7852.662	+ 5.3
7896.679	- 1.4
7897.636	- 2.0
7898.630	- 1.2
7899.621	- 2.0
8127.890	- 2.0
8178.722	- 9.9
8179.715	- 7.3
8237.676	- 1.0
8268.588	- 5.8
8269.576	- 4.0
8270.641	- 6.0
8271.777	+ 0.7
HD 20487	
7511.654	- 1.5
7581.627	- 3.0
7583.624	- 2.6
7584.630	+ 0.5
7852.672	- 2.5
8127.896	- 9.7
8131.888	-16.5
8177.742	+ 1.1
8178.731	- 2.3
8179.730	+ 9.0
8237.690	- 4.4
8268.601	+19.6
8269.586	+14.3
7270.594	+10.8
8271.582	+18.3
HD 20809	
7510.756	- 0.8
7511.694	- 6.2
7581.638	+ 6.9
7583.633	+ 0.3
7584.641	+ 4.7
7849.624	+ 1.7
7852.694	- 0.1
7896.686	- 1.4
7897.643	+ 4.4
7898.636	+ 4.6
7899.626	- 1.2
8127.911	+ 2.0
8177.752	+ 6.2
8178.743	- 6.5
8179.755	-10.3
8237.701	+ 7.1
8268.632	+ 3.7
8269.597	+ 9.4
8270.652	- 6.0
8271.790	+ 8.0
HD 20842	
7581.650	- 2.3
7583.644	- 5.6
7584.652	- 6.9
7849.957	- 0.7
7852.708	+ 0.3
8127.924	- 2.8
8131.911	- 2.1
8177.768	+ 2.7
8178.757	- 2.0
8179.769	+ 4.0
8237.716	- 1.7
8268.645	+ 5.8
8269.618	+ 7.2
8270.844	- 0.7
8271.605	+ 3.7
HD 20863	
7511.709	- 1.3
7581.665	+ 1.5
7583.656	+ 1.6
7584.667	+ 1.1
7849.788	+ 3.7
7852.731	+ 1.9
7897.656	+ 1.9
7898.649	+ 3.4
7899.637	+ 3.0
8127.952	- 1.1
8178.778	- 2.2
8179.793	+ 8.3
8237.757	+ 1.6
8268.667	+ 4.7
8269.628	+ 5.4
8270.684	+ 1.7
8271.798	+ 0.2
HD 20931	
7581.680	- 3.7
7583.668	+ 3.9
7584.684	- 3.9
7852.748	- 0.1
8127.970	+ 2.6
8131.933	- 0.5
8178.805	+ 1.8
8179.814	+ 4.3
8237.783	+ 1.2
8268.687	+ 4.6
8269.666	+ 0.9
8270.618	+ 4.1
8271.625	+ 3.5
HD 20961	
7581.699	+ 1.2
7584.711	- 7.9
7852.776	- 1.0
8127.990	- 0.3
8131.864	+ 1.9
8177.826	+ 3.6
8178.827	+ 0.7
8179.847	+ 4.6
8268.707	+ 0.1
8269.699	- 0.1
8270.760	- 0.3
8271.664	- 0.2
HD 21071	
7510.777	- 0.4
7511.725	-10.4
7581.707	+ 5.7
7583.686	+ 5.3
7584.723	- 6.7
7849.630	- 1.1
7852.791	+ 2.7
7896.694	+ 2.3
7897.684	- 0.7
7898.673	+ 1.8
7899.653	- 1.4
8128.878	+ 6.8
8177.839	+ 2.2
8178.840	- 2.4
8179.860	- 1.0
8237.769	- 0.3
8268.716	- 1.4
8269.638	0.0
8270.662	- 4.9
8271.807	+ 5.1
HD 21091	
7581.721	+ 3.5
7584.735	- 2.7
7849.991	+ 1.7
7852.922	+ 0.3
7898.688	+ 2.4
8128.889	- 6.4
8131.959	- 4.3
8177.852	+ 0.2
8178.861	+ 4.9
8179.872	+ 8.3
8268.726	+ 3.7
8269.714	+ 0.8
8270.858	+ 0.5
8271.687	+ 3.3
HD 22281	
7511.740	- 3.7
7581.732	0.0
7584.750	+ 0.8
7849.645	- 0.4
7852.801	+ 1.9
7896.699	- 5.4
7898.712	+ 4.0
7899.666	+ 4.2
8128.913	+ 2.6
8177.877	+ 8.1
8178.876	- 0.7
8179.888	+ 8.7
8268.739	+ 6.1
8269.682	+ 2.4
8270.673	+ 6.4
8271.815	+ 1.9
HD 21278	
7510.833	+20.6
7511.751	+14.4
7581.741	+ 0.6
7583.719	-13.8
7584.757	-23.5
7849.654	- 8.0
7852.821	+ 2.8
7896.718	+ 4.8
7897.714	+ 9.1
7898.737	+15.7
7899.677	+17.2
8128.927	-23.5
	+49.4
8177.884	+ 4.7
8178.881	+ 8.1
8179.893	+13.9
8239.862	- 7.2
8268.752	+25.6
	-45.4
8269.722	+25.3
	-49.0
8269.867	+25.1
	-43.2
8270.642	+29.2
	-50.5
8271.822	+26.6
	-39.7
HD 21279	
7511.773	-19.2
7581.748	+ 2.4
7584.768	+13.2
7849.832	+ 1.5
7852.946	-12.1
7897.728	+ 9.0
7898.737	+ 7.6
7899.702	+ 5.5
8128.941	- 4.4
8177.891	+13.2
8178.888	+ 5.9
8179.900	+14.9
8268.762	+ 7.9
8269.729	+ 5.3
8270.873	+ 4.5
8271.706	+ 8.6
8296.650	- 8.6
8298.655	- 4.8
HD 21362	
7510.840	- 2.5
7511.790	-11.9
7581.758	- 7.4
7584.777	- 9.8
7849.659	- 7.4
7852.826	- 8.1
7896.726	- 3.8
7897.744	+ 7.4
7898.766	+ 2.5

