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

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1. INTRODUCTION

(H. van Woerden)

The subject of interstellar matter is one of the most active fields of astronomical research to-day. Observational information spans the full electromagnetic spectrum from long radio waves to gamma rays and includes cosmic-ray particles. Results of chemical research find as much application now as mathematical methods. Interstellar matter plays a leading role in galactic and extragalactic research, and contributes increasingly to stellar astronomy and in solar system studies.

The six volumes of *Astronomy and Astrophysics Abstracts* for 1973–75 contain some three thousand references relevant to our Commission. The present *Report* attempts to present a strongly systematic review, a more highly ordered and more selective bibliography than the *Abstracts* can provide, together with some critical evaluation of recent progress. In order to avoid undue overlap with Commission 40, which undertook compilation of a full bibliography of radio astronomy, we have restricted ourselves to key references in our reviews of radio-astronomical work; this particularly refers to the section on Interstellar Molecules.

A great number of books, conference proceedings and review papers wholly or partly concerned with interstellar matter have been published. We list some of the more prominent or general ones here; many others, in particular the more specialized ones, are mentioned in the appropriate sections of this Report.

Monographs and Other Books

Encrenaz, P.: 1974, *Les Molécules Interstellaires*, Delachaux et Niestlé, Neuchatel (in French).
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Schatzman, E. and Biermann, L.: 1974, *Cosmic Gas Dynamics*, Wiley, N. York.
Verschuur, G. L. and Kellermann, K. I. (eds.): 1974, *Galactic and Extragalactic Radio Astronomy*, Springer, Berlin.
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Symposium Reports, Conference Proceedings, etc.

Gordon, M. A. and Snyder, L. E. (eds.): 1973, *Molecules in the Galactic Environment* (Symp. Charlottesville, Oct. 1971), Wiley, New York.
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Pinkau, K. (ed.): 1974, *The Interstellar Medium* (NATO Advanced Study Inst. Schliersee, April 1973), Reidel, Dordrecht.
Cosmovici, C. B. (ed.): 1974, *Supernovae and Supernova Remnants* (Symp. Lecce, May 1973), Astrophys. Space Science Library, Vol. 45, Reidel, Dordrecht.
Kerr, F. J. and Simonson, S. C. (eds.): 1974, 'Galactic Radio Astronomy', *IAU Symp.* **60**.
Osborne, J. L. and Wolfendale, A. W. (eds.): 1975, *The Origin of Cosmic Rays* (NATO Advanced Study Inst.), Reidel, Dordrecht.
Solid State Astrophysics (Symp. Univ. College, Cardiff, July 1974), Astrophys. Space Science Library Vol. 55, 1975.
Trimble, V.: 1975, 'The Origin and Abundances of the Chemical Elements' (based on a NATO Advanced Study Inst. Cambridge, England, July–August, 1974), *Rev. Mod. Phys.* **47**, 877.

Review papers

Aannestad, P. A. and Purcell, E. M.: 1973, *Ann. Rev. Astron. Astrophys.* **11**, 309.
Field, G. B.: 1974, *Highlights Astron.* **3**, 37.
Kaplan, S. A. and Pikel'ner, S. B.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 113.
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Wentzel, D. G.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 71.
Wickramasinghe, N.C. and Nandy, K.: 1972, *Rep. Progr. Phys.* **35**, 157.
Zuckerman, B. and Palmer, P.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 279.

2. SUPERNOVA REMNANTS

(J. E. Baldwin)

The most important advances in this field in the last three years have been the establishment of a theoretical framework, which enables the vast range of new observational data to be assessed in terms of specific models, and the improvement in the sensitivity and angular resolution of the X-ray, optical and radio observations to a stage where common features appear in the structures of the remnants. Most of the topics mentioned in this survey were covered at the Lecce Symposium on Supernovae and Supernova Remnants (11.012.015) and some at the *IAU Symp.* **60** on Galactic Radio Astronomy. Another major review, by Woltjer (08.125.020), appeared in late 1972.

The *theoretical work* on supernova remnants (SNR), rather than on the supernova phenomenon itself which is not discussed here, has concerned principally their dynamical evolution. The earlier work of Woltjer and of Cox in identifying the main stages of evolution of SNR and in determining the cooling rates of hot plasma has formed the basis of several detailed numerical investigations of spherically symmetric hydrodynamic models of the supernova ejecta expanding into the surrounding interstellar gas. Rosenberg and Scheuer (09.125.001) used simple assumptions regarding the properties of the ejected material in the initial phase of the expansion, the material swept up during the blast wave stage, and the cooling of the gas in the late stages of evolution of a remnant. Their calculations confirmed that these three stages identified by Woltjer do in fact occur but that the transitions between them are of very long duration.

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Gull (09.125.002) investigated the early phases of SNR, in particular the Rayleigh-Taylor instabilities in front of the supernova ejecta giving rise to an amount of turbulent energy which he showed to be just that necessary for the radio emission. Recent, more detailed calculations by Cowie (*Monthly Notices Roy Astron. Soc.* **173**, 429, 1975) confirm that this process is an important one. Chevalier (11.125.016) used more accurate values for the cooling coefficients and for the magnetic pressure terms to investigate the later stages of SNR as for example in parts of the Cygnus Loop. He also extended the calculations to situations where the supernova exploded in a stratified medium, to find solutions where the remnant can burst through the galactic HI disk and supplement a hot halo (*Astrophys. J.* **198**, 355, 1975). An interesting suggestion of Cox and Smith (11.125.028) emphasizes that the number density of SNR is sufficiently large that we should expect the old remnants to be interconnected forming continuous tunnels of high-temperature, low-density material throughout the interstellar medium. Other calculations by Straka (11.125.026) and by Mansfield and Salpeter (11.125.064) have also attempted to take account of many different physical processes of energy transfer that can occur during the expansion of SNR. The different models show a satisfactory measure of agreement in the results, indicating that the main features of the evolution of SNR are apparently not sensitive to small changes in the assumptions made. The dynamical time scale of the models is determined mainly by the energy released in the explosion, the mass ejected and the density of the surrounding interstellar gas. An important feature of the expansion, identified by McKee (11.125.013), is the backward travelling shock wave which probably provides the heating necessary for the gas responsible for the X-ray emission. Details of the phenomena observed in the filaments of Cas A and Tycho are discussed by Bychkov (11.125.005, 11.125.012). The models discussed so far assume no injection of energy to the SNR after the initial explosion. Cases where the central pulsar continues to be an important source of particles and field have been discussed by Pacini and Salvati (10.125.040).

In *X-ray studies* there have been new developments both in mapping the structure of SNR and in determining the X-ray spectra. The distribution of emission is now known for several remnants ranging from the youngest, Cas A (Fabian *et al.*, 09.125.007), to Vela (Moore and Garmire, *Astrophys. J.* **199**, 680, 1975), IC443 (Charles *et al.*, *Astrophys. Letters* **16**, 133, 1975), Pup A (Zarnecki *et al.*, 09.125.019) and the Cygnus Loop (Charles *et al.*, *Astrophys. J.* **196**, L19, 1975). In several cases the distributions of the radio, optical and X-ray emission have features in common but with no very strong overall correspondence. But in the Cygnus Loop good agreement was found, particularly in the brightest part of the optical nebula NGC 6992-5, where the radiation at all wavelengths appears to originate in the same regions. In the Cygnus Loop a central X-ray source was reported by Rappaport *et al.* (10.125.035), but a recent search at higher sensitivity by Snyder *et al.* (*Nature* **258**, 214, 1975) has not been able to confirm their finding.

