RADIO MAPS OF CONDENSATIONS IN H II REGIONS

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SUMMARY

High resolution maps of the H II regions DR 21, W 49A and W 3 have been made with the Cambridge One-Mile radio telescope at 5 GHz with a half-power beamwidth of 6.5 arc sec. Compact regions are clearly visible with sizes typically in the range 0.1-1.0 pc. The peaks of two of the condensations in W 49A are very close to OH emission regions, as is that of G 133.9 +1.1 in W 3, which has a turnover frequency of 18 GHz. Comparison of radio data with optical isophotes of W 3 indicates a range of at least 12 magnitudes in the obscuration for different parts of the source. The most obscured part contains a group of four condensations one of which has a clear ring structure 0.5 pc in diameter. By combining data from W 3, W 49, W 58 and DR 21 it is shown that the condensations are probably surrounded by neutral hydrogen and that some, at least, must contain more than one of the earliest type stars known. The time scale of evolution and the connection between H II condensations and subgroups of OB stars in associations is discussed. The discovery of a small continuum radio source close to the W 75(N) OH source is also described.

I. INTRODUCTION

It has recently become apparent that some H II regions contain compact condensations of ionized gas with electron densities one or more orders of magnitude greater than those of the surrounding diffuse regions. It has been suggested by Mezger et al. (1967a) that these condensations are the remnants of recently formed O stars. Condensations are often associated with regions of molecular activity and have so far been found in DR 21 (Ryle & Downes 1967), W 3 and W 49 (Mezger et al. 1967a), NRAO 591 (Hughes & Butler 1969) and W 58 (Wynn-Williams 1969b). Most of the evidence for the existence of these condensations has been based hitherto on analyses of the continuum radio spectra of the sources, since their angular diameters are in all cases much less than the beamwidth of any single-dish radio telescope.

In this paper new aperture synthesis observations of DR 21, W 49A and W 3 are described, made with the Cambridge One-Mile radio telescope. These display the structure of the sources in greater detail than has been possible previously and have allowed the properties of the condensations to be individually determined.

Maps of all three sources at 5 GHz are presented. At this frequency the half-power beamwidth is 6.5 arc sec in right ascension. Maps of DR 21 at 2.7 GHz and of W 3 at 0.4 and 1.4 GHz are also included, results for DR 21 and W 49 at 0.4 and 1.4 GHz having already been published (Ryle & Downes 1967; Wynn-Williams 1969a, hereafter called Paper I). In the final two sections of the paper the properties of the condensations described in this paper and a previous paper (Wynn-Williams 1969b, hereafter called Paper II) are compared and their evolution and relevance to the problem of star formation are discussed.
2. THE OBSERVATIONS

The operation of the Cambridge One-Mile radio telescope, which consists of one movable and two fixed 18-m paraboloids, has been fully described elsewhere (Elsmore, Kenderdine & Ryle 1966). Observations are usually made at two frequencies simultaneously; before the summer of 1968 at 0·4 and 1·4 GHz, latterly at 2·7 and 5·0 GHz, though because of technical difficulties no data are available for W 3 or W 49 at 2·7 GHz. At 5 GHz the response pattern of the telescope is a pencil beam with half-widths 6·5 arc sec in right ascension and 6·5 cosec δ arc sec in declination. Proportionally lower resolution is obtained at lower frequencies.

As in earlier papers, the declination scale of the maps has been compressed so as to make the synthesized beam appear circular. At 2·7 and 5·0 GHz 3C 147 was used as a calibration source with flux densities as given by Kellermann, Pauliny-Toth & Williams (1969): at 408 and 1407 MHz the calibration of the flux density scale is as described by Mackay (1969). Throughout the paper all coordinates are for epoch 1950.0.

3. DR 21

DR 21 is part of the diffuse H II region W 75 and is the most intense of the sources listed by Downes & Rinehart (1966) in their 5 GHz survey of the Cygnus X region. It is 3 arc min away from the OH source W 75(S) and was the first compact H II region to be recognized as such, having been studied over a wide range of frequencies by Ryle & Downes (1967), who also mapped the source at 1407 MHz with a resolution of 23 arc sec.

Figs 1 and 2 are the new maps of the source made during the summer of 1970 at 2·7 and 5·0 GHz with beamwidths of 12 × 18 and 6·5 × 9·7 arc sec respectively. The 5 GHz map shows the source to be double, confirming the result of Webster & Altenhoff (1970) at 2·7 GHz. The northern component is unresolved, and there is some evidence of a low density envelope around the source with a brightness temperature of about 300 K and a flux density of about 4 × 10^{-26} W m^{-2} Hz^{-1}. This envelope may represent a continuation of Ryle and Downes' component B, traces of which are visible at 2·7 GHz to the east of the source. The measured properties of the components are listed in Table I, the diameters being those of the uniform density ellipsoid of gas which would produce the observed broadening. This is a more useful parameter than the Gaussian width of a source, since it is directly related to the model used in Section 6.

### Table I

<table>
<thead>
<tr>
<th>Component</th>
<th>Declination</th>
<th>Brightness Temperature</th>
<th>Flux Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>20^h 37^m 14^s 3^a</td>
<td>&lt;4·5' x &lt;7'</td>
<td>1·0</td>
</tr>
<tr>
<td>Southern</td>
<td>20^h 37^m 14^s 3^a</td>
<td>14' x 22'</td>
<td>16</td>
</tr>
<tr>
<td>Envelope</td>
<td>-</td>
<td>~30'</td>
<td>4</td>
</tr>
</tbody>
</table>

Flux densities are in units of 10^{-26} W m^{-2} Hz^{-1}

The integrated flux densities of DR 21 are 14 and 21 × 10^{-26} W m^{-2} Hz^{-1} at 2·7 and 5·0 GHz, the accuracy being about 10 per cent. These values are in agreement.
FIGS 1 and 2. DR 21 at 2697 and 4993.8 MHz. The contour intervals are 420°K at 2697 MHz and 305°K at 4993.8 MHz.
with those of Wendker (1970) and Webster and Altenhoff (1970) at 2.7 GHz, and with those of Ryle & Downes (1967) and Reifenstein et al. (1970) at 5.0 GHz.

