Radial velocity measurements and sine-curve fits to the orbital velocity variations are presented for the eighth set of 10 close binary systems: AB And, V402 Aur, V445 Cep, V2082 Cyg, BX Dra, V918 Her, V502 Oph, V1363 Ori, KP Peg, and V335 Peg. Half of the systems (V445 Cep, V2082 Cyg, V918 Her, V1363 Ori, and V335 Peg) were discovered photometrically by the Hipparcos mission, and all systems are double-lined (SB2) contact binaries. The broadening function method permitted improvement of the orbital elements for AB And and V502 Oph. The other systems have been observed for radial velocity variations for the first time; in this group are five bright ($V < 7.5$) binaries: V445 Cep, V2082 Cyg, V918 Her, KP Peg, and V335 Peg. Several of the studied systems are prime candidates for combined light and radial velocity synthesis solutions.

Key words: binaries: close — binaries: eclipsing — stars: variables: other

On-line material: machine-readable table

1. INTRODUCTION

This paper is a continuation in a series of papers of radial velocity studies of close binary stars (Lu & Rucinski 1999; Rucinski & Lu 1999; Rucinski, Lu, & Mochmacki 2000; Lu, Rucinski, & Ogloza 2001; Rucinski et al. 2001; Rucinski et al. 2002; Rucinski et al. 2003) and presents data for the eighth group of 10 close binary stars observed at the David Dunlap Observatory. Selection of the targets is quasi-random: At a given time, we observe a few dozen close binary systems with periods shorter than 1 day, brighter than 11 mag, and with declinations greater than $\pm 15^\circ$. We publish the results in groups of 10 systems as soon as reasonable orbital elements are obtained from measurements evenly distributed in orbital phases. For technical details and conventions, and for preliminary estimates of errors and uncertainties, see the interim summary paper Rucinski (2002a, hereafter Paper VII). With this paper, we decided to introduce some minor changes into the reduction process: We used the pair of IRAF routines NOAO.IMRED.SPEC.FITCOORDS and NOAO.IMRED.SPEC.TRANSFORM to rectify images of the spectra and improve wavelength calibrations; the procedure of cosmic-ray removal was done using a separate, stand-alone program (Pych 2003).

We estimate spectral types of the program stars using our classification spectra. These are compared with the mean $B-V$ color indexes taken from the Tycho-2 catalog (Hög et al. 2000) and the photometric estimates of the spectral types using the relations published by Bessell (1979).

The observations reported in this paper have been collected mostly during the year 2002; exceptions are: BX Dra and V335 Peg, for which some observations were collected in 2001, and V918 Her, for which some observations were in 2003 May. The ranges of dates for individual systems can be found in Table 1.

All systems discussed in this paper, except AB And and V502 Oph, have been observed for radial velocity variations for the first time. We have derived the radial velocities in the same way as described in previous papers. See Paper VII for a discussion of the broadening-function approach used in the derivation of the radial velocity orbit parameters: the amplitudes $K_1$, the center-of-mass velocity $V_0$, and the time-of-primary-eclipse epoch $T_0$.

This paper is structured in a way similar to that of previous papers in that most of the data for the observed binaries are in two tables consisting of the radial velocity measurements (Table 1) and their sine-curve solutions (Table 2). The data in Table 2 are organized in the same manner as in previous papers. In addition to the parameters of spectroscopic orbits, the table provides information about the relation between the spectroscopically observed epoch of the primary-eclipse $T_0$ and the recent photometric determinations in the form of the
$O - C$ deviations for the number of elapsed periods $E$. It also contains our new spectral classifications of the program objects. Section 2 of the paper contains brief summaries of previous studies of individual systems and comments on the new data. Figures 1–3 show the radial velocity data and solutions. Figure 4 shows the BFs for all systems; the functions have been selected from among the best-defined ones around the orbital phase of 0.25 using the photometric system of Guthnick & Prager (1927). Oosterhoff (1930) gave a photometric ephemeris. Twenty years later, Oosterhoff (1950) reported discovery of the period variation. Since that time, AB And became a target of numerous photometric investigations. On the basis of the photometric observations, Landolt (1969) determined the spectral type of K2 V. He also noted asymmetries in the light curve. The asymmetries have been explained in Bell, Hilditch, & King (1984) and Djurasevic, Rovithis-Livaniou, & Rovithis (2000) by a model with photospheric spots. Demircan et al. (1994) suggested that observed period variability may be a result of the orbital motion in a wide triple system. The third body should be a white dwarf in such a case. Strömgren photometry presented by Rucinski & Kaluzny (1981) suggested the spectral type of AB And to be G5.