Extensions of the X-ray spectra to low energies have been obtained for Cas A (Charles *et al.*, *Astrophys. J.* **197**, L61, 1975), Pup A (Charles *et al.*, *Monthly Notices Roy Astron Soc.* **170**, 61 p, 1975), Tycho (Coleman *et al.*, 10.125.035; Hill *et al.*, *Astrophys. J.* **200**, 158, 1975) and IC443 (Winckler and Clark, 12.125.005). It is now generally assumed that the main component in the X-ray spectra is a thermal one. Temperatures obtained range from about 2×10^6 K in the Cygnus Loop to about 1.6×10^7 K in Tycho and 3×10^7 K in Cas A. Values differ between authors by up to a factor of two, not so much due to uncertainties in the measurements as in deciding what type of fitting to adopt. It is clear that in some cases, e.g. Cas A, no single temperature can give a good fit to the observations. The deviations have been variously attributed to emission from Fe lines by Serlemitsos *et al.* (10.125.005), to a finite temperature range in Cas A by Charles *et al.*, and to line emission associated with an enhanced Si abundance in the remnants Pup A, Cygnus Loop and Vela X by Burginyon *et al.* (*Astrophys. J.* **200**, 163, 1975).

The work on the *optical remnants of supernovae* continues to be carried out by a surprisingly small band of astronomers. To bring together widely scattered data, Van den Bergh *et al.* (10.125.013) have compiled an optical atlas of 23 of the 24 known SNR. More recently Irvine and Irvine (11.125.036) have found a new optical remnant corresponding to the radio remnant PKS 1209-51/52. Miller (11.125.010) has extended work to the ultra-violet to obtain a photograph of the whole of the Vela remnant. Interferometric work for radial-velocity measurements by Lozinskaya has now been carried out on the remnants W28 (10.125.008), HB9 (11.125.027), VRO 42.05.01 (11.125.026), IC443 (*Astron. Zh. Letters* **1**, 25, 1975), γ Cyg (*Astron. Zh.* **52**, 515, 1975) and CTB1 (*Astron. Zh. Letters* **1**, 24, 1975). Advances in the field of spectroscopy have included the identification of many emission lines in SNR spectra by Danziger and Dennefeld (11.125.048) and the comparison of spectra with Cox's models of cooling of the gas in the SNR shell. Osterbrock and Costero (10.125.007) in Vela X and Osterbrock and Dufour (10.125.029) in N49 find good agreement with these theoretical models as opposed to that expected from photoionisation. The high excitation conditions in SNR were emphasized by the discovery of the coronal line of Fe XIV in Vela X by Woodgate *et al.* (*Astrophys. J.* **200**, 715, 1975). It suggests temperatures of $2-3 \times 10^6$ K, giving additional confirmation of the thermal origin of the X-rays.

Distances to SNR remain an area of controversy. The possibility of finding the still-existing OB associations in which type-II supernovae have exploded has been discussed by Akhundora *et al.* (11.125.025), and Johnson (*Publ. Astron. Soc. Pacific* **87**, 89, 1975) has collected data on the early-type stars in the fields of several SNR. Uncertainties in the stellar distances do not yet allow definite identifications to be made, but the method gives perhaps the best hope of accurate distance determinations in the future. Radio measurements have again used 21-cm H I absorption lines for distance determinations giving, for example, distances to Tycho's SNR and 3C58 of $\geqslant$ 6 kpc and $\geqslant$ 8 kpc (Goss *et al.*, 10.125.019, Williams *et al.*, 10.125.020), larger distances than previously accepted.

A case where the distance is not in serious doubt is that of the Magellanic Clouds, and here Mathewson and Clarke have found 9 SNR in the Large Cloud (09.125.010) and two in the Small Cloud (09.125.042). In the Galaxy many new identifications have been reported (Clark *et al.*, 10.125.031), and Berkhuijsen (12.125.024) has suggested that another radio loop may be a very old SNR.

A large amount of effort has been devoted to the mapping of the intensity and polarised distributions over SNR over a wide range of *radio frequencies*. This range now extends from 80 MHz (Dickel, 10.125.003), through other relatively low frequencies such as 200 MHz and 400 MHz on the Cygnus Loop and S147 (De Noyer, 12.125.061), to 2700 MHz where a very large amount of work has been done by Willis (10.125.002) on 15 remnants, by Velusamy and Kundu (11.125.024) on 24, and by Baker *et al.* (09.125.038) on 2 others. Higher frequencies and higher angular resolutions have revealed new features in several SNR. Observations of the Cygnus Loop at 2.7 and 10.7 GHz (Keen *et al.*, 10.125.018) have confirmed the non-thermal character of the emission even at these high frequencies. The shortest wavelengths used for mapping so far are the 1.7–3.7 mm band used by Zabolotny *et al.* (*Astron. Zh.* **52**, 665, 1975) for the Crab nebula. Other new maps with high resolution are those of HB21 at 1.4 GHz by Hill (12.125.021), and of 3C10 by Duin and Strom (*Astron. Astrophys.* **39**, 33, 1975) which shows a clear radial magnetic field pattern similar to that found earlier in Cas A and which may be common to all young SNR. Kepler's SNR, mapped by Gull (*Monthly Notices Roy Astron. Soc.* **171**, 263, 1975), showed a very close similarity to Tycho's SNR, which is interesting in view of its height above the galactic plane of about 1200 pc. In IC443 (Duin and van der Laan, *Astron. Astrophys.* **40**, 111, 1975) the correspondence of the radio and optical emission is even more detailed than previously known. The highest angular resolution achieved so far is 2″ used on Cas A at 5 GHz by Bell *et al.* (*Nature* **257**, 463, 1975). A number of new structural features are revealed whilst some condensations remain essentially unresolved.

New features in the radio work have been the discovery of H I shells around HB21 by Assousa and Erkes (10.125.038) and around W44 by Knapp and Kerr (12.125.002) and Sato (12.125.032). Whether these are H I shells associated with the supernova remnant itself or due to a dense cloud surrounding the original star is not yet clear. Radio recombination lines of hydrogen have also been detected near W44 (Bignell, 10.125.054) and further discussed for other remnants by Downes and Wilson (12.125.003). It is likely that they originate on the line of sight to the remnants, but it is disturbing that one of the best tests to distinguish radio H II regions from SNR is now less clearcut. Secular variations in the flux densities of SNR have provided two new puzzles. The radio emission from the supernova 1970g in M101 has a curious history (Goss *et al.*, 09.125.102), and the rate of decrease of flux density of Cas A at 38 MHz has shown a sudden reduction (Erickson and Perley, *Astrophys. J.* **200**, L83, 1975). A final new type of observation has been the detection of circular polarisation in the Crab nebula (Weiler, *Nature* **253**, 24. 1975).

This rich array of new material should lead to advances in understanding the physics of SNR. So far, comparisons of observation with the theoretical models suggest that the latter are basically correct. It remains difficult to identify the exact stage of development and the input parameters for any individual SNR. In particular we do not yet know in what proportions Types I and II supernovae are represented among the remnants we see. But that should not obscure the important steps made in these last three years.

3. RELATIVISTIC GAS AND MAGNETIC FIELDS

(T. K. Menon)

The distribution of non-thermal radio radiation had been used, for many years, to infer the characteristics of the relativistic-electron component of cosmic rays and the magnetic fields producing the non-thermal radiation. Similarly the chemical composition of the nucleonic component of cosmic rays observed in the solar vicinity, combined with a model for propagation of cosmic rays, had been used to infer the properties of the interstellar medium through which the cosmic rays had passed in their travel towards the solar vicinity. However the recent discovery of extended emission of γ-rays along the galactic phane has made it possible to establish a direct connection between the nucleonic component of cosmic rays and the interstellar matter density. The energetic galactic γ-rays are assumed to be the result of the interaction of cosmic rays with interstellar matter.