The spectrum of the source has been recently discussed by Downes, Maxwell & Rinehart (1970); it is thermal, optically thick at frequencies below about 5 GHz. The northern component has a flux density of $1.0 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ at 5 GHz, which, when compared with the value of $2.9 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ at 2.7 GHz determined by Webster & Altenhoff (1970), would at first sight indicate that it has a non-thermal spectrum. However comparison of the present map at 2.7 GHz (Fig. 1) with that of Webster and Altenhoff suggests that the latter authors have overestimated the brightness of the northern component, probably as a result of the poor sidelobe response of the N.R.A.O. instrument. Comparison of the 2.7 GHz map (Fig. 1) with the 5 GHz map after numerical smoothing to the same beamwidth supports the hypothesis that the northern component has a flat spectrum in this range and that it is probably another example of a compact H II region. As pointed out by Webster and Altenhoff the difference in the positions of the brightness peak at 1.4 GHz (Ryle & Downes 1967) and at 2.7 and 5.0 GHz may be explained by the difference in optical depth between the northern and southern components.

The peak brightness temperature of DR 21 at 2.7 GHz is 5500°K; this is a lower limit to its electron temperature. Because of the difficulty in determining the contributions of the low brightness envelope to the flux density at low frequencies it is not possible to make a useful estimate of the electron temperature from the angular size and optically thick flux density of the source. However there is no evidence that the temperature is significantly different from the typical values for Galactic H II regions of 10^4°K obtained by Hellming & Davies (1970).

The position of the W 75(S) OH source has been determined by Raimond & Eliasson (1969) to be $20^h 37^m 14.7^s \pm 0.4^s$, $42^\circ 12.09'' \pm 3''$. A second source, W 75(N), at $20^h 36^m 51.8^s$, $42^\circ 25.5^s$ has been found by Zuckerman et al. (1969) and by Rydbeck, Eldér & Kollberg (1969). The technique of source removal (Neville, Windram & Kenderdine 1969) was applied to the data available at 0.4 and 1.4 GHz (Ryle and Downes, private communication) as well as at 2.7 and 5.0 GHz to enable a search to be made for continuum emission from these positions.

### Table II

Flux densities of point sources close to the positions of OH emission in W 75

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>W 75(S)</th>
<th>W 75(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>408</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>1407</td>
<td>&lt;0.1</td>
<td>0.11 ± 0.03</td>
</tr>
<tr>
<td>2607</td>
<td>&lt;0.15</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>4993.8</td>
<td>&lt;0.15</td>
<td>&lt;0.2</td>
</tr>
</tbody>
</table>

Units are $10^{-26}$ W m$^{-2}$ Hz$^{-1}$

The results are summarized in Table II in the form of upper limits to the flux density of a point source close to the OH position. The limits for W 75(N) at 2.7 and 5.0 GHz are derived from direct observation rather than from a re-analysis of the DR 21 data. No significant emission was found from the W 75(S) source at any frequency but a small continuum source (diameter < 20 arc sec) was discovered close to the W 75(N) source at 1407 MHz. Its position, accurate to within ± 5 arc sec, is $20^h 36^m 51.3^s$, $42^\circ 27.23''$ (1950.0), and its proximity to the OH source is shown in

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Fig. 3. Since the radio spectrum of the source is unknown it cannot be concluded that it is a compact H II region, although Zuckerman et al. (1969) found 'marginally significant' emission of about $0.4 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ from close to this position at the much higher frequency of 8 GHz. It would clearly be of great value to ascertain the spectrum of the continuum emission and to obtain an interferometric position for the OH source.

![Diagram of W 75(N) OH and 1407 MHz contours]

**Fig. 3.** The region of sky around the W 75(N) OH source at 1407 MHz. The crosses show the position of the OH source as determined by Zuckerman et al. (1969—ZBDP) and by Rydbeck et al. (1969—REK). The contour interval is 16°K.

4. **W 49**

W 49 (3C 398) has been extensively studied by Mezger et al. (1967b) and by the author in a previous paper (Paper I). It was established that the source consists of a thermal component (A) with a complicated double structure, associated with two regions of OH emission, separated by about 12 arc min from component (B), a supernova remnant. From a study of its radio spectrum Mezger et al. (1967b) concluded that the thermal component contained one or more high density compact H II condensations.

It was decided to confine 5 GHz observations to W 49A only, because to have observed the whole source would have required 64 days observing time. As it was 16 days were needed to map just the brightest parts of W 49A, components A$_{51}$ and A$_{59}$ (Paper I). The weaker non-thermal component, W 49B, did not affect these observations because it fortunately lay close to the first minimum of the envelope polar response of the 18-m paraboloid.
Fig. 4. W 49A at 4995 MHz. The contour interval is 40 K and the crosses mark the positions of OH emission determined by Eliasson (1969).
Fig. 4 shows the map of the source at 5 GHz. The half-power beam of the telescope in this part of the sky is $6.5 \times 42$ arc sec, so that the declination scale is here compressed by a factor 6.4. The basically double character of the source is still evident, but it can be seen that the larger component, designated A51 in Paper I, consists of at least five components embedded in a more diffuse envelope. In Paper I it was shown that the overall east–west extent of the thermal component is 8 arc min when the easterly extension towards the non-thermal component is included. This is larger than the 5 arc min radius of the first grating ring, so that structure on this scale is lost in Fig. 4. A second disadvantage of the fact that only the brightest parts of the source were mapped is that any fine structure in the 1407 MHz easterly extension produces faint grating rings crossing the source from north to south, effectively causing fluctuations in the zero level of the map. To minimize this effect the zero level was redetermined by subtracting from each point on the map the mean sky brightness determined a few arc min directly north and south of the source. Fig. 4 is the final map produced after this process.

![Image](image.jpg)

**Fig. 5. Integrated east–west profiles of W 49A at 1407 and 4995 MHz after convolution to the same beamwidth.**

As a combined result of the loss of the low spatial frequency components and of the redetermination of the zero level the apparent flux density of W 49A is lower than has been obtained by previous observers at 5 GHz: integration of the brightness distribution of Fig. 4 yields a total flux density of $35 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$, which is significantly less than the values of $59.8 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ determined by Mezger et al. (1967b) and $54.7 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ determined by Gardner & Morimoto (1968). Although part of this discrepancy, up to 15 per cent of the measured flux density, may be attributed to noise and errors in calibration, it is evident that not all the low brightness regions of W 49A are fully represented in Fig. 4. This will not significantly affect the sizes, positions and flux densities of the compact H II condensations, which are the main objects of study in this paper. The measured parameters of these condensations are listed in Table III, the measured size in each coordinate being the diameter of a sphere of gas of uniform density which would produce the observed broadening of the beam.