The first spectroscopic observations of this object were published by Struve et al. (1950). AB And was then classified

### Table 1

**DDO Observations of the Eighth Group of 10 Close Binary Systems**

<table>
<thead>
<tr>
<th>HJD $-$2,400,000</th>
<th>Phase</th>
<th>$V_1$</th>
<th>$\Delta V_1$</th>
<th>$V_2$</th>
<th>$\Delta V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>52494.8051</td>
<td></td>
<td>0.1749</td>
<td>$-235.6$</td>
<td>$-0.7$</td>
<td>94.5</td>
</tr>
<tr>
<td>52494.8176</td>
<td></td>
<td>0.2126</td>
<td>$-251.7$</td>
<td>2.3</td>
<td>98.8</td>
</tr>
<tr>
<td>52494.8284</td>
<td></td>
<td>0.2451</td>
<td>$-260.6$</td>
<td>$-0.2$</td>
<td>99.8</td>
</tr>
<tr>
<td>52495.6065</td>
<td></td>
<td>0.5896</td>
<td>97.0</td>
<td>0.2</td>
<td>$-111.7$</td>
</tr>
</tbody>
</table>

Notes.—Table 1 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content. Velocities are expressed in km s$^{-1}$. The deviations $\Delta V_1$ are relative to the simple sine-curve fits to the radial velocity data. Observations leading to entirely unseparable broadening- and correlation-function peaks are marked by ellipses; these observations may eventually be used in more extensive modeling of broadening functions.

* The data given 0.5 weight in the orbital solution.