TABLE 2—*Continued*

Helio. JD 2440000+	ρ (km s^{-1})
7899.684	+ 1.1
8128.954	- 0.4
8177.898	- 9.3
8178.896	+ 1.8
8179.907	+ 4.4
8268.777	- 4.4
8269.747	- 1.6
8270.694	- 7.0
8271.832	- 6.6
HD 21398	
7511.809	- 4.9
7849.854	+ 1.8
7852.966	+ 3.2
7898.781	+ 2.7
7899.723	+ 3.9
8128.967	- 3.8
8129.974	+ 2.0
8177.905	+ 1.3
8178.904	- 1.5
8179.915	+ 3.0
8268.786	+ 2.2
8269.756	- 0.2
8271.722	- 0.9
HD 21428	
7510.847	- 9.3
7511.826	-14.5
7849.664	- 6.1
7852.832	- 4.0
7896.734	- 3.9
7897.776	+ 3.2
7898.798	+ 2.0
7899.750	- 1.1
8129.864	- 3.0
8130.901	- 3.9
8177.913	- 1.3
8178.910	- 0.8
8179.921	- 2.1
8268.801	- 4.7
8269.812	- 6.7
8270.728	- 7.9
8271.836	- 1.2
HD 21455	
7849.675	- 1.1
7852.838	- 1.6
7896.742	- 6.8
7897.784	- 3.5
7898.805	+ 7.4
7899.757	+ 5.9
8129.868	+ 0.2
8130.860	0.0
8177.919	+ 1.8
8178.916	- 0.1
8179.926	+ 1.7
8268.806	+ 2.6
8269.815	+ 4.8
8270.736	+ 4.8
8271.842	+ 5.5
HD 21479	
7849.886	- 0.5
7899.773	- 0.2
8129.878	+11.9
8130.875	+ 9.0
8131.972	- 4.8
8177.930	+ 5.1
8178.926	+ 3.8
8179.939	+ 4.8
8268.816	+16.2
8269.773	+ 9.3
8270.823	+ 7.5
8271.739	+10.6
8296.673	- 1.6
8298.675	- 4.8
HD 21551	
7511.831	- 4.9
7849.689	- 5.8
7852.845	- 2.0
7896.768	- 0.9
7897.794	- 2.1
7898.815	- 0.4
7899.795	+ 4.0
8129.888	- 0.6
8177.939	+ 8.6
8178.940	+ 1.0
8179.946	+12.5
8268.825	+ 1.0
8269.820	+ 3.2
8270.832	+ 1.2
8271.859	- 0.2
HD 21641A	
7849.700	+ 2.1
7852.864	- 1.3
7896.779	- 4.9
7897.812	+ 1.4
7898.826	+ 5.4
7899.805	+ 3.8
8129.895	+ 0.4
8177.944	+14.8
8178.946	+11.8
8179.952	+11.2
8268.833	+ 2.3
8269.834	+ 2.8
8270.886	- 1.6
8271.850	- 0.1
8296.623	- 4.5
8298.675	- 2.0
HD 21672	
7511.873	- 2.2
7849.714	- 9.3
7852.874	- 4.6
7896.791	+11.3
7897.824	+10.1
7898.836	+ 9.9
7899.816	+ 7.3
8129.902	- 5.3
8177.951	+ 5.3
8178.954	- 4.8
8179.959	+ 5.1
8268.857	+ 6.2
8269.842	+ 2.0
8270.896	+ 0.5
8271.868	+ 0.9
8296.600	- 0.3
8298.624	- 6.4