In order to compare the new data with those described in Paper I the brightness distribution in Fig. 4 was convolved with a smoothing function so as to give it the
Measured parameters of condensations in W 49 A

<table>
<thead>
<tr>
<th>(a (\pm 0 \cdot 1\text{s}))</th>
<th>(\delta (\pm 10\text{s}))</th>
<th>Size</th>
<th>(S_{4995})</th>
<th>OH Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>(19^h 07^m 47^s 18^s)</td>
<td>(9^\circ 00' 10'')</td>
<td>(&lt; 7'' \times &lt; 40'')</td>
<td>2:0</td>
<td>—</td>
</tr>
<tr>
<td>(19^h 07^m 48^s 18^s)</td>
<td>(9^\circ 01' 45'')</td>
<td>(10'' \times 47'')</td>
<td>1:2</td>
<td>—</td>
</tr>
<tr>
<td>(19^h 07^m 48^s 15^s)</td>
<td>(9^\circ 00' 22'')</td>
<td>(&lt; 7'' \times &lt; 40'')</td>
<td>1:1</td>
<td>—</td>
</tr>
<tr>
<td>(19^h 07^m 49^s 95^s)</td>
<td>(9^\circ 01' 07'')</td>
<td>(&lt; 7'' \times &lt; 40'')</td>
<td>2:3</td>
<td>(19^h 07^m 49^s 9 \pm 0 \cdot 4^s) 9 (01' 18'\pm 2'')</td>
</tr>
<tr>
<td>(19^h 07^m 51^s 25^s)</td>
<td>(9^\circ 00' 10'')</td>
<td>(15'' \times &lt; 40'')</td>
<td>7:0</td>
<td>—</td>
</tr>
<tr>
<td>(19^h 07^m 58^s 30^s)</td>
<td>(9^\circ 00' 01'')</td>
<td>(11'' \times &lt; 40'')</td>
<td>6:0</td>
<td>(19^h 07^m 58^s 2 \pm 0 \cdot 4^s) 8 (59' 58'\pm 2'')</td>
</tr>
</tbody>
</table>

Flux densities are in units of \(10^{-26}\) W m\(^{-2}\) Hz\(^{-1}\) and are accurate to about 15 per cent. OH positions are by Raimond & Eliasson (1969)

same resolution as at 1407 MHz. The resulting brightness distribution, integrated over the declination range of the source, is compared with that at 1407 MHz in Fig. 5, the areas under the curves being proportional to the integrated flux densities at the appropriate frequencies. In order to allow for the loss of the lowest spatial frequency components at 5 GHz, the zero level of the 5 GHz profile has been raised to the level of the low brightness extension east of 19\(^h\) 08\(^m\) 05\(^s\). This displacement is somewhat artificial, but not unreasonable in view of the discussion in Paper I about the possible existence of a continuation of the easterly extension around components A\(_5\) and A\(_9\). Fig. 5 shows that condensations 5 and 6 (Table III) are still self-absorbed at 1407 MHz and that there is probably some self-absorption elsewhere in the source as well. In view of the uncertainty of the zero levels of the profiles the low value for the 5 GHz flux density near 19\(^h\) 07\(^m\) 57\(^s\) is probably not significant, and cannot be taken to imply the presence of non-thermal emission in the source.

The crosses in Fig. 4 mark the positions of the centres of OH emission in W 49A as determined by Raimond & Eliasson (1969). It can be seen that they are very close to the peaks of emission from condensations 4 and 6 (Table III). Intense H\(_2\)O emission has been observed close to the OH source associated with condensation 4 (Cheung et al. 1969), but none from the other OH source. Condensation 4 is not resolved in either direction and, because of its proximity to the brighter condensation 5, it is not possible to tell whether it is self-absorbed at 1400 MHz. Condensation 6, however, which is associated with the second of the OH sources is quite strongly self-absorbed, and it may well have structure on a scale finer than can be discerned in Fig. 4. The physical conditions in the condensations are discussed in Section 6.

5. W 3

Observations at 1.95 cm with the N.R.A.O. 140-foot telescope (Mezger et al. 1967a, Schraml & Mezger 1969) showed that the radio emission is concentrated in three separate regions. Two of these are associated with sources of molecular line emission and new data on them are presented here. The first, G 133.7 + 1.2, which is the strongest source of continuum emission in W 3 and is associated with strong water vapour (Knowles et al. 1969) and weak OH emission (Turner 1970), has been mapped in this paper at 408, 1407 and 4995 MHz. The second, G 133.9 + 1.1, which is strong at both OH and H\(_2\)O frequencies, has been mapped at 4995 MHz only, being too faint at lower frequencies. Since the continuum emission from the latter is so weak and was discovered only after a careful search (Mezger et al. 1967a)
it has become customary to refer to it as W 3(OH) to distinguish it from the more extensive and more powerful W 3 (continuum) source. They are discussed separately below.

(a) W 3 (continuum) – G 133·7 + 1·2

Fig. 6 shows the 408 MHz map of G 133·7 + 1·2 made in 1967 with a resolution of 80 × 91 arc sec. The technique of Neville et al. (1969) has been used to remove a grating ring from component G 133·8 + 1·4 which originally crossed the map. The source has an overall size of about 6 × 9 arc min and an integrated flux density \((20 \pm 3) \times 10^{-28} \text{ W m}^{-2} \text{ Hz}^{-1}\). It can be divided into two main regions of interest (i) the diffuse southern part, below declination 61° 51′, which is very faint at 1407 and 4995 MHz, and (ii) the compact northern part which is self-absorbed at 408 MHz and has been mapped in greater detail at higher frequencies. The H 109α recombination line map of Rubin & Mezger (1970) displays no systematic changes in the radial velocity of the H II in this region, so there is no evidence to suggest that the northern and southern regions are physically distinct.

