34. INTERSTELLAR MATTER AND PLANETARY NEBULAE (MATIÈRE INTERSTELLAIRE ET NÉBULEUSES PLANÉTAIRES)

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MONOGRAPH

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PLANETARY NEBULAE

G. S. Khromov

(Where possible, references are given according to the system used by *Astronomy and Astrophysics Abstracts*; an abbreviation '*LAS*, 1972' denotes papers reported at the *Liège International Astrophysical Symposium* of 1972.)

Radiation mechanisms

One of the most important recent contributions to the explanation of the optical radiation of planetary nebulae (PN) has come from photoelectric observations of the hydrogen spectrum of NGC 7027, by J. Miller (05.133.023). He showed that the apparent conflict between the observed and theoretical intensities of the higher Balmer lines in this object was due to observational errors; somewhat later this conclusion was confirmed by J. Kaler, S. Czyzak and L. Aller (06.133.023). This result is supported by the fact that all recent theoretical attempts to explain the contradiction have failed (van Blerkom, D., 02.133.015), M. Seaton (02.132.015), M. Brocklehurst and M. Seaton (*Monthly Notices*, 1972, **159**, 179). J. Miller (*LAS*, 1972) later showed that the exact intensities of the first Balmer lines in several PN agree with the theory as well, and there is no need to invoke corrections for self-absorption. Thus, within the precision of the best observations, there are no obvious discrepancies with the theory of the Balmer decrement (J. Miller and W. Mathews, *Ap.J.*, 1972, **172**, 593). This theory is presented in the most recent papers by M. Brocklehurst (03.132.006, 03.132.024) and seems to be complete.

Consequently there are now no difficulties of principle in the theory of the He II recombination spectrum, though the more complicated spectrum of He I still needs a better interpretation. Improved atomic data have made it possible reliably to calculate the populations of the He I levels, without taking into account the metastability of the 2^3S state (R. Robbins (03.132.020, 06.132.005), D. Cox and E. Daltabuit (06.022.003), M. Brocklehurst (*Monthly Notices*, 1972, **157**, 211)). The metastability of this state probably does not significantly influence the other levels; however the problem of the population of the 2^3S state, which is connected with the interpretation of the λ10830 line, has its own significance. S. Persson (04.132.003) and R. Robbins (04.132.030) have attempted to explain the low intensity of this line in PN in terms of absorption by dust. An improvement of the atomic data, and of the theory for the equilibrium of 2^3S state, makes this hypothesis redundant; recently G. Drake and R. Robbins (*Astrophys. J.*, 1972, **171**, 55) have obtained good agreement between the calculated and observed intensities of the λ10830 line in several objects.

Some years ago M. Seaton suggested that the weak permitted lines of some heavy ions originate as a result of direct excitation by the optical radiation of the central star of the nebula. This hypothesis has been given some additional support by J. Kaler (*Ap.J.*, 1972, **173**, 601); recently E. Leibowitz (*Monthly Notices*, 1972, **157**, 97 and 115) has suggested an independent observational test of this hypothesis, based on the detection of the weak polarization of the C IV-lines, which is a consequence of their radiative excitation.

Studies of the optical continua of PN have acquired a new significance in connection with the problem of the far-infrared emission. The papers by R. Brown and W. Mathews (03.132.036) and by H. Gerola and N. Panagia (04.132.007, 05.132.037) contain further developments of the theory of the optical continuum. The latter authors have shown that H^- radiation may become significant at low electron temperatures. Some new measurements of the continua of 16 PN in the region of the Balmer jump are reported by E. Kostjakova (04.133.018, 06.133.007, *LAS*, 1972). I. Danziger and L. Goad (*LAS*, 1972) have made photoelectric measurements of the continuum in the region $\lambda\lambda$3600–11000 for six planetary nebulae; R. Noskova (*LAS*, 1972) has measured the continuum of NGC 7027 in the region near λ9000. It seems that the theory of the optical continuum is now quite satisfactory. However, the precision of the latest observations is rather low; according to J. Miller and W. Mathews (*op. cit.*) it is not better than 20%. Observations of the weaker He I and He II continua (see J. Kaler, P. Lee and L. Aller (05.133.003)) should therefore be treated as being only qualitative.

The most exciting new results on planetary nebulae come from infrared observations. The measurements by G. Gillett and W. Stein (03.132.008), D. Rank *et al.* (04.133.010), F. Gillett, R. Knacke and W. Stein (05.132.003), F. Gillett, K. Merrill and W. Stein (*Ap.J.*, 1972, **172**, 367) have shown that far-infrared excesses in the continuum are common in planetary nebulae. Recently data have appeared on radiation at even lower frequency, in the region $\lambda\lambda$100–700μ (D. Harper and F. Low (05.131.060), J. Houck *et al.* (*Ap.J.*, 1972, **169**, 31)). Moreover we have obtained the first measurements of high-frequency infrared radiation at $\lambda\lambda$1·0–3·5μ (G. Khromov and V. Moroz (06.133.029), D. Allen (*LAS*, 1972), S. Persson and J. Frogel (*LAS*, 1972)). These observations show that infrared excesses appear only for $\lambda > 2{\cdot}2\mu$.

It is now generally agreed that these excesses are due to radiation by heated dust particles within or near the nebulae (see J. Mathis (03.132.001, 06.132.006), Krishna Swamy (04.131.037, 05.133.033), W. Kovach (06.133.011), J. Gürtler (*Astron. Nachr.*, 1971, **293**, 267), Y. Terzian and D. Sanders (*Astron. J.*, 1972, **77**, 350), D. Flower (*LAS*, 1972)). However it must be stressed that there is a lack of reliable data on the physical and chemical properties of the particles, and on their spatial distribution, and this makes the theory rather speculative. We urgently need an independent indication that there is actually dust present.

The original idea that the far-infrared radiation is due to the contribution from some infrared forbidden lines has now been abandoned. However, the idea has led to studies of the infrared emission-line spectrum. In the observational papers quoted above there are also data given concerning the intensities of some far-infrared forbidden lines. New computations have been published by D. Flower (03.133.011); but the agreement between the theory and observations is still rather poor. Some new observations of emission lines in the near-infrared were made by E. Kolotilov and R. Noskova (*Astron. Tsirc.*, 1972, No. 697), R. Noskova (*op.cit.*), Y. Andrillat, A. Baranne and M. Duchesne (*LAS*, 1972); the infrared spectrum of IC 418 up to 1·7μ was obtained by R. Kovar *et al.* (06.133.027).

Studies of the continuous radio emission from planetary nebulae are summarized in the catalogue by L. Higgs (06.133.032). It contains data for more than 550 PN, and radio spectra for more than 150 of them. New observations are still adding to these data (H. Johnson (*LAS*, 1972)). The relevant theoretical ideas, as well as the main observational data, have been discussed in a review by J. Heckathorn (05.133.027). (See L. Higgs (*LAS*, 1972)). Theoretical studies have shown that planetary nebulae are thermal radio emitters; the theory of this emission is in satisfactory agreement with observation. Observations of the radio lines are progressing well. Some unsuccessful attempts to detect high level recombination lines of hydrogen initiated a series of theoretical papers, in which this failure was explained by the large optical thickness at radio frequencies (L. Goldberg (03.133.005)), or by imperfections of the Stark theory (C. Wynn-Williams (04.133.001), D. Hoang-Bihn (05.133.001), M. Brocklehurst and S. Leeman (06.022.054)). However, recently R. Rubin and P. Palmer (05.133.022), Y. Terzian and B. Balick (*Astrophys. Lett.*, 1972, **10**, 41) and Goad and Chaisson (*LAS*, 1972) have definitely found the H 85α and H 94α lines. No significant discrepancies with the theory were noted, although the failure to detect the H 109α line still needs to be explained (Y. Terzian (*LAS*, 1972)).

A recent attempt to detect neutral hydrogen in some planetary nebulae by the 21 cm-line was unsuccessful (A. Thompson and R. Colvin (03.133.019)); however B. Turner (05.133.021) reported OH-radiation at 1667 MHz from NGC 2438. But E. Hardebeck (*Ap.J.*, 1972, **172**, 583) has cast doubt on this discovery.

Physical parameters

The determination of the main physical parameters of the material in planetary nebulae is the inverse problem to that of the interpretation of their observed spectra. It demands more detailed observational data and more refined models, and can be treated independently. The observational basis for the relevant studies is provided by optical spectra obtained at high dispersion and with a good signal-to-noise ratio. According to these criteria the most valuable recent publications are the papers by the Californian group (03.132.035, 04.133.022, 04.133.027, 06.133.009 and *Ap.J.*, 1972, **172**, 361) as well as the photoelectric measurements by M. Peimbert and S. Torres-Peimbert (06.133.005). A catalogue of the absolute intensities of the bright spectral lines in 171 PN has been published by B. Vorontsov-Veljaminov *et al.* (04.133.025), supplemented with similar measurements for 65 nebulae in the direction of the Galactic Centre (04.133.005, *LAS*, 1972). There are numerous publications of ordinary observations of selected nebulae, some of them in narrower spectral bands (see T. Krueger, L. Aller, S. Czyzak (03.132.034), C. O'Dell and Y. Terzian (03.133.027), L. Aller and M. Walker (04.132.018), L. Aller, S. Czyzak and E. Buerger (04.133.027), S. Tamura (05.133.024), L. Kondratjeva (06.133.008), H. Johnson (*LAS*, 1972), D'Odorico, V. Rubin, K. Ford (*A and A*, 1972, in press), M. Peimbert (*LAS*, 1972), Vray and Dossin (*LAS*, 1972) and others). A fairly complete review on the spectrophotometry of planetary nebulae is contained in a paper by J. Kaler (*LAS*, 1972).

Reliable atomic data are needed for the evaluation of the electron density and temperature from the relative intensities of the forbidden lines. Among the numerous relevant papers we refer to reviews by R. Garstang (06.022.101), A. Nikitin (06.061.012) and S. Czyzak and L. Aller (*LAS*, 1972). The soundest contribution to this field is the calculation of the collision strengths for ions with $3p^3$ configurations (S. Czyzak *et al.* (03.022.063)). This offers opportunities to make better use of spectrophotometric information (T. Krueger, L. Aller, S. Czyzak (03.132.034), H. Saraph and M. Seaton (03.133.020), L. Aller *et al.* (04.132.033), S. Czyzak *et al.* (*Proc. Nat. Acad. Sci.*, 1970, **66**, 282)). Estimates of N_e and T_e for different PN may be found in many publications. We note a study by M. Peimbert (06.133.006) because of the high precision of the observational data that he used, a paper by J. Kaler which includes more than 200 objects, and the catalogue by L. Higgs (*op.cit.*).

The best way to determine the complete set of the physical parameters of a planetary nebula is to compare the observed spectrum with one predicted by a model. Studies of this kind (see M. Perinotto (05.132.001, 06.132.004)) show that 'homogeneous' theoretical models are too crude. Unfortunately, nothing definite is known about the systematic variation of density with radius. The question of the reality of large-scale variations of T_e also remains open (see J. Gürtler (04.132.037), M. Perinotto (06.132.004), M. Peimbert, S. Tamura (*op.cit.*)). Doubts remain on the cause of the differences between temperatures determined from the radio continuum and from the forbidden lines (L. Higgs (*LAS*, 1972)). It seems probable that these discrepancies are not real, especially since there is good agreement between the temperatures determined from high-level recombination lines, the Balmer decrement and the forbidden lines (Y. Terzian and B. Balik, R. Rubin and P. Palmer, W. Mathews and J. Miller (*op.cit.*)).

To get better agreement between theory and observation some authors have included small-scale density fluctuations in their models (see R. Kirkpatrick (04.133.017)). But the precision of the theoretical spectra remains too low; obviously, because there are numerous uncertainties in the models (see D. Hummer and M. Seaton (*LAS*, 1972)).

Morphology, structure and dynamics

To study the morphology of PN one needs large-scale pictures in different spectral lines. Such pictures are found in papers by A. Vaughan (04.133.007), C. Hua and R. Louise (04.133.021), E. Capriotti, R. Cromwell and R. Williams (05.133.012), W. Ford and V. Rubin (05.133.020), R. Fisher and S. Cain (06.132.038), P. Proisy (*A and A*, 1972, **20**, 115), H. Eppis, H. Ford and L. Aller (priv. comm., 1972). A series of papers by W. Feibelman (04.133.019, 05.133.010, 06.133.025) presents photographs and isophotes in some spectral lines for eleven PN. Recently new morphological information has been derived from radio observations at high resolution (W. Webster, J. Wink and W. Altenhoff (04.133.006), M. Kaftan-Kassim (*LAS*, 1972)). In particular, these observations may give us information on the distribution of electron temperature and on the physical conditions in the inner parts of nebulae, where the optical emission is too weak. An optical and radio astronomical study of NGC 6888 by H. Habing *et al.* (in press) shows that the method is promising.

The inner structure of planetary nebulae is inhomogeneous and complicated, and there seem to exist small-scale fluctuations of density, temperature and ionization. A study of these fluctuations has been undertaken by R. Williams (03.133.008) and by E. Capriotti, R. Cromwell and R. Williams (*op.cit.*). A search for fluctuations in the forbidden lines of O II and A IV was proposed by R. Kirkpatrick (*LAS*, 1972); L. Aller and S. Czyzak (priv. comm) have noted that the Mg I 4571 Å line is a good indicator of low ionization regions. The origin of small condensations and filaments in diffuse and planetary nebulae has been considered by K. Nordsieck (05.132.023, 05.133.004), E. Capriotti (05.133.030) J. Hunter and S. Sofia (06.133.020). D. van Blerkom and T. Arny (*Monthly Notices Roy. Astron. Soc.*, 1972, **156**, 91) explain radial filaments as being regions screened off from the direct ionizing radiation by primeval dense blobs; G. Sage and M. Seaton (*LAS*, 1972) have shown that the heating of a shadowed region is entirely provided by the diffuse *Lc*-radiation. The origin of the blobs is explained by E. Capriotti (*Ap.J.*, in press) in terms of an instability of the ionization front in young planetary nebulae. A similar opinion has been expressed by W. Kovach (*op.cit.*), who considered the evolution of a young dust-filled nebula. But in general we know too little about small-scale condensations in planetary nebulae, and many theoretical models are based upon the structure of only one object-NGC 7293.

The morphology and the structure of planetary nebulae both depend on their dynamics. In addition to the traditional spectroscopic method of measuring radial velocities we now have interferometric methods; these are more sensitive, but harder to interpret. A careful study of the dynamics in IC 418 was made by D. Osterbrock (03.133.007), who, in particular, paid attention to some difficulties in the interpretation of the radial velocity picture, caused by the lack of a reliable three-dimensional model of an inhomogeneous expanding planetary nebula. The large nebula NGC 6853 has been studied most intensively by interferometric methods. T. Bohuski, M. Smith and D. Weedman (04.133.016), C. Hua and R. Louise (*op.cit.*), V. Doroshenko (05.133.031), J. Meaburn (06.133.001), A. Danks (06.133.030) all agree that this nebula resembles a thin expanding shell in the [N II] line, while in Hα and [O III] it is more like a thick expanding gas cloud with complex internal motions. Analogous conclusions have been reached by K. Taylor for NGC 7293 (priv. comm. by J. Meaburn, 1972) and by Ford and Rubin for NGC 7009 (*op.cit.*). The expansion of IC 3568 was studied by T. Bohuski *et al.* (*op.cit.*) and that of NGC 1360 and NGC 2474–5 by V. Doroshenko and V. Doroshenko and E. Kolotilov (*Soviet Astron. J.*, in press).

The most important result of these investigations is that velocities of expansion are rather small, i.e. 16–35 km s^{-1}. Only V. Doroshenko assumes velocities up to 60–70 km s^{-1} in some parts of NGC 6853; however such velocities can be interpreted in terms of ordinary gas dynamics. Another important conclusion is that the turbulent velocities in planetary nebulae are small, as is confirmed by observations of the radio lines (Y. Terzian (Cornell University Preprint, 1972)).

The nuclei of planetary nebulae

A very important contribution is due to L. Smith and L. Aller (02.133.013, 05.114.040), who have developed a classification of the spectra of nuclei, and found marked differences from the spectra of ordinary Wolf-Rayet and Of stars. Following these ideas, N. Sanduleak (05.114.044) has suggested a promising method to select the former or future nuclei of PN by the emission of the O VI doublet, which is probably characteristic only for the nuclei. D. van Blerkom (05.133.029) has found agreement between, on the one hand, the hypothesis by Smith and Aller on the definite physical difference of the nuclei from the WR-stars and, on the other, the parameters of two planetary nebulae having nuclei with WR-like spectra. A more detailed study by P. Lee is in progress (priv. comm. by L. Aller, 1972).

Several new spectra of nuclei were obtained by N. Sanduleak (*op.cit.*), and by S. Brown, N. Higginbotham and P. Lee (04.133.028). Photometric observations of nuclei for the determination of their temperatures were reported by M. Kazarian (05.133.011) and V. Doroshenko (*op.cit.*). V. Arhipova and M. Saveljeva (*LAS*, 1972) have studied the variability of nuclei and have found that those of NGC 6572, IC 4997 and, probably, NGC 6891 and Hu 2-1 show a variability by about $0\overset{m}{.}$ over 3 yr. The observations of FG Sge by V. Arhipova (03.122.109, 06.123.070) confirm the annual variability of this star, accompanied with changes in its spectral type. L. Kohoutek and G. Senkbell (*LAS*, 1972) have presented additional arguments for the duplicity of the nucleus of NGC 2346; S. Brown *et al.* (*op.cit.*) have done the same for the nucleus of NGC 3132.

Nuclei of planetary nebulae are similar to white dwarfs and some attempts have been made to find additional support for this view. B. Lasker and J. Hesser (05.133.016) looked for rapid light pulsations in the nuclei of 16 PN, but failed to find any. N. Nikitin, V. Kuvshinov and A. Severny (06.142.076) measured the circular polarization of the nuclei of IC 4593, NGC 6891 and BD + 30° 3639; only in the last case was a weak effect found. However, BD + 30°3639 is a star-like object; the interpretation of these observations is therefore not clear.

An important result has been reported by G. Miley, W. Webster and J. Fullmer (03.133.024), who discovered a point-like radio-source in the centre of NGC 7027. The brightness temperature of the source is about 10^6K and it may be a kind of hot corona around an invisible nucleus. Such observations could strongly influence theories of the internal structure of the nuclei and of their atmospheres. The present state of the latter theory is none too good. Theoretical models of planetary nebulae are rather dependent on the ultraviolet spectrum of the nuclei, and show that the older model atmospheres are unsatisfactory. New model atmospheres are described by N. Sakhibullin (*Trudy Gor. Astron. Obs. of Kazan*, 1970, No. 37, 55) and by J. Casinelli (05.133.019). However, there are no reliable direct ways to verify such models.