### Table 2

**Spectroscopic Orbital Elements**

<table>
<thead>
<tr>
<th>Name</th>
<th>Spectral Type</th>
<th>Other Names</th>
<th>$V_0$</th>
<th>$K_1$ ($K_2$)</th>
<th>$e_1$ ($e_2$)</th>
<th>$T_0 - 2,400,000$</th>
<th>$P$ (days)</th>
<th>($M_1 + M_2$) $\sin^3 i$</th>
<th>$q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB And........</td>
<td>EW/W</td>
<td>SAO 73069</td>
<td></td>
<td>$-27.53(0.67)$</td>
<td>130.32(1.17)</td>
<td>5.13 $52,503,044(4)$</td>
<td>0.3318919</td>
<td>0.560(7)</td>
<td></td>
</tr>
<tr>
<td>V818 Her......</td>
<td>EW/W</td>
<td>HIP 114508</td>
<td></td>
<td>232.88(0.83)</td>
<td>8.20</td>
<td>$-0.0105$</td>
<td>1.648(20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V402 Aur......</td>
<td>EW/W</td>
<td>HD 282719</td>
<td></td>
<td>$+40.82(0.93)$</td>
<td>41.94(0.83)</td>
<td>4.33 $52,448,969(16)$</td>
<td>0.603491</td>
<td>0.201(6)</td>
<td></td>
</tr>
<tr>
<td>V445 Cep......</td>
<td>EW/W</td>
<td>HD 210431</td>
<td></td>
<td>$+40.69(0.95)$</td>
<td>20.33(0.85)</td>
<td>4.57 $52,470,584(21)$</td>
<td>0.448776</td>
<td>0.167(10)</td>
<td></td>
</tr>
<tr>
<td>V2082 Cyg.....</td>
<td>EW/A</td>
<td>HD 109191</td>
<td></td>
<td>122.08(2.04)</td>
<td>11.55</td>
<td>$+0.0072$</td>
<td>0.134(6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V502 Oph......</td>
<td>EW/W</td>
<td>HD 150484</td>
<td></td>
<td>$-42.56(0.85)$</td>
<td>82.71(1.03)</td>
<td>6.38 $52,452,749(7)$</td>
<td>0.45339</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1263 Ori.....</td>
<td>EW/A</td>
<td>HD 88994</td>
<td></td>
<td>$+37.89(2.02)$</td>
<td>44.88(2.46)</td>
<td>16.32 $52,466,112(17)$</td>
<td>0.714084</td>
<td>0.238(5)</td>
<td></td>
</tr>
<tr>
<td>BX Dra.........</td>
<td>EW/A</td>
<td>HIP 78891</td>
<td>$-26.11(3.43)$</td>
<td>80.01(2.46)</td>
<td>8.87 $52,248,298(34)$</td>
<td>0.579027</td>
<td>0.289(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V918 Her......</td>
<td>EW/W</td>
<td>HIP 151701</td>
<td></td>
<td>$-25.72(0.74)$</td>
<td>53.93(0.49)</td>
<td>3.45 $52,555,849(14)$</td>
<td>0.57481</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V502 Oph......</td>
<td>EW/W</td>
<td>HD 150484</td>
<td></td>
<td>$-42.56(0.85)$</td>
<td>82.71(1.03)</td>
<td>6.38 $52,452,749(7)$</td>
<td>0.45339</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1363 Ori.....</td>
<td>EW/A</td>
<td>HD 89949</td>
<td></td>
<td>$+37.89(2.02)$</td>
<td>44.88(2.46)</td>
<td>16.32 $52,466,112(17)$</td>
<td>0.714084</td>
<td>0.238(5)</td>
<td></td>
</tr>
<tr>
<td>KP Peg.........</td>
<td>EW/A</td>
<td>HIP 23808</td>
<td></td>
<td>219.30(4.18)</td>
<td>21.62</td>
<td>$+0.0196$</td>
<td>0.825(45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V335 Peg.......</td>
<td>EW/A</td>
<td>HD 216417</td>
<td></td>
<td>$-15.41(0.43)$</td>
<td>44.61(0.27)</td>
<td>2.47 $52,330,164(15)$</td>
<td>0.810720</td>
<td>0.262(4)</td>
<td></td>
</tr>
<tr>
<td>F5V</td>
<td></td>
<td>HIP 105882</td>
<td>$-26.11(3.43)$</td>
<td>80.01(2.46)</td>
<td>8.87 $52,248,298(34)$</td>
<td>0.579027</td>
<td>0.289(16)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes.—The spectral types given in the second column are all new and relate to the combined spectral type of all components in a system. The convention of naming the binary components in this table is that the more massive star is marked by the subscript "1" so that the mass ratio is defined to be always $q \leq 1$. Figs. 1–3 should help identify which component is eclipsed at the primary minimum. The standard errors of the circular solutions in the table are expressed in units of last decimal places quoted; they are given in parantheses after each value. The center-of-mass velocities ($V_0$), the velocity amplitudes ($K_1$), and the standard unit-weight errors of the solutions ($e$) are all expressed in kilometers per second. The spectroscopically determined moments of primary minima are given by $T_0$; the corresponding $O - C$ deviations (in days) have been calculated from the most recent available ephemerides, as given in the text, using the assumed periods and the number of epochs given by $[E]$. The values of $(M_1 + M_2) \sin^3 i$ are in solar mass units.

* V1363 Ori: early to mid F type.
respectively, as listed in Table 1. The component eclipsed at the minimum corresponding to phases of available observations that were not used in the solutions because of the blending of lines. All panels have the same vertical range phase interval 0.0–0.5. The open symbols indicate observations contributing half-weight data in the solutions. Short marks in the lower parts of the panels show to be G5 V. Radial velocity curves obtained by Hrivnak (1988) seven spectra; therefore, this result was rather preliminary.