![Figure 6. W 3 (continuum) at 408 MHz. The contour interval is 178°K.](image)
Radio maps of condensations in H II regions

FIGS 7 and 8. W 3 (continuum) at 1407 MHz and 4995 MHz. The contour intervals are 400 K at 1407 MHz and 220 K at 4995 MHz.
(i) The diffuse southern component. This component has an indication of a ring structure with a diameter of 4.5 pc at a distance of 3 kpc (Reifenstein et al. 1970). To obtain the spectral index of this region its brightness temperature was compared with that of the corresponding region in the 15.4 GHz map of Schraml & Mezger (1969). The brightness temperature $T_B$ is related to the mean spectral index $\alpha$ by the relation

$$T_B \propto \nu^{-(2+\alpha)}$$

With $T_{408} = 1000^\circ$K and $T_{15400} = 1.0^\circ$K a value of $\alpha$ of $-0.1$ is obtained. A 50 per cent error in either brightness temperature corresponds to a change in $\alpha$ of $\pm 0.2$. The fact that $\alpha$ is close to zero indicates that the emission from the diffuse southern region is almost certainly thermal, although it would not be out of the question that this part of the source is a supernova shell with a very flat spectrum.

The brightness temperature at 408 MHz indicates that the emission measure is about $4 \times 10^4$ pc cm$^{-6}$, assuming an electron temperature of $10^4$K. With a diameter of 4.5 pc the electron density of the region is about 100 cm$^{-3}$, a value which is reasonable for a diffuse H II region. The large rectangle in Plate I, reproduced from the red Sky Survey print, represents the area covered in the 408 MHz map and it can be seen that there is considerable H$\alpha$ emission corresponding to the southern radio component.

H$\alpha$ isophotes have been published by Ishida & Ohashi (1967) and analysed by Ishida & Kawajiri (1968). From these it may be seen that there is a peak in the optical brightness around 02$^{h}$ 22$^{m}$, 61$^\circ$ 48$'$ that corresponds approximately to the radio source. Comparing the radio and optical brightness by applying the formulae given by Ishida and Kawajiri shows that the obscuration here is about 3 magnitudes at the wavelength of H$\alpha$. There is a second peak of optical emission some 8 arc min to the east where the radio brightness temperature is less than $300^\circ$K at 408 MHz. This means that the obscuration is less than 2 magnitudes at this point.

In their search for possible exciting stars in H II regions Higgs & Ramana (1968) found only two candidates in W 3; BD $+61^\circ$ 417 and BD $+61^\circ$ 411. Of these the first, a BO star, is too far east to cause significant ionization in G 133.7+1.2. The other star, BD $+61^\circ$ 411, whose position is marked on Plate I, is an O8 star with a total extinction ($A_v$) of 3.9 magnitudes (Sato 1970). The excitation parameter for the diffuse southern component is 77 pc cm$^{-2}$, which is larger than the value calculated for an O8 star of 30 pc cm$^{-2}$ (Rubin 1968) or 72 pc cm$^{-2}$ (Prentice & ter Haar 1969). Since because of geometric effects only about 10 per cent of the ionizing photons from BD $+61^\circ$ 411 reach G 133.7+1.2 it may be concluded that the southern component contains hidden sources of ionizing radiation.

(ii) The compact northern components. The smaller rectangle inside the large one in Plate I represents the area of the 1407 and 4995 MHz maps (Figs 7 and 8), which correspond to the northern part of the source in Fig. 6. The 1407 MHz map, with a resolution of 23 x 26 arc sec, was made simultaneously with that at 408 MHz; that at 4995 MHz, with a resolution of 6.5 x 7.4 arc sec, in the autumn of 1969. Eight aerial spacings were used at 1407 MHz, and 16 at 4995 MHz; in both cases interference by grating rings prevented mapping of the low brightness southern region. It was, however, possible to establish that nowhere in that area were there peaks with sky brightness temperatures comparable with those of the three components visible in Fig. 7. Neither was there any sign at 1407 MHz of any such
PLATE I. Reproduction of the red Sky Survey print of W 3 (IC 1795). The small rectangle on the left represents the area of the map of the OH source (Fig. 10). The other two rectangles represent the areas of the maps of the continuum source at 408 MHz (the large rectangle) and 1407 and 4995 MHz (the smaller rectangle). The white cross marks the position of the O8 star BD +61° 411.
components in the region of G 133·8 + 1·4, the third main component of Schraml and Mezger, although the presence of grating rings again prevented the mapping of this component at either frequency.

Figs 7 and 8 show that at least four compact components are present in the centre of W 3, superimposed on a fluctuating background which is probably an extension of the diffuse southern region. The measured parameters of the condensations are listed in Table IV and their radio spectra, derived from the observations at three frequencies, are shown in Fig. 9. The three strongest components all have thermal spectra: that of the weakest, C, is uncertain since its flux density was only measurable at one frequency. Except for component A, the large shell shaped condensation, the widths in each direction in Table IV represent the diameter of the optically thin sphere of gas of uniform density which would produce the same

![Graph showing radio spectra of condensations in W 3](image)

**Fig. 9.** The radio spectra of the condensations in W 3. The 15·4 GHz W 3(OH) point is from Schraml & Mezger (1969).

**Table IV**

<table>
<thead>
<tr>
<th>Component</th>
<th>Size</th>
<th>Flux Density (10⁻²⁹ W m⁻² Hz⁻¹)</th>
<th>S_408</th>
<th>S_1407</th>
<th>S_4995</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>61° 52' 49 ± 5''</td>
<td>45'' × 35''</td>
<td>1·7</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>B</td>
<td>61° 52' 21 ± 2''</td>
<td>15'' × 18''</td>
<td>&lt;0·4</td>
<td>2·2</td>
<td>8·3</td>
</tr>
<tr>
<td>C</td>
<td>61° 52' 46 ± 2''</td>
<td>&lt;4·5'' × &lt;5·2''</td>
<td>&lt;0·4</td>
<td>0·6</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>61° 52' 55 ± 2''</td>
<td>15'' × 21''</td>
<td>0·9</td>
<td>1·9</td>
<td>2·2</td>
</tr>
<tr>
<td>OH</td>
<td>61° 38' 56·8 ± 0·5''</td>
<td>&lt;4·5'' × &lt;5·2''</td>
<td>—</td>
<td>—</td>
<td>0·4</td>
</tr>
</tbody>
</table>

Flux densities are accurate to about 15 per cent, and are in units of 10⁻²⁹ W m⁻² Hz⁻¹.

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broadening as is observed in Fig. 8. In the case of component A the size is a direct estimate of the overall extent of the source.