The system of planetary nebulae

The number of known planetary nebulae is growing by approximately 1% per year (M. Kazarian and E. Parsamian (05.133.013), L. Kohoutek (*A and A*, 1972, **16**, 291), B. Vorontsov-Veljaminov *et al.* (*Astron. Tsirc.*, in press)). The study of PN in the Magellanic Clouds is also in progress (N. Sanduleak, D. MacConnel and P. Hoover (05.159. 010) and B. Westerlund (06.159.017)). Useful work in identifying common objects in several lists of PN has been published by M. Chopinet and M. Lortet-Zuckermann (*A and A.*, 1972, **18**, 166). They plan now to compile a list of the dubious PN in the Perek-Kohoutek Catalogue, and to develop observational criteria to distinguish the real planetary nebulae from similar emission objects. It follows from papers by M. Lortet-Zuckermann (*LAS*, 1972) and by P. Swings (*LAS*, 1972) that this problem is not at all simple.

There is no good and stable definition of what constitutes a planetary nebula, and this causes difficulties and conflicts in their classification. Disagreements exist for many interesting objects, such as NGC 7635 (V. Doroshenko (05.132.010), H. Johnson (*LAS*, 1972), L. Deharveng-Baudel (*LAS*, 1972)), YM 29 = A 21 (H. Johnson (*op.cit.*), H. Johnson and V. Rubin (05.132.002), Y. Terzian (05.132.022), M. Chopinet and M. Lortet-Zuckermann (06.132.020), T. Lozinskaya (*Astron. Tsirc.*, 1972,**668**), V. Doroshenko and V. Essipov (*Soviet Astron. Journ.*, in press)), NGC 6164–5 (R. Catchpole and M. Feast (04.132.012)), FG Sge (D. Faulkner and M. Bessel (04.133.030)) or Sh 266, where J. Frogel and S. Persson (*Astrophys. Letters*, 1972, **11**, 95) have found an infrared-point-source.

The question of the 'purity' of the class is even more urgent in the case of star-like planetary nebulae, where we have no morphological information, and the distances are poorly known. Evolutionary effects in small young planetary nebulae make the problem especially difficult. A good illustration of the whole situation comes from the study of the peculiar object HBV 475 (D. Crampton *et al.* (03.133.022), L. Kohoutek and H. Bossen (04.113.003), Y. Andrillat (*LAS*, 1972)); the question whether this intriguing object is a young planetary nebula remains open in spite of intensive studies. Another object of this kind was discovered by L. Kondratjeva (*Astron. Tsirc.*, in press). B. Vorontsov-Veljaminov *et al.* (*LAS*, 1972) have found a curious correlation of the excitation of starlike PN with the distance from the Galactic Centre.

Planetary nebulae generally belong to the Galactic Disc population. The object K 648 in the globular cluster M 15 remains the only example of its kind (W. Feibelman (03.133.025)). An attempt to find planetary nebulae in open clusters has also failed (G. Akhundova and Z. Sseidov (04.133.026)).

To study the galactic distribution one needs a distance scale. This scale for PN is usually based on their Hβ-fluxes. New data on these fluxes for 116 southern PN have been published by L. Perek (05.133.026). J. Cahn and J. Kaler (05.133.017) have revised the distances to about 600 PN using the most reliable photometric data, and their own model of the galactic absorption. They estimate that the number of planetary nebulae in the Galaxy is about $(3–4) \times 10^5$. Another new distance-scale, based on radio-astronomical data, has been developed by L. Higgs (06.133.032). Some comments on this method have been published by H. Smith (05.133.009).

There are two important questions connected with the distance-scale. The first is to make the right correction for interstellar absorption. A review of the methods is published by V. Arhipova (04.133.024), and some critical comments on the model by Chan and Kaler have been made by V. Arhipova and O. Dockuchaeva (06.131.027) and L. Aller and D. Milne (*Austral. J. Phys.*, 1972, 25, 91). The second question concerns the zero-point of the scale. There are no reliable new trigonometric parallaxes for the absolute calibration of the scales, and we have to rely upon the statistical ones. A. Deutsch and O. Orlova (05.133.025) have analysed the radial velocities for 348 PN, and the proper motions for 42 of them, and have found that the average parallax of the system corresponds to the old scale by C. O'Dell.

The galactic distribution of the objects reflects their role in the evolution of the Galaxy and their chemical composition. The analysis of chemical abundances in PN encounters the same difficulties as the determination of their physical parameters; consequently the precision and reliability of the data are low (see L. Aller and S. Czyzak (*LAS*, 1972)). Some new results have been reported by J. Kaler (03.133.026, *LAS*, 1972), M. Peimbert and S. Torres-Peimbert (06.133.010), and for the nebula K 648 by M. Peimbert (*LAS*, 1972). J. Kaler found large individual differences in the O/H ratio, and M. Peimbert has shown that planetary nebulae are enriched by nitrogen relative to oxygen, in comparison with galactic H II regions. He also confirmed that neon and oxygen are more deficient in K 648 than in other PN. M. Seaton (06.132.039) has confirmed that the helium abundance in planetary nebulae is close to that in H II regions. The chemical evolution of planetary nebulae before the ejection from their nuclei, and their role in the chemical evolution of the Galaxy, have been considered by S. Torres-Peimbert and M. Peimbert (06.131.134).

The origin and evolution of the planetary nebulae

This is the most fundamental problem in the whole study of the planetary nebulae, and should relate to all the accumulated data. In fact, its connection with other branches of the physics of these objects is rather weak. The picture of the evolution of a typical nebula remains entirely qualitative; it is believed that the nebula is expanding freely into interstellar space, and that the velocity of this expansion is determined by gas pressure and by the initial conditions.

The evolution of young planetary nebulae is considered by Kovach, Capriotti, van Blerkom and Arny (*op.cit.*). The ionization structure and possible observable properties of such objects have been studied by P. Harrington (*LAS*, 1972); D. George (*LAS*, 1972) showed that in some cases the dynamical effect of the Lα-pressure is negligible in comparison with that of the gaseous pressure. Finally, F. Kahn (*LAS*, 1972) has indicated some possible observational effects caused by the overheating of the gas at the ionization front in young planetary nebulae. However, up to now we have no accepted model of young evolving PN, in which the state of ionization is calculated with allowance made for the evolutionary decrease of density and the time dependence of the luminosity of the nucleus.

According to one of the popular ideas a planetary nebula forms as a result of mechanical disturbances in the outer layers of a red giant. Probably these disturbances are not caused by a radial explosion (see M. Tomasko (04.065.093)), although this idea still attracts attention (R. Louise (*LAS*, 1972)). It seems more probable that the ejection of matter results from relaxation oscillations in the shell helium source, or from an imbalance in the ionization equilibrium (Roxburgh and Paczynski). Some calculations by B. Paczynski (03.065.079) show that the envelope of a red giant with mass in the range 0·8–3·5 $M_\odot$ can actually grow unstable after the formation of two shell sources. P. Wood (*LAS*, 1972) has reported that this instability can grow quite rapidly and may be accelerated even more by relaxation oscillations in the helium source.

However, there is a rival mechanism, in which a PN forms under the action of radiation pressure. According to D. Faulkner (04.133.023) the stellar envelope may be expelled from the nucleus with a speed of about 20 km s^{-1} after a rapid evolutionary increase of the luminosity. A. Finzi and R. Wolf (05.133.008) have considered a quasi-equilibrium separation of the envelope from the inner hydrogen shell source under the combined action of radiation and gas pressure. This idea has been developed by G. Kutter (05.065.043), A. Finzi (*LAS*, 1972), W. Sparks and G. Kutter (*LAS*, 1972). B. Paczynski (06.133.019) believes that radiation pressure acting on dust may also be of importance, and R. Louise and S. Roux (*Compt. Rend. Acad. Sci. Paris*, 1972, **274**, B294) indicate the possible influence of the rotation of the star. All these proposals suffer from the difficulty that the specific properties of the star, at the moment of its destruction, cannot be obtained directly from a computation of the earlier evolution of the red giant (D. Osterbrock (*LAS*, 1972)).

The relevant aspects of the theory of the stellar structure and evolution are considered in the excellent review by E. Salpeter (06.133.004). We still cannot definitely identify the ancestors of planetary nebulae, but most authors agree that they must be long-period or irregular variables. It may also be that all stars with masses between 1 to $4M_\odot$ pass through the planetary nebula stage. Modern estimates show that the spatial density of PN is similar to that of white dwarfs (see Chan and Kaler (*op.cit.*)). On the H-R diagram the transition of the nuclei into white dwarfs is quite obvious (C. O'Dell (05.126.023)). According to B. Paczynski (*Acta Astron.*, in press) some low mass nuclei of old planetary nebulae may evolve back into the region of the high luminosity; perhaps an example is given by the case of FG Sge.

SUPERNOVA REMNANTS

J. E. Baldwin

The most striking feature of the last three years in this field has been the flood of new radio observations. From a situation where we had detailed information about only a handful of objects as dissimilar as Cas A, the Crab nebula and Vela X we now have distributions of brightness for many remnants at a wide range of wavelengths and with details of their linearly polarized emission. It is now possible to see what range of properties exist in the remnants, what features are typical and how a picture of their evolutionary tracks can be pieced together.

Several surveys of supernova remnants, and collections of earlier data, have been published, including a list of 97 by Milne (03.125.016), some 200 galactic sources including 15 newly recognised remnants by Goss and Shaver (04.141.103/104), a total of 113 by Downes (05.125.018) and a recent list of 116 by Ilovaisky and Lequeux (*Astr. Astrophys.*, **18**, 169, 1972). The authors have often been concerned in making good estimates of distances for the objects in their lists. Some specific investigations have been made for this purpose using absorption by different constituents of the interstellar gas, combined with an assumed model of galactic dynamics to deduce distances. 18 distances were determined by Wilson (04.125.018) using absorption by formaldehyde and OH and an important survey of H I absorption profiles made by Hughes, Thompson and Colvin (06.141.192) formed the basis of several more determinations.

Disputes about the membership of these lists still occur and illustrate the difficulty, for objects of low surface brightness superimposed on a comparably bright galactic background, of distinguishing reliably objects having non-thermal radio spectra from those having flat, and therefore maybe thermal, spectra. 3C 391 is a recent case of a well known source now recognised as a supernova remnant (Caswell *et al.*, 05.141.101; Kesteven and Bridle 06.141.039).

Several objects studied in the Large Magellanic Cloud are also believed to be remnants of supernovae (Clark *et al.*, 06.125.017); Mathewson and Clark (preprint 1972) have noticed a remarkable phenomenon which they interpret as the ejection of radio sources from supernova remnants in the Large Cloud.

Mapping of supernova remnants continues at many observatories, those of large angular size, and presumably older, receiving most attention since it is for these objects that adequate angular resolution can be achieved over a wide range of frequencies. Maps with resolutions varying from a few minutes down to one minute of arc have been made of the following: the Cygnus Loop at frequencies of 408 MHz (Colla *et al.*, 06.132.042) at 1420 MHz (Moffat, 06.132.011) and at 5 GHz (Kundu and Becker, *Astr. J.*, **77**, 459, 1972); IC 443 at 408 MHz (Colla *et al.*, 06.125.029), at 1420 MHz (Hill, *Mon. Not. R. Astr. Soc.*, **157**, 419, 1972), at 4·17 GHz (Hirabayashi and Takahashi, *Proc. Astr. Soc. Jap.*, **24**, 231, 1972), at 2·7 and 5 GHz (Milne, 06.125.002), at 6·7 GHz (Dickel, 05.125.033) and at 10·7 GHz (Kundu and Velusamy, *Astr. Astrophys.*, **20**, 237, 1972); Puppis A at 408 MHz (Green, 06.125.026), at 2·7 and 5 GHz (Milne, 06.125.002 and Kundu, 04.125.014);

W 28 at 2·7 and 5 GHz (Milne, 05.125.001 and Kundu, 05.125.012) and at 4·17 GHz (Hirabayashi, *ibid*); the supernova of AD 1006 at several frequencies (Milne, 06.125.025 and Kundu, 04.125.014). Many others have been mapped at only one frequency so far.

Measurements of linear polarization form an important part of some of these observations and other investigators have mapped the polarization of several remnants (Whiteoak and Gardner, 06.141.244 and Milne, *Aust. J. Phys.*, **25**, 307, 1972).

The most important results derived from this wealth of new data are

(1) The radio emission is distributed in a shell, often incomplete or broken, but nearly always with a well defined outer boundary to the brighter regions.

(2) The correlation between the optical filaments and the radio emission becomes more striking as the resolution of the radio observations is improved. For bright filaments there is very detailed agreement between the radio and optical distributions. Fainter filaments tend to lie along the outer boundary of associated radio emission.

(3) There is disagreement concerning variations in spectral index across any particular remnant (see for example 06.125.002 and *Mon. Not. R. Astr. Soc.*, **157**, 419, 1972). Consequently the role of thermal radiation from the optical filaments is also in dispute. No variations of spectral index have yet been established beyond doubt.

(4) The percentage linear polarization is frequently 5–10% and reaches 30% in some places. Where the percentage is high, the direction of the magnetic field deduced is usually tangential to the boundary of the source. Where it is low it often bears no obvious relation to the structure of the source. In some cases (e.g. IC 443, *Astr. Astrophys.*, **20**, 237, 1972) the field direction seems determined perhaps by the prevailing field in the neighbourhood of the remnant.

Much remains to be done in filling out this picture but the most urgent need at present is for a much wider range of optical investigations of carefully selected remnants. Such observations are admittedly expensive in observing time, and in the period under review there have been, for old supernova remnants, measurements on only the Cygnus Loop (Doroshenko, 03.132.014) to determine Hα halfwidths and radial velocities and on the Monoceros nebulosity (Lozinskaya, 06.132.041) which determined its rate of expansion. For many remnants we need observations of radial velocities and proper motions of filaments, and evidence of association with dust clouds or H II regions with measurable distances. Uncertainties in distance are the most obvious gap in our present knowledge which could in some cases be filled by existing techniques. The investigation of excitation conditions in the optical filaments is another important field which has received relatively little attention. The concentration of resources on one or two objects well adapted for both optical and radio work seems an aim obviously worthy of some discussion.

X-ray work on old remnants has developed and several are now known. For others, disputed identifications have been made. GX5-1 was suggested as a remnant by Milne (05.125.021), challenged by Ilovaisky and Ryter (05.141.208) and further observations supporting their view are reported by Braes *et al.* (*Nature*, **236**, 392, 1972). Most detail in the X-ray work is available for Puppis A and Vela X (Palmieri *et al.*, 05.125.009 and Seward *et al.*, 06.142.069) and for the Cygnus Loop (Grader *et al.*, 04.142.004, Gorenstein *et al.*, 05.125.016) for which the angular structure is now crudely known. The origin of the radiation is still a matter of controversy and is likely to remain so until more accurate spectra are available (e.g. Tucker, 05.125.017).

The case for the features of the radio continuum background known as the North Polar Spur, the Cetus arc and other Loop structures also being remnants of supernovae has been pursued (Haslam *et al.*, 05.157.006, Berkhuijsen *et al.*, 06.155.009) based on the discovery of the association of H I with these features (Berkhuijsen *et al.*, 03.157.004). Further optical evidence has been produced on both the Cetus arc (Elliott and Meaburn, 03.132.027) and Loop III (Elliott, 03.132.037). Soft X-rays have also been detected from the North Polar Spur (Bunner *et al.*, *Astrophys. J.*, **172**, L67, 1972).

Young supernova remnants have also received attention. Van den Bergh has discussed Cas A as the youngest known remnant (05.125.028), measured the expansion over a period of 17 yr (04.125.022) and the spectra of the filaments (05.125.031). Very high resolution maps have been made by Rosenberg at 2·7 GHz (03.141.083) and 5 GHz (04.141.154) showing some tens of very condensed knots of emission and weak polarization of about 5%. The polarization at 1·4 GHz (Baldwin *et al.*, 04.141.081) is only ~1% and at 2·7 and 5 GHz Downs and Thompson (*Astr. J.*, **77**, 120, 1972) find only about 5%. Further values have been obtained of the secular decrease in flux density (Baars and Hartsuijker, *Astr. Astrophys.*, **17**, 172, 1972).

The expansion of Tycho Brahe's supernova remnant has been detected by van den Bergh (06.125.003). At radio wavelengths maps have been made at 10·7 GHz by Kundu (05.125.003) and at 1·4 and 2·7 GHz by Weiler and Seielstad (05.141.010). These authors find that the magnetic field is essentially radial. They also studied 3C 58, the only remnant, apart from the Crab nebula, in which emission is distributed throughout the volume rather than in a shell. The magnetic field is surprisingly uniformly aligned, a result confirmed by Kundu and Velusamy (*Astr. Astrophys.*, **20**, 237, 1972). An attempt has been made to identify 3C 58 with the supernova of AD 1181 (Stephenson, *Q.J.R. Astr. Soc.*, **12**, 10, 1971). A lunar occultation of Kepler's supernova has been used (Hazard and Sutton, 05.125.004) to determine its angular size. X-ray spectra have been obtained for Cas A and Tycho's SN (Gorenstein *et al.*, 03.125.007) but the physical origin is uncertain as in the case of the older remnants.

The Crab Nebula had its own *IAU Symposium* (No. 46) at the time of the last IAU General Assembly, and continues to resist classification with other remnants. The very wide range of observations is still being extended. A flux density at 10 μ has been obtained (Aitken and Polden, 06.134.004), and an upper limit in the 30–300 μ range (Furniss *et al.*, *Nature Phys. Sci.*, **236**, 6, 1972), a UV spectrum from OA 2 (Johnson, preprint 1972), polarized X-rays from the nebula (Novick *et al.*, preprint 1972) and γ-rays of 10^{11}–10^{12} eV (Fazio *et al.*, *Astrophys. J.*, **175**, L117, 1972) detected. The radio emission has been mapped at 3·4 mm by Epstein *et al.* (05.132.027) and at 3·5 mm by Matveenko (05.134.009). These results show that the structure is the same at all radio wavelengths. The polarization at 1·4 GHz was discussed by Wright (04.134.010) and at 2·7 GHz by Conway (05.134.023). Observations by Wilson (05.134.021 and *Mon. Not. R. Astr. Soc.*, **157**, 229, 1972) at 2·7 and 5 GHz establish that the filaments are both associated with the depolarization of the nebula and are themselves sources of radio continuum. The conclusion regarding depolarization is also reached by Weiler and Seielstad (*OVRO*, preprint 1972). Perhaps the most unexpected radio observation is that of Wrixon *et al.* (05.141.082) at 1·87 cm showing a decrease in the total flux density of 20% over a period of 5 months. Previously no secular change of flux density had been detected with certainty.

Rees (05.134.006) has developed further the theory of low frequency electromagnetic waves to account for the Crab nebula's properties, whereas Gratton (*Astrophys. Sp. Sci.*, **16**, 81, 1972) has, on more conventional lines, developed the theory of electron diffusion with energy losses, to deduce the spectrum of the nebula in the radio and optical ranges. Wilson (*Mon. Not. R. Astr. Soc.*, **160**, 355, 1972) has been able to test this type of theory which he finds to give a satisfactory fit to the observations. Preliminary results on the reddening of the Crab nebula using the S II lines (Miller, *Bull. Amer. Astr. Soc.*, **4**, 233, 1972) offer the hope of correcting the spectrum in the infrared and optical region with some accuracy. A search by Landstreet and Angel (05.134.005) failed to detect any circularly polarized light from the nebula, expected on Rees' theory.