HD 21699	
7511.889	- 1.2
7849.734	+ 3.7
7852.882	+ 2.9
7896.830	+ 2.6
7896.835	+ 4.5
7898.848	+ 5.3
7899.824	+ 3.3
8129.909	- 2.9
8177.955	+ 2.7
8178.959	+ 4.5
8179.964	+ 3.0
8268.854	+ 5.0
8269.847	+ 2.1
8270.904	+ 3.8
8271.882	+ 4.0
HD 21931	
7849.906	+ 0.5
7899.841	+ 3.0
8129.918	- 1.7
8131.984	- 1.3
8177.972	+ 5.5
8178.968	+ 0.4
8179.971	+ 9.2
8268.866	+ 1.8
8269.791	+ 1.6
8270.806	+ 3.9
8271.755	- 1.6
HD 22136	
7511.902	- 3.6
7849.744	+ 5.2
7852.889	+ 1.7
7896.848	+ 1.2
7898.857	+ 3.7
7899.858	+ 4.3
8129.931	+ 1.8
8177.982	+ 3.8
8178.984	+ 2.2
8179.982	+ 3.8
8268.881	+ 4.2
8269.858	+ 0.9
8270.911	- 2.2
8271.890	+ 2.7
HD 22192	
7849.753	+ 2.5
7852.903	- 1.0
7896.837	+ 4.2
7897.841	+ 0.1
7898.865	- 0.4
7899.865	+ 2.4
8129.946	+ 1.7
8178.000	+ 4.5
8178.989	+ 2.5
8179.987	+ 3.4
8268.913	+ 3.2
8269.853	+ 2.2
8270.916	+ 2.8
8271.897	+ 4.0
HD 22401	
7849.935	+ 3.8
7849.881	- 0.5
8129.955	+ 0.8
8177.992	- 5.5
8178.996	- 3.3
8179.995	- 2.8
8268.900	+ 4.9
8269.805	+ 4.1
8270.780	+ 5.9
8271.770	- 1.6
HD 22928	
7511.917	- 4.2
7848.837	- 1.2
7852.906	- 0.4
7896.841	-67.6
	+60.9
7897.845	-55.9
	+90.7
7898.868	+ 5.7
7899.893	- 0.9
8129.963	- 5.0
8178.001	-77.4
	+93.4
8179.003	-78.4
	+83.4
8180.004	+ 2.1
8268.917	+65.3
	-58.6
8269.863	-16.0
8270.919	-37.1
	+52.6
8271.904	-71.6
	+83.2
HD 24760	
7511.919	+28.3
7849.764	+16.9
7852.908	-47.4
7896.844	+24.6
	-56.4
7897.849	-22.6
7898.870	+45.9
	-57.8
7899.895	-45.5
	+47.6
8129.965	+52.9
	-25.4
8178.003	-46.4
	+47.9
8179.005	-16.0
8180.005	+45.2
	-39.1
8268.920	+34.2
	-56.2
8269.567	-19.2
8269.865	-33.1
8270.574	+ 9.3
8270.921	+34.8
	-41.5
8271.565	+41.7
	-29.9
8271.902	- 4.4
HD 25940	
7849.766	+10.9
7852.910	+ 7.3
7896.848	+ 7.1
7897.853	+ 8.4
7898.874	+ 7.8
7899.899	+13.9
8129.966	+18.3
8178.004	+12.5
8179.006	+15.9
8180.006	+13.6
8268.924	+11.3
8269.851	+11.1
8270.924	+ 9.3
8271.905	+11.9