The distribution of galactic γ-ray radiation in the galactic phane shows remarkable similarity to the distribution of non-thermal radio radiation and seems generally correlated with galactic structural features and particularly with arm segments. Several models of the distribution of cosmic rays or of gas density have been proposed, based on the γ-ray distribution, 21-cm data as well as CO measurements. Since the γ-ray absorption is very low, it should be possible in the future to obtain a detailed model of gas distribution for the whole galactic plane.

Models of magnetic-field distribution in the solar neighborhood as well as over the whole galaxy have been derived, using new data of polarization rotation measures for pulsars and extragalactic sources and background polarization surveys. There have also been new theoretical approaches to the problem of life time and confinement of cosmic rays in the disc of the galaxy. The question of the origin of cosmic rays has been dealt with in a number of papers but the choice between the galactic and extra-galactic origin remains open.

Review Papers and Conference Proceedings

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Wentzel, D. G.: 1974, *Ann. Rev. Astron. Astrophys.* 12, 71.
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Osborne, J. L. and Wolfendale, A. W. (eds.): 1975, *The Origin of Cosmic Rays*, Reidel, Dordrecht.
Proc. Intern. Cosmic-Ray Conf., München 1975 (in press).

Bibliography from Astron. Astrophys. Abstracts

09.061.002	09.141.530	09.143.001	09.143.005	09.155.024
09.156.001	09.156.003	09.158.028		
10.012.003	10.012.004	10.062.022	10.080.005	10.080.028
10.125.034	10.143.016	10.143.017	10.143.022	10.143.023
10.143.028	10.143.034	10.143.035	10.143.047	10.143.049
10.143.053	10.143.054	10.143.059	10.155.040	10.155.056

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10.156.001	10.156.002	10.156.003		
11.131.118	11.143.001	11.143.002	11.143.005	11.143.007
11.143.013	11.143.014	11.143.020	11.143.026	11.155.001
11.155.023	11.155.026	11.155.055	11.155.058	11.156.002
11.156.003	11.158.002			
12.125.006	12.125.035	12.131.214	12.143.001	12.143.003
12.143.005	12.143.006	12.143.013	12.143.016	12.143.019
12.143.022	12.155.076	12.155.080	12.155.081	12.156.001
12.156.002	12.156.004			

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4. PLANETARY NEBULAE

(G. S. Khromov)

A. *Introduction*

We have had to summarize about 250 papers on planetary nebulae (PN) and related topics. The 1972 Liège International Astrophysical Colloquium (10.012.017) was fully devoted to Planetary Nebulae. The majority of results presented there were mentioned in our previous report (10.131.137) and will not be quoted again. We further mention the following monographs and review papers:

Osterbrock, D. E.: 1974, *Astrophysics of Gaseous Nebulae*, Freeman, San Francisco.
Miller, J. S.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 331.
Thompson, A. P.: 1974, *Vistas Astron.* **16**, 309.
Khromov, G. S.: 1975, *Planetary Nebulae*, Moscow, (in Russian, popular review).

B. *Catalogues, Surveys, New Discoveries*

A Bibliographical Index of Planetary Nebulae for 1965–1975 has been prepared by Acker and Marcout (*Astron. Astrophys. Suppl.*, submitted). This paper updates the 1967 Perek-Kohoutek Catalogue and brings the number of known PN (including dubious ones) to 1139. Sanduleak (1975, *Publ. Warner and Swasey Obs.* **2**, No. 1) has published a Catalogue of Confirmed Planetary Nebulae in the Southern Milky Way, noted on low-dispersion objective-prism plates.

Some new corrections to the Perek-Kohoutek Catalogue were published by Allen and Fosbury (*Observatory* **95**, 15, 1975) and by Kondratjeva (08.132.011). Fifteen new galactic planetary nebulae were discovered by Allen (09.133.022), Van den Bergh *et al.* (09.133.005), Kazarjan and Oganesjan (09.133.024), Vorontsov-Vel'aminov and Kostyakova (08.133.011).

One more attempt to find PN in globular clusters by Peterson (09.133.014) has given negative results. On the other hand Tifft, Connolly and Webb (08.153.004) reported a probable association of a planetary nebula with the open cluster NGC 2818. The discovery of 26 PN-like objects in 3 nearby galaxies was announced by Ford, Jenner and Epps (10.133.005).

Radio and infrared observations of PN require good positional information; improved positions were published by Allen (09.133.003), Bronnikova, Orlova and Shestopalova (12.133.017), and Milne (09.133.025). The ESO Sky Atlas Group has started a new catalogue of southern nebulae (see Holmberg *et al.*, 12.133.033.034).

Several new spectroscopic surveys of planetary nebulae were carried out or started; half of them in the Southern sky; see Sanduleak and Stephenson (08.132.026), Dossin and Vreux (10.133.019), Ringuelet and Mendez (09.133.009). The spectra of PN in the region of the Galactic Centre were studied by Vorontsov-Vel'aminov *et al.* (*Astron. Zh.* **52**, 264, 1975). Kondratjeva has obtained slit spectra of 50 stellar-like planetary nebulae, most of which had not been studied before (*Astron. Zh. Letters*, in press).

Broad-band surveys of the infrared radiation of planetary nebulae were published by Khromov (11.133.007), Willner and Becklin (08.133.005), Persson and Frogel (09.133.033), Allen (09.133.007), Allen and Glass (11.113.022), Cohen and Barlow (12.133.022). The volume of data on the infrared continuum of planetary nebulae is now comparable to that on the broad-band optical emission of these objects.

New radio surveys of PN were published by Terzian and Dickey (10.133.054), Sistla, Kojoian and Chaisson (10.133.066), Milne and Aller (12.133.025; *Astron. Astrophys.* **38**, 183, 1975), Cahn and Rubin (11.133.011).

A search for planetary nebulae in the Uhuru-2 Catalogue was made by Cahn (10.133.057); only one, dubious coincidence was found.

C. *Radiation Mechanisms*

Rather little work has appeared on the classical astrophysical problems relevant to planetary nebulae. Important publications with new or improved collisional cross-sections for heavy ions are due to Eissner and Seaton (10.022.048), Seaton (*Monthly Notices Roy. Astron. Soc.* **170**, 475, 1975), Bahng and Nussbaumer (09.114.087), Brocklehurst (08.133.022) and Simpson (*Astron. Astrophys.* **39**, 43, 1975).

Bohlin and Stecher have described the first observation of the ultraviolet spectrum of NGC 7027 (12.133.036); strong lines of C IV, He II and C III are noted.

The helium singlet spectrum in PN was studied by Bernat and Robbins (10.133.013, 10.133.038, 11.132.006). They show that the interpretation of these lines requires exact treatment of the radiation transfer; the optical thickness of the nebulae in the He II Ly-α line can be estimated.

Harrington (08.133.006) claims that the Bowen [O III]-lines can be explained in terms of the traditional fluorescence mechanism; the contradictions in the interpretation of these lines still remain.

The classical problem of resonance radiation transfer in PN-like objects has been considered by Nagirner (09.063.015) and Vityazev (Thesis, Univ. of Leningrad, 1973). The latter studied an expanding model with a velocity gradient and admixture of dust. The Ly-α-transfer in a dust-filled nebula was also considered by Panagia and Ranieri (10.132.025). The spectrum and intensity of ionizing radiation, escaping from a PN of finite optical thickness, were studied by Khromov (*Astrophysics*, in press).

The hypothesis of graphite dust as the source of the powerful infrared radiation of PN seems now commonly accepted. The dust is heated by trapped Ly-α and perhaps Lyman continuum. Both observation and theory (*op cit.* and Vityasev (09.133.023), Persson and Frogel (09.133.022, 10.133.901), Busoletti *et al.* (12.133.033)) show no obvious contradictions in this hypothesis.