The results were modiﬁed to include proximity effects. The measured radial velocities gave the following orbital parameters: \( K_1 = 130.3 \text{ km s}^{-1} \), \( K_2 = 265 \text{ km s}^{-1} \). An extensive discussion on the system with the combined light and radial velocity solution was presented by Hrivnak (1988), who classiﬁed the spectral type of AB And to be G5 V. Radial velocity curves obtained by Hrivnak (1988) were modiﬁed to include proximity effects. The measured radial velocities gave the following orbital parameters: \( V_0 = -24.6 \pm 0.9 \text{ km s}^{-1} \), \( K_1 = 115.7 \pm 0.7 \text{ km s}^{-1} \), and \( K_2 = 235.7 \pm 1.5 \text{ km s}^{-1} \).

For the preliminary moment of eclipse \( T_0 \), as referred to in Table 2, we used the moment of Pribulla et al. (2002). Similar to the previous researchers, we ﬁnd the system to be a W-type contact binary. Our spectral type, G8 V, is slightly later than the spots and partly because of the small number of calibrated light curves even for this popular system.

The Hipparcos parallax, 8.34 ± 1.48 mas, gives the distance of 120 ± 20 pc. The observed proper motion is moderately large (Hog et al. 2000), resulting, for the assumed distance, in tangential velocities of \( V_{\text{RA}} = 109 \text{ km s}^{-1} \) and \( V_{\text{decl}} = -53 \text{ km s}^{-1} \) and the combined spatial velocity of \( V = 74 \text{ km s}^{-1} \). Because the observed variability of the period and of \( V_0 \) can be interpreted as an inﬂuence of a companion, the parallax may be incorrect; the large error is consistent with that. The direct, parallax-based estimate of \( M_\text{P} \) = 4.1 ± 0.4 marginally agrees with the one from the absolute-magnitude calibration (Rucinski & Duerbeck 1997), \( M_\text{P}(\text{cal}) = 5.0 \); however, \( V_{\text{max}} = 9.5 \) is also poorly deﬁned, partly because of the spots and partly because of the small number of calibrated light curves even for this popular system.

The masses of the components are very well deﬁned, \( M_1 \sin^2 i = 1.06 M_\odot \) and \( M_2 \sin^2 i = 0.59 M_\odot \), and are surprisingly large for components of a G8/K2 contact system. We have seen a very similar situation in AH Vir (Lu & Rucinski 1993), which is also a system consisting of massive but unusually cool components. It is very likely that the strong magnetic activity of AB And and AH Vir may have something to do with this anomaly.
2.2. V402 Aur

V402 Aur was discovered as a variable by Oja (1991) during an UBV photometric survey of astrometric standard stars. The light curve and ephemeris were published 3 years later (Oja 1994). The spectral type derived from Henry Draper Extension Charts is F0 (Nesterov et al. 1995). Spectral type in the SIMBAD database is F2. The spectral type corresponding to \(B-V=0.40\) derived from the Tycho-2 catalog (Hög et al. 2000) is F3-4. Our new spectral type is F2V.

The mass ratio is small, \(q = 0.20\). Similar depths of the eclipses and the well-defined broadening functions strongly suggest that V402 Aur is a contact binary of the W type (with the assumed moment of the primary eclipse, as referred to in Table 2 of Pribulla et al. 2002). The small sum of the masses for an early-F system, \((M_1 + M_2) \sin^3 i = 0.99 \pm 0.03 M_\odot\), is consistent with the small photometric amplitude of 0.17 mag, both being due to the low inclination of the orbit.