TABLE 3

RADIAL VELOCITY RESULTS FOR α PERSEI STARS

HL	HD	Spectral Type	V sin i (km s⁻¹)		n	<ρ> (km s⁻¹)	σ	Conclusion
					Cluster Members			
383	20365	B4 IV	145	A	20	+0.3	±2.2	Constant velocity
401	20418	B5 Vn	320	A	19	-1.9	4.2	Constant velocity
423	20487	A1 Vn	280	K	15	+3.	10.2	SB1, P=21ᵈ.21
557	20809	B5 V	250	S	20	+1.3	5.4	Constant velocity
575	20842	A1 V	85	K	15	-0.1	4.0	Constant velocity
581	20863	B8.5 V	200	K	17	+2.0	2.6	Constant velocity
612	20931	A2 V	85	K	14	+1.6	2.8	Constant velocity
625	20961	B9.5 Vsn	25	K	12	+0.2	3.1	Constant velocity
675	21071	B7 Vsn	70	A	20	+0.1	4.2	Constant velocity
692	21091	A0 V	340	A	14	+1.2	3.8	Constant velocity
735	21181	B8.5 Vn	345	A	16	+2.3	3.9	Constant velocity
774	21278	B5 V	75	A	21	+1.2	16.7	SB2, P=21ᵈ.695
775	21279	B8 V	200	K	18	+4.	9.2	SB1, P=21ᵈ.222
810	21362	B5 Vn	385	A	18	-3.5	5.4	Constant velocity
817	21375	A1 Vn	270	K	15	-2.2	12.7	SB1, P=30ᵈ.90, Cass. spectra
831	21398	B9 V	135	A	13	+0.7	2.8	Constant velocity
835	21428	B3 V	200	A	17	-3.8	4.3	Constant velocity
861	21455	B6 Ve	150	A	15	+1.4	3.9	Constant velocity
868	21479	A1 V	180	K	14	+4.7	6.4	Probable SB1
875	21481	A0 Vn	250	K	16	-8.1	8.2	Constant velocity, Cass. spectra
904	21551	B8 Vn	380	A	15	+1.0	4.7	Constant velocity
955	21641A	B8.5 V	215	A	16	+2.6	5.7	Probable SB1
965	21672	B8 V	225	A	17	+1.5	6.3	Probable SB1
985	21699	B5 Vp(He wk)sn	50	A	15	+2.9	2.2	Constant velocity
1082	21931	B9 V	205	A	11	+1.9	3.3	Constant velocity
1153	22136	B8 IV: sn	25	A	14	+2.1	2.5	Constant velocity
1164	22192	B5 Ve + shell	385	A	14	+2.3	1.7	Constant velocity
1259	22401	A0 Vp(Sr,Cr,Si)	45	K	10	+0.6	3.9	Constant velocity
		Mean	192		15.8	+1.3		
					Non-members			
....	20315	B7 V	250	S	16	+ 4.	13.9	SB1, P=36ᵈ.5
....	22928	B5 IVn	255	S	15	-22.8	40.6	SB2
....	24760	B0.5 III(stand.)	153	H	18	- 1.	35.2	SB2, P=2ᵈ.4826
....	25940	B4 Ve	250	S	14	+11.4	3.3	Constant velocity

NOTE.—References for $V \sin i$: A, Abt & Hunter 1962; H, Hoffleit & Jaschek 1982; K, Kraft 1967; S, Slettebak & Howard 1955.

TABLE 4

CASSEGRAIN RADIAL VELOCITIES OF TWO STARS

Heliocentric JD 2,440,000+	ρ (km s⁻¹)	Heliocentric JD 2,440,000+	ρ (km s⁻¹)
HD 21375		HD 21481	
3761.939	+18	3761.959	−7
3762.908	+6	3762.924	−6
3763.948	+11	3763.965	−29
4239.737	+6	4239.760	−13
4240.871	−1	4240.898	−14
4242.768	+7	4241.759	−1
4243.700	0	4242.750	−4
4244.683	+6	4243.717	−7
4245.673	+9	4244.668	−8
4509.922	−16	4245.641	−12
4510.898	−20	4509.951	−1
4511.900	−17	4510.915	−6
4512.895	−10	4511.918	+8
4568.898	−9	4512.910	−4
4569.754	−23	4568.915	−7
		4569.770	−18

TABLE 5

ORBITAL ELEMENTS

HD	Period (days)	T 2,440,000+	K (km s^{-1})	γ (km s^{-1})	e	ω	$a \sin i$ (10^6 km)	$f(\mathcal{M})$ ($\mathcal{M}_\odot$)	$\mathcal{M} \sin i$ ($\mathcal{M}_\odot$)	$O-C$ (km s^{-1})
Cluster Members										
20487	21.21 ±0.02	7265.5 ±0.4	13 ±1	+3.	0.0 ±0.1	0 ±7	3.79	0.00484	...	5.4
21278	21.695 ±0.004	6714.5 ±0.2	22.7 ±0.9	+1.2 ±0.7	0.12 ±0.04	109 +3	6.72	...	0.555	4.7
			49. ±3.				14.51	...	0.257	4.1
21279	21.222 ±0.007	7521.4 ±0.2	21 ±6	+4 ±1	0.74 ±0.08	183 ±8	4.12	0.00621	...	4.0
21375	30.90 ±0.09	3765.8 ±2.8	19 ±3	+1.5 ±1.4	0.6 ±0.1	125 ±19	6.46	0.0125	...	3.8
Nonmembers										
20315	36.5 ±0.1	7531.7 ±0.1	20 ±3	+4 ±2	0.3 ±0.2	312 ±9	9.58	0.0263	...	5.2
24760	2.4826 ±0.0001	8130.6 ±0.1	42 ±3	−1 ±2	0.22 ±0.07	118 ±20	1.40	...	0.110	14.3
			52 ±5				1.73	...	0.089	15.7

period of 0^d.56664. The fourth highest star (HD 20315) in Figure 1 is an SB1 nonmember with orbital elements listed in Table 5 and velocity curve shown in Figure 3. The fourth nonmember (HD 25940) has a constant radial velocity.