The observations of infrared emission have been extended up to 150 μ (Johnson (08.133.003), Telesco *et al.* (12.133.025)). Details in the infrared spectra have been reported by Danziger (*Astron. Astrophys.* **38**, 475, 1975), Aitken and Jones (10.133.056), Jameson *et al.* (11.141.612), Bregman and Rank (*Astrophys. J.* **195**, L.125, 1975), Geballe and Rank (09.133.036), Gillett, Forrest and Merrill (10.133.001), and Hilgeman (08.133.014). Some of these details are identified with emissions of hydrogen, [A III], [S IV], and provisional identifications of the others with carbonates like $MgCO_3$ are proposed.

The location and origin of the radiating particles were studied both observationally and theoretically; see Jameson *et al.* (11.141.612), Busoletti *et al.* (12.133.033), Hunter (09.133.006), Knacke and Dressler (09.133.011), Becklin, Neugebauer and Wynn-Williams (10.133.070), Leibowitz (10.132.060), Osterbrock (10.133.063, 12.133.031). It looks as if hot dust is mixed with the ionized gas and its optical absorption is negligible; see also Hamilton and Liller (10.133.033), Persson and Frogel (09.133.022). Khromov (*Astron. Zh. Letters* **1**, No. 8, 1975) has found a definite correlation between the hydrogenic and infrared surface brightnesses of planetary nebulae; it follows that the initial quantity of dust in all very young PN is approximately the same. Later, in the expanding nebula, the concentration of particles and the density of the heating Ly-α radiation go down and the total infrared emission falls very rapidly.

There has been no more discussion about the origin of radio emission from planetary nebulae. New radio surveys were quoted in Section B; earlier observations and recent theoretical work are reviewed by Higgs (09.133.001) and Thompson (12.133.018). New data on individual nebulae were published by Sistla and Kaftan-Kassim (11.141.018), Harris (*Monthly Notices Roy. Astron Soc.* **170**, 139, 1975) and Wright *et al.* (*Nature* **250**, 715, 1974). The problem of radio recombination lines keeps attracting attention. The H 85α line was detected in 3 PN by Terzian *et al.* (12.133.012, 12.133.020); Bignell reported successful observations of the H 76α line in three objects (12.133.023). The theoretical interpretation of the patterns and intensities of these lines is not straightforward; however, no major difficulties are expected; see Hoang-Binh (09.131.094, 09.133.019), Mottmann (09.133.029), Terzian *et al.* (*op cit.*), Higgs (12.133.030).

Goss, Rieu and Winnberg have failed to detect OH-emission from the planetary nebula NGC 2438 (10.131.231).

D. *Physical Parameters*

The optical spectra of planetary nebulae, supplemented with photometrical, infrared and radioastronomical data, provide the basis for physical studies of these objects. Apart from the afore-mentioned spectral surveys, a number of optical spectra of individual objects were published by Swings (10.133.069), Sanduleak and Stephenson (08.114.165), Schwartz and Peimbert (09.133.007), Kaler, Czyzak and Aller (09.133.013), Ringuelet and Mendez (09.133.020, 09.133.010), Czyzak and Aller (09.133.028), Aller *et al.* (09.133.034), Danziger, Frogel and Persson (10.132.012), Kolotilov and Noskova (*Astron. Zh.* **50**, 962, 1973), Robbins (10.133.062), Kovar, Kovar and Potter (10.133.067), Persson and Frogel (11.131.529), Lee *et al.* (12.133.004), Perinotto (12.133.015) and Leibowitz (*Astrophys. J.* **196**, 191, 1975).

Khromov (*Astron. Zh.*, in press) has collected the spectro-photometrical data on 77 PN and analyzed their completeness and precision; both are rather low. In the typical case the precision of measurements of relative line intensities is about 30% and varies with the brightnesses of line and nebula.

Danziger and Goad identified [C I]-lines in NGC 7027 (09.133.035). Lutz (12.133.040) has derived electron densities from [O II]-lines in 12 PN. Papers on electron temperatures were published by Hua (12.133.009) and Bohuski *et al.* (11.133.010). In the detailed review by Seaton (12.132.044) it was shown that the electron temperatures in planetary nebulae should be about 10^4 K and variations can not be very large; this conclusion is important for many aspects of the physics of PN.

Many authors continued studying the effects of small-scale density fluctuations in PN: Boeshaar *et al.* (10.133.012, 11.133.003, 12.133.027), Hunter and Nightingale (09.133.006, 12.133.024), Terzian and Dickey (10.133.054), Warner and Rubin (12.133.006; *Astrophys. J.* **198**, 593, 1975), Williams (10.133.006), Holm (08.133.017). However the impression arises that no one has definitely detected such fluctuations. Most of the effects discussed can be understood in terms of large-scale inhomogenities and of ionization and density gradients in the expanding nebula (Khromov, *Astron. Zh.*, in press).

E. *Morphology, Structure and Dynamics*

The last three years were unprecedented as to the amount of work on the structure of planetary nebulae. Monochromatic images of many PN in different spectral lines one can find in papers by Andrillat and Duchesne (11.133.006), Barrette and Wehlau (10.133.003), Bernat *et al.* (10.133.062), Goad (10.133.060), Louise (11.133.002) and Warner (12.133.039). In addition isophote pictures were published in papers by Dopita and Gibbons (*Monthly Notices Roy. Astron. Soc.* **171**, 73, 1975), Coleman, Reay and Worswick (*Monthly Notices Roy. Astron. Soc.* **171**, 415, 1975) and Proisy (12.133.013). Stratification effects in NGC 7009 are discussed by Aller and Epps (*Astrophys. J.* **197**, 175, 1975).

The optical observations are supplemented by radiosynthesis observations by Balick, Bignell and Terzian (09.133.037), George, Kassim and Hartsuijker (10.133.065, 12.133.014), Scott

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(09.133.018, *Monthly Notices Roy. Astron. Soc.* **170**, 487, 1975), Sistla and Kassim (12.133.033), Terzian, Balick and Bignell (11.133.008), Willis, George and Kassim (12.133.028). In general the radio-brightness pictures are quite similar to the optical ones.

Faint outer extensions of some PN were studied by Kaler (11.133.017), Millikan (*Astron. J.* **79**, 1259, 1974), Coleman *et al.* (*Monthly Notices Roy. Astron. Soc.* **171**, 415, 1975) and Araya, Blanco and Smith (07.133.012).

Results on the radial and angular expansion of planetary nebulae were presented by Acker (*Astron. Astrophys.* **40**, 415, 1975), Grandi (09.133.026), Kaler and Aller (12.133.032), Meaburn (10.131.077), Orlova (08.133.013) and Taylor (11.133.001). Obviously these dynamical characteristics are physically connected with the morphology and structure. However, there are no strict mathematical methods for a combined analysis of isophote pictures and expansion velocities. An attempt to develop such methods was undertaken by Hekela, Chifka and Hubený (08.133.001, 002 and 010; 10.133.072); analogous work was started by Khromov.

Recent theoretical work on the nebular structure is based upon the idea of radial filamentary inhomogeneities. Such a model has been constructed for NGC 7662 by Kirkpatrick (08.133.007), is discussed by Boeshaar (10.133.059), and Pikelner (10.133.017, 11.064.058) developed a theory of the dynamical role of the stellar wind in the formation of nebular structure. However, the possibilities for application of traditional gas dynamics to PN are not exhausted indeed; see Mallik (*Astrophys. J.* **197**, 355, 1975).