The brightest parts of W 3 have been observed by Webster & Altenhoff (1970) with the N.R.A.O. interferometer at 2.7 GHz. The position of their component 1 agrees well with that of component B of this paper, but their analysis of component A into four smaller Gaussian components does not seem to be justified by the appearance of the source in Fig. 8. Nevertheless their flux densities of components A and B, of 26 and $3.8 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$, agree quite well with the spectra in Fig. 9. Schraml & Mezger (1969) concluded that at 15.4 GHz the whole region represented on the 408 MHz map had a flux density of $64 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$, while the brightest part, roughly corresponding to the four condensations now visible, had a flux density of $35 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$. The approximate agreement between the latter value and the value of $42 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ obtained in this paper confirms that there is not much self-absorption at 5 GHz. Other radio observations of W 3 are all of too low a resolving power to enable a useful comparison to be made with the present results.

An interesting feature of the group of condensations is that one of them, component A, has such a well-formed shell structure, with thickness about one third of its diameter. Despite its appearance, the possibility that the source is a supernova remnant is ruled out completely by its radio spectrum (Fig. 9); if the turnover at 3 GHz were caused by synchrotron self-absorption a magnetic field of some $10^{11}$ Gauss would be required in the shell. This is quite unreasonable, so it may be confidently concluded that component A is an H II condensation with a low density region at its centre. This is unusual in H II regions and has not been observed on such a small scale before; the Rosette nebula, the ‘classic’ shell H II region, is 32 pc in diameter (Menon 1962), whereas component A has a diameter of only about 0.4 pc.

As can be seen in Plate I all four condensations are located in a region of very high optical obscuration. According to Ishida & Kawajiri’s (1968) data, the H$\alpha$ flux density here is less than $3 \times 10^{-8}$ erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$, while the radio brightness temperature reaches 3000 K at 5 GHz in the centre of component B. The calculated obscuration at this point is 12.5 magnitudes at H$\alpha$ wavelengths, which corresponds to a total absorption ($A_V$) of 14.7 magnitudes (Johnson 1968). There is thus an enormous range of obscuration in W 3 and a very uneven distribution of dust. The location of this dust and its connection with the structure of the component A are discussed further in Section 6.

The position of the H$_2$O emission is given by Knowles et al. (1969) as 02h 21m 51s, 61° 52′ 2 with an uncertainty of $\pm 1$ arc min. The weak OH emission originates from the same point (Turner 1970). This is close to component B but it is not yet possible to associate the molecular emission confidently with any particular condensation. Nevertheless, the presence of such a clear group of compact H II regions so close to a region of molecular activity is highly significant and, in view of the divergent appearance and properties of the four condensations now visible, it would be of great interest if the position of the H$_2$O emission were measured more accurately.

(b) $W 3(OH) - G 133.9 \pm 1.1$

Separate observations were also made of the W 3 (OH) source, the compact H II region first discussed by Mezger et al. (1967a). Fig. 10 is the map obtained from a
4-spacing synthesis with the One-Mile radio telescope at 5 GHz. The source is unresolved and has a flux density of \((0.4 \pm 0.1) \times 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}\). According to Schraml & Mezger (1969) the 15.4 GHz flux density is \(3.0 \times 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}\), which indicates that the source is self-absorbed at 5 GHz. Above 15 GHz its spectrum is uncertain, although data in the paper by Mezger et al. (1967a) indicate that the source is optically thin at that frequency. Observations of this source at higher frequencies are obviously desirable.

![Radio map of W 3(OH) at 4995 MHz](image)

**Fig. 10.** W 3(OH) at 4995 MHz. The northern and southern crosses are the OH positions determined by Raimond & Eliasson (1969) at 1667 and 1665 MHz respectively. The contour interval is the same as that in Fig. 8.

The two crosses in Fig. 10 represent the centres of OH emission as determined by Raimond & Eliasson (1969), the northern and southern being the mean positions at 1667 and 1665 MHz respectively. The position of the peak of the 5 GHz continuum radiation given in Table IV is derived from an examination of the phase variation of the fringes at the maximum spacing used, and is accurate to about 0.5 arc sec in each coordinate. Raimond and Eliasson quote a position for the 1665 MHz emission source of:

\[ 02^h 23^m 16.8^s \pm 0.2^s \]
\[ 61^\circ 38' 54'' \pm 1'' \]

The 1665 MHz source is coincident with the 1667 MHz position to within 2 arc sec, and with the H$_2$O position to within 1 arc min (Knowles et al. 1969). There is thus a discrepancy of about 2.5 times the mean error between OH and H II continuum positions. This is probably not significant in view of the work of Moran et al. (1968) who showed that the OH emission originates in several sources spread over 1.2 arc sec in right ascension and 2.3 arc sec in declination. Also, if a temperature of $10^4$ K is assumed for its brightness temperature when optically thick, the mean diameter of the continuum source must be 1.7 arc sec. The discrepancy in position is therefore comparable with the observed sizes of the OH and H II sources so that their positions may, in fact, coincide. More accurate values for the absolute positions of the components of OH emission would now be of value.
6. INTERPRETATION OF THE RESULTS

(a) Physical conditions in the condensations

Mezger & Henderson (1967) have given formulae showing how, from a knowledge of the free-free flux density ($S_{ff}$), the angular size ($\theta$), the distance ($d$) and the electron temperature of an H II region, it is possible to estimate a value for its electron density ($N_e$) if a simple model is assumed. In Table V the derived parameters of all the condensations observed in this paper and in Paper II are listed. For comparison purposes the table also includes the Orion nebula, M 42, data for which are taken from the work of Schraml & Mezger (1969). In all cases the calculations are based on a model of a uniform sphere of gas of constant electron density with an electron temperature of $10^4$ K, which is typical of diffuse H II regions (Hjellming & Davies 1970). Except for W 3(OH) and W 58A the diameters quoted are derived directly from the maps and represent those of optically thin spheres of gas of uniform density which would give the observed half-widths when convolved with the beam of the telescope. For this reason the diameters for the components of W 58 are larger than the Gaussian diameters given in Paper II. In the case of W 3(OH) and W 58A, the optically thick parts of their spectra were used to estimate their angular size, again assuming an electron temperature of $10^4$ K. In most cases the diameters given in Table V are the means of the north-south and east-west diameters but for W 49, where the north-south resolution is poor, the east-west diameter alone has been used. The distances to the nebulae are in general derived from their radial velocities, and have been taken from papers by Schraml & Mezger (1969), Reifenstein et al. (1970) and Thompson, Colvin & Hughes (1969). As discussed by Thompson et al., the distance to DR 21 is very uncertain. Also included in Table V are the derived values of the emission measure through the centre of the condensation ($E_0$), the mass of ionized hydrogen it contains ($M_{HI}$), and its excitation parameter ($U$).