For the cluster members indicated in Figure 1, HD 21278 is the only star with a substantial velocity amplitude. It is an SB2 with elements listed in Table 5 and velocity curve shown in Figure 4. We add as squares in Figure 4 the four measures (J. A. Morse, private communication) of the primary listed by Morse et al. (1991); they are slightly low, again indicating that our velocity system is slightly higher than theirs. The next two lower dispersion points in Figure 1 are for HD 20487 and HD 21279. They are SB1's with elements given in Table 5 and velocity curves shown in Figures 5 and 6. However for HD 21279 the power spectrum shows that $P = 31^d.2$ is almost as strong as $P = 21^d.2$. Of the four stars (HD 21672, 21479, 21641A, 20809) along the top edge of the band in Figure 1, the first three yield SB1 velocity curves of $K = 8$–9 km s^{-1}, $P = 18^d.54$, $11^d.77$, and $21^d.09$, and $O-C$ values of 4.3, 4.6, and 2.3 km s^{-1} that are not completely convincing. They are called "probable SB1" in Table 3.

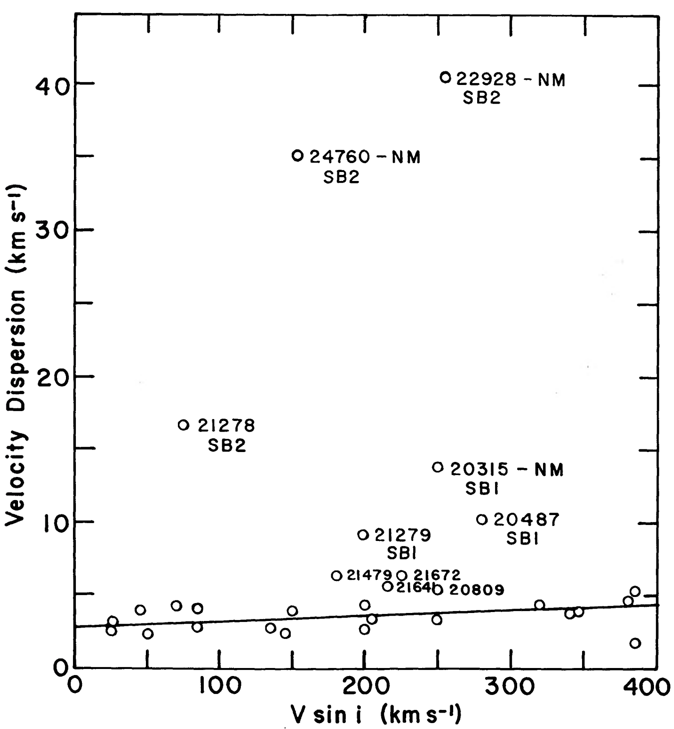

FIG. 1.—The dispersion in the radial velocities is plotted against the rotational velocity for each star. The band of circles with $\sigma = 2$–5 km s^{-1} probably represents the constant-velocity stars; it slopes upward due to increasing inaccuracies in measuring velocities with increasing rotational velocity. Individual stars above the band are marked with their Henry Draper numbers and "NM" for nonmembers of the α Persei cluster.

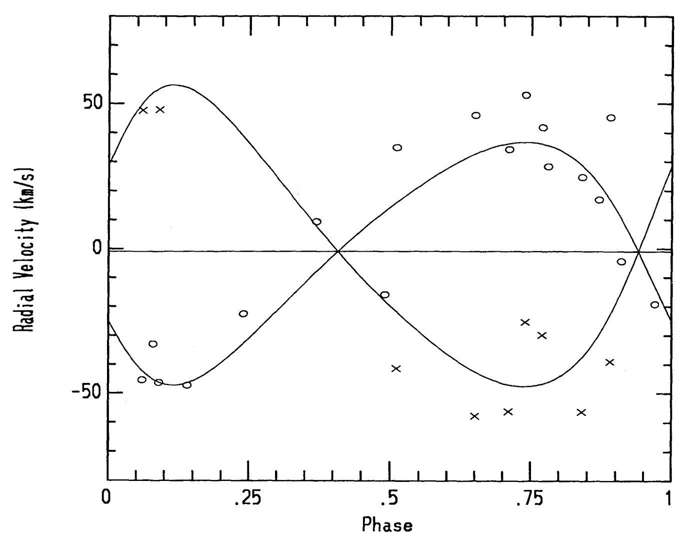

FIG. 2.—Radial velocity measures and computed velocity curve for the SB2 nonmember HD 24760. The circles represent the primary, and the crosses represent the secondary.