F. *Nuclei*

Earlier results on the nuclei of PN were reviewed by O'Dell (12.133.019). New attempts to detect circular polarization of nuclei were undertaken by Kemp, Wolstencroft and Swedlund (08.116.015), Rich and Williams (11.126.014), Shulov and Belokon' (09.126.004) and by Wolf (*Astron. J.* **77**, 576, 1972); no polarization was definitely found in the nuclei of 10 PN. A search for high-frequency brightness fluctuations in nuclei of PN was started by Alekseev (10.133.055).

The anomalous behaviour of FG Sagittae, which undergoes rapid changes of spectrum and luminosity, was studied by Christy-Sackmann and Despain (11.065.094), Flannery *et al.* (10.133.004), Langer *et al.* (11.114.106), Papoušek (10.122.168), Sparks and Kutter (10.122.016), Rose (12.065.148) and Wenzel (11.133.019).

Greenstein (07.133.013) and Ford (06.122.110) have studied the nuclei of NGC 1514 and A 58 respectively. Cudworth (10.118.007) has found visual duplicity in the nuclei of 5 PN. The theoretical ultra-violet spectrum of nuclei was computed by Sahibullin (*Proc. Kazan' Observatory* **39**, 16, 1973).

G. *The System of Planetary Nebulae; Chemical Composition*

The absence of a generally adopted definition of planetary nebulae leads to difficulties in their classification. Some obvious corrections to the general list of PN were mentioned in Section B. Two other dubious cases, NGC 6164/5 and M 2-9, are discussed by Pişmiş (*Rev. Mexic. Astron. Astrof.* **1**, 45, 1974), Johnson (08.117.014), Allen and Swings (07.133.022), Van den Bergh (11.133.014) and Purton *et al.* (*Astrophys. J.* **195**, 479, 1975). Methodical comments on the discovery of PN were presented by Cesco and Gibson (10.113.006). According to Cohen and Barlow (*op.cit.*) and Allen (*op cit.*), we can distinguish PN from other emission-line objects by the characteristics of their infrared emission. Khromov (*Astron. Zh.*, in press) has developed a spectroscopic criterion for typical PN.

Radial velocities and proper motions of PN were published by Brown and Lee (09.133.038), Cudworth (12.133.038), Smith and Weedman (08.133.012); the latter authors studied the kinematics of PN in the Large Magellanic Cloud to determine the type of this galaxy. An important result, on the trigonometric parallax of NGC 7293 ($0''.001 \pm 0''.005$), was published by Dahn, Behall and Christy (09.133.027).

Modernized distance-scales were published by Riherd (09.133.030), Lutz (09.131.058, 10.131.148) and Milne and Aller (*op cit.*); in the last papers the methods of stellar astronomy were used to estimate distances by the amount of interstellar absorption.

Melnik and Harwit (12.133.008; *Monthly Notices Roy. Astron. Soc.* **171**, 441, 1975) have found a correlation between the position angles of the major axes of PN and the direction of the galactic equator. Greig (07.155.026) and Smith (10.133.014 discussed different characteristics of PN from the point of view of their distribution in the Galaxy. The same problem has been considered by Iwanowska (11.133.016), with the conclusion that a statistical connection should exist between positional characteristics and chemical composition of these objects (see also Van den Bergh, 10.133.009).

The abundances of chemical elements in various PN were studied by many authors: Aitken and Jones (10.133.056), Ahern (*Astrophys. J.* **175**, 635, 1975), Buerger (09.133.012), Geballe and Rank (09.133.036), Lee and Kenning (10.133.007), Kaler (11.133.005), Simpson (*op cit.*), Sistla *et al.* (10.133.066, 12.133.005) and Shields (*Astrophys. J.* **195**, 475 1975). Jenner, Ford and Epps (09.133.016) have determined the He abundance in a planetary nebula in the galaxy NGC 185. On average these results support the traditional view that the chemical composition of PN is similar to that of galactic nebulae and normal stars; some exceptions may occur, as well as a correlation of abundances with the kinematics of planetary nebulae.

H. *Origin and Evolution*

This problem is of a synthetic nature, and consequently the most complicated. Several recent studies of stellar-like compact objects with low-excitation emission spectra aim at identification of the earliest evolutionary stages of the planetary nebulae. Such investigations were reported by Andrillat and Houziaux (10.114.148), Arhipova, Dokuchaeva and Mandel' (11.133.009, 08.114.001, 09.123.013), Ciatti, D'Odorico and Mammano (12.114.029), Fitzgerald and Pilovaki (12.114.056), Knacke (08.113.004), Kondratjeva (*Astron. Tsirk.* 827, 1974) and Richter (08.114.080). Somewhat later evolutionary stages can probably be traced among the common stellar-like PN; see Sanduleak and Stephenson (*op cit.*), Kondratjeva (*Astron. Zh.*, in press), Kostyakova (11.133.020) and Vorontsov-Vel'aminov *et al.* (*Astron. Zh.* 52, 264, 1975). The influence of the evolution upon observational properties and physical parameters of PN was discussed by Bohuski and Smith (09.133.017, 12.133.021), Fibelman (12.133.034) and Lutz (11.133.018). The thermal structure of a young PN with an H I shell is studied by George (10.133.048, 11.133.015). Khromov (*Astron. Zh.*, in press) has found that the density of PN falls from 10^7 to 10^2 cm^{-3} along the observable part of their evolutionary track.

Much theoretical work attempted to understand conditions in the stellar precursors of PN, and to suggest an appropriate mechanism for the separation of the nebula from its nucleus; see Alexander (08.133.015), Buchler and Mazurek (12.065.153), Faulkner and Wood (08.065.095), Joss *et al.* (09.065.088), Gusseinov (10.133.073), Katz, Malone and Salpeter (11.065.101, 12.133.030), Kutter and Sparks (08.064.006; 12.065.050), Mengel (10.065.085), Rose and Smith (07.065.070, 08.064.012), Roomjantsev (08.065.025), Scott (09.133.008), Stry (10.133.068, *Astrophys. J.* **196**, 559, 1975). A review of earlier work one may find in a paper by Paczińsky (*Postepy Astron.* **21**, 9, 1973). No crucial success in the understanding of PN in the framework of the theory of stellar evolution seems to have been achieved for the last three years.

The nuclei of PN became the target of careful investigation as possible precursors of the white dwarfs. Theoretical papers, discussing the properties and probable evolution of PN nuclei, were published by De Angelis *et al.* (10.133.002, 11.133.004), Fontaine, Thomas and Van Horn (10.126.010), Kovetz and Shaviv (10.133.007), Redkoborody (08.126.021), Sion (10.126.008) and Van Horn (11.133.013). Katz, Malone and Salpeter (*op cit.*) have made the promising suggestion that the next stage of evolution of the nuclei may be identified as hot ultraviolet stars, which effectively ionize the interstellar matter before being transformed into faint white dwarfs. The probable contribution of the nuclei to the heating of the interstellar medium was discussed also by Rose and Wenzel (09.131.057), and by Terzian (12.133.007, 12.155.044). It is obvious that the whole problem of the formation and evolution of planetary nebulae and their nuclei requires more observational data and theoretical work.

5. H II REGIONS

(M. Peimbert)

The research on H II regions has advanced considerably in the last three years. Data have been gathered at an accelerated pace from the far UV to radio wavelengths involving the study of physical conditions, and in particular the presence of dust particles and molecules in, or near, these regions. In what follows we will review papers representative of the work carried out since the last IAU General Assembly; advances related to dust, molecules and radio astronomy are reviewed elsewhere in these reports.

An excellent book by Osterbrock (*Astrophysics of Gaseous Nebulae*, 1974, Freeman), which includes the basic theory and a survey of some of the most relevant papers on the observational study of gaseous nebulae, provides a very powerful tool for the study of H II regions.