Most authors believe that the relation of pulsars to supernova remnants is a crucial one, at least in the early stages, but it has proved hard to obtain evidence bearing on this problem. There are now five known associations of supernova remnants and pulsars: the Crab nebula, Vela X, IC 443, (Davies *et al.*, *Nature*, **240**, 229, 1972), CP 1919 and a radio source noted by Caswell *et al.* (04.141.161), PSR 1154–62 and G296·8–0·3 (Large and Vaughan, *Nature Phys. Sci.*, **236**, 117, 1972). Two of the pulsars lie on the edge or outside the remnant but the high speed measured from the interstellar scintillations of the pulsar PSR 0329+54 (Galt and Lyne, *Mon. Not. R. Astr. Soc.*, **158**, 281, 1972) indicates that the space motions of pulsars can be very fast, presumably as a result of the supernova explosion.

A number of attempts to assess the relative rates of supernovae and the creation of pulsars in the Galaxy have been made, most recently by Ilovaisky and Lequeux (*Astr. Astrophys.*, **20**, 347, 1972).

It seems likely that most supernovae do produce pulsars. The energy balance between the pulsar and the remnant has been discussed for both the Crab nebula and for Vela X (Borner and Cohen, *Astr. Astrophys.*, **19**, 109, 1972; Tucker, 06.125.001; Colgate and Silk, 06.132.036; Brandt *et al.*, 06.132.004).

In the earlier stages of evolution, consideration has been given to the formation from the initial flash of Strömgren spheres, which may remain as fossils long after the stellar remnant has faded (Kafatos and Morrison, 06.125.010; Goldsmith, *Astr. Astrophys.*, **16**, 286, 1972). The temperature of the envelope in the early stages has been calculated by Mustel (06.125.004). A classification of the phases through which a supernova remnant evolves has been made by Woltjer (04.125.019). Calculations on models of the evolution of remnants through these phases have been made by Scheuer and Rosenberg (*Mon. Not. R. Astr. Soc.*, **161**, 27, 1973) and by Gull (*Mon. Not. R. Astr. Soc.*, **161**, 47, 1973).

In his analysis of the radio properties of a large sample of supernova remnants Milne (03.125.016) found a relation between the surface brightness and the physical diameter of a remnant. With more and improved distance determinations, this has now been reanalysed by several authors with similar conclusions, but finding different values of the index relating surface brightness to diameter. Caution in the interpretation of these results is urged by Woltjer in an excellent review of supernova remnants which was published on the day the present brief report was completed.

INTERSTELLAR PLASMAS

F. D. Kahn

Large scale features

Observations of pulsars have provided some of the most valuable information on plasmas in interstellar space. It has been deduced from such observations that the interstellar electron density is, on average, about 0·1 electrons cm^{-3}. This applies to the part of space outside the well defined H II regions. Clearly the electrons must come from more than just the atoms of minority constituents like C, Fe, Na, and so on, whose ionization potentials are below that of hydrogen. Therefore there is a conflict with the long-held view that electrons in H I regions arise from the ionization produced by photons with energy below the Lyman limit.

The next most important result concerns the measurement of the interstellar magnetic field. Here observation is made possible by the fact that pulsars often emit radiation with a plane polarized component. It is assumed that the plane of polarization is the same at all frequencies when the radiation enters the interstellar medium after leaving the pulsar. As it propagates further, the Faraday rotation effect turns the plane of polarization. At frequency ω the total angle of rotation is proportional to $\omega^{-2}\int n_e H_{\parallel} dl$. A comparison of the rotation measure with the dispersion measure gives an average value for $H_{\parallel}$, the line of sight component of the magnetic field. The average is weighted by the local electron density. The results obtained by R. N. Manchester show that the typical field strength is 10^{-6} G, and that in the mean the lines of force lie parallel to the direction of galactic rotation (Manchester, *Ap. J.*, **167**, L101, 1971).

This is a very satisfactory conclusion. The clear association that is found between rotation measure and direction in the Galaxy establishes that both the rotation measure and the dispersion measure arise from a physical effect in interstellar space, and not in the circumpulsar region. Further the topology inferred for the magnetic field is such that the interstellar plasma can take part in the differential rotation of the Galaxy without the need for frequent reconnection of lines of force. If the lines of force were wound helically around the spiral arms (as has been suggested sometimes), such reconnections would have to occur on time scales of the order of 10^8 yr. Recent work by Parker (*J. Plasma Phys.*, **9**, 49, 1973), shows that reconnection may not be as easy to achieve as had previously been thought. Therefore the actual field topology seems to be physically most reasonable, from this point of view.

There is, however, a third effect which cannot immediately be understood. The cosmic ray particles in the Galaxy are fairly closely confined to a motion along the magnetic lines of force. For a field strength of 10^{-6} G, the Larmor radius is about $10^3\chi$ (in cm) when the particle energy is χ (in eV). The linear scale of the Larmor rotation is very small in comparison with the scale of the Galaxy, for all except the highest energy cosmic rays. Now in first approximation the lines of force are circles lying in the galactic plane and concentric with the Galaxy. It would therefore not be surprising if there were a uniform distribution of the momentum components of the cosmic ray particles perpendicular to the magnetic field. This is in fact found. But one would not expect the ensemble of cosmic rays to take part in the rotation of the Galaxy. Nevertheless observations show that the mean velocity of the cosmic rays near the Sun is the same as that of a typical Population I object (Meyer, 02.143.015). In other words the cosmic ray gas moves, on average, like the interstellar gas or, better, like the thermal interstellar plasma. This suggests that there is a mechanism which causes the high energy plasma to be dragged around by the thermal plasma.

Small scale features

The observation of small scale inhomogeneities in the interstellar plasma indicates what this mechanism is. Again the best evidence comes from pulsar studies, with additional information from radio outbursts on X-ray sources (Rickett, 04.141.012, Anderson *et al.*, *Nature Phys. Sci.*, **239**, 117, 1972).

There have been several papers on the twinkling of pulsars. Here the average intensity of a pulsar fluctuates, typically on a timescale of half an hour. Fluctuations are correlated at neighbouring frequencies, over a bandwidth of the order of 100 kHz (Rickett).

The intensity fluctuations are ascribed to inhomogeneities in the refractive index of the interstellar medium. Thus the pulsar radiation is not propagated along straight lines. Over a long enough distance the ray path becomes sufficiently distorted to explain the observed fluctuations in the radiation field. (See, for example, Kahn, 06.131.113).

Variations in refractive index must, of course, be due to fluctuations in electron density. A given set of fluctuations at a given instant will produce different effects at different frequencies, since the refractive index depends on the frequency. Clearly then the nature of the twinkling, and the relation between the twinkles observed at different frequencies, must depend on the path length, the correlation length for fluctuations in the electron density, and the rms amplitude $\langle \delta n_e{}^2 \rangle^{1/2}$ of the fluctuations. The available observations are consistent with values of the order of $\langle \delta n_e{}^2 \rangle^{1/2} \sim 10^{-3}$ cm^{-3} and a correlation length $l \sim 10^{12}$ cm.

The length l is very short, by interstellar standards, but the amplitude of the density fluctuations seems reasonable enough. It is hard to see how any gas dynamical wave motion could arise and persist on a length scale that is so much shorter than the typical mean free path ($\sim 10^{16}$ cm). But a plasma wave motion seems more suitable. In particular it is very likely that the fluctuations are due to short wavelength Alfvén waves, propagating in the interstellar plasma. It is easy to estimate the amplitude of the magnetic field fluctuations that these waves produce. If the amplitude of the electron density fluctuations is of the order of 1%, then the typical displacement of the plasma is of the order of 1% of the correlation length, and so the disturbance in the magnetic field strength is also about 1% of the average field strength. Clearly the Alfvén waves do not require much energy. Even so it has occasionally been suggested that dissipation of energy by the Alfvén waves can produce a significant input of heat into the interstellar medium (Wentzel, 05.131.011).

In an interstellar cloud with n_H atoms per cm^3 an ion will collide with a neutral atom about once in every $10^9 n_H{}^{-1}$ s. The wave energy dissipates on about this time scale. From the estimate above the energy density is about $10^{-4}\overline{H^2}/8\pi \sim 2{\cdot}5 \times 10^{-18}$ erg cm^{-3}, in a typical Alfvén disturbance. The corresponding heating rate is therefore $2{\cdot}5 \times 10^{-27} n_H$ erg cm^{-3} s^{-1}, or $2{\cdot}5 \times 10^{-27}$ erg/atom s. But a much larger heating rate is required to maintain the thermal balance in H I regions.

Nevertheless the waves are important, since they scatter cosmic ray particles and redistribute their momenta. The cosmic ray gas will therefore tend, in the mean, to move with the thermal plasma. Collisions of ions with atoms then couple the motion of the plasma with that of the neutral gas. This explains the observed state of motion of the cosmic ray plasma. But further the waves themselves are probably excited by an interaction with the cosmic rays.

It is generally believed that cosmic rays are injected into the interstellar medium by various sources at various positions at various times. A streaming motion then ensues, as the cosmic rays spread out from their points of injection. If the cosmic ray gas has a substantial mean streaming velocity (above the Alfvén speed) relative to the thermal plasma, then an instability results. This excites the waves which form the irregularities in the plasma density which in turn scatter the cosmic rays. In general there is thus a self-limiting process which holds down the cosmic ray streaming velocity to the Alfvén speed. But there is one proviso. As Wentzel has pointed out, the instability will be killed by ion-atom collisions if the density of the neutrals is too high. Therefore Alfvén waves are suppressed and cosmic-ray streaming is not inhibited in the high-density phase of an H I region; the scattering effects arise mainly in the low density phase (and of course in H II regions).

The interstellar twinkling effect was also observed, indirectly, during the radio outburst of Cygnus X3 September 1972. Two weeks after the outburst an attempt was made (at 408 MHz) to determine the angular size of the source, and it gave an apparent value of 1″. From the evidence of various absorption features at 21 cm wavelength it was known that the distance to the source is about 10 kpc. The inference seemed to be that the source had grown to a radius of 0.05 pc (or 0·15 light years) after a lifetime of only 0·04 yr. The discrepancy is explained in terms of interstellar twinkling. Individual rays from the source are refracted through an angle of 1″, typically. The effect is larger than one would expect from a medium with $\langle \delta n_e{}^2 \rangle^{1/2} = 0{\cdot}001$ and $l = 10^{12}$ cm. It is therefore significant that the line of sight to Cygnus X3 intercepts a very large H II region.

Finally there has been a disagreement among various eminent authors concerning the effect of electron density fluctuations on the interpretation of the dispersion measures themselves. Lerche (03.131.017) pointed out that fluctuations in n_e will introduce a frequency dependent, but non-linear, effect on the dispersion measure. This statement was later criticised by Elsässer and Gräff (04.141.069) and Ginzburg and Erukhimov (05.141.123). Inasmuch as the ray paths are distorted from a straight line, the typical path length to the source will clearly be increased. There is consequently an increase in the measured value of $\int n_e \, dl$, when the integration is made along the actual path. But in practice this non-linear effect becomes noticeable only below a frequency of about 10 MHz, well outside the range in which observations of the dispersion measure are usually made.

The thermal balance in the interstellar gas

The observed interstellar electron density of $\bar{n}_e \sim 0{\cdot}1$ cm^{-3} cannot be produced simply by photoionization of minority constituents in the gas. It also implies a relatively high rate of energy loss (Dalgarno and McCray).

Therefore an effective method must be found of bringing heat to the gas, so that thermal balance may be maintained, and of providing the necessary ionization. A favourite hypothesis to resolve both problems is that the heating as well as the ionization are due to the presence of 'supra-thermal particles' (stp's). The typical stp is a charged particle, say a proton, with an energy of around 10 MeV, rather like a sub-relativistic cosmic ray particle. The required density for the stp's is easily estimated-and turns out to be far greater than one would obtain from a simple extrapolation of the known cosmic ray spectrum down to 10 MeV. In particular the observed cosmic ray energy spectrum follows a power law $n(E) \propto E^{-2{\cdot}6}$. Such a law reinforces the view that the process of cosmic-ray acceleration is of the Fermi type. But if the spectrum is extrapolated back to 10 MeV the resultant particle density is much too low to explain the stp's.

Perhaps this is not relevant. The stp's and the cosmic rays may well originate in radically different processes. For example supernova explosions have been suggested as possible sites where stp's may gain their energy. Yet one would be happier if there were some independent evidence that stp's do actually exist. Detection of stp's within the solar system is hindered by the hydromagnetic and plasma irregularities at the interface of the solar wind with the interstellar medium. Low energy particles, like stp's, would be much more severely scattered than the higher energy cosmic rays, so that any observation of stp densities in interplanetary space would be quite unrepresentative. The fairest remark seems to be that at present there is no direct evidence from observation either for or against the stp hypothesis.

But perhaps there are other effects that must follow if the stp's do actually exist. An stp heats the interstellar gas via a space charge interaction. Basically the energy of the stp –itself a charged particle – is transferred to the interstellar electrons. An interaction with an electron at distance D from the track of the stp transfers an amount of energy $(m_p/m_e)\,(e^4/D^2E)$, where E is the energy of stp, assumed to be a proton of mass m_p. Effective collisions will occur at any distance from the obvious minimum e^2m_p/Em_e, at which the electron acquires a velocity of the same order as that of the incident stp, out to the Debye length $\omega_p{}^{-1}\sqrt{kT_e/m_e}$. ($\omega_p$ is the plasma frequency $\sqrt{4\pi n_e e^2/m_e}$). In typical interstellar conditions these distances are, respectively, 4×10^{-11} cm and 10^3 cm. The energy transferred ranges from 5 keV to 10^{-23} eV. In relatively close collisions (out to about 10^{-9} cm) even an electron bound into an H atom can be given enough energy to eject it from the atom, and so to ionize the atom. However the integrated cross-section for energy transfer to free electrons is much (about ten times) larger than that for transfer to electrons bound in neutral atoms.

Unless the degree of ionization is low, much less than 10%, a substantial fraction of stp energy is therefore given directly to free electrons and converted into disturbances in the electron density distribution, that is into space charge waves. These waves persist for a time of the same order as the time of free flight of an interstellar electron. Landau damping effects would only become important at the shorter wave-length end of the spectrum, and in any case not much energy is contained amongst the waves there. In this way a random electrostatic field disturbance is set up in interstellar space. In turn it affects the motion of the electrons and reduces their time of free flight, to a value of the order of $\tau=(\tau_c/\Omega_p)^{1/2}\,(v_{th}/U)^{1/2}$. Here $\Omega_p{}^2=4\pi n_H e^2/m_e$ and v_{th} is the typical electron thermal speed. From the data given by Dalgarno and McCray $\tau_c\sim\ 10^{11}$ s, $v_{th}\sim10^7$ cm s^{-1}, $U\sim3\times10^9$ cm s^{-1} and $\Omega_p\sim2\times10^4$ s^{-1}. The value thus found for τ is of the order of 10^2s, compared with a value of the order of 10^4 s if the electron time of free flight is limited by collisions with other charged particles. This effect reduces both the electrical conductivity and the electron thermal conductivity by about two orders of magnitude.

Perhaps this effect will prove to be too subtle to detect. But then another promising possibility exists. The stp's must originate somewhere: supernovae have already been mentioned as a possible source. If production occurs in such sudden events the stp's must subsequently spread through the interstellar gas. As in the case of cosmic rays a rapid streaming of stp's will cause Alfvén waves to grow, and any spreading out will therefore take place by diffusion, rather than streaming. But what happens in places where the Alfvén waves have not yet grown to large enough amplitude, and the stp's have a definite streaming velocity? If the streaming velocity is rather larger than the electron thermal velocity then space charge waves are readily excited by a collective instability. This leads quite rapidly to an increase in the random (or thermal) speeds of the electrons in the ambient plasma, until the tail of the electron thermal velocity distribution begins to reach the streaming speed of the stp's, say 3×10^9 cm s^{-1}. At this stage the electron temperature would be a few times 10^6K, and energy loss by radiation becomes rather efficient. On the other hand the electrostatic instability is damped by the spread in electron velocities. But when the electron energy has been lost through radiation the instability will be reactivated. Thus the space charge waves are kept simmering, the electron gas is maintained at a few million degrees, and the stp's lose their energy at as fast a rate as the plasma can get rid of it. There is even the possibility that the plasma turbulence will accelerate selected charged particles to relativistic energies, as described by Kadomtsev and Tsytovich (04.131.105). Therefore it might be feasible to identify the sources of suprathermal particles by the discovery of shell like regions, in a state of rapid expansion, in which the plasma is anomalously hot and near which there perhaps exists an expanding source of synchrotron radiation.

FINE STRUCTURE IN HII REGIONS

D. E. Osterbrock

During the past several years there has been a rapid increase in the amount of good research published on the fine structure in H II regions. That this structure exists has been known for a long time, since the first large-scale photographs of gaseous nebulae were taken, but the difficulties in studying it in the past have been, in the optical spectral region, the extreme faintness of most nebulae, so that high-dispersion spectral information over a large spectral range could not be obtained, and in the radio-frequency range, the small angular sizes of the structures, so that high-resolution spatial information could not be obtained. These difficulties are now being overcome by the development of image tubes, image dissectors, large radio dishes, and aperture-synthesis arrays, and as a result our knowledge of the fine structure in H II regions, though still seriously incomplete, is growing at a relatively rapid pace.

Chopinet, Lortet-Zuckerman, Garnier, Deharveng-Baudel, Georgelin, and their collaborators have made many optical studies of dense ionized condensations in H II regions, including the knot 3C 153·1 in NGC 2175 (06.131.031), and the knot Sh2-157A in Sh2-157 (Chopinet and Lortet-Zuckerman, *AA*, **18**, 373, 1972; Deharveng-Baudel, *AA*, preprint). Both knots have diameters of order 1 pc, and are immersed in much larger H II regions. The spectrum of Sh2-157A shows relatively low ionization (weak [O III], strong [N II]), and the relative strengths of the [S II] $\lambda\lambda$ 6717, 6731 lines show a very inhomogeneous electron-density distribution, with maximum of order $N_e \sim 3 \times 10^3$ cm^{-3}. The peak densities are considerably higher than the root-mean-square electron density in the knot derived from radio-continuum measurements, $N_e \sim 10^2$ cm^{-3}, and show there is still considerable unresolved fine-structure within these small knots. They must indicate the presence of large volumes of high-density neutral gas within the knots. Likewise Deharveng-Baudel (preprint) has observed the [S II] lines in bright globule A in NGC 7635 and again found a very inhomogeneous density distribution, with maximum $N_e \sim 1{\cdot}2 \times 10^4$ cm^{-3}.

Rubin and Turner (05.131.077) used radio and optical measurements to discuss the emission nebula K 3-50. The [S II] lines indicate $N_e \sim 3 \times 10^5$ cm^{-3}, and these authors suggest that this nebula is a young compact H II region. Radio data indicate two other objects, H 2–3 and H 2–6, are similar in many respects to K 3–50 and also probably compact H II regions.