Fig. 11 shows the electron densities ($N_e$) of the condensations listed in Table V plotted against their diameters ($2R$), with lines of constant mass and constant excitation parameter superposed. The excitation parameter, $RN_e^{2/3}$, is a measure of the total number of ionizing photons emitted by the exciting stars, and is nearly independent of the diameter of the source and of any assumptions about its geometry. Since, in most cases, the diameter of a source is less well known than its flux density or distance, observational errors will tend to shift the points in Fig. 11 along lines of constant excitation parameter. The five condensations for which only an upper limit is known for the diameter will behave similarly.

Fig. 11 shows that there is a negative correlation between the density and size of an H II condensation, with the small ones tending to have the higher densities. H II condensations, being both hot and dense, will expand whether or not they are surrounded by either neutral or diffuse ionized gas. Depending on whether it is ionization bounded or density bounded an H II region will expand along a line of constant excitation parameter (i.e. constant rate of ionization and recombination) or constant mass. Fig. 11 shows that there is a range of about $10^8$ in the masses of the ionized condensations, but that the range of the excitation parameters is much smaller. If the condensations are to be regarded as representative of a single class of object then the simplest explanation for the above result is that the condensations are ionization bounded and are expanding into a region of neutral gas rather than straight into the diffuse H II region usually found surrounding these objects.
### Table V

**Derived physical parameters of H II condensations**

<table>
<thead>
<tr>
<th>Source</th>
<th>$S_{ff}$</th>
<th>$d$</th>
<th>$\theta$</th>
<th>$2R$</th>
<th>$N_e$</th>
<th>$E_c$</th>
<th>$M_{H II}$</th>
<th>$U$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(10^{-26} W m^{-2} Hz^{-1})</td>
<td>(kpc)</td>
<td>(arc sec)</td>
<td>(pc)</td>
<td>(10^3 cm^{-3})</td>
<td>(10^6 pc cm^{-6})</td>
<td>(M_\odot)</td>
<td>(pc cm^{-2})</td>
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<td></td>
</tr>
<tr>
<td>Northern</td>
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<td>3</td>
<td>&lt;6</td>
<td>&lt;0.087</td>
<td>&gt;17</td>
<td>&gt;26</td>
<td>&lt;0.15</td>
<td>29</td>
</tr>
<tr>
<td>Southern</td>
<td>16</td>
<td>3</td>
<td>17</td>
<td>0.25</td>
<td>15</td>
<td>52</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>14</td>
<td>&lt;7</td>
<td>&lt;0.48</td>
<td>&gt;9.0</td>
<td>&gt;39</td>
<td>&lt;13</td>
<td>103</td>
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<td>2</td>
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</tr>
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<tr>
<td>A</td>
<td>31</td>
<td>3</td>
<td>40</td>
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<td>1.7</td>
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<td>210</td>
<td>1100</td>
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</tr>
<tr>
<td>A</td>
<td>11</td>
<td>8</td>
<td>6</td>
<td>0.23</td>
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<td>33</td>
<td>1.3</td>
<td>0.95</td>
<td>1.1</td>
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<td>62</td>
</tr>
<tr>
<td>C</td>
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<td>8</td>
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<td>33</td>
<td>60</td>
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<tr>
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<td>270</td>
<td>0.65</td>
<td>2.3</td>
<td>3.5</td>
<td>8.4</td>
<td>57</td>
</tr>
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</table>

Data for Orion A are taken from Schraml & Mezger (1969).

$S_{ff}$ for W 58A is taken from Downes et al. (1970).
This conclusion must be regarded as very tentative because of the strong selection effects operating on the limited sample of H II regions. The most important of these is that lines of limiting flux density for optically thin sources at particular distances are parallel to the lines of constant excitation parameter, making condensations with excitation parameter less than 25 pc cm$^{-2}$ difficult to detect unless they are nearer than 3 kpc. However additional evidence for the hypothesis that the condensations are surrounded by neutral gas is given in the following section.

(b) Dust and gas surrounding the condensations

Some idea of the properties of the region of gas into which the condensations are expanding may be obtained from a further analysis of the obscuration in front of the four compact condensations in W 3. Schraml & Mezger (1969) have pointed out how common it is to find obscuring matter in H II regions, and in Paper II it was shown that the four components of W 58 have widely differing degrees of obscuration. It is therefore reasonable to assume that the dust in W 3 is physically related to the source.

As shown in Section 5 the obscuration in W 3 is at least 12 magnitudes greater in front of the condensations than elsewhere in the source. If it is assumed that the
obscurring layer is in the vicinity of W 3 it is possible to work out a minimum value for the mass of dust it contains. The projected area of the obscuring layer must be at least $0.6 \times 0.6$ pc$^2$ in order to hide component A. An assumed value for $A_\pi$ of $4 \times 10^4$ mag g$^{-1}$ cm$^2$ of dust (Allen 1964) leads to a total mass of $0.5M_\odot$ of dust. O’Dell, Hubbard & Peimbert (1966) have shown that in many, though not all, HI regions the concentration of dust is similar to that of interstellar space. Adopting a gas/dust ratio of 80, therefore (Allen 1964) the obscuring layer must contain $40M_\odot$ of hydrogen. Because of the geometry of the problem this value is a lower limit but is nevertheless considerably more than the mass of ionized gas in the condensations. This eliminates the possibility that all the obscuration is caused by dust associated with the ionized gas itself and supports the suggestion that this condensation borders onto a region of neutral gas.

Unless the obscuration is due to the fortuitous location of a particular small cloud in the line of sight the mass of gas associated with the W 3 condensations will be greater than $40M_\odot$. It is a reasonable hypothesis that the obscuring matter hiding the condensations completely surrounds them. Two plausible configurations for this obscuring matter are (i) in a cloud enveloping all four condensations and (ii) in shells surrounding each condensation separately.