Habing (12.012.025) presented a very interesting review on recent studies of H II regions. Terzian (12.132.030) and Terzian and Balick (*Fundamentals of Cosmic Physics*, **1**, 301) presented reviews on emission nebulae based mainly on radio observations.

Maršálková (11.131.515) compiled a catalogue of H II regions and a list of objects previously classified as H II regions that are SN remnants, planetaries or galaxies. Felli and Perinotto (11.131.511) studied thirty-four faint objects appearing in the Sharpless Catalogue of H II Regions and found that two are planetary nebulae, two are reflection nebulae, and six probably are evolved planetaries. Chopinet, Georgelin and Lortet-Zuckermann (10.132.029) presented evidence for the existence of hot stars associated with a number of small galactic nebulae, rendering unnecessary other mechanisms of ionization suggested previously. Chopinet, Deharveng and Lortet-Zuckermann (11.131.505) made an optical study of Sh-255, 257 and 269 and suggested that these objects might represent an early stage of evolution of H II regions. Deharveng (12.131.524) studied optically Sh 2-156 and 2-157A, two small probably young galactic H II regions. Glushkov, Denisyuk and Karyagina (*Astron. Astrophys.* **39**, 481, 1975) studied compact H II regions in 13 extended nebulae; they presented values for the density, emission measure and absorption at Hα.

Pikelner and Sorochenko (10.132.001) suggested that shock waves produce the non-uniform density distribution observed in M 42 and other nebulae; these waves are generated by the pressure of a high-temperature, low-density gas heated by the stellar wind from the ionizing stars. Lozinskaya (09.132.025) found from Hα Fabry-Pérot observations of NGC 2359 that the shell around HD 56925 has an Hα linewidth of 150–200 km s^{-1} and a shell expansion of 55 ± 25 km s^{-1}. Deharveng and Maucherat (12.131.509) from interferometric Hα radial velocities of NGC 3199 derived an expansion of 30 km s^{-1} around the ionizing Wolf-Rayet star; they suggested that, as in the case of NGC 2359 and NGC 6888, this expansion is produced by ejection of material from the central stars. Wendker, Smith, Israel, Habing and Dickel (*Astron. Astrophys.* **42**, 173, 1975) presented high-resolution radio and optical observations of NGC 6888. Smith (09.132.027) observed gas motions in the Rosette nebula; he suggested that mass loss from the central cluster of stars is the source of energy that drives the observed supersonic motions. Deharveng (10.132.045) from optical observations of M 42 has found line splitting that extends over distances as large as several minutes of arc and indicates velocity differences as large as 25 km s^{-1} along the line of sight. Dopita, Gibbons, Meaburn and Taylor (09.131.009) observed large scale line splitting in five galactic H II regions. Dopita (12.131.503) suggested that the break-up of the neutral gas and dust cloud around a cocoon star could produce the fast internal motions observed in H II regions. From an optical study of the Carina nebula, Deharveng and Maucherat (*Astron. Astrophys.* **41**, 27, 1975) found that the expansion velocity of the ionized gas is $\geq$ 25 km s^{-1}, while that of the neutral gas is considerably smaller; moreover Dickel (11.132.003) found for this object that the pattern of molecular observations is compatible with an outward expansion at a rate of about 7 km s^{-1}.

Seaton (12.132.044) presented a review of *electron temperature* determinations in gaseous nebulae. The relatively low electron temperatures derived in the last twelve years are found to be in disagreement with the most recent theoretical and observational work. Beuermann (09.132.027) obtained $\langle T_e \rangle \leq 8500$ K from radiofrequency absorption measurements of the

Gum nebula; this result might indicate that this object is an evolved H II region instead of the fossil remnants of the Vela supernova. Reynolds (preprint) observed the Hα, [N II] and [O III] lines at eight positions in the Gum nebula; in five positions he detected two components with a typical separation of 40 km s^{-1}, from the line profiles he derived $\langle T_e \rangle \sim 12\,000$ K.

Simpson (10.132.038) from photoelectric spectrophotometry of M 42 derived accurate electron temperatures, *electron densities, and chemical abundances.* Dopita (10.132.006, 10.132.046, 12.132.016), based on photoelectric photometry of M 42, M 8 and M 20, studied their temperature and ionization conditions and found that in M 42 oxygen is underabundant by a factor of four; the results by Simpon and the large deficiency in the dust-to-gas ratio in the center of M 42 seem to indicate that the oxygen deficiency, if present, is considerably smaller than the value derived by Dopi̇ta. Aitken and Jones (11.131.522) from observations of the Ne II line at 12.8 μ in G 333.6–0.2 found a neon abundance in the 7.63 to 7.93 range.

Churchwell, Mezger and Huchtmeier (11.131.59) presented observations of He and H radio recombination lines of 39 galactic H II regions; they obtained $0.06 \leq N(He^+)/N(H^+) \leq 0.10$ for spiral arm H II regions and $\langle N(He^+)/N(H^+) \rangle \leq 0.02$ for three giant H II regions near the galactic center; they reviewed the He abundance determinations by other authors. Danziger (12.131.527) from optical photoelectric observations derived $N(He^+)/N(H^+) \simeq 0.11$ for the southern H II regions NGC 3576, RCW 38 and NGC 6537; he discussed the difference between this result and the low value for NGC 6537 obtained from radio recombination-line observations. Dopita, Elliot and Meaburn (11.132.012) from optical electronographic observations of M42 derived $0.104 < N(He)/N(H) < 0.132$.

Since the suggestion by Mathis (06.132.006) that *dust might be important in the radiative transfer* of helium and hydrogen ionizing photons, many authors have worked on this subject; most of the papers published in 1973 and 1974 implied that dust is very important, however it seems that the opposite trend is found in the most recent papers. Mezger, Smith and Churchwell (11.131.538) studied the infrared excess radiation from H II regions; they found that dust grains affect significantly the radiative transfer of H II regions, and that selective absorption of helium ionizing photons by dust within the ionized gas might be responsible for the low He^+/H^+ ratios observed in three regions near the galactic center. A similar suggestion to explain the low He^+/H^+ ratio was advanced by Jura and Wright (11.131.528). Alternatively, Brown and Lockman (*Astrophys. J.* **200**, L155, 1975) recently detected H76α and He76α in Sgr B2 and found that $N(He^+)/N(H^+) = 0.085 \pm 0.015$; this result apparently indicates that the selective absorption of helium ionizing photons, if present, is not very significant; Brown and Gómez-González (*Astrophys. J.* **200**, 598, 1975) considered the transfer of recombination-line radiation that crosses a cold, partially ionized, gas and found that at low frequencies the inferred $N(He^+)/N(H^+)$ value may appear anomalously low. It is clear that observations of Sgr B2 at even higher frequencies are needed to provide more elements into this problem.

Leibowitz (09.131.130) from the study of NGC 2024 found some observational evidence suggesting that the presence of dust grains in an H II region reduces the He^+/H^+ abundance ratio. On the other hand, Balick (preprint) did not confirm the NGC 2024 observational evidence by Leibowitz and reached the opposite conclusion that dust grains are probably not significant in the radiative transfer of H II regions. By comparing Balmer emission lines with radio fluxes for M 42, Leibowitz (10.132.060) estimated an optical thickness at Hβ due to internal dust, between 2.5 and 9 mag.

Evidence for *dust depletion in compact H II regions* from infrared observations was presented by Zeilik, Kleinmann and Wright (*Astrophys. J.* **199**, 401, 1975); Soifer and Pipher (*Astrophys. J.* **199**, 663, 1975); and Gillett, Forrest, Merrill, Capps and Soifer (*Astrophys. J.* **200**, 609, 1975). In particular Gillett *et al.* found dust-to-gas ratios 20-200 times smaller than typical interstellar values. Johnson (9.131.184) compared the infrared nebular luminosity to the stellar luminosity in five H II regions and found that the infrared nebular luminosity exceeds the accountable stellar luminosity in M 17; he also compared 100-μ and 6-cm flux densities for diffuse nebulae (9.132.005).