Münch and Persson (05.132.016) measured the strengths of H I and He I emission lines, as well as the nebular continuum, with 3″ spatial resolution in M 42, using the multichannel spectrometer on the 200-inch. Hale telescope. The observed Balmer gradient was used to determine the extinction at each point. They showed that the dust must be well mixed with the ionized gas, and that fluctuations in gas density are well correlated with fluctuations in dust density.

H. Dickel and Wendker are continuing to study the physical properties and spatial distribution of the nebulae in the Cygnus X spiral feature by comparing calibrated Hα and 11-cm maps.

Wynn-Williams (05.131.034) used the Cambridge One-Mile radio telescope for aperture-synthesis observations at 5 GHz with a halfpower beamwidth of approximately 6″.5 to make high-resolution maps of the H II regions DR 21, W 49A and W 3. He found that compact condensations of ionized gas, with sizes typically in the range 0·1–1 pc, are observable. Indicated electron densities in the condensations range from 10^3 cm^{-3} to $> 10^4$ cm^{-3}. In several cases these condensations coincide closely with OH sources. Comparison with optical observations shows large local variations in the amount of interstellar extinction, and the condensations are probably surrounded by neutral hydrogen and are being ionized by very young, hot luminous stars within them.

Habing, Israel and de Jong (*AA*, **17**, 329, 1972) used the Westerbork aperture-synthesis array to study the H II region NGC 7538 at 1·4 GHz in the continuum at a resolution of about 20″. Immersed in the nebula is an unresolved source (diameter < 0.3 pc) which from the measured flux has electron density $N_e \gtrsim 3 \times 10^3$ cm^{-3}. This (radio-frequency) bright knot coincides in position with an OH Class I source, and these authors summarize earlier published aperture-synthesis measurements of several other H II regions by several other groups, in which coincidences between bright knots and OH sources are noted from accurately measured positions. The interpretation given is that the bright knots are regions of high density in which O stars have very recently formed and begun to ionize and expand the gas immediately around them. The optical emission of the bright knot is still largely absorbed by the surrounding dust ('cocoon star'), and the OH emission probably occurs in one or more involved protostars that have not yet reached the main sequence. The gas density in the OH emitting regions must be sufficiently low ($N_H \lesssim 10^6$ cm^{-3}) so that the population inversion is not collisionally quenched. Habing, de Jong and Israel are continuing this program and have already found several more bright knots or compact H II regions involved in larger H II regions.

Aperture-synthesis radio continuum observations of numerous H II regions have been made, including measurements at 2·7 GHz of M 42, W 3 and DR 21 by Webster and Altenhoff (03.132.012, 04.141.061), M 17 and W 49A by Webster, Altenhoff and Wink (06.132.033). On account of the limited spacings available, as well as the limited range of rotation of the beam pattern on the nebulae, the halfwidths of the beam are approximately $8'' \times 11''$ at $\delta = +60°$, but approximately $9''$ (more or less E-W) $\times 23''$ at $\delta = 0°$. In all the nebulae observed, structure is seen down to the limit of angular resolution of the instrument. This is not surprising, as optical photographs of M 42 and M 17 show fine structure to much smaller angular scales. But since the radio measurements are not affected by interstellar extinction it is possible to make plausible assumptions about temperatures, and from the measurements derive mean values of densities and thus masses. Peak densities of individual 'components' (seen down to the quoted beam sizes) are of order 6×10^2 cm^{-3} (in W 49A) up to 4×10^4 cm^{-3} (in M 8).

Balick made aperture-synthesis measurements of the H II regions DR 21, W 51 (two of the components), W 33, NGC 2264 and IC 410, using the NRAO three-element interferometer at 8·1 GHz and 2·7 GHz, with resolutions of approximately 3″ and 10″ respectively. Some of these nebulae were found to have fine structure with sizes of order 0·03 pc, peak densities $N_e \approx 3 \times 10^4$ cm^{-3}, and masses $\approx 0{\cdot}1$ $M_\odot$. This fine structure would of course rapidly disappear, so mechanisms which might confine or resupply the density were explored. The most plausible mechanism is that high density H I condensations imbedded within the H II region are constantly being ionized. A model of the central core of NGC 1976 based on this idea was shown to be compatible with all optical and radio observations of this object. All this material is contained in Cornell Ph.D. thesis; only part of it has been published (*Ap.J.*, **176**, 353, 1972).

Miley, Turner, Balick and Heiles (03.131.111) used the NRAO radio-link interferometer at 2·7 GHz with a separation of 35 km, corresponding to a lobe separation of about 0″6, to observe two components or 'superbright radio knots' previously detected in W 51 with the three-element interferometer. In the radio-link measurements fringes were detected, corresponding to a peak brightness temperature $\sim 7 \times 10^5$ K on a circular Gausssian model, and not less than 10^5 K on any reasonable model. This is so much higher than the kinetic temperatures that result from photoionization heating of nebular gas by early-type stars that it suggests that some other input process is also at work. It is a very important result, difficult to interpret, and the observation should be repeated by other groups.

Dibaj (04.132.027) observed globules and comet-like nebulae in several H II regions, mostly by direct Hα photographs. Densities in the bright rims around some globules were determined to be of order $N_e \approx 10^2$ to 10^3 cm^{-3}, and the densities of neutral gas inside the globules are deduced to be higher by factors of order 30.

Rots, Schwarz and van Woerden (*AA*, **16**, 344, 1972) emphasized that the objects observed by a particular instrument of a particular kind are strongly selected by the properties of the instrument (angular resolution, for instance) and by the operational definition the observer applies to isolate the objects studied. They discuss this idea in the context of the 'cloudlets' previously observed by Heiles at 21 cm with the NRAO 300-ft telescope, and emphasize that these probably include objects of many different natures. The same remark of course applies to 'condensations', 'density fluctuations'. 'bright knots', 'compact H II regions', and must always be kept in mind in interpreting observational results.

Heiles (03.131.069) observed OH line profiles with the NRAO 140-foot telescope at various positions within four dust clouds. In one cloud a self-absorbed H I 21-cm line profile is observed.

The kinetic temperatures in the clouds are of order 5K, the H° density is low ($\sim 0{\cdot}3\ \mathrm{cm}^{-3}$), while indirect evidence indicates the H_2 density is much higher ($\sim 40\ \mathrm{cm}^{-3}$). Ames and Heiles (03.131.070) combined optical (color and interstellar absorption-line) measurements with radio measurements of the region $l^{\mathrm{II}} = 100°$–$140°$, $b^{\mathrm{II}} = 13°$–$17°$ to show that the interstellar H I there is concentrated in two thin ($\lesssim 10$ pc) sheets, which are approaching each other supersonically and are now colliding in one part of the region.

Bok, Cordwell and Cromwell published a large amount of quantitative observational data on the properties of globules, largely obtained from direct photographs with the Arizona 90-in. reflector (*Dark Nebulae Symposium*, ed. B. T. Lynds, 33). From the observed extinction, the most probable mass of the globule (assuming a normal gas to dust ratio of 100) can be estimated. These range from as small as $10^{-2}\ M_\odot$ to as large as nearly $10^2\ M_\odot$. Bok and Cordwell (preprint) collected a large amount of observational material on dark absorbing clouds, and listed in tabular form the positions and properties (so far as they are known) of many of these objects.

Louise (03.132.021) has studied the bright rim in NGC 7000 and measured the electron-density profile in it by microphotometering a very narrow-band (4 Å) Hα plate. He finds the density distribution to be in agreement with previous theoretical calculations of Pottasch, which took into account the ionization structure and the flow of matter near the front.

Studies of M 8 and M 20 by Bohuski (*Ap.J.*, preprint) using a Fabry-Perot interferometer yielded line profiles of Hα, [N II] λ 6583, and [O III] λ 5007 indicated mass motions which were generally subsonic, and which were smallest in λ 5007. In M 20, where the assumption of similar emitting regions for Hα and [N II] may be nearly fulfilled, the line widths and line intensities of these lines indicate higher temperatures near the edge of the H II region than near the center. Photographic photometry of the [S II] doublet λλ 6717, 6731 indicates the existence of high-density knots (up to $\sim 6000\ \mathrm{cm}^{-3}$). Profiles across bright rims suggest electron densities up to 10 times greater in the rims than in the nearby regions.

Danks (04.132.016) measured photoelectrically [S II] λ 6717/λ 6731 line ratios at many points in the bright central region (about 8′ diameter) of M 42. He showed that values of N_e derived from these [S II] measurements are in good agreement with published values of N_e derived from [O II] measurements, and that the measured densities range from a high of about $2 \times 10^4\ \mathrm{cm}^{-3}$ near the center, to about $6 \times 10^2\ \mathrm{cm}^{-3}$ at the edge of the region observed. Danks and Meaburn (05.132.021) made further measurements of [O II] and constructed an electron-density model for M 42, and by comparison with the radio continuum measurements confirmed that the average value of the 'degree of condensation' $\langle N_e^2 \rangle / N^2_{e\ \mathrm{local}} \approx 0{\cdot}05$. Measurements of [O II] λ 3729/λ 3726 in M 42 were also made by Caplan (*AA*, **18**, 408, 1972).

Hjellming, Davies, Gordon, Wallace, Andrews and Churchwell in a series of papers (03.131.081, 05.132.007, 06.131.010, 06.131.011) studied the information that can be drawn from measurements of H I radio-recombination lines. By measuring several lines with different Δn (α, β, γ, δ and ε lines) and approximately the same λ (to minimize differences in angular resolution) one can use a non-LTE analysis and solve for both temperature and electron density (since the relative populations of the high levels are determined by collisional effects whose rates depend on N_e), assuming a homogeneous ('one-layer') model of the nebula. Then comparing with the emission measure, the amount of clumping can be determined on a quantitative scale. Peak densities of order $10^3\ \mathrm{cm}^{-3}$ to $10^4\ \mathrm{cm}^{-3}$ are found in several H II regions measured, including M 8, M 17, M 42 and W 51, and the highest $N_e \approx 10^5\ \mathrm{cm}^{-3}$ was determined in W 3.

However, Brocklehurst and Leeman (06.022.054) used accurate collisional cross sections for transitions among the highly excited levels of H° to calculate the pressure broadening ('Stark broadening') of the radio-frequency recombination lines of H I, essentially confirming earlier classical calculations of Griem. Their work was verified by Peach (*Ap.L.*, **10**, 129, 1972) using the full quantum-mechanical impact theory. Brocklehurst and Seaton (06.131.072, *M.N.*, **157**, 179, 1972) used these calculations to study the observed lines in H II regions, and in particular in M 42. They showed that the high electron densities deduced from the relative strengths of the recombination lines, by the various authors quoted above, would certainly lead to wider profiles than are in fact observed. Part of the discrepancy comes from the way in which the observations are reduced to derive profiles, but the remainder must be due to variable electron density within the nebula. Line profiles computed from models with a smooth decrease in density from $N_e \approx 10^4$ cm^{-3} at the center to $N_e \approx 10^2$ cm^{-3} have the same general properties as the observed profiles. In this type of model the continuum generated in the denser inner regions produces very effective maser action in the outer, lower-density regions. The next step is to take density fluctuations into account, and work in this direction is in progress.

Burke *et al.* (03.131.075) observed H_2O sources in W 3, W 49 and M 42 at 1·35 cm with the VLBI. None of the sources were resolved, to a limit of about 0″003, corresponding to minimum brightness temperatures as high as 10^{13} K.

Johnston *et al.* (05.131.081) made three-station long-baseline interferometer measurements of the H_2O $6_{16} \rightarrow 5_{23}$ rotational-line radiation from W 49. The H_2O source was found to consist of many individual features, all of which are less than 0″0005 in size, lying within a circle of diameter ~ 1″5. The H_2O source is quite close to one of the OH sources in W 49.

Hills, Janssen, Thornton and Welch (*Ap. J.*, **175**, L59, 1972) made further interferometric measurements to determine accurate positions of the H_2O sources in M 42, W 3, W 49A and W 51. They found that the H_2O sources are close to the OH and other molecular and infrared sources in these H II regions, but are not in general coincident with them.

Repeated observations by Sullivan (05.131.091) of the 1·35 cm H_2O line in W 3, W 49 and M 42 show large changes in times of the order of months in the complex frequency structure of the line profiles and in the intensity, width, apparent radial velocity and polarization of the individual features. Each of the features that together make up the H_2O profile arises from a separate dense region in or near the H II region that is able to sustain maser emission. On one possible model a typical maser has $T \sim 500°$, dimensions $1 \times 1 \times 10^2$ AU, and H_2O density ~ 10^4 cm^{-3}.

Electron temperatures have been measured in several H II regions by Louise (03.131.096) by comparison of the line widths of Hα and [N II] λ 6583, taking advantage of the different atomic weights of H and N and the consequent difference in thermal Doppler broadening. A correction (amounting to about $+10^3$ K in most cases) due to the fine structure of Hα has been calculated by Dyson and Meaburn (05.132.017). However, narrow-band interference-filter photographs in Hα, [N II], and [O III] by Smith (*AA*, **16**, 482, 1972) clearly show that the distribution of excited H^+ and N^+ ions is far from identical in H II regions, particularly close to bright rims, and the basic assumption of the method is not fulfilled. The detailed quantitative temperatures derived in this way are therefore open to serious question. Further line-profile measurements by Dopita, Gibbons and Meaburn (*AA*, **22**, 33, 1973) show that in M 42 comparison of Hβ and [O III] profiles gives a better determination of T than does comparison of Hα and [N II], because in this nebula the main stages of ionization (in the central part) are H^+, N^{+2} and O^{+2}.

Line profiles of Hα and [N II] λ 6583 were measured with a photo-electric Fabry-Perot interferometer at many points in M 8 and M 42 by Dopita (*AA*, **17**, 165, 1972). The angular resolution used was 40″ diameter, and the measurements were reduced to give the temperature and turbulent velocity on the assumption that excited N^+ and H^+ have the same spatial distribution. Temperatures ranging from 6×10^3 to 1×10^4 K are observed in both nebulae, and turbulent velocities of order 6 to 12 km s^{-1}.

Meaburn (06.131.091) used a Fabry-Perot interferometer to look for high-velocity wings or components of [O III] λ 5007 in several bright H II regions, to check earlier reports of such features by Gershberg, Shcheglov, Lee and others. He found definite evidence of non-Gaussian wings up to −60 km s^{-1} in M 16 and M 17, of line doubling with separations up to 20 km s^{-1} in M 8 and M 17, and also suspected small components with radial velocities up to −55 km s^{-1} (with respect to the mean velocity) in M 8 and M 42.

Louise (*AA*, **18**, 475, 1972) measured interferometrically line profiles of Hα and [N II] λ 6583 in the η Car nebulosity. With the angular resolution used (4′ diam) the line profiles are mostly complex, with two or more components. The turbulent velocities are higher than in most other H II regions.

Allen (*Ap.J.*, **172**, L55, 1972) surveyed several H II regions in the infrared (2·2 μ) and found quite a few bright infrared objects which are not late-type stars, which are too faint to be photographed in the ordinary blue or red spectral regions, and which he suggested may be protostars.

Several theoretical discussions of the origin and the stability of condensations in a gaseous nebula, though specifically developed for planetary nebulae, may also prove applicable to H II regions (see report by Khromov).

Theoretical work has been continued at Leeds, by research students of Goldsworthy, on the internal dynamics of H II regions. Briscoe has studied the effects of hardening of the ionizing radiation by absorption, and the details of the bright-rim structure. Ampomah has developed numerical solutions of expanding H II regions, and has found (contrary to previous results) that strong D-type ionization fronts do occur in the region of transition from weak R-type to weak D-type fronts. Berry has made improvements on the gas flow around a neutral globule being ionized by a spherically symmetrical radiation field originally studied by Dyson. All these are as yet unpublished Leeds Ph.D. theses.

Dibaj (06.132.040) has studied the motions that are responsible for the origin of globules and 'comet-tail structures' in H II regions. He believes that the globules themselves first condense as a result of magnetic forces. Then elephant-trunk structures form from these globules as a result of the magneto-gravitational Rayleigh-Taylor instability. The elephant-trunk structures become comet-tail structures or cometary nebulae when hot stars form near their ends.

Dyson and de Vries (*AA*, **20**, 223, 1972) studied theoretically the dynamical effects of postulated 'stellar-wind' mass loss from early type stars on the surrounding nebulae. They investigated whether this energy-input mechanism could be responsible for the highly supersonic velocities (of relatively small amounts of gas) observed earlier by Shcheglov and by Meaburn (see above), but they found that the mass-loss rates required from the stars is so large that it is unlikely that this is the mechanism.

Dyson has calculated the response of isothermal globules of neutral hydrogen to axially symmetric ultra-violet radiation fields. Globules in hydrostatic equilibrium respond with high surface density and low surface curvature in the direction of a high radiation field. Conversely, they respond with low surface density and high surface curvature in the direction of low radiation field. Globules having negligible self gravity in general have uniform densities. They adopt low surface curvature towards high radiation field, and vice versa. It is possible however, to have a radiation field which causes internal pressure gradients within the globule. The globule then drifts slowly towards the minimum in the radiation field.

Kahn has considered the formation of an early type star from a cloud of gas plus dust. The dust particles are melted if they approach too close to the star. The radiation from the star is absorbed by the nearest surviving dust particles, and re-emitted in the infra-red. Radiation pressure effects due to this secondary radiation are not important. The infall of gas into the star continues until the radiation pressure at the boundary of the dust free region is large enough to balance the ram pressure of the infalling gas. The structure then becomes unstable and breaks up. This model may give a description of objects like the one observed by Habing Israel and de Jong (see above), in NGC 7538.

HIGH LEVEL RECOMBINATION LINES

T. K. Menon

This review covers the main results obtained in the field of high level radio-frequency recombination lines since the extensive review by Dupree and Goldberg. The above authors have discussed in detail the theory of formation of these lines under various physical conditions. We shall first discuss the new observational results and then the developments in the theoretical interpretation of data. A comprehensive bibliography of work in this area will be found as part of the report of Commission 40.

Observational results

A number of new hydrogen and helium recombination lines have been measured, especially extending the range to higher quantum numbers and higher order transitions. Most of the measurements have been concerned with discrete H II regions. However, one of the most interesting results was the detection of recombination lines from diffuse interstellar gas (Gottesman and Gordon, Jackson and Kerr). Since the original detection, surveys have been made, in the galactic plane, of the lines from the diffuse gas (Davies *et al.*, Gordon and Cato). The lines from a few H II regions have been studied with high angular resolution. The anomalous recombination lines attributed to carbon have been detected in a number of new H II regions (Menon, Davies). The unambiguous detection of recombination lines from planetary nebulae NGC 7027 and IC 418 has been reported (Terzian and Balick). Line radiation, from a high emission measure condensation in W 3, has been detected using the Westerbork array.