Considering the first case, there is a definite suggestion in Plate I, and more particularly in Ishida & Kawajiri’s (1968) isophotes, that there is a particularly thick obscuring cloud around the position of the condensations with a diameter of about $2\frac{1}{2}$ minutes of arc. A cloud with this diameter ($\sim 2$ pc) would need a gas density of $5 \times 10^3$ cm$^{-3}$ and a mass of $500M_\odot$ to produce the required obscuration. This density is approximately the same as that of the H II gas in the condensations.

The second alternative, that the obscuration is in the form of a shell around each condensation, is in line with the observations by Reddish (1967) of dust-imbedded stars and the proposals by Davidson & Harwit (1967) that a shell of dust can be produced around a newly-formed star by the action of radiation pressure on the grains after the star first becomes luminous. If a shell of radius $R$ is produced by the expulsion of dust from a spherical region around the exciting stars, the surface density of dust in the shell is $M/4\pi R^2$ when $M$ is the mass of dust in the outward moving shell. A shell of diameter $0.6$ pc would under these circumstances need to contain the dust accumulated from $120M_\odot$ of gas to achieve the observed opacity. The mean density of the original un-ionized gas would have been about $4 \times 10^4$ cm$^{-3}$ which is not much more than is found in several of the compact condensations, and less than in the W 3(OH) source. If each of the four condensations in W 3 is surrounded by a similar cloud the total mass of neutral gas in W 3 is again about $500M_\odot$—more than this if some of the dust was destroyed by sputtering.

Both models therefore lead to the conclusion that there may be several hundred solar masses of neutral gas around the W 3 condensations. This is much more than the total mass of ionized gas in the nebula, including that of the diffuse regions, and means that the gas/star ratio is much higher than was suggested by Schraml & Mezger (1969). The gas could be atomic or molecular but, if atomic, should be detectable at 21 cm. The only available data are from the Maryland 21-cm survey (Westerhout 1969) but the resolution of these is too low to be useful, especially as there are features nearby which may be associated with the supernova remnant HB 3 (Caswell 1967) rather than the H II region. A high resolution study of the H I in W 3 and in other H II regions might settle this point.
(c) The ionization of the condensations

As stated in Section 6(a) the excitation parameter, $U$, derived for the condensations is only weakly dependent on the electron temperature and the model assumed. The values of this parameter in Table V are much more reliable than the masses or densities. The excitation parameter gives a direct measure of the number of ionizing photons absorbed by the nebula and is hence a most useful guide to the identity of the ionizing stars. Values of excitation parameters for early-type stars have been calculated by Rubin (1968) and by Prentice & ter Haar (1969). Those of the latter authors are considerably higher; for example Prentice and ter Haar calculate the value for an O5 star to be $95$ pc cm$^{-2}$, whereas Rubin’s value is only $65$ pc cm$^{-2}$. For less massive stars the discrepancy is even greater. Whichever of the values is assumed it may be concluded that at least 5 out of the 17 condensations listed in Table V have excitation parameters larger than those of the earliest main-sequence stars known in the Galaxy. Most of the other condensations require at least one O7 star to maintain their ionization. There are several possible explanations of this result.

(i) Some of the exciting stars are brighter than any known main sequence stars. The mass of an O5 star, about $35 M_\odot$ (Hjellming 1968), is still less than the $60 M_\odot$ limit of Schwarzschild & Härm (1959). It is therefore possible that stars earlier than O5 exist in the condensations. The optical rarity of such stars might be due to the frequency with which they are surrounded by dust clouds (Reddish 1967). It is also possible that the excitation is by very luminous non-main-sequence stars; Prentice & ter Haar (1969), for example, have calculated that the excitation parameter for the Wolf–Rayet star $\gamma^2$ Vel. is $232$ pc cm$^{-2}$, which is more than enough to ionize any of the condensations. However either explanation entails a substantial population of objects whose association with H II regions has not been established.

(ii) The exciting stars are main sequence stars in a temporary superluminous stage. As discussed in the following Section (6 (d)) the short ages of the condensations imply that the stars in their centres are still at an early stage of their evolution and may not yet be in their stable main-sequence configuration. Calculations (Hjellming 1968) for 15 and 30 $M_\odot$ stars indicate that, after the initial rise while the stars are contracting on to the main sequence, the excitation parameter does not vary by more than 20 per cent. There is no observational or theoretical evidence that contracting stars are at any stage superluminous in the ultra-violet.

(iii) The condensations are ionized by a group of stars. Clustering on a small scale is common among O and B stars and Blaauw (1964) has remarked on the tendency for them to form subgroups in associations and clusters. As is well known, the Orion nebula is ionized by the ‘Trapezium’ star cluster, a group of four O stars, and Strand (1958) estimated there to be $200 M_\odot$ of stars within a volume of 1.6 cubic parsecs in the middle of the nebula. Sharpless (1954) has compiled a list of O-type multiple systems of the Trapezium type and has pointed out that all O associations contain nuclear clusters characterized by multiple systems as in the Trapezium. It seems to be a feature of O stars that they are found in small groups such as these and therefore the most natural explanation for the large excitation parameters of the condensations is that each contains several, rather than only one, O stars. If so, the origin of H II condensations should not be identified as closely with that of Reddish’s (1967) highly reddened single cocoon stars as has been suggested by Mezger (1968) and others.
(d) Time scale of evolution of the condensations

There is as yet no direct way of estimating the ages of H II condensations. None of them has an associated stellar cluster, so any discussion of their lifetimes must be based on gas dynamics. Possible models for the evolution of compact H II regions have been discussed by Mathews (1969) and by Davidson (1970). Neither model is strictly applicable to the condensations described here since Mathews’ model is density bound for much of its life and Davidson’s model is very much dependent on the evolution of a single massive star at its centre.

Detailed discussions of gas dynamics are outside the scope of this paper but the discovery that at least one of the condensations, W 3 A, has a well-formed shell structure is a great help in estimating the time scale of its evolution. The dynamics of shell-type H II regions have been discussed by Mathews (1966, 1967), who proposed several mechanisms by which they might be generated. That most favoured by Mathews (1967) is similar to the one described by Davidson (1970). When a new star is formed its luminosity reaches a high value before its temperature has become high enough to ionize the surrounding gas. Interstellar grains are accelerated outwards by radiation pressure thereby sweeping the surrounding neutral gas into a shell by the action of viscous forces. As the new star contracts and becomes hot enough to emit ultra-violet photons, the gas in the shell becomes ionized and the velocity of sound in it increases dramatically. The ionized gas will now diffuse back into the hole in a characteristic time $R(\gamma - 1)/2c$ (Mathews 1967), where $R$ is the radius of the shell and $c$ is the velocity of sound. The existence of a visible shell is thus a transitory phase in the evolution of a condensation.