Schiffer and Mathis (12.132.056) presented new optical observations of the scattered continuum in M 42 and discussed several theoretical models for the dust distribution. Hua (11.132.022) from the study of the optical continuum energy distribution of M 42 derived the contribution due to scattered light and the value of the electron temperature. Bohlin and Stecher (preprint) found, from observations in the 1200- to 2850 Å range with 20 Å resolution, that most of the continuum emission from M 42 is due to dust-scattered light. Carruthers and Page (preprint) obtained direct imagery in the 1050–1600 Å range of a 20°-diameter field in Cygnus that includes NGC 7000.

Petrosian and Dana (*Astrophys. J.* **196**, 733, 1975) obtained approximate radiative-transfer solutions of dusty nebulae. Balick (*Astrophys. J.*, in press, 1975) considered the possible effects of dust on the ionization and thermal structure of photoionized nebulae. Panagia and Ranieri (9.132.013) studied the transfer of Ly-α radiation in a spherically symmetric hydrogen nebula; they discussed extensively the results on the mean number of scatterings and the emergent profiles. Robbins and Bernat (11.132.006) studied the transfer of resonance-line radiation in the He I singlets for nebular models consisting of differentially expanding uniform spheres.

Mallik (*Astrophys. J.* **197**, 355, 1975) computed the theoretical temperature and emission-line structure at the *edges of H II regions*. Macpherson (12.131.517) made a theoretical model of an H II–H I boundary. Schmidt (12.132.024) gathered data on the ionization, density and temperature across bright rims in M 42, NGC 2264, NGC 6820 and IC 1396; the observations were compared with theoretical computations by Pottasch. Louise and Sapin (09.132.030) observed the Horsehead Nebula with interference filters centered on Hα and [N II], and studied the variation of this ratio toward the bright rim. Grandi (*Astrophys. J.* **196**, 465, 1975; *Astrophys. J.* **199**, L43, 1975) studied the starlight excitation of permitted lines in M 42; he found that this mechanism explains the difference in the filamentary structure shown by the permitted and the forbidden O I pictures presented by Munch and Taylor (12.132.022).

Herbig (12.131.173) estimated that the age of a typical isolated *globule* in the Rosette nebula is of the order of 10^4 yr and that these objects are not protostars. Dopita, Dyson and Meaburn (11.131.531) suggested that the ionized core of M 42 is caused by two major ionization fronts entering into a large mass of neutral material which contains many dense neutral globules. Stasinska (09.131.022) computed H_2 equilibrium abundances for different models of neutral globules inside H II regions. Dyson (10.131.052; 12.131.075) computed self-consistent structures for axially symmetric globules exposed to axially symmetric radiation fields.

Considerable effort directed to elaborate improved *models of M 42* (the Orion Nebula) based mainly on radio observations was carried out by Zuckerman (10.132.011), Pyatunina (10.132.020), Batchelor (11.132.019), Balick, Gammon and Doherty (11.132.004), Balick, Gammon and Hjellming (12.131.549), Gulyaev and Sorochenko (12.132.039), and Dopita, Isobe, and Meuburn (*Astrophys. Space Sci.* **34**, 91 1975). Simpson (*Astron. Astrophys.* **39**, 45, 1975) computed emissivity coefficients for the forbidden lines expected in the 2μ to 300μ region, and from her model of M 42 (10.132.038) predicted its spectrum in that wavelength range.

Grasdalen and Cohen (09.132.006) presented evidence indicating that the *diffuse nebulae at high galactic latitudes*, although they show Hβ in emission, are reflection nebulae illuminated by the integrated light of the Galaxy. Reynolds, Scherb and Roesler (10.131.140; 12.155.025) found that the diffuse galactic Hα emission yields $\langle n_e{}^2 \rangle \simeq 0.05$ cm^{-6} and it is probably produced by an ionized component of the interstellar gas which is distributed throughout the interstellar medium. Torres-Peimbert, Lazcano-Araujo and Peimbert (12.114.017) and Cruz-González, Recillas-Cruz, Costero, Peimbert and Torres-Peimbert (*Rev. Mexic. Astr. Astrof.* **1**, 211, 1974) found that O and B stars outside dense H II regions, of which a considerable fraction are runaway stars, yield $\langle n_e{}^2 \rangle \simeq 0.05$ cm^{-6}, in good agreement with the value derived by Reynolds *et al.* Thuan (*Astrophys. J.* **198**, 307, 1975) studied the possibility that the intercloud medium is ionized by runaway stars. Elmergreen (*Astrophys. J.* **198**, L31, 1975; *Astrophys. J.* **205**, in press, 1976) showed that O stars outside dense H II regions are in general surrounded by H II regions with a density close to unity, and that probably they do not ionize a significant volume of the interstellar medium; he also developed a model in which B stars ionize a larger volume of space than do O stars.

Hodge (12.131.554) presented a survey of the study of *H II regions in other galaxies*, specially of their spatial distribution and relation to galactic structure; he presented a thorough review of Hα surveys of galaxies. Strom, Strom, Grasdalen and Capps (12.131.528) observed extragalactic H II regions at 10 and 20 μ; in some cases they found upper limits substantially lower than those predicted from the observed centimeter radio flux. Schmidt-Kaler and Feitzinger (*Astrophys. Space Sci.*, in press) suggested that the supergiant H II-complex 30 Doradus is the mildly active galactic nucleus of the LMC. Peimbert (*Ann. Rev.* **13**, 113, 1975) presented a review on chemical composition of extragalactic gaseous nebulae; the abundance differences and abundance gradients derived from H II regions were studied in detail. Smith (*Astrophys. J.* **199**, 591, 1975) studied the chemical abundances of H II regions in nearby spirals and irregular galaxies. Peimbert and Torres-Peimbert (*Astrophys. J.* **203**, in press, 1976) from H II regions in the SMC found a pregalactic $N(\mathrm{He})/N(\mathrm{H}) = 0.074 \pm 0.006$ and $\Delta Y/\Delta Z = 2.7 \pm 1$.

6. NEUTRAL HYDROGEN

(H. van Woerden)

This section reviews information coming mainly from the 21-cm line of neutral hydrogen; the Ly-α observations are summarized by Morton in the next section. A systematic comparison of Ly-α and 21-cm data has been made by Heiles and Jenkins (1976, *Astron. Astrophys.* **46**, 333). The distribution and motions of hydrogen on a galactic scale are considered in the Report of Commision 33.

A. *21-cm Line Surveys*

The past triennium has brought publication of the first complete, fully-sampled surveys of the northern sky. These surveys were made with the Hat Creek 25-m telescope of the University of California; their resolution is 0°.6 in angle, 2 km s^{-1} in velocity.

Weaver and Williams (09.157.009) surveyed the galactic belt between longitudes $l = 10°$ and 250°, latitudes $b = -10°$ and $+10°$; they give an atlas of 38961 line profiles T_a (V) on a grid of 0°.5 by 0°.25 in l, b, as well as (12.157.007) contour maps T_a (b, V) at constant l. Weaver has discussed results of this survey in terms of galactic structure at *IAU Symposia* Nos. 38, 39 and 60. The survey has been extended (Weaver and Williams, 12.157.008) to $|b| = 30°$ on a 2°.5 by 0°.5 grid, again published as profiles and contour maps.