Theoretical interpretation

The observed line intensities of recombination lines from an H II region depend in general on three parameters of the nebula, $<T_e>$, $<N_e>$, $<E>$. For a theoretical calculation of the line to continuum ratio of a particular line from a specific nebula we have to have knowledge of the above parameters suitably averaged over the line of sight and the beamwidth, as well as knowledge of the b_n parameters specifying the departure from LTE. These latter parameters depend again on T_e and N_e. Under conditions of LTE the three average parameters of the nebula can be determined, in principle, from observations of three lines. However the observations are never good enough for that type of determination. A number of discussions has been published by Hjellming and his collaborators of the various methods of determining the parameters of a number of H II regions from observations of the recombination lines under conditions of LTE and non-LTE.

They conclude from their analyses that the differences in the theoretical values of the b_n factors computed by different methods do not affect the non-LTE determinations of $<T_e>$. They also reach the general conclusion that the values of $<E>$ obtained from such solutions are large compared with the emission measures obtained from radio continuum data. However solutions for particular values of $<E>$ and $<N_e>$ will require knowledge of accurate values of the b_n factors. The above calculations assume a constant average density throughout the nebula. Brocklehurst and Seaton using a different method of analysis reach the same conclusion for constant density models. However they point out that such high emission measures and consequent high densities are not compatible with the lack of impact broadening observed for the recombination lines by a number of workers. Hence they adopted a model of varying density from the center with a lower central $<E>$. They find that their model gives good agreement with observations of line intensities as well as line profiles. They emphasize, however, that local density fluctuations have to be taken into account to obtain a good agreement with all optical and radio data. The lack of observed Stark broadening in the lines from Orion A and M 17 has been interpreted, by Brocklehurst and Leeman, as being the effect of density fluctuations in the nebulae.

The hydrogen to helium ratio, determined from the helium recombination lines, is found to be about 9 percent for most H II regions studied, provided allowance is made for the spectral type of the ionizing star.

Menon showed that the anomalous recombination line observed in the direction of M 17 is most likely formed in an H I region near the H II region, thus confirming the earlier suggestion of Zuckermann and Palmer. The flux density is of the order of 6% of the hydrogen line at H 167α, but this ratio has been found to increase with n for a number of sources by Pedlar and by Davies. The mechanism of excitation of these lines is not yet well understood. There have been recent claims by Ball *et al.* and by Chaisson of the discovery of an α line of hydrogen from an H I region.

Analyses of recombination line data from diffuse interstellar gas have been made by Gordon and Gottesman, Gordon and Cato and by Davies *et al.* They all agree that distributed ionized hydrogen appears mainly to be confined to galactic radii less than about 8 kpc and that the ionization is noticeably less in a region within 2 kpc of the Sun. There is considerable disagreement, however, about the values of T_e and N_e for these regions. While Davies *et al.* prefer a value of about 6000K for $<T_e>$ and about 2·0 cm^{-3} for $<N_e>$ the other authors suggest a value of 1000K for $<T_e>$ and about 0·15 cm^{-3} for $<N_e>$. The main reason for the discrepancy is the manner in which the thermal contribution to the continuum temperature has been estimated. This matter has to be looked into in more detail before we can compare the various derived parameters with values derived from pulsar observations.

INTERSTELLAR MOLECULES

B. J. Robinson

Since 1969 molecular spectroscopy has become a major astronomical tool, providing a means of studying very cool and extremely dense interstellar clouds which are likely sites for star formation. Most of the gaseous material in the clouds appears to be in the molecular form. There are now 137 observed molecular lines, most of which can be assigned to 35 terrestrially identified molecules; about 8 of the lines have not yet been identified, and may be produced by molecules which are transient and rare under laboratory conditions. Many polyatomic organic molecules are observed with up to seven atoms: HC_3N, HCOOH, CH_2NH, CH_3OH, CH_3CN, $HCONH_2$, CH_3CHO and CH_3C_2H.

Radio observations

With the exception of H_2, the new molecules have been discovered in the radio spectrum at wavelengths between 36 cm and 1·7 mm. Table 1 lists the frequencies of the known lines, the transitions involved (mainly rotational) and the sources with which they are associated. The rapid rate of discovery has been the result of improved receiver sensitivity and the development of instrumentation for very short wavelengths. The new centimetre-wavelength lines have been found with the Green Bank 43 m, Haystack 37 m and Parkes 64 m telescopes; the millimetre-wave lines have all been found using the accurately-figured Kitt Peak 11 m telescope. A complete bibliography is contained in the Commission 40 report.

The most widespread molecules are CO, OH, CS, HCN, H_2S, H_2O, H_2CO and NH_3. Most molecules (28 species) are found at the galactic centre, which is the sole source of molecules with more than 5 atoms. The diatomic and triatomic molecules are also found abundantly in Orion-A (16 species), W51 (15), IRC + 10216 (8) and DR21 (7). Dark obscuring clouds contain large quantities of OH, H_2CO and CO.

After H_2, CO is the most abundant molecule with column densities ranging from 10^{17} to 10^{19} mols cm^{-2}. For the galactic centre the optical depth of $^{12}C^{16}O$ is about 90. Most of the other molecules have column densities in the range 10^{13} to 10^{16} cm^{-2}. There is surprisingly little drop in column density as one moves from diatomic molecules like CN and CS through to polyatomic molecules like HC_3N, CH_3OH, $HCONH_2$, etc. The sensitivity limit for most observations is about 10^{13} to 10^{14} mols cm^{-2}, and a wide range of complex molecules is likely to be found when sensitivity can be improved by an order of magnitude.

For many molecules a number of transitions are observed and the identification is certain. For CN, H_2O, OCS, H_2S, HCOOH and CH_3C_2H the identification depends on only one line, but the high precision with which the line frequency can be measured (about 1 part in 10^5) usually leaves little doubt about the assignment. The lines at 89·2, 90·7 and 169·3 GHz are not known in laboratory microwave spectroscopy, and the assignment of a group of five lines near 25 GHz to methanol is not certain.

UV observations

The development of rocket techniques has led to the detection of electronic transitions of dia-

Table 1. Interstellar molecules observed at radio frequencies

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
No.of atoms	Molecule Name	Formula	Ground state transition	Frequency GHz	Em. or abs.	Column density mols cm^{-2}	Sources Sgr B2	Sgr A	Ori A	W51	DR21	IRC +10216	W3	NGC 2264	Other
2	Hydroxyl	^{16}OH	$^2\Pi_{3/2}$, $J=3/2$, $F=1-2$	1.612231	A & E		*	*	*	*	*		*		≈ 200
			" " $F=1-1$	1·665401	A & E		*	*	*	*	*		*	*	"
			" " $F=2-2$	1·667358	A & E	$10^{12}-10^{16}$	*	*	*	*	*		*		"
			" " $F=2-1$	1·720533	A & E		*	*	*	*			*		> 100
			$^2\Pi_{3/2}$, $J=5/2$, $F=2-2$	6·030739	E								*		1
			" " $F=3-3$	6·035085	E		*				*		*		5
			$^2\Pi_{3/2}$, $J=7/2$, $F=4-4$	13·441371	E								*		
			$^2\Pi_{1/2}$, $J=1/2$, $F=0-1$	4·660242	E		*		*						
			" " $F=1-1$	4·750656	E		*								
			" " $F=1-0$	4·765562	E		*						*		2
		^{18}OH	$^2\Pi_{3/2}$, $J=3/2$, $F=1-1$	1·63753	A		*	*							
			" " $F=2-2$	1·63948	A		*	*							
	Carbon monoxide	$^{12}C^{16}O$	$J=1-0$	115·2712	E	$10^{17}-10^{19}$	*	*	*	*		*	*		> 20
		$^{13}C^{16}O$	"	110·2014	E		*	*		*		*			5
		$^{12}C^{18}O$	"	109·7822	E		*			*					
	Cyanogen	CN	$N=1-0$	113.491	E	10^{15}	*	*	*	*		*			
	Carbon monosulphide	$^{12}C^{32}S$	$J=3-2$	146·96916	E	10^{14}			*	*	*	*			
		"	$J=2-1$	97·9810	E		*							*	≈ 3
		"	$J=1-0$	48·99100	E		*								≈ 5
		$^{12}C^{34}S$	$J=2-1$	96·413	E		*								
		"	$J=1-0$	48·20695	E		*								
		$^{13}C^{32}S$	$J=2-1$	92·494	E		*								
		"	$J=1-0$	46·24747	E		*								
	Silicon monoxide	SiO	$J=2-1$	86·847	E	10^{13}	*		*						
			$J=3-2$	130·2684	E	10^{13}	*								
3	Water	H_2O	$6_{16}-5_{23}$	22·23508	E	Maser	*		*	*	*		*		> 25
	Hydrogen cyanide	$H^{12}C^{14}N$	$J=1-0$	88·63185	E	10^{15}	*	*	*	*	*	*	*	*	3
		$H^{13}C^{14}N$	$J=1-0$	86 34005	E			*	*			*			
		$H^{13}C^{14}N$	$J=2-1$	172·6777	E				*						
		$H^{12}C^{15}N$	$J=2-1$	172·1081	E				*		*	*			
		$D^{12}C^{14}N$	$J=1-0$	72·41482	E	4×10^{12}			*						
		$D^{12}C^{14}N$	$J=2-1$	144·82786	E				*						
	Carbonyl sulphide	OCS	$J=9-8$	109.4628	E	10^{14}	*								

Table 1 (continued)

(1) No.of atoms	(2) Molecule Name	(3) Formula	(4) Ground state transition	(5) Frequency GHz	(6) Em. or abs.	(7) Column density mols cm^{-2}	(8)	(9)	(10)	(11)	(12) Sources	(13)	(14)	(15)	(16)
							Sgr B2	Sgr A	Ori A	W51	DR21	IRC +10216	W3	NGC 2264	Other
3	Hydrogen sulphide	H_2S	1_{10}–1_{01}	168·76276	E	10^{14}	*		*	*	*		*	*	2
4	Ammonia	NH_3	$J, K=1,1$–$1,1$	23·69448	E	10^{16}	*	*	*	*	*		*		6
			2,2–2,2	23·72271	E		*	*		*					2
			3,3–3,3	23·87011	E		*	*		*					2
			4,4–4,4	24·12939	E		*								
			6,6–6,6	25·05604	E		*								
			2,1–2,1	23·09879	E		*								
			3,2–3,2	22·83417	E		*								
	Formaldehyde	$H_2{}^{12}C^{16}O$	1_{10}–1_{11}	4·829660	A	10^{12}–10^{16}	*	*	*	*	*		*		≈ 100
			2_{11}–2_{12}	14·48865	A		*	*		*					3
			3_{12}–3_{13}	28·97485	A		*								
			2_{12}–1_{11}	140·83953	E			*	*	*			*		
		(para-)	2_{02}–1_{01}	145·60297	E				*						
			2_{11}–1_{10}	150·49836	E				*						
		$H_2{}^{13}C^{16}O$	1_{10}–1_{11}	4·593089	A		*	*		*					
		$H_2{}^{12}C^{18}O$	1_{10}–1_{11}	4·388797	A		*								
	Thio-formaldehyde	H_2CS	1_{10}–1_{11}	1·04648	A					*					
			2_{11}–2_{12}	3·13938	A	10^{16}	*	?							
	Isocyanic acid	HNCO	1_{01}–0_{00}	21·9817	E	10^{14}	*								
			4_{04}–3_{03}	87·92545	E		*								
			4_{14}–3_{13}	88·239	E		*								
5	Cyano-acetylene	HC_3N	$J=1$–0, $F=1$–1	9·097036	E		*								
			$F=2$–1	9·098332	E	10^{16}	*								
			$F=0$–1	9·100279	E		*								
			$J=8$–7	72·8	E		*								
			$J=9$–8	81·3	E		*								
			$J=10$–9	91·0	E		*								
			$J=11$–10	100·1	E		*	*	*	*					
	Formic acid	HCOOH	1_{10}–1_{11}	1·638805	E	10^{13}?	*								
	Methanimine	CH_2NH	1_{10}–1_{11}, $F=0$–1	5·28900			*								
			$F=2$–2	5·28982	E	10^{14}	*								
			$F=2$–1	5·29065			*								
			$F=1$–2	5·29085			*								
			$F=1$–1	5·29170			*								

Table 1 (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
No.of atoms	Molecule		Ground state transition	Frequency GHz	Em. or abs.	Column density mols cm^{-2}	Sources								
	Name	Formula					Sgr B2	Sgr A	Ori A	W51	DR21	IRC +10216	W3	NGC 2264	Other
6	Methanol	CH_3OH	1_1–1_1 (A)	0·834267	E	?	*	*							
			3_1–3_1 (A)	5·00532	E	?	*								
			4_2–4_1 (E_1)	24·93347†	E	10^{16}			*						
			5_2–5_1 (E_1)	24·95908†	E				*						
			6_2–6_1 (E_1)	25·01814†	E				*						
			7_2–7_1 (E_1)	25·12488†	E				*						
			8_2–8_1 (E_1)	25·29441†	E				*						
			1_0–0_0 (A)	48·37260	E	10^{16}	*								
			1_0–0_0 (E)	48·37709	E		*								
			5_1–4_0 (E_2)	84·52121	E	10^{17}	*								
	Methylcyanide	CH_3CN	6_5–5_5	110·3307	E		*								
			6_4–5_4	110·3497	E		*								
			6_3–5_3	110·3645	E		*	?							
			6_1–5_1	110·3814	E		*	*							
			6_0–5_0	110·3835	E	10^{14}	*	*							
	Formamide	$HCONH_2$	1_{10}–1_{11}, $F = 1$–1	1·538135	E		*	*							
			$F = 1$–2	1·538693	E		*	*							
			$F = 2$–1	1·539295	E		*								
			$F = 1$–0	1·539570	E		*								
			$F = 2$–2	1·539851	E	10^{15}	*	*							
			$F = 0$–1	1·541018	E		*	*							
			2_{11}–2_{12}, $F = 2$–2	4·61714	E		*								
			$F = 3$–3	4·61900	E		*								
			$F = 1$–1	4·62001	E		*								
7	Acetaldehyde	CH_3CHO	1_{10}–1_{11}	1·065075	E	10^{14}	*	*							
			2_{11}–2_{12}	3·195167	E	10^{14}	*								
	Methyl-acetylene	CH_3C_2H	5_0–4_0	85·45729	E	?	*								
?	U89.2	?	?	89·1890	E			*	*	*			*	*	1
?	U90.7	?	?	90·6639	E				*					*	
?	U169.3	?	$J = 2$–1?	169·3361	E				*						

† Assignment not certain.

Table 2. UV absorption lines of interstellar molecules

(1)	(2)	(3)		(4)	(5)	(6)
Molecule						
Name	Formula	Transition		Wavelength Å	Column density mols cm^{-2}	Reference
–	CH	$A^2\Delta - X^2\Pi$,	(0,0), $R_2(1)$	4300·30	10^{13}	
		$B^2\Sigma^- - X^2\Pi$,	(0,0), $P_{Q_{12}}(1)$	3890·21		
			(0,0), $Q_2(1) + Q_{R_{12}}(1)$	3886·41		
			(0,0), $R_2(1)$	3878·77		
		$C^2\Sigma^+ - X^2\Pi$,	(0,0), $P_{Q_{12}}(1)$	3146·01		
			(0,0), $Q_2(1) + Q_{R_{12}}(1)$	3143·20		
			(0,0), $R_2(1)$	3137·53		
–	$^{12}CH^+$	$A^1\Pi - X^1\Sigma$,	(0,0), R(0)	4232·54	10^{13}	
			(1,0), R(0)	3957·70		
			(2,0), R(0)	3745·31		
			(3,0), R(0)	3579·02		
			(4,0), R(0)	3447·08		
	$^{13}CH^+$	$A^1\Pi - X^1\Sigma$,	(0,0), R(0)	4232·08		1
Cyanogen radical	CN	$B^2\Sigma^+ - X^2\Sigma^+$,	(0,0), P(3)	3876·84	10^{12}	
			(0,0), P(2)	3876·30		
			(0,0), P(1)	3875·77		
			(0,0), R(0)	3874·61		
			(0,0), R(1)	3874·00		
Hydrogen	H_2	$B^1\Sigma_u - X^1\Sigma_g$,	(0,0)	1108	$1{\cdot}3 \times 10^{20}$	2
			(1,0)	1092		
			(2,0)	1077		
			(3,0)	1063		
			(4,0)	1049		
			(5,0)	1037		
			(6,0)	1024		
			(7,0)	1013		
Carbon monoxide	$^{12}C^{16}O$	$A^1\Pi - X^1\Sigma^+$,	(1,0)	1509·65	8×10^{15}	3
			(2,0)	1477·46		
			(3,0)	1447·26		
			(4,0)	1418·97		
			(6,0)	1367·56		
			(8,0)	1322·10		
			(9,0)	1301·37		
			(10,0)	1281·83		
	$^{13}C^{16}O$	$A^1\Pi - X^1\Sigma^+$,	(2,0)	1478·8	7×10^{13}	3
			(3,0)	1449·3		
			(4,0)	1421·4		
			(6,0)	1370·8		

References to Table 2:

1. Bortolot, V. J., Thaddeus, P. (1969) *Astrophys. J.*, **155**, L17.
2. Carruthers, G. R. (1970) *Astrophys. J.*, **161**, L81.
3. Smith, A. M., Stecher, T. P. (1971) *Astrophys. J.*, **164**, L43.

tomic molecules in the far UV. To the 30 yr-old identifications of CH, CH^+ and CN (in the near UV) have been added H_2 and CO; the observed interstellar absorption lines are listed in Table 2.

Carruthers observed strong absorption of ξ Persei by the Lyman resonance bands of H_2, with a column density of 10^{20} cm^{-2}. Only this one detection of H_2 has been made, although theory suggests that the hydrogen will be mostly molecular in dark clouds with visual absorption greater than 1·5 mag. The Lα absorption of ξ Per gives a column density of 4×10^{20} cm^{-2}, so that a substantial fraction of the total hydrogen is molecular where the visual extinction by dust is only 1 mag.

Smith and Stecher have observed CO absorption in the spectrum of ζ Ophiuchi, with a column density of 8×10^{15} cm^{-2}. This is several orders of magnitude below that observed at 115·3 GHz in Orion A, Sgr B2, Cloud 4, etc. Similarly the CN absorption at 3876 Å gives column densities of 10^{12} cm^{-2}, while the emission line at 113·5 GHz requires 10^{15} cm^{-2}. Thus the molecules observed in the UV are in less dense clouds than those observed at radio wavelengths; the denser clouds are believed to be rich in dust, which would lead to high obscuration in the UV.

Diffuse interstellar lines

No convincing identification of the 25 diffuse interstellar absorption lines (such as 4430 Å) has been made. Johnson points to a wavelength correspondence of many lines with the spectrum of magnesium porphyrin Mg $C_{46}H_{30}N_6$, but it is hard to see why the medium should selectively produce this molecule without also producing many chemically related species.

Densities and temperatures of molecular clouds

The observation that most radio lines are in emission shows that they are not in equilibrium with the radiation field and that collisional excitation is important. Collisions with hydrogen atoms or molecules are expected to dominate, as few ions are expected in dense dust clouds where the UV is highly absorbed (leaving low-energy cosmic rays to produce ionisation at a low level).