For W 3 A, where the shell has a maximum radius of 0.3 pc, this refilling time is about $10^4$ years. This represents an approximate upper limit to the time since the condensation began to be considerably ionized. This is also approximately the time taken by a newly formed $30 M_\odot$ star to contract far enough towards the main sequence to begin to emit an appreciable number of ionizing photons (Davidson 1970). The time taken for the dust shell to form depends very much on the density distribution in the neutral gas at a stage long before ionization is visible. Application of the formulae given by Mathews (1967) shows that a dust shell of radius 0.3 pc could form around a $30 M_\odot$ star enveloped in a cloud of density $10^6$ cm$^{-3}$ in about 30 000 years.

The only other observational evidence bearing on the time scale of evolution of H II condensations is what Mezger et al. (1967a) term the ’RMS turbulent velocity’ in DR 21, which was obtained from the Doppler broadening of the H 109α recombination line. If this velocity ($V_T$) is interpreted as an expansion velocity then a characteristic time for evolution of the source is $2R/V_T$. In the case of DR 21, where $V_T$ is 25 km s$^{-1}$, this time is $10^3$ yr, which is of the same order as the time scale in W 3 A. It must be pointed out, of course, that there is no real justification for interpreting $V_T$ as an expansion velocity since other motions in the gas, including rotation, are quite likely. However it is interesting that Thompson et al. (1969) were able to interpret one of the features in their H I absorption profile of DR 21 in terms of a thin shell of neutral gas surrounding the source with an expansion velocity of 20 km s$^{-1}$.

Thus there is some justification for believing that condensations a few tenths of a parsec across evolve significantly over periods of $10^4$ years. It is unwise to refer to this as the age of a condensation since $10^4$ years is comparable with the Kelvin–Helmholtz contraction time of their likely central stars with the result that condensa-
tions become visible comparatively gradually. Despite the lack of a dynamic model the time scales derived here are in broad agreement with those derived from the models of Davidson (1970) and Mathews (1969) for the evolution of high-density, dust-filled H II regions. A more detailed model would have to take account of the conclusion in Section 6(c) that some condensations contain several stars, presumably with different contraction times. This is bound to have an important effect since, in the mechanism described, the formation and dispersal of the shell depends on the time variation of the ratio of ultra-violet photons to the total number of emitted photons. It is therefore by no means certain that all condensations pass through a shell stage in their evolution.

(e) Condensations and stellar subgroups

Each of the H II regions discussed in this paper contains more than one compact component: two condensations have been found in DR 21, four in W 58, five in W 3 and six in W 49. Since it has been shown that many of the condensations contain more than one OB star it is tempting to think of these as progenitors of Blaauw’s (1964) subgroups in OB clusters and associations. The average mass of one of Blaauw’s subgroups, however, is 2,000 $M_\odot$, so unless the efficiency of star formation is very much higher than previously thought (as suggested by Schraml & Mezger 1969) it is unlikely that a single condensation together with its associated stars is massive enough to become a subgroup in its own right. Also the discussion in Section 6(d) implies that all the condensations in one H II region are formed within $10^5$ years at the most. This is two orders of magnitude less than the average lifetime of an association so that it is unlikely that groups of stars from neighbouring condensations would subsequently remain distinguishable as individual subgroups. It seems more probable that all the stars in a group of condensations will eventually form one subgroup, perhaps containing several multiple systems of the type described by Sharpless (1954). The estimate of the mass of neutral hydrogen around the condensations in W 3 supports this hypothesis.

7. Conclusions

From the study of H II condensations in this paper and in Paper II it is possible to draw the following general conclusions.

(i) The condensations are thermal. All condensations for which it has been possible to plot spectra show evidence of self-absorption. In W 49A self-absorption is visible in at least two resolved condensations and, in the discussion in Paper II, it was shown that most, if not all, of the components in W 58 have thermal spectra. Almost all the condensations have been resolved by the telescope and in no case does the observed brightness temperature exceed that of a blackbody at $10^{40}$K. It is thus unnecessary to invoke non-thermal emission mechanisms such as that suggested by Hughes (1969) involving synchrotron radiation from collapsing proto-stars, though this might be necessary to explain the very bright knots of emission whose existence in the H II region W 51 has been proposed by Miley et al. (1970).

(ii) The condensations are closely associated with clouds of dust and neutral gas. This conclusion is based on the observations discussed in Section 6 showing that (a) the condensations appear to be ionization rather than density bound, (b) there are large and varying amounts of obscuration associated with W 3 and W 58, and (c) that the shell structure in W 3A is most easily explicable as being the result of
radiation pressure on dust grains in the nebula. The mass of neutral gas in W 3 may be several times greater than the mass of ionized gas.

(iii) Each condensation is ionized by a group of stars rather than by a single star. As described in Section 6(c) the excitation parameter of several of the condensations is larger than that of any single star indicating that the gas is maintained in an ionized state by a group of OB stars. The short time-scales involved in the evolution of the condensations confirm that the gas they contain is part of the cloud out of which the stars were formed.

(iv) Condensations tend to be found in groups. This result was discussed in Section 6(e) and is immediately apparent from a glance at Figs 2, 4 and 8 of this paper and Fig. 1 of Paper II. This clustering is probably a result of processes connected with star formation but it is incorrect to regard H II condensations as progenitors of subgroups in OB clusters and associations.

(v) Condensations are close to OH sources. The connection between compact H II regions and OH centres has been discussed in several papers (Mezger et al. 1967a; Mezger & Robinson 1968). However, the studies of W 49A and W 3(OH) in this paper have revealed that there is a much closer positional agreement between them than has been assumed hitherto. In W 3(OH) the projected separation is no more than the sum of the physical sizes of the H II and OH regions, and the remaining observational errors do not necessarily preclude positional coincidence. In view of this association the discovery of a continuum radio source 2 arc min away from the W 75(N) OH source is particularly interesting, even though its spectrum has not yet been established. Unfortunately in neither W 3 nor W 49A is it yet possible to tell whether the OH emission comes from inside the H II region or from near its ionization front.

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