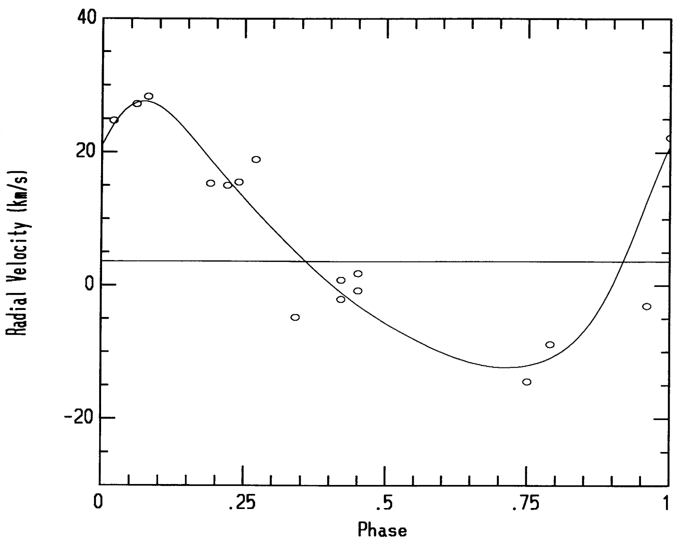

FIG. 3.—Radial velocities and computed curve for the SB1 nonmember HD 20315.

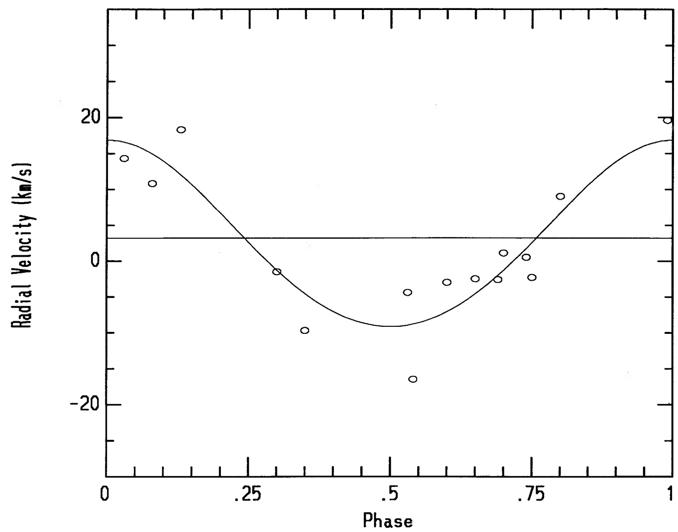

FIG. 5.—Radial velocities and computed velocity curve for HD 20487

3. CONCLUSIONS

For the 28 brightest members of the α Persei cluster, we have found only four binaries with velocity amplitudes $K_1 > 10$ km s^{-1}. The resulting frequency of spectroscopic binaries is 14%. For comparison, a recent study (Abt, Gomez, & Levy 1990) of 116 (mostly field) B2–B5 stars yielded 35 SB1's or SB2's for a frequency of 30% with $K_2 > 20$ km s^{-1}. For most other open clusters (Abt & Sanders 1979; Crampton, Hill, & Fisher 1976), the frequency is in excess of 30%. Only for the Pleiades, the only other cluster with an unusually high mean rotational velocity, the frequency of binaries (Abt et al. 1965; Pearce & Hill 1975) with confirmed elements and $K_1 > 10$ km s^{-1} is also low, namely five out of 25 B6–A1 members or 20%. We thus confirm our initial suspicion that clusters with high mean rotational velocities are deficient in spectroscopic binaries.

Another interesting result is that all four discovered binaries have relatively long periods (21^d–31^d). In the Abt et al. study of 116 B2–B5 stars, 15 out of 35 spectroscopic binaries have periods less than 10 days and 20 out of 35 have periods less than 21 days. The absence of short-period binaries in the α Persei cluster seems unusual. This result is not statistically strong because of the low frequency of binaries, but as we shall see below, it was expected.

A third interesting result is the small velocity amplitudes, implying small secondary masses. All four binaries have $K_1 =$ 13–23 km s^{-1} while for the 11 B2–B5 binaries with periods between 10 and 40 days, $K_1 =$ 23–88 km s^{-1} with an average of 36 km s^{-1}. For the SB2 (HD 21278), the mass ratio, $\mathcal{M}_2/\mathcal{M}_1$, is 0.46. From the mass functions for the three SB1's, the minimum mass ratios are 0.13, 0.12, and 0.18. For a mean value of $\langle \sin^3 i \rangle = 4/3\pi$, the statistical mean mass ratios are 0.17, 0.16, and 0.24. Therefore the mass ratios are probably all in the range 0.1–0.5.