2.3. V445 Cep

Variability of V445 Cep was discovered by Hipparcos. The light curve and ephemeris were published 3 years later (Oja 1994). The spectral type derived from Henry Draper Extension Charts is F0 (Nesterov et al. 1995). Spectral type in the SIMBAD database is F2. The spectral type corresponding to \(B-V=0.40\) derived from the Tycho-2 catalog (Hög et al. 2000) is F3-4. Our new spectral type is F2V.

The mass ratio is small, \(q = 0.17 \pm 0.01\), is small. We also find a very small value of \((M_1 + M_2) \sin^3 i = 0.134 \pm 0.006 M_\odot\). This result, together with small photometric amplitude, suggests a small inclination angle of the orbit. The system seems to be a contact binary, but small amplitudes of radial velocities and photometric variability make it difficult to derive the orbital parameters.

The results of low-resolution spectroscopic observations were presented by Grenier et al. (1999). The star was classified as A2 V. The radial velocity of the whole system \(V_\text{r} = 38.6 \pm 9.6 \text{ km s}^{-1}\) is in a good agreement with our \(V_0 = 40.69 \pm 0.95 \text{ km s}^{-1}\).

The color index \(B-V = 0.123\) was found in the Tycho-2 catalog (Hög et al. 2000). This corresponds to a spectral type A4. Our spectral type is A2 V. The system is bright, \(V_\text{max} = 6.82\), which, together with the Hipparcos parallax, gives \(M_V = 1.58 \pm 0.13\). Thus, this is one of the best-determined luminosities for an A spectral-type contact binary.

2.4. V2082 Cyg

This star was listed as a variable candidate by Hoffleit (1979). Its variability was confirmed by Hipparcos. The light curve from Hipparcos has a small amplitude of only 0.05 mag and similar depths of the eclipses. We used the Hipparcos data for the preliminary \(T_0\).

The spectral type of V2082 Cyg in the SIMBAD database is F0, while our spectral type is F2V. \(B-V = 0.313\) from the Tycho-2 catalog (Hög et al. 2000) corresponds to the spectral type F1. V2082 Cyg is most probably an A-type contact binary.
although the secondary component is faint (the relative luminosity from the broadening function, $L_2 = 0.10 \pm 0.02$), so that we cannot exclude a semidetached configuration. The system must be viewed at a very low inclination angle, which would explain the small photometric and radial velocity amplitudes, leading to poorly resolved broadening functions, with the partly merged signatures of both components (see Fig. 4).

The radial velocity of the system was previously measured by Layden (1994) at low resolution, $V_r = 75 \pm 30$ km s$^{-1}$. The radial velocity was also measured again by Solano et al. (1997), and the result $V_r = 24 \pm 3$ km s$^{-1}$, is in agreement with our result $V_r = 26.11 \pm 3.43$ km s$^{-1}$ within the respective errors. The moment of the primary eclipse referred to in Table 2 was taken from the Hipparcos catalog.

2.6. V918 Her

Variability of this star was discovered by Hipparcos. The spectral type of this star in the SIMBAD database is A2. Grenier et al. (1999) classified its spectrum as A5 V. Our spectral classification of V918 Her is A7 V. The $B-V$ index from the Tycho-2 catalog (Hög et al. 2000) is 0.249 and corresponds to a spectral type A8/9 V, which may indicate some reddening.

The radial velocity of the system measured by Grenier et al. (1999), $V_r = -33.9 \pm 7.2$ km s$^{-1}$, is different from our result of $V_r = -25.72 \pm 0.74$ km s$^{-1}$.

We find the object to be an A-type contact binary. Otherwise the system is rather inconspicuous, but is bright, $V_{\text{max}} = 7.30$, and thus was included in the magnitude-limited sample of Rucinski (2002b). We have adopted $T_0$ from the Hipparcos catalog.