The rate at which rotational levels tend to equilibrate with the 3K relict radiation (10^{-5} to 10^{-10} s^{-1}) increases with ν^2 and $|\mu|^2$ (ν = frequency; $|\mu|$ = dipole matrix element). For collisional excitation to dominate millimetre-wave transitions in several molecules (HCN, CH_3CN, H_2CO,...) with large dipole moments requires a density of H_2 exceeding 10^6 cm^{-3}. For these densities the mass of the Sgr B2 cloud must be at least 5×10^5 $M_\odot$; such a cloud will be unstable with a gravitational collapse time of $(\varrho G)^{-1/2} = 30000$ yr.

The temperatures of the dense clouds are low. The 115 GHz radiation from CO in Orion is optically thick and well resolved, and the observed brightness temperature of 40K is likely to be close to the kinetic temperature T_k. CO is optically thick in some dark clouds and yields T_k of 5K to 20K. In Sgr B2 comparison of the intensities of the (1,1) and (2,2) lines of NH_3 gives kinetic temperatures between 20K and 80K. The molecules presumably play a role in cooling the clouds.

Formation and destruction of molecules

The existence of concentrations of polyatomic molecules shows that earlier ideas on the slow rate of production, and the high rate of dissociation, need major revision. As yet, little is known about how these molecules form.

In the cold, dense clouds a substantial fraction of the C,O and N atoms appear to be combined in molecules, while the remaining hydrogen is predominantly molecular. Dust and high H_2 densities are believed to shield the molecules from short-λ UV photons so that the lifetime against dissociation is long. Molecules are dissociated by X-rays and cosmic rays, with some loss by exchange reactions and by adsorption on dust grains. In Orion A the molecular distribution shrinks from that of CO via CS to H_2CO as the dissociation energy falls; in Sgr B2 the distribution is extended for OH, CO and H_2CO and more localized for the complex molecules such as HC_3N.

For the low-density clouds ($n_H \approx 50\ \mathrm{cm}^{-3}$) in the direction of ζ Ophiuchi, Solomon and Klemperer have shown that Herbig's observations can be quantitatively accounted for by two-body association to form CH and CH^+, followed by exothermic exchange reactions to form CO and CN. These processes would produce little OH.

Association and exchange reactions are too slow to form the polyatomic molecules, and the low temperature of the gas inhibits chemical reactions with non-zero activation energy. So Salpeter and Watson, Williams and others have investigated whether the grains provide surfaces where adsorbed atoms and molecules could be retained long enough to form more complex molecules. However, the grain temperatures (5K to 15K) are probably too low to allow these molecules to escape, unless grain-grain collisions, shock waves or cosmic ray bombardment sputter or evaporate the molecules, or even decompose the grains.

An alternative view is that the molecules (and dust) form in the dense atmospheres of stars by many-body collisions and are later expelled. This is a likely origin for dust, but the molecules are unlikely to survive the UV radiation from the star – which would dissociate them in tens of years. It would also be difficult to produce the massive molecular clouds in this way.

Isotopic abundances

At radio wavelengths observations of ^{18}OH, $^{13}C^{16}O$, $^{12}C^{18}O$, $^{13}C^{32}S$, $^{12}C^{34}S$, $H^{13}C^{14}N$, $H^{12}C^{15}N$, $H_2{}^{13}C^{16}O$ and $H_2{}^{12}C^{18}O$ have promised information on the abundances of $[^{12}C/^{13}C]$, $[^{16}O/^{18}O]$, $[^{14}N/^{15}N]$ and $[^{31}S/^{34}S]$ since the excitation of the various isotopic species should be very similar. However, the optical depth of the most common isotopic species has turned out to be quite high and ill-determined, so that the ratios of the observed intensities tend to give *lower limits* to the abundance ratios. For the optically thin lines of $^{13}C^{16}O$ and $^{12}C^{18}O$ or $H_2{}^{13}C^{16}O$ and $H_2{}^{12}C^{18}O$ the intensity ratios are near 5 – consistent with the terrestrial abundances $[^{12}C/^{13}C] = 89$ and $[^{16}O/^{18}O] = 499$. Thus the $[^{12}C/^{13}C]$ ratio is sure to be much higher than the value of 4 produced by hydrogen burning in stars in the C-N-O cycle.

The optical observation of $^{13}CH^+$ by Bortolot and Thaddeus and the rocket measurements of $^{13}C^{16}O$ by Smith and Stecher set *upper limits* on the $[^{12}C/^{13}C]$ ratio of 82 and 105 respectively, both quite close to the terrestrial ratio.

Jefferts *et al.* have announced the very significant discovery of the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ lines of deuterated hydrocyanic acid ($D^{12}C^{14}N$) in Orion-A. The high optical depth of $^1H^{12}C^{14}N$ makes it difficult to determine the abundance ratio [H]/[D]. However, the observed $J = 2 \rightarrow 1$ line of $D^{12}C^{14}N$ is almost as intense as that observed for $^1H^{12}C^{15}N$, which shows that [H/D] in Orion is comparable with $[^{14}N/^{15}N]$, and an order of magnitude below the [H/D] limit set by the lack of absorption by the 327 MHz hyperfine line of deuterium in Cas A.

Interstellar masers

Extensive observations have been made of the maser emission from OH and H_2O, and of the refrigerated absorption in H_2CO. An extensive bibliography is contained in the Commission 40 report.

Hydroxyl: Many new OH masering sources have been found in searches of H II regions at 18 cm by Downes, Turner, Robinson *et al.*, and Winnberg *et al.* Most of the sources show the strong 1665 and 1667 MHz emission associated with H II regions, but a surprising number have strong 1612 MHz emission of the type normally associated with IR stars. This type of 1612 MHz emission from objects in the Cal. Tech. IR survey and from Mira variables has been investigated extensively by Wilson and Barrett, Caswell *et al.* and Rieu *et al.*; a number of Mira variables emit only at 1665 and 1667 MHz. Hardebeck has measured precision positions for many of the OH-IR objects and some main-line OH emitters.

High resolution continuum maps of H II regions show a striking association of OH emission with highly compact condensations (Wynn-Williams *et al.*, Martin and Downes, Habing *et al.*), the OH sources being at the edge of the compact H II regions.

Interferometry has been used by Cooper *et al.* to produce detail 'maps' of the OH masering sources in W3, W49, Sgr B2, W51 and DR 21. Within an area of diameter 10^3 to 10^4 AU lie numerous bright spots with dimensions of about 10 AU and characteristic radial velocities and sense of circular polarisation. This distribution suggests a collapsing gas cloud, fragmented into a number of protostars. Davies *et al.* have used the same interferometer to map the OH/IR source NML Cygnus; a large number of bright spots are contained within an area 1000 AU across. The receding components lie outside those with a velocity of approach, and suggest an expanding gas cloud which is also rotating.

Emission from several excited rotational states of OH has been observed (see Table 1). In W3 and DR 21 Rydbeck *et al.* noted a correspondence of the circular polarisation patterns for the $^2\pi_{3/2}$, $J=5/2$ and $^2\pi_{3/2}$, $J=3/2$ transitions which strongly suggested Zeeman splitting in fields of 5×10^{-3} gauss; Gardner *et al.* noticed a similar correspondence in NGC 6334A. This interpretation is consistent with the lines observed in the $^2\pi_{1/2}$, $J=1/2$ and $^2\pi_{3/2}$, $J=7/2$ states (Zuckerman *et al.*). However, VLBI measurements show that the RH and LH circularly polarised components originate in spatially separated regions.

The association of OH emission with IR objects and the observation of emission from excited rotational states have both given support to IR pumping models for the satellite-line masers. For the 1665/1667 MHz masers collisional excitation shows most promise, particularly the dissociation of H_2O by H atoms to form OH in excited states (Gwinn *et al.*).

Water Vapour: Searches for 22.235 GHz H_2O masering sources by Knowles *et al.*, Meeks *et al.*, Turner *et al.* and Johnston *et al.* have shown that the H_2O masers are closely associated with OH maser emission at 1665 and 1667 MHz. About a third of the OH masers show H_2O emission, the H_2O emitters being found close to compact H II regions. Schwarz and Barrett find weak H_2O emission associated with IR stars that show 1665/1667 MHz emission (although U Her is an H_2O source without OH emission).

Hills *et al.* have measured the H_2O positions interferometrically, and find that the H_2O and OH masers can be separated by up to 10000 AU. Thus somewhat different conditions are needed for the excitation or creation of the two molecules.

VLBI measurements on H_2O masers yield sizes less than 0·0005″ (Johnston *et al.*). The larger size of the OH masers (0·05 to 0·005″) is attributed to scattering by irregularities in the interstellar plasma; these can be independently monitored by pulsar observations. The brightness temperature of H_2O masers can exceed 5×10^{13}K, and the radiated power can be as high as 10^{33} erg s^{-1} in a frequency band of only 1 MHz. The VLBI map of the H_2O sources in W49 shows a similar distribution of bright spots to the OH maps.

Marked changes occur in the frequency structure of the H_2O profiles and in the intensity, width, apparent radial velocity and linear polarization of the individual features. Time scales for the changes range from 10 days to several months. The temporal changes in H_2O profiles are larger and faster than in OH profiles, which suggests that the OH masers are more highly saturated.

Inversion of the 6_{16}–5_{23} transition in water may take place by collisional excitation to higher rotational levels followed by a selective cascade, by the formation of molecules in high rotational levels followed by a cascade, or by far-IR fluorescence.

Formaldehyde: Formaldehyde in dark clouds absorbs the 2·7 K relict radiation, so that the 1_{10}–1_{11} transition must be anti-inverted, with an excitation temperature of about 0·8 K. Refrigeration mechanisms proposed include collisional excitation and reradiation, IR pumping via higher vibrational levels, and an augmentation of the relict radiation at millimetre wave-lengths. Conditions in dark clouds are not sufficiently known to select between these proposals, although collisions must be ineffective at low temperatures.

Other Molecules: Comparison of several transitions in other molecules (e.g. CH_3OH, H_2CS) reveals smaller departures from thermodynamic equilibrium between the states, which indicate that rotational excitation is always a competion of interaction with the microwave and IR radiation fields and collisions with neutral molecules and with ions.

Galactic centre region

The region within a few hundred parsec of the galactic centre has a complex distribution of dense and massive molecular clouds ($M \approx 10^5 M_\odot$). The area has been surveyed for OH absorption by Robinson and McGee, for H_2CO absorption by Gardner and Whiteoak and by Scoville *et al.*, and for CO emission by Solomon *et al.*

The dynamical implications of the galactic centre observations are covered in the Commission 33 report.

Negative results

Behind the extensive literature on the discovery of complex molecules lies a vast amount of unpublished data on unsuccessful searches for at least as many molecules again. This data is certain to be valuable for an understanding of how molecules are formed, and why chemically related molecules differ greatly in abundance. Since authors are reluctant to report negative results and editors are equally reluctant to publish them, the IAU itself might provide a means of collecting and disseminating such results. To be useful the results would need to give adequate detail on the transition, adopted rest frequency, frequency range searched, frequency resolution, flux density or T_b limit reached, sources searched, etc.

Biological implications

The fact that complex organic molecules can form and survive in the harsh interstellar environment suggests that they can readily be formed in planetary atmospheres. Many of the simpler organic molecules observed (H_2O, NH_3, HCN, H_2CO, ...) have been the starting points for experiments to synthesize biological molecules in model planetary atmospheres.

Molecules such as formamide, formic acid and methanimine can be classed as pre-biotic. It seems plausible that formic acid (HCOOH) and methanimine (CH_2NH) could react to produce the simple amino acid glycine (NH_2CH_2COOH). In the next few years there will be considerable search activity for such biologically significant molecules.

Future expectations

(a) Both microwave and infrared observations can be expected to yield much information on the dense, cool clouds where molecules abound and star formation is likely to be taking place. The discoveries of the past three years highlight the need for high sensitivity microwave radiometers and precision antennas for millimetre wavelengths. Increased sensitivity is sure to lead to the discovery of a greater variety of molecules. In the infrared there is a pressing need for higher sensitivity detectors and for increased spectral resolution.

(b) Rocket and satellite observations in the UV are likely to detect more simple molecules in clouds of lower density where the obscuration by dust is not too high.

(c) Improved sensitivity at radio wavelengths will allow the measurement of isotopic abundances for molecules where the common species has low optical depth. These ratios will be very important for an understanding of the nucleogenesis of the interstellar matter.

(d) How complex molecules form and how long they survive in interstellar clouds are areas of considerable ignorance. New ideas are urgently needed.

NEUTRAL HYDROGEN AND RELATED PROBLEMS

H. van Woerden and H. C. D. Visser

1. *Instrumentation*

Two great new instruments have been put to use in 21-cm line studies. The Parkes hydrogen-line interferometer (Radhakrishnan *et al.*, 07.033.001) can give angular resolutions of 2′ to 6′ and velocity resolutions ΔV between 0·2 and 20 km/s; it has been used to measure absorption spectra of 78 sources, with $\Delta V = 2$ km/s. At Westerbork, an 80-channel spectrometer (Allen *et al.*, *AA*, in press) allows simultaneous aperture synthesis at 8 frequencies with 10 interferometers, giving angular resolution of 0′5, but poor velocity resolution: $\Delta V = 25$ km/s; this instrument which was designed for extragalactic work, is also being used in absorption on 2 discrete sources (Schwarz and Wesselius; Goss *et al.*, 1973, *AA*) and in emission on a high-velocity cloud (Hulsbosch *et al.*).

Most of the hydrogen-line surveys published since 1969, however, have been made with beamwidths of about 0°6 (25-m dishes) and velocity resolutions $\Delta V \sim 2$ km/s (i.e. bandwidths 8 to 12 kHz). Exceptions to these numbers are noted below; these include the great surveys at the Green Bank 91-m and Parkes 64-m dishes, with beamwidths of about 0°2. For some of the major surveys, instrumental properties and reduction procedures are reported in detail (Kerr, 02.157.002; Westerhout, 03.157.028; Tolbert, 06.157.003; Weaver and Williams, 1973, *AA Suppl.*). Burton (04.157.003) discusses the standard procedures for hydrogen-line measurements at Dwingeloo.

The high sensitivity of present-day low-noise receivers has made quite weak signals ($T_b \leqslant 1$ K) measurable; consequently, accurate knowledge of the receiver zero level (or 'baseline') has become of great importance. Wrixon and Heiles (07.033.019) have used the horn reflector at Crawford Hill, for which these problems are much less severe, to find positions with very weak 21-cm profiles, which may serve as zero-line standards.

Following an initiative in IAU Commission 40, several observers have compared their brightness-temperature scales to those of others (Penzias *et al.*, 03.157.003; Westerhout, 03.157.028; Velden, 04.155.040; Harten, 07.155.091; Pöppel and Vieira, *AA Suppl.*, in press; Williams, *AA Suppl.*, in press). This is important since the internal accuracy of the better surveys is of the order of 1 %, while the external errors of T_b-scales may be about 10 %. The paper by Williams is particularly thorough and enlightening.

The survey results are often published in the form of contour maps, showing $T_a(b, V)$ at constant l, or some other permutation or combination of variables; a number of papers give complete atlases of line profiles, thus preserving the full detail and accuracy of the original material. The biggest surveys contain between 10^4 and 10^5 independent profiles, thus presenting a formidable problem not only of data handling, but particularly of digestion by the astronomer; Westerhout (03.157.016) has taken recourse to motion pictures.

In the following we shall summarize the main characteristics of the major surveys; a complete tabular compilation is available on request.

2. *Galactic belt and equator*

Great efforts have gone into high resolution surveys of the galactic belt. Westerhout (03.157.028) has published a second, improved and extended edition of the Maryland-Green Bank Galactic 21-cm Line Survey (beam 0°2), which covers the region $-1° \leqslant b \leqslant +1°$, $11° \leqslant l \leqslant 235°$ almost completely with $T_a(\alpha, V)$ maps at constant δ. A third edition is in preparation. The Parkes Hydrogen-Line Survey of the Milky Way (beam 0°24, band 8 km/s) contains $T_a(b, V)$ maps at $-2° \leqslant b \leqslant +2°$ for $l = -60°(1°)\ +60°$ (Kerr, 02.157.002) and at $-6° \lesssim b \lesssim +4°$ for $l = 190°(5°)\ 300°$ (Hindman and Kerr, 04.155.036). Thus, the southern surveys span a wider latitude range, but have much thinner longitude coverage. And, while the Parkes beam is cleaner than that of the Green Bank dish, the velocity resolution used sofar is unfortunately low. However, these shortcomings are being remedied. A new Parkes survey by Kerr and Harten (see *BAAS* 4, 113, 1972) with $\Delta V = 2$ km/s (and 0°24 beam) contains scans between $b = \pm 2°$ or $\pm 4°$, roughly every 0°5 in longitude at $280° < l < 340°$. Verschuur at Green Bank has made constant-latitude scans from $l = 10°$ to 230° at latitudes $\pm 2°$ (2°) $\pm 10°$ (2°5) $\pm 22°5$. These new surveys are still in the reduction stage.

Special surveys have been made on the galactic equator. The Parkes survey (0°24, 8 km/s) includes (Kerr and Hindman, 04.155.034) contour maps drawn from profiles taken at $l = 185°5$ (1°) 299°5, 300° (1°) 60°, and also (Kerr, 02.157.002) maps from closely spaced profiles, at $l = -64°$ (0°1) $+63°5$. The new Kerr-Harten survey (0°24, 2 km/s) has profiles at $l = 220°$ (0°05) 350°. Westerhout (1971) has circulated $T_a(l, V)$ maps constructed from the Maryland-Green Bank Survey, and covering the equator with resolutions of 0°.2 or (after smoothing) 0°.6, and $\Delta V = 2$ km/s. Together, Kerr and Westerhout have now fully covered the galactic equator at high resolution. Burton (04.157.003) has published Dwingeloo profiles at $l = -6°$ (1°) 120°, along with profile integrals and maps $T_b(l, V)$.

The search for high-velocity hydrogen by Dieter (07.157.002) includes a low-latitude section at $|b| < 15°$, $l = 10°$ (2° or 1°) 250°, in which mainly negative velocities (−300 to −50 km/s, roughly) have been studied.

Another Berkeley Survey, by Weaver and Williams, is in press (*AA Suppl.*). The Hat Creek 25-meter dish (beam 0°.59) and 100-channel receiver (band 2 km/s), fully automated and well calibrated, have completely covered the region $10° \leqslant l \leqslant 250°$, $-10° \leqslant b \leqslant +10°$ with a dense grid (0°.5 in l, 0°.25 in b) of profiles. These will be published in a 481-page atlas, with 81 profiles per page. The calibration techniques followed should make this survey the most homogeneous one to date. With its wide latitude coverage, and more modest angular resolution, it beautifully supplements the Maryland-Green Bank Survey.

The Carnegie all-sky survey by Tuve (see below) covers the galactic belt to $|b| = 16°$ with steps of 1° and 2° in b, and 4° in l.

These great surveys, totaling more than 10^5 independent profiles, present a rich and challenging source of information on galactic structure and interstellar physics! Their analysis makes progress (see Kerr, 02.155.009, and Weaver, 03.155.028), but very much work remains to be done. And, in addition, there are many surveys of smaller regions.