Heiles and Habing (11.157.005) published an almost-complete survey of hydrogen with velocities $-92 < V < +75$ km s^{-1} at latitudes $|b| \geqslant 10°$ and declinations $\delta > -30°$, in the form of contour maps $T_a(l, V)$ at constant b. Heiles (11.157.006) claims absolute accuracies of ± 0.1 K for the zero level of the survey, ± 10% for its absolute intensity scale and 2% for its internal scale consistency. Heiles (1975, *Astron. Astrophys. Suppl.* **20**, 37) has further published H I column density maps N_{H} (l, b), and discussed various results of the survey at *IAU Symposium* No. 60 (12.131.132). The analysis of the survey has been considerably fostered by photographic representations, including the use of colour to represent velocity (Heiles and Jenkins, 1976, *Astron. Astrophys.* **46**, 333); we discuss various conclusions in the following subsections.

New high-resolution (0°.2) studies at low latitudes have been made at Green Bank (Westerhout) and Parkes (Kerr, Harten and Ball), and will soon be published. The surveys by Lindblad (12.157.003), Burton and Verschuur (10.157.003), and by Tuve and Lundsager (1973, Carnegie Inst. Washington Publ. No. 630) provide thinner coverage of wider regions, the latter reaching to high latitudes. Extensive surveys of the southern sky have been carried out at Parkes (0°.8 beam) by Kerr and Bowers at $|b| < 10°$ and by Miss Cleary. For other surveys we refer to the Reports of Commissions 33 and 40. Surveys of high-velocity hydrogen are mentioned in Subsection H.

Considerable differences of intensity scale have long been known to exist between various major surveys. Harten, Westerhout and Kerr (1975, *Astron. J.* **80**, 307) find that the new Parkes and Maryland-Green Bank surveys, the Weaver-Williams survey, and that by Muller and Westerhout (1957) are on the same scale to within 5%; so are the Dwingeloo surveys (Van Woerden, Takakubo and Braes, 1962, *Bull. Astron. Inst. Neth.* **16**, 321), while the scale of Heiles and Habing agrees within 10% with that of Dwingeloo. Williams (09.157.010) has carefully studied four regions used as calibration standards.

Westerhout, Wendlandt and Harten (10.157.006) published correction procedures to correct the earlier Green Bank 300-ft surveys for 'error-beam' effects. A thorough study of side-lobe effects in 21-cm profiles has been made by Kalberla at M.P.I., Bonn (unpublished); the effects are of great importance in measurements of faint 21-cm line emission such as that from an intercloud medium.

B. *Temperature and Density*

Much work has been done on interstellar temperatures and densities, in connection with the two-component model for the interstellar medium.

(i) *The intercloud medium* (ICM) – A variety of methods have been applied. Mebold (07.131.115) studied the wide components (velocity dispersion $5 \leqslant \sigma \leqslant 17$ km s^{-1} of profiles at $b = +30°$. The variation of velocity V and dispersion σ with longitude, due to differential galactic rotation (DGR), provides information on the distribution of distances, hence on the z-distribution, Mebold finds an exponential distribution, with scale height 210 pc and peak density $n_{HO} = 0.20$ cm^{-3}. The profile width in the absence of DGR, caused by thermal and turbulent broadening, sets an upper limit of 9000 K on the kinetic temperature T_k. Falgarone and Lequeux (09.131.041), applying the same method to emission profiles observed by Radhakrishnan *et al.* (07.131.002), find a Gaussian z-distribution of dispersion $\sigma(z) = 230$ pc and $n_{HO} = 0.155$ cm^{-3}, and a kinetic temperature of 3000 K.

Baker and Burton (1975, *Astrophys. J.* **198**, 281), in a model study to be discussed below, derive $\sigma(z) = 120$ pc and $n_{HO} = 0.17$ cm^{-3}, from a large body of low-b profiles.

Applying statistical methods to the analysis of emission profiles (see Subsection C), Baker (09.157.002), Hachenberg and Mebold (09.131.170), and Mebold *et al.* (11.131.506) find values T_k between 4800 and 5700 K. This method implies that the ICM is not fully smooth but consists of turbulence cells.

Comparison of 21-cm absorption [optical depth $\tau(V)$] in the spectra of continuum sources with neighbouring emission [brightness temperature $T_b(V)$] gives the spin temperature T_s; this procedure requires component analyses of the absorption and emission spectra, since components of different T_s may overlap. The velocity dispersion in a component yields T_k, and n_H may be derived from $T_b(V)$ through the standard procedures for differential galactic rotation. The great absorption surveys of Hughes, Thompson and Colvin (06.141.192) and Radhakrishnan *et al.* (07.131.002) had insufficient sensitivity to detect the low optical depth of the intercloud medium; hence, they could only place lower limits of 600–800 K on T_s, and upper limits of 10000 K on T_k. New, sensitive measurements of Cas A and Cyg A by Davies and Cummings (1975, *Monthly Notices Roy. Astron. Soc.* **170**, 95) and by Mebold and Hills (1975, *Astron. Astrophys.* **42**, 187) unambiguously detect the ICM in absorption, with T_s in the range 1500–8000 K for the Jodrell Bank, 3000–8000 K for the Effelsberg measurements; the agreement is generally quite good. Davies and Cummings find $680 < T_s < 2000$ K in Vir A, but here the attribution of the weak absorptions to the ICM might be questioned. Both authors find $n_H = 0.1$–0.3 cm^{-3} in front of Cas A; and smaller values for the absorptions of Cyg A, which occur at quite high z. Mebold and Hills show that their findings remain valid if the ICM is clumpy.

In summary, three fully independent methods now agree in establishing an intercloud medium of scale height 200 pc, peak density 0.2 H atoms cm^{-3}, and temperature 5000 K, with each of these parameters probably accurate within a factor 2.

(ii) *The clouds* – The earlier absorption studies of Hughes *et al.* (06.141.192) and Radhakrishnan *et al.* (07.131.002; see also the analysis by Quiroga: 1975, *Astrophys. Space Sci.* **35**, 67) had given spin temperatures in the range 20–200 K, clustering around 70 K; velocity dispersions (with*in* a cloud!) 1–6, mostly 2–4 km s^{-1}; and densities of possibly 10–100 cm^{-3}. Radhakrishnan and Goss (07.131.005) found an average of 2.5 clouds per kpc on a line of sight in the galactic plane. The new observations by Davies and Cummings (1975, see above), Lazareff (1975, *Astron. Astrophys.* **42**, 25) and Mebold and Hills (1975, see above) give T_s in the range 40–500 K; the higher values represent warmer clouds of low optical depth, whose detection required the higher sensitivity now available. Lazareff explicitly finds a correlation of τ and T_s. Greisen (10.131.054 and 10.155.022), studying several strong sources in aperture synthesis,

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discovered considerable substructure of scales ∿ 1 pc in the absorbing clouds; he finds $50 < T_s < 150$ K, $0.6 < \sigma < 1.1$ km s^{-1} and n_H up to 100 cm^{-3}. In a later interferometer study, Greisen (1976, *Astrophys. J.* **203**, 371) finds that scale of 0.3 pc are much less frequent than those of 1 pc.

The self-absorption effects observed in dense, cool clouds may also provide estimates of T_s and n_H. Crutcher and Riegel (11.131.054), reanalyzing their observations of a big cloud in the region l ∿ 0° (cf. 07.155.025), derive T_s = 40 K, n_H = 20 cm^{-3}. Knapp (11.131.542,543) has studied 88 dust clouds for selfabsorption effects; she finds T_s ∿ 16–40 K. The gas in these dust clouds must be predominantly molecular hydrogen, as indicated by the radio of H I to OH and H_2CO; the amount of atomic hydrogen is quite modest.

Studies of 21-cm emission alone do not yield spin temperatures. The densities found in those studies – see next subsection – range from 0.1 to 100 cm^{-3}, velocity dispersions from 1 to 5 km s^{-1}.

Baker and Burton (1975, *Astrophys