2.7. V502 Oph

V502 Oph was discovered to be an eclipsing binary by Hoffmeister (1935). The first ephemeris based on visual observations was published by Lause (1937). Over the years, the star has been the subject of numerous investigations. The light curve of the system is not stable and the orbital period was found to undergo a change in the years 1955–1966 (Binnendijk 1969). The period is successively decreasing, but the rate of the change observed in the years 1989–2003 has not been constant (J. M. Kreiner 2003, private communication). For Table 2, we adopted $T_0$ from the Hipparcos catalog. We found, however, that the orbital period from the Hipparcos catalog definitely does not fit our spectral data. We established that the period which fits our data best is 0.453390 days and this period was used for calculating the orbital elements in Table 2.

Observations of V502 Oph with the VLA revealed that it is a binary radio source (Hughes & McLean 1984). Since W UMa type systems usually show low radio activity (Rucinski 1995), this may suggest the existence of an optically undetected companion to the eclipsing binary system (Hughes & McLean 1984). The presence of a late-type tertiary component was in fact noticed in the spectrum of V502 Oph by Hendry & Mochnacki (1998).
The pioneering investigation on the radial velocity orbit of this W UMa type variable was done by Gratton (as described in Struve & Gratton 1948). The derived orbit elements based on these old observations, \( V_r = 37 \text{ km s}^{-1} \), \( K_1 = 95 \text{ km s}^{-1} \), and \( K_2 = 235 \text{ km s}^{-1} \), are surprisingly close to the values presented in Table 2. Radial velocity measurements presented later by Struve & Zebergs (1959) generally supported earlier results; the \(-13 \text{ km s}^{-1} \) shift in the mass-center velocity was considered insignificant in view of the low accuracy of the measurements. The spectra of the components were classified as G1 V for the primary and F9 V for the secondary component, reflecting the fact that this is a W-type contact system with a slightly hotter secondary.

The spectral type in the SIMBAD database is G2 V+. The spectral type of V502 Oph based on the Tycho-2 color...
index (Hög et al. 2000), $B-V = 0.615$, is G1, which is close to G0 V found by us.

2.8. V1363 Ori

The variability of V1363 Ori was discovered by Hipparcos. The spectral type derived from Henry Draper Extension Charts is F5 (Nesterov et al. 1995), while in the SIMBAD database it is F8. The $B-V = 0.56$ color index derived from the Tycho-2 catalog (Hög et al. 2000) corresponds to a spectral type of F9. For technical reasons, we were not able to obtain a good classification spectrum of the star; we can only confine it to the early to mid-F spectral type.

The light curve of this variable presented by Gomez-Forrellad et al. (1999) shows the O’Connell effect. This paper presents spectral classifications, radial velocity data, and circular orbital solutions for the eighth group of 10 close binary systems observed at the David Dunlap Observatory. All systems are double-lined (SB2) contact binaries. Half of the systems (V445 Cep, V2082 Cyg, V918 Her, V1363 Ori, V335 Peg) were discovered photometrically by the Hipparcos mission and two are well known, frequently observed contact systems (AB And, V502 Oph), which had been previously observed spectroscopically but for which our broadening function method permitted improvement of the orbital elements. We spectroscopically detected very weak companions of V2082 Cyg, KP Peg, and especially V335 Peg. We note that V445 Cep, V2082 Cyg, V918 Her, KP Peg, and V335 Peg are bright binaries with the observed $V_{\text{max}} < 7.5$. They were previously considered in the rigorously selected, magnitude-limited sample of Rucinski (2002b).

3. SUMMARY

This study was done while W. Pych held the NATO Postdoctoral Fellowship administered by the Natural Sciences and Engineering Council of Canada (NSERC); he also acknowledges the support from the Polish Grant KBN 2 P03D 029 23. The NSERC supported research of S. M. R. and of R. M. B. through a research grant to T. Bolton. W. O., G. S., and K. G. acknowledge the travel and subsistence support from the NATO collaborative linkage grant PST.CLG.978810, as well as the Polish KBN grant 2-P03D-006-22. The research has made use of the SIMBAD database, operated at the CDS, Strasbourg, France and accessible through the Canadian Astronomy Data Centre, which is operated by the Herzberg Institute of Astrophysics, National Research Council of Canada.

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