3. *The central region of the Galaxy*

The hydrogen in the galactic centre region has been last reviewed by Kerr (1967). Since then, surveys of high-velocity hydrogen in this region have been made by Van der Kruit (03.155.017), by Simonson and Sancisi (*AA Suppl.*, in press), and – with a 2° beam, but very high sensitivity: 0.06 K! – by Sanders *et al.* (07.155.003, 07.155.027, 07.157.010). In addition, Mader (06.155.018) has used the Maryland survey for a similar study. Kazès and Aubry (*AA*, in press) have studied absorption by hydrogen in the spectra of discrete sources in the region.

Particular interest is attached to hydrogen at high *forbidden* velocities, which is observed several degrees from the plane in opposite (l, b) quadrants. Van der Kruit (03.155.017, and 06.155.002) ascribes these features to explosions in the galactic nucleus. Sanders and Wrixon interpret Van der Kruit's feature as an expanding and rotating ring at R = 2.4 kpc, but invoke recent explosions for other, newly detected features. The matter requires further clarification by systematic observations of high sensitivity and adequate angular resolution (0°.6 or better). Wrixon is now using the 140-ft at Green Bank, and Cohen made observations of 0°.5 resolution at Jodrell Bank.

High-velocity hydrogen has also been observed in the central region of the Andromeda Galaxy (Whitehurst and Roberts, 1972, *Ap. J.* **175**, 347). Menon and Ciotti (04.155.001) find expansion motions of 15 to 30 km/s in the inner parts of our galaxy, at R ~ 4.5 kpc.

In his theory of the cloud structure of the interstellar medium, Hills (07.131.052) has predicted the scale size for structures in the galactic-centre region. It should be of interest to compare these predictions to the high-resolution observations of molecules.

4. *Low-latitude regions; galactic studies*

Surveys of hydrogen at low latitudes have mostly been interpreted in terms of large-scale (spiral?) structure and kinematics of the Galaxy. The classical scheme is first to derive or assume a circular-rotation law, and then to derive the density distribution. In a fine review of this subject, Kerr (02.155.009) has stressed the great effects of non-circular motions on the analysis. The studies summarized by Kerr had mostly ignored these effects, and this situation has largely persisted since then. However, Burton and Shane (03.155.047) have incorporated large-scale streamings as predicted by the density-wave theory into their analysis of the Sagittarius and Scutum Arms (04.157.004;

05.155.001; 06.157.001; 06.157.006; 07.155.002) and attempted to solve for density distribution and velocity field simultaneously. Burton (07.155.061) applies the same procedure outside the solar circle, at $90° < l < 120°$. Yuan (03.157.020) computes 21-cm line profiles from the density-wave theory and compares these with observations.

Most other low-latitude studies employ a circular-rotation law. We mention the following surveys: $-4° < l < +24°$ by Simonson and Sancisi (*AA. Suppl.*, in press); $120° \leqslant l \leqslant 240°$ by Velden (04.155.040 and .041); $165° < l < 240°$ by Bystrova (1972, *Izvestia SAO* **4**, 130); $230° < l < 280°$ by Goniadski and Jech (03.157.017); $270° < l < 310°$ by Garzoli (04.155.003); $302° < l < 310°$ by Vieira (05.155.017); see also Kerr and Kerr (04.155.002).

Weaver (03.155.028) has, from the Berkeley survey and using the Schmidt mass model for circular rotation, derived a spiral map which differs considerably from that presented by Kerr (03.155.026). These differences, and the general problem of deriving spiral patterns, have been discussed and somewhat alleviated in a 'spiral workshop' at Maryland (04.155.012). A detailed summary of this subject falls in the domain of Commission 33.

Verschuur (*AA*, submitted) has studied the Perseus spiral feature, particularly at $105° < l < 137°$, and discusses the relationships of the gas in this region to clusters and associations. Humphreys (1972, *AA* **20**, 29) compares the distribution and motions of stars and H I gas in the Carina Arm; she finds good overall correlation, but some weak streaming motions. Minn and Greenberg (05.155.051) find systemic differences between stellar and H II velocities in several arms. McCutcheon and Shuter (04.157.005), from a comparison of recombination-line and H I velocities, conclude that Cygnus X must be in the Orion Arm.

Mezger *et al.* (03.155.015) compared the large-scale kinematics of H I and H II and found quite good agreement. However, the distribution of H I peaks further out from the centre than does that of H II (Mezger 03.155.027).

Varsavsky and Quiroga (03.155.030) suggest that the galactic plane may be corrugated.

5. *Extensions to high z*

Several investigators have studied hydrogen at large distances from the galactic plane. In the region $10° \leqslant l \leqslant 24°$ Simonson (05.155.019) finds nine concentrations, at R = 3·5 to 4·7 kpc, $|z| = 0{\cdot}2$ to 1·3 kpc, with sizes of 300 to 500 pc, masses of 10^5 to 10^6 $M_\odot$ and velocity dispersions of 7 to 11 km/s. In his analysis of the region $22° \leqslant l \leqslant 42°$, Shane (06.157.006) finds evidence for a 'galactic envelope', with density 0·05 H cm^{-3} in the plane, dispersion in z 0·3 kpc, and velocity dispersion 11 km/s. Garzoli (04.155.003) describes how the galactic plane bends downward towards $l \sim 290°$. Burton and Verschuur study the vertical distribution of hydrogen at longitudes $35° < l < 40°$, out to $|b| = 30°$.

Kepner (03.155.019) has surveyed the region $l = 48°$ to 228°, $b = +6°$ to 20°. She finds (cf. also Oort (03.155.029)) gas associated with the spiral arms outside the solar circle, reaching $z \sim 1$ to 2 kpc, with densities of a few percent of those at low z; these results are similar to those of Habing in 1966. Other features, which show no concentration to low b, she considers as distant high-velocity clouds. Davies (07.155.038) and Verschuur (in press) carry the Habing–Kepner thoughts even further: they ascribe *all* high-velocity clouds to high-z extensions of outer spiral arms (cf. next section).

6. *High-velocity and high-latitude hydrogen*

Several high-quality surveys now cover the sky down to $\delta \sim -30°$ in considerable detail. In the velocity range -100 to $+100$ km/s there are 3 major surveys (1000 to 2000 profiles each), and one super-survey, all with beamwidths ~ 0°6, bandwidths ~ 2 km/s and rms noise ~ 0·5 K. The Penticton Survey (grid 5°) by Venugopal and Shuter (04.157.001) appeared as profile atlas. For the Dwingeloo-Groningen High-Latitude Survey ($|b| \geqslant 15°$, grid 2°5 to 5°, bandwidth 4 km/s, V – 150 to $+60$ km/s) Tolbert (06.157.003) published a profile atlas and contour-maps $T_b(b, V)$, and column densities N_{H} in various V-intervals. The Carnegie Survey by Tuve (in press) (beam 0°8, grid 5° to 10° at

$|b| \geqslant 20°$, narrower in the galactic belt) will show profiles and Gaussian components. The Berkeley Survey by Heiles and Habing (ready for press) gives complete sky coverage for $|b| \geqslant 10°$: its contour maps are based on (about 10^5) profiles taken at spacings of $0\overset{\circ}{.}3 \times 0\overset{\circ}{.}6$.

The aim of these 4 surveys has mostly been a general study of hydrogen in the solar neighbourhood, including gas at 'intermediate velocities'. Searches for higher velocities have mostly been concentrated in the range -250 to -50 km/s, and are therefore incomplete. High sensitivity (typically 0.1K rms) has been reached by using wide bands (10 to 20 km/s), but sky coverage has remained rather thin. Meng and Kraus (03.131.102) at Ohio State (beam $0\overset{\circ}{.}2 \times 0\overset{\circ}{.}7$, bandwidth 20 km/s) scanned the sky at $|b| > 10°$ in α, making 1° steps in δ from $-10°$ up; they publish maps and tabular data for the high- and intermediate-velocity clouds found. At Hat Creek (beam $0\overset{\circ}{.}6$, band 2 km/s!, rms noise 0.04K), Dieter (07.131.056) made the Berkeley High-Latitude Survey, with $\Delta l \cos b \sim 5°$ at $b = -85°(2°) - 15°$ and $+15°(2°) + 75°$, published in contour maps; her low-b survey was mentioned in Section 2. Van Kuilenburg (07.157.001 and 07.157.005) at Dwingeloo scanned the sky at $|b| > 15°$ in α, with $2\overset{\circ}{.}5$ steps in δ; he searched negative velocities at $\delta > 0$, and $V = +60$ to $+270$ km/s at $\delta < 0$. His only positive-velocity cloud was confirmed by Wannier, Wrixon and Wilson (07.157.008), who used the Bell Labs 2-ft horn reflector (beam 2°) with the lowest-noise receiver to date (rms noise 0·01 K!) in a survey of the region $252° < l < 322°$, $+10° < b < +30°$; the Bell search at $+300 < V < +600$ km/s was unsuccessful. Further surveys have been made by Hulsbosch (dissertation, Leiden, 1973, to be published), especially also at low b.

Encrenaz *et al.* (05.155.018), Hulsbosch (1968 and 1973), Rickard (05.131.017) and Verschuur *et al.* (07.131.095) have studied individual HVCs in detail; Wannier and Wrixon (07.157.011) observed the south galactic pole feature to be 60° in extent and to vary some 300 km/s in velocity over this length. Both Rickard and Verschuur *et al.* find much small-scale structure from their high-resolution (300 ft) observations. Rickard, Verschuur (05.131.083) and Wesselius (*AA*, in press) have determined detailed properties of intermediate-velocity clouds (IVCs).

From the Groningen High-Latitude Survey, Wesselius and Fejes (*AA*, in press) have determined the distribution and velocity field of gas with intermediate negative velocities (INV), and compared it to the distributions of high- and low-velocity gas. Comparisons with Ca^+ absorption-line data, and the close correspondence of a great INV complex with a 'hole' in the low-velocity gas distribution, lead them to an estimate of $z = +70$ pc for the INV gas. Earlier, Oort (02.161.008) has estimated $z = 1000$ pc from more limited material. Since the distribution and properties of INV and HV gas are broadly similar, most investigators assume a related origin and comparable distance for both. However, no direct measures of HVC distance are available so far, although Kerr and Knapp (07.131.132) have made an attempt, and Hulsbosch (06.131.033 and .090) has listed suitable stars – cf. also Svolopoulos (02.115.005). In fact, Kerr and Sullivan (02.131.049) interpreted the HVCs as satellites of the Galaxy at 50 kpc distance, and Verschuur (01.161.004) even placed them as uncondensed galaxies in the Local Group.

The sky distribution of HVCs made Rickard (05.131.017) ascribe them to a super-explosion in the Perseus Arm. Oort (02.161.008 and 04.158.010) rather interpreted the HVCs as halo gas, pushed down by infalling intergalactic gas and replenished by explosions in the disk; such infall will continue long after the principal collapse of galaxies, and the present observed rate agrees with expectation. The high-sensitivity surveys of Dieter show weak, widely distributed gas at high negative velocities; she interprets this (05.131.056) as a shell of gas bounding the outer edges of the galactic spiral structure, and extending to $|z| = 3.5$ kpc; this shell shares in the galactic rotation, but has in addition an inward velocity of 125 km/s. Davies (07.155.038) and Verschuur (*AA*, in press) ascribe all high-velocity clouds to high-z extensions of outer spiral arms. Davies explains the high-b HVCs as bits broken off from the high-b IVCs and falling into the centre. Verschuur considers the high-b IVCs as related to the Perseus Arm. It seems unclear what one should then think about an INV complex covering the North Galactic Pole; Hulsbosch and Oort (*AA*, in press) agree that Verschuur's model deserves attention for clouds at lower latitudes, but reject it at high latitudes.

Verschuur (05.131.083) has advocated a 'snowplow' model involving an old supernova remnant for IVCs. Wesselius and Fejes (*AA*, in press) also consider a possible supernova origin for their INV gas complexes, but prefer a modified Blaauw-Tolbert model, in which an inflow of high-velocity gas disturbs the local gas layer.

Some of the physics involved in high-velocity cloud collisions has been discussed by Chow (06.131.148), and by Wentzel (06.131.101).

There is a sore spot in all this work. Virtually nothing at all has been done on high-velocity or high-latitude hydrogen from the Southern hemisphere, and consequently a quarter of the sky is still 'terra incognita'.

7. *The solar neighbourhood and Gould's Belt*

In the distribution of low-velocity gas at high latitudes, Fejes and Wesselius (*AA*, in press) find a 'hole' centred on the pole of Gould's Belt, and some high-density ridges which together form a feature inclined 45° to the galactic plane; Van Woerden has coined the name 'scheve schijf' (tilted disk) for this. The relation of this disk to the hole and the INV features requires further clarification. Harten (07.155.091) confirms the 'scheve schijf'. He further finds a narrow 'local component' in profiles all over the sky, and represents this by an expanding shell of age 65 million years and expansion velocity 4 km/s, containing 70000 $M_\odot$ and associated with Gould's Belt; this model closely agrees with work by Lindblad (1967). This expanding ring is also found by Hughes and Routledge (07.131.074); they give a much higher mass estimate, and make $V_{exp} = 6$ km/s, $T_g \simeq 40$K. The relationships between local gas and Gould's Belt have further been discussed by Goldstein and MacDonald (02.131.040) and by Hansen (05.131.136).

Falgarone and Lequeux (*AA*, in press) discuss density and layer thickness in the solar neighbourhood. Seki (in press) finds an anomalous gas/dust ratio in the region of the INV-feature discussed above.

8. *Correlations with continuum loops, supernova remnants and pulsars*

Berkhuijsen *et al.* (03.157.004 and 06.155.009) have announced an excess of neutral hydrogen on the outer gradients of Loop I, the North Polar Spur; they suggest the loops are (super-?) supernova remnants. Fejes, in a study of the Virgo region (05.155.006), found evidence for expanding motions, and later (06.157.005) for correlation of H I and Loop IV. The subject has been reviewed by Haslam *et al.* (05.157.006) and by Fejes and Wesselius (*AA*, in press). Since then, Fejes and Verschuur have studied Loop III; at its outside, they find irregular structures and motions – for Loop I, they question the conclusion of Berkhuijsen *et al.* The issue remains quite open, it seems.

Dickel (in press) has studied H I in regions around supernova remnants. Verschuur (04.131.039) finds evidence for two expanding H I shells, each at 2°–3° from a pulsar; also he gives column densities towards 10 pulsars. Sancisi and Klomp (07.141.529) publish profiles and column densities in the direction of 25 pulsars.

9. *Neutral hydrogen in or near* H II *regions, associations and clusters*

Thompson and Colvin (03.133.019) find no detectable H I in or around six planetary nebulae.

From aperture-synthesis observations at Cambridge, Wright (05.132.009) estimates the H I and H II content of NGC 604, the biggest H II region in the galaxy M 33. Bridle and Kesteven (04.131.041) find an enormous, rotating H I complex (mass 160000 $M_\odot$, $T \sim 55$ K) surrounding the source K3–50. Sato (03.131.063) has studied the Maryland-Green Bank Survey for relationships of H I with clusters and H II regions in the Perseus Arm; Verschuur (in press), in a similar study, finds the H I to expand away from the optical objects. Riegel (05.131.042) discusses cold H I surrounding W31. Bystrova *et al.* (03.157.019) looked for H I connected with NGC 2264 and λ Ori.

Much information on hydrogen associated with H II regions is contained in the Parkes Survey of 21-cm absorption (07.131.003 and .004).

Fejes (*AA*, in press) finds a deficiency of low- and negative-velocity H I in a region around α Vir; this can be explained by ionization.

Sancisi and Van Woerden will soon publish an extensive survey of H I in the nearby associations in Lacerta, Perseus, Taurus and Scorpius-Ophiuchus. Preliminary analyses of this survey have been published (03.152.012, 03.152.013, Sancisi, 1972, *Proc. IAU Coll.* **17**, in press). Sancisi (*AA*, in preparation) finds in Per OB2 and Sco OB2 dense shells of expanding hydrogen ($V_{exp} \sim 5$ km/s, mass $\sim 10^4\ M_\odot$, radius ~ 20 pc); he suggests that the stars of the associations have formed from these shells and that the expansion is due to a supernova explosion.

In the Orion region Gordon (04.157.006) finds 70000 $M_\odot$ of H I; the velocity pattern indicates rotation, no large scale expansion. Barnard's ring has no obvious relationship to the H I distribution. The column densities N_H are correlated inversely to the ages of Blaauw's stellar groups. Menon (03.132.022) suggests that H I in the 'Dark Bay' close to the Trapezium is approaching the Nebula at 14 km/s. For an H I-cloud near NGC 2024 and ζ Ori, recombination line measurements by various workers (04.131.091, 06.131.002, 06.132.037) give H II/H I ratios around 3×10^{-4}; Dupree (06.131.110) finds from the C line $n_e > 1$ cm^{-3} for $T_e < 100$K.

Tovmassian (03.153.015) has looked for H I in 4 young clusters. Kerr and Knapp (*AJ*, in press) place upper limits on the hydrogen abundance in 12 globular clusters.

10. *Gas and dust*

For a good, but now incomplete, review of this subject see Heiles (06.131.016).

The dispute about the relative abundances of dust and hydrogen has continued. Wesselius and Sancisi (05.131.016), statistically comparing high-latitude hydrogen and galaxy counts, find no general correlation, but only in special regions (e.g. the Gould Belt). Seki (in press), using similar material, concludes that the gas/dust ratio varies over the sky, and suggests a relationship with the local disturbance of the gas layer. Schmidt (04.131.141), comparing hydrogen emission and stellar colour excesses, finds no correlation; but Rohlfs (05.131.099) reports good correlation between colour excesses and 21-cm absorption, which favours cold clouds. Jenkins and Savage (in press) have good correlation between colour excesses and Lyman α-absorption (on the same line of sight!).

In dense dust clouds, 21-cm emission is not correspondingly enhanced (Garzoli and Varsavsky, 03.157.015 and many earlier papers). The standard explanation used to be: most of the hydrogen there is molecular. However, Sancisi and Wesselius (04.131.015) showed the emission deficit in the Taurus clouds may well be due to selfabsorption by cold hydrogen. Several authors have found selfabsorption effects: Riegel and Jennings (02.131.030), Simonson (05.131.082 and 05.155.008), and Sancisi (05.131.084). Knapp (1972, Maryland thesis), using a high velocity resolution, sees H I self-absorption in 50 % of her many clouds; comparison with OH indicates underabundance of hydrogen.

Only one observation of H_2 is available so far: Carruthers (04.131.023) measured the UV Lyman band in ξ Per, a moderately obscured bright star.

Theoretical calculations by Solomon and Wickramasinghe (02.131.096) and by Hollenbach *et al.* (05.131.002) indicate that H_2 may dominate over H I in dense, dark, very cold clouds; elsewhere, hydrogen will be mostly atomic. Condensation of solid hydrogen has been considered by Nakano (06.131.133). However, Solomon and Werner (05.131.059) showed that, even in dense clouds, destruction of H_2 by low-energy cosmic rays will sustain a significant abundance of H atoms. Thus, the varieties of observational and theoretical results seem reasonably consistent.