Fourth, the four definite binaries and even the three probable binaries are not slow rotators, i.e., $\langle V \sin i \rangle = 206$ and 207 km s^{-1} for the two groups, compared with $\langle V \sin i \rangle = 197$

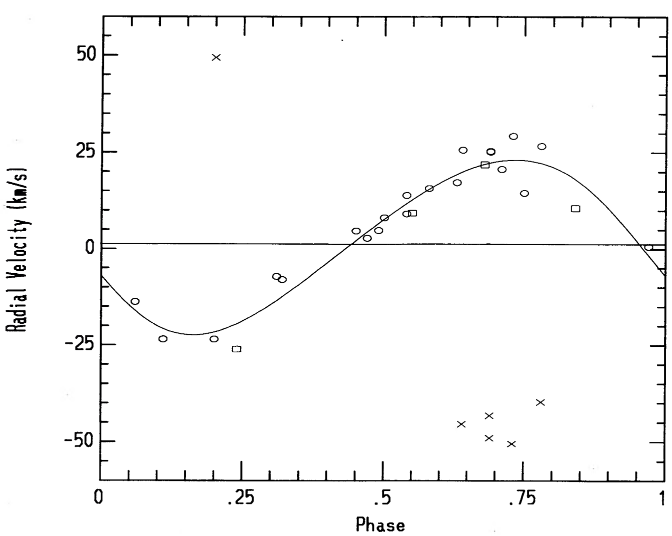

FIG. 4.—Radial velocities (*circles*) and the computed velocity curve for the (1991). The crosses represent some measures for the secondary.

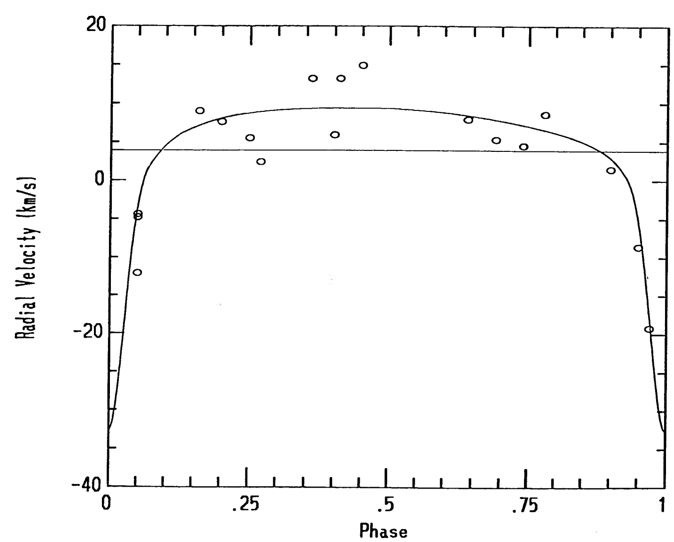

FIG. 6.—Radial velocities and computed velocity curve for HD 21279

TABLE 6

BINARY CHARACTERISTICS IN THREE OPEN CLUSTERS

CLUSTER (1)	AGE (10^6 yr) (2)	AGE (τ_{ff}) (3)	NUMBER OF BINARIES (4)	$\mathcal{M}_2/\mathcal{M}_1$ (5)	MEDIAN P (days) (6)
Orion Nebula	1	1	4	0.19–0.35	20
α Persei	10	2	4	0.1–0.5	21
IC 4665	50	25	4	0.1–1.0	10

km s^{-1} for all 28 members. Of the eight stars with $V \sin i < 100$ km s^{-1}, only one (HD 21278) is a binary. This result is similar to that in the Orion Nebula cluster (Abt, Wang, & Cardona 1991) where the four discovered binaries have average rotational velocities ($V \sin i = 135$, 145, 160, and 320 km s^{-1}) but unlike that of IC 4665 (Morrell & Abt 1991) where the four discovered binaries all have small rotational velocities (30, 25, 35, and <50 km s^{-1}) and constitute most ($\frac{2}{3}$) of the stars with $V \sin i < 50$ km s^{-1}

4. INTERPRETATION

We will attempt to explain these conclusions and those in other recent papers in terms of binary formation in open clusters by capture, either as three-body interactions or with ambient interstellar clouds to absorb angular momentum. We have given up on fission or bifurcation as a mechanism of binary formation, partly because recent theoretical work (Durisen & Tohline 1985) has shown that for compressible viscous gases, fission does not occur in contracting rotating ellipsoids, but rather disks, rings, and spiral arms are formed; and partly because all the secondary mass functions in young and intermediate-age clusters can be explained by capture alone.

Aarseth & Hills (1972) have shown (see Abt et al. 1990 for a summary of their data) from *n*-body calculations that in a 120 star cluster with subclustering, the formation and disruption of binaries changes from an initial set of wide binaries of predominant mass ratios of 0.25 to (in roughly a free-fall time) binaries with predominant mass ratios of 1.0. The reasons for these changes are that initially a massive star will pair with the most frequent neighbors, namely the predominant low-mass stars; but as the massive stars acquire and lose companions repeatedly, there is a tendency for them to form stable systems with stars of similar masses.