11. *Gas temperature and optical depth*

The brightness temperatures, T_b, measured in emission depend both on spintemperature, T_s, and on optical depth, τ. Separation of both variables is not possible in general. Observation of self-absorption effects furnishes estimates of (or at least limits to) T_s and τ, but such values are model-dependent. Many dense dust clouds (references see previous section) appear to have $T_s < 75$K, and sometimes even $T_s \sim 20$K. From saturation effects in a galactic survey, Schmidt-Kaler and Pospieszczyk (04.131.030) find $\langle T_s \rangle = 52$K for cold clouds; Rohlfs (05.131.055) derives $T_s = 100$K from the variation of T_b with longitude, but this analysis is criticized by Burton (07.131.012). Low-noise, narrow-band observations of two high-latitude clouds (Verschuur, 02.131.015; Verschuur and Knapp, 05.131.106; Knapp and Verschuur, in preparation) give saturated profiles indicating $T_s = 24$ K and 17 K; Rohlfs, Braunsfurth and Mebold (*AJ*, in press) show that noise biases the analysis towards lower T_s, but the effect on the Verschuur-Knapp results is relatively minor.

Measurements of the 21-cm line in absorption in the spectra of discrete continuum sources allow direct determination of τ, provided the 'expected' emission profile at the source position can be interpolated, or eliminated ('resolved out') by interferometry at high angular resolution (Radhakrishnan *et al.*, 07.033.001). If the absorbing hydrogen can be identified with a component in the expected profile, its T_s follows as well. Until recently, work had been only done for a dozen strong sources (Clark, 1965, *Ap. J.* **142,** 1398). At Parkes (210-ft single dish and 210 + 60-ft interferometer) and at Owens Valley (2 × 90-ft interferometer), more than a hundred absorption spectra have now been measured. At low galactic latitudes, Kerr and Knapp (04.155.035), Radhakrishnan *et al.* (07.131.003) and Goss *et al.* (07.131.004) have determined optical depths, and made comparisons with absorptions by molecules; Radhakrishnan *et al.* and Goss *et al.* give full component analyses of their spectra and detailed discussion. Determination of T_s is rarely possible at low galactic latitudes (Burton, 04.157.004; Hughes and Routledge, 04.131.113; Chaisson, 07.131.058; Kazès and Aubry, *AA*, in press; Greisen, 1972, thesis Caltech), but measures on large numbers of high-latitude sources at Owens Valley (Hughes *et al.*, 06.141.192) and at Parkes (Radhakrishnan *et al.*, 07.131.002) have given reliable results. Both Hughes *et al.* and Radhakrishnan *et al.* find cold clouds (temperatures $T_s < 100$ or 200 K) and a hot intercloud medium ($T_s > 600$ K); in addition, there may be some gas of intermediate temperature.

For cold clouds, Hughes *et al.* derive an average $T_s = 71$ K, with standard deviation 29 K; Radhakrishnan *et al.* find T_s values between 20 and 200 K, with a median ~ 80 K. These results are in substantial agreement with earlier work by Clark (1965) and by Mebold (1969). Radhakrishnan *et al.* further find that the denser clouds ($\tau > 0{\cdot}5$) are somewhat colder (median $T_s \sim 65$ K), and that the component widths measured exceed those predicted for thermal motions. The column densities through the clouds range between $0{\cdot}25$ and 10×10^{20} atoms cm^{-2}, averaging 3×10^{20} atoms cm^{-2}, and the mean separation between clouds is about equal to the equivalent thickness of the hydrogen layer; an arbitrary line of sight thus meets $1{\cdot}5 \times 10^{20}$ cosec $|b|$ atoms cm^{-2} of cold hydrogen. Radhakrishnan and Goss (07.131.005) find $N(\tau) \propto e^{-\tau}$ for the statistics of optical depths of clouds.

The hot intercloud medium is seen in emission but not in absorption. Thus, limits only can be given to its temperature. Radhakrishnan *et al.* (07.131.002) find $T_s > 750$ K, Hughes *et al.* (06.141.192) $T_s > 600$ K. Radhakrishnan *et al.* observe 1.4×10^{20} cosec $|b|$ atoms cm^{-2} of intercloud gas on an average line of sight; thus, the masses of cold cloud gas and of hot intercloud gas in the solar neighbourhood are about equal, and the surface density $N_H = \int_{-\infty}^{+\infty} n_H \, dz$ of the intercloud medium equals 2.8×10^{20} atoms cm^{-2}. From Radhakrishnan's data, Falgarone and Lequeux (*AA*, in press) derive an equivalent layer thickness, $\zeta = 585$ pc, and an average intercloud gas density in the solar neighbourhood, $n_0 = 0{\cdot}155$ cm^{-3}, with $N_H = n_0 \zeta$; they believe the z-distribution is Gaussian, and the velocity dispersion σ_V in the intercloud medium is about 6 km/s. Mebold (07.131.115) has analyzed the broad components in profiles at intermediate latitudes, with the following results: $n_0 = 0{\cdot}20 \pm 0{\cdot}06$ cm^{-3}, $\zeta = 420 \pm 140$ pc, exponential distribution $n_0 \exp(-z/\frac{1}{2}\zeta)$, $N_H = 2{\cdot}6 \times 10^{20}$ cm^{-2}, $\sigma_V = 8{\cdot}8$ km/s (after correction for differential galactic rotation); from the velocity dispersion follows a kinetic temperature $T_k < 9400$ K. Schwarz, in an unpublished study, finds $n_0 = 0{\cdot}19$ cm^{-3} and $\zeta = 260$ pc. In the inner parts of the Galaxy, Shane (06.157.006) estimates $n_0 = 0{\cdot}05$ cm^{-3}, $\zeta = 750$ pc (Gaussian distribution), $N_H = 1{\cdot}2 \times 10^{20}$ cm^{-2}, $\sigma_V = 11$ km/s. All these results appear reasonably consistent, but leave the temperature still quite uncertain. There are, however, two other sources of information. (1) Measurements of distributed emission in the recombination lines by Gottesman and Gordon (04.131.114) and by Jackson and Kerr (06.131.014) give electron temperatures, $T_e = 1100$ K (uncertain by a factor 8) and 2400 ± 1000 K, respectively, with average square densities $\langle n_e^2 \rangle = 0{\cdot}09$ (uncertain by a factor 20) and $0{\cdot}32 \pm 0{\cdot}19$. (2) A comparison of column densities of hydrogen and of electrons (from dispersion measures of pulsars) by Grewing *et al.* (03.131.092) indicates $T_e \sim 10000$ K for high-latitude and $T_e \sim 2000$ K for low-latitude sources; these values would be affected, however, by possible presence of H II regions in the line of sight to the pulsars.

The observational results summarized appear to confirm the two-component model of the interstellar medium developed by Pikel'ner, Spitzer, Field and others. However, Greisen (1972, thesis Caltech) says that the observational evidence for a hot intercloud medium is poor; wide components are also present in his absorption spectra, and their considerable optical depths, together with the low T_b measured in emission, imply low values of T_s, i.e. the wide components must represent superpositions of narrow components due to cold clouds. Further, De Jager (03.141.203), Colvin *et al.* (04.141.047) and Hughes *et al.* (06.141.192) all find some evidence for intermediate temperatures. Could this be evidence for the (unstable) third phase allowed by the theory?

For a detailed discussion of theoretical work on the two-phase model, we refer to the review by Dalgarno and McCray (1972, *Ann. Rev. Astr. Aph.* **10**, 375).

12. *Distances of radio sources from 21-cm absorption*

Observation of the 21-cm line in absorption in the spectrum of a radio source allows determination of its distance or, at least, placement of a lower limit on this. Using a model of galactic rotation, the velocities of the absorbing hydrogen may be interpreted in terms of distance; it is even better to do this via comparison with the emission profiles in the surroundings. Emission features lacking in the absorption spectrum are assumed to be behind the source. Goss *et al.* (03.141.189) have outlined four methods to resolve the distance ambiguity for sources at $|l| < 90°$.

The procedure has been applied to large numbers of galactic sources by Kerr and Knapp (04.155.035), Radhakrishnan *et al.* (07.131.003), and Goss *et al.* (07.131.004). Smaller numbers of sources have been placed by Kazès and Rieu (03.141.115), Bridle and Kesteven (04.131.041), Burton (04.157.004), Riegel (05.131.042), Kazès (06.131.089), Hughes *et al.* (06.141.192) and Kazès and Aubry (*AA*, in press). The procedure has also served to determine distances of pulsars (see e.g. Guélin *et al.* (06.141.061) and other references in the Report of Commission 40). Together with dispersion measures, these distances then serve to estimate mean electron densities; Encrenaz (1972, thesis) and Gomez-Gonzales *et al.* (1972) summarize the data and give $\langle n_e \rangle = 0{\cdot}025$ cm^{-3}.

13. *Cloud structure*

In an earlier section, we discussed the structural features on the galactic scale. We turn here to the features smaller than, say, a kiloparsec. Three independent studies have been devoted to structures in the Perseus Arm. Sato (03.131.063), in an analysis of the Maryland-Green Bank Survey, distinguishes 5 classes of 'components', ranging from small, isolated clouds (density 1 to 10 H cm^{-3}, size 5 to 25 pc, column density $\sim 2 \times 10^{20}$ H cm^{-2}, optical depth 0·1 to 0·25, velocity dispersion 1 to 2 km/s) to a diffuse background of 0·3 H cm^{-3}; the classes appear somewhat to overlap in their properties. Gosachinsky (1972, *Izvestia SAO* **4**, 136) analyses 4 selected areas of the Maryland-Green Bank Survey and finds numerous concentrations of size 50 × 200 pc and density 3 H cm^{-3}, making up two-thirds of the Perseus Arm's hydrogen mass. Perry and Helfer (07.155.066) apply a statistical analysis to 4 segments of the Perseus Arm, representing the density fluctuations by superpositions of randomly located spherical clouds. They describe the cloud mass spectrum by a power law $f(m) \propto m^{-\beta}$, with $\beta = 1{\cdot}75 \pm 0{\cdot}15$ for $10^3 < m < 10^6\ M_\odot$. This exponent agrees quite well with results obtained from other data at lower masses by Scheffler (1966, 1967: dust clouds), Penston *et al.* (1969, *MN* **142**, 355: Ca II) and Reddish and Sloan (1971, *Obs.* **91**, 70: dust clouds). It also agrees with the mass spectra for hydrogen clouds derived by Field and Hutchins (1968, *Ap. J.* **153**, 737) and by Schwarz (in preparation).

Da Rocha Vieira (05.155.017) determines sizes and densities of various features in the Centaurus region.

Ames and Heiles (03.131.070) have determined the distances of 2 'sheets' of hydrogen discussed earlier by Heiles (1967) and find that these sheets are less than 10 pc thick. Rots *et al.* (07.131.024) criticize the procedures followed by Heiles (1967) in defining 'cloudlets' and determining their properties; they state that the list of cloudlets must be inhomogeneous, and the distribution functions of cloudlet properties distorted by selection effects.

Schwarz (1973, in preparation) has made a highly detailed study of cloud structure and kinematics in Camelopardalis and Cepheus. He has used computerized procedures to combine Gaussian profile components into clouds. The resulting maps show quite irregular and filamentary cloud shapes.

Knapp and Verschuur (in preparation) have mapped the detailed structure and kinematics of two thin, cold clouds at high latitude.

While the above studies are all based on emission observations, absorption measurements have also yielded structural information. Greisen (1972, thesis Caltech), in an aperture-synthesis study of the brightest radiosources, finds structures of 1 pc size and even smaller, densities 10 to 1000 atoms cm^{-3}, and masses 3 to 100 $M_\odot$. Schwarz and Wesselius (in preparation) have used the Westerbork array to map the absorption in front of 3C 10 and 3C 58 at $0\rlap{.}'5$ resolution.

Theoretical work on the cloud structure of the interstellar medium has been reported in several papers. Penston and Brown (04.131.087) consider the cloud-intercloud phase change. Hills (07.131.052) explains clouds by compression of unionized material between Strömgren spheres, and predicts masses and densities for these clouds. Schwarz, McCray and Stein (1972, *Ap. J.* **175**, 673) discuss cloud formation in a cooling medium. Taff and Savedoff (preprint) compute statistically the cloud spectrum resulting from cloud collisions. Shu *et al.* (07.131.080) consider the effects of galactic shocks in an interstellar medium with two stable phases; they find that, while the intercloud medium is compressed by a factor 9 on entering the shock wave, the cloud density increases by a factor 40, which may lead to star formation.

14. *Kinematics and magnetic fields*

The motions of interstellar hydrogen have been viewed from various aspects in the preceding sections. In fact, the determination of cloud properties from Gaussian profile components by Schwarz and others implies that clouds are defined kinematically (or, better, as concentrations in phase space).

One aspect should be added here. Kerr (03.155.026) and Harten (07.155.091) have demonstrated the presence of 'tumbling' (or 'rolling') motions in spiral arms, from both Parkes and Green Bank observations. This effect had first been found by Rougoor (1964) in the 3-kpc Arm.

Several workers have attempted to explain these rolling motions. Fujimoto and Miyamoto (02.131.013 and 03.151.049) have developed MHD models for helical magnetic fields in spiral arms, and show that such fields cannot be stationary without rolling motions. Alternatively, Fujimoto and Tanahashi (05.155.015) suggest that rolling motions may be related to the free precession suggested by Lynden-Bell (1965) to account for the warp of the galactic plane. Yuan and Wallace (1972, *BAAS* 4, 316) showed that a spiral density wave in conjunction with the bending of the galactic plane can account for the phenomenon. Harten (07.155.091), too, explained the rolling with a three-dimensional extension of Lin's two-dimensional theory.

From the Zeeman-splitting of the 21-cm line, magnetic field strengths have now been determined in a large number of clouds. Verschuur (04.156.002) has summarized his many papers on this subject. A relationship between field strength and gas density appears indicated; extrapolation leads to a field of 1 to 3 μG at a mean intercloud density, in excellent agreement with various other determinations. The relationship suggests that frozen-in fields are amplified in contracting clouds. Verschuur has further suggested that clouds at high galactic latitudes are elongated along magnetic field lines. Later measures of Zeeman-splitting have been published by Verschuur (05.131.078) and by Brooks *et al.* (05.114.071).

15. *Comparisons with Lα-measurements*

Interstellar Lα-absorption was first observed with sounding-rockets by Morton *et al.* (1967).

Since then, several other rockets and a short-wavelength spectrometer aboard OAO-2 have observed a large number of stars in the Lα-line (Savage and Jenkins, 07.131.030). For many stars the OAO-equivalent widths were significantly larger than those determined by rockets earlier. These discrepancies were attributed to an improper estimate of the stellar continuum level in the rocket data, to neglect of the broad damping wings, and to a blending of the interstellar Lα-line with adjacent stellar lines in the OAO-data. Except for the measurements made in the direction of Scorpius (Jenkins *et al.*, 02.131.098), most observations appear to show that the H I columnar density determined from the 21-cm line is larger than that from Lα-absorption, even if a correction is applied for the additional contribution from hydrogen beyond the stars. Jenkins (03.114.100) considered several effects which might introduce uncertainties in the Lα-measurements. Clumpiness of the gas could be a possible explanation, while Kovach (07.131.069) considered a modification of the 21-cm transition probability by the Stark effect on charged dust grains; however, neither of the possibilities seems to be very satisfactory at the moment.

INTERSTELLAR DUST

Unfortunately the account of work on dust was not received in time for inclusion in this Report. Fortunately there was a very comprehensive discussion of progress in this subject at *IAU Symposium* **52** (Albany, 1972). The outstanding discovery of the past few years has undoubtedly been the detection of interstellar circular polarization, by Martin, Angel and Illing. A detailed description is given by P. G. Martin (*Monthly Notices*, **159**, 179, 1972) and by P. G. Martin, R. Illing and J. R. P. Angel (*ibid.*, **159**, 191, 1972).

A PERSPECTIVE ON OUR RESEARCHES

There has obviously been a great deal of activity in the study of interstellar matter. This report deals only with some of the lines of research pursued by our members, since there was not space enough to deal satisfactorily with all aspects of our subject. But we can conclude that, according to its own terms of reference, our branch of science is in a healthy state: many new discoveries have been made, and many good problems still wait for investigation. This is highly satisfactory.

Every now and again we should, however, ask ourselves whether our work is useful to anyone else. In order to be able to pursue our interests we ask for considerable help from others; what do we give back in return? What are our contributions to astronomy in general, to other branches of science and to the interests of the lay public?

There are of course many ways in which interstellar studies are relevant to other astronomers. The main theme of modern astronomy is the attempt to describe the history and evolution of the Universe in general, and of our system of stars in particular. Interstellar studies have long played a key role in the mapping of the Galaxy: the overall galactic structure was first determined by the observation of interstellar hydrogen, and now the exploration continues with attention being given to finer but highly significant details. Examples are the high-velocity clouds, motions at the galactic centre, and a more exact description of spiral structure.

The stars themselves form from interstellar matter, and much of the stellar material eventually returns to space. The recent discoveries of compact H II regions, with infra-red and OH maser sources, probably identify for the first time individual nebulae where star formation is in progress. On the other hand we can observe the return of material to space in our studies of planetary nebulae and supernova remnants.

On the larger scale the density wave theory of spiral structure explains where star formation should be expected in the Galaxy. The physical process very much depends on the mixture of gas and plasma present; in this case cosmical gas dynamics and M H D must clearly be understood before the description is complete.

The study of interstellar matter also has much to contribute in relation to other branches of science. For example the propagation of cosmic rays through space depends on conditions in the interstellar plasma, and the entry of cosmic rays into the solar system is determined by interactions at the interface of the solar wind with interstellar space. At lower energies interstellar matter offers physicists and chemists a chance to investigate reactions taking place under conditions of low density that are not attainable in the laboratory. There is clearly much to be learned from the physics of interstellar masers, from the surface chemistry of interstellar grains and from the influence of radiation fields on chemical reactions. In electrodynamics interesting new effects probably occur in the interstellar plasma by interaction with low-frequency radiation from such sources as pulsars (and black holes?).

Finally what benefit does the lay public derive from what we do? If we confine ourselves to purely material questions the answer must be: not very much. But we do contribute significantly towards the solution of some of the oldest problems that have puzzled humanity. We do so by our part in the attempt to describe the evolution of the Galaxy and the formation of stars. It may be, though, that the new interstellar chemistry is even more significant. For a long time, life scientists have speculated on the conditions that prevailed on the primeval Earth, and on their relation to the origin of life. A great difficulty has always been to understand how the Earth acquired its original content of organic material. Can it be that much of this content derives from the nebula out of which the Earth was formed? This question alone justifies the great effort being made in the study of interstellar molecular chemistry.

In summary, then, it goes without saying that we find our work interesting and rewarding. But we can also reasonably hope that our scientific colleagues, and the lay public, will consider it to be relevant and important.

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President of the Commission