In Table 6 we summarize the results for three clusters: the Orion Nebula cluster (Abt et al. 1991), α Persei cluster (results above), and IC 4665 (Morrell & Abt 1991). Columns (2) and (3) give approximate ages in 10^6 yr and in units of the free-fall times (τ_{ff}). The remaining columns give the numbers of binaries, range of mass ratios, and median periods. For IC 4665, two of the binaries are SB2's having mass ratios of 0.88 and 0.97; the other two are SB1's having minimum mass ratios of 0.10 and 0.33 but mean values of 0.13 and 0.48.

We see that for the two clusters with ages of the order of the free-fall time, the binaries are wide ones (median periods of 20 days), and the mass ratios are all small, i.e., low secondary masses. But for a cluster of age 10–100 free-fall times, the binaries have evolved so that half have mass ratios near 1.0 and they have shorter periods (median of 10 days). And with the occurrence of shorter periods, tidal effects will cause reduced rotational velocities so that all the binaries in the older cluster have small $V \sin i$, whereas among the wide binaries in the young clusters, the values of $V \sin i$ are similar to those of single stars.

These results, unfortunately, are based on small numbers of clusters and binaries, so some of the results are uncertain. And age is not the sole pertinent factor; cluster mass also should enter. But extremes in mass ratios, i.e., small values for young clusters and some large values in older clusters, will not disappear by adding more clusters. At least we now have a working model against which future measures can be compared.

We thank Daryl Willmarth for considerable help with the reductions and John Morse and Charles Prosser for advanced preprints of related studies.

REFERENCES

Aarseth, S. L., & Hills, J. G. 1972, A&A, 21, 255
Abt, H. A. 1978, PASP, 90, 692
Abt, H. A., Barnes, R. C., Biggs, E. S., & Osmer, P. S. 1965, ApJ, 142, 1604
Abt, H. A., Gomez, A. E., & Levy, S. G. 1990, ApJS, 74, 551
Abt, H. A., & Hunter, J. H., Jr. 1962, ApJ, 136, 381
Abt, H. A., & Sanders, W. L. 1973, ApJ, 186, 177
Abt, H. A., Wang, R., & Cardona, O. 1991, ApJ, 367, 155
Boss, B. 1910, AJ, 26, 163
Crampton, D., Hill, G., & Fisher, W. A. 1976, ApJ, 204, 502
Crawford, D. L., & Barnes, J. V. 1974, AJ, 79, 687
Dickman, R. L. 1985 in Protostars and Planets II, ed. D. C. Black & M. S. Matthews (Tucson: Univ. Arizona Press), 150
Durisen, R. H., & Tohline, J. E. 1985, in Protostars and Planets II, ed. D. C. Black & M. S. Matthews (Tucson: Univ. Arizona Press), 534
Eddington, A. S. 1910, MNRAS, 71, 43
Fekel, F. C. 1985, in IAU Coll. 88, Stellar Radial Velocities, ed. A. G. D. Phillip & D. W. Latham (Schnectady, NY: L. Davis), 339
Harmanec, P. 1989, Bull. Astron. Inst. Czechoslovakia, 40, 201
Harris, D. L., III. 1956, ApJ, 123, 371
Heard, J. F., & Petrie, R. M. 1967, in IAU Symp. 30, Determination of Radial Velocities and Their Applications, ed. A. H. Batten & J. F. Heard (London: Academic), 179
Heckmann, O., Dieckvoss, W., & Kox, H. 1956, Astron. Nach., 283, 109
Heckman, O., & Lübeck, K. 1958, Z. Astrophys., 45, 243
Hoffleit, D., & Jaschek, C. 1982, The Bright Star Catalogue (4th rev. ed.; New Haven: Yale Univ. Obs.)
Kapteyn, J. C. 1910, Trans. Int. Solar Union, 3, 215
Kraft, R. P. 1967, ApJ, 148, 129
Latham, D. W. 1985, in IAU Coll. 88, Stellar Radial Velocities, ed. A. G. Davis Phillip & David W. Latham (Schnectady, NY: L. Davis), 21
Levato, H. 1976, ApJ, 203, 680
Morgan, W. W., Hiltner, W. A., & Garrison, R. F. 1971, AJ, 76, 242
Morrell, N., & Abt, H. A. 1991, ApJ, 378, 157
Morse, J. A., Mathieu, R. D., & Levine, S. E. 1991, AJ, 101, 1495
Pearce, J. A., & Hill, G. 1975, Publ. Dom. Astrophys. Obs., 14, 319
Petrie, R. M., & Heard, J. F. 1969, Publ. Dom. Astrophys. Obs., 13, 329
Prosser, C. F. 1992, AJ, in press
Roman, N. G., & Morgan, W. W. 1950, ApJ, 111, 426
Slettebak, A., & Howard, R. F. 1955, ApJ, 121, 102
Trullols, E., Rossello, G., Jordi, C., & Lahulla, F. 1989, A&AS, 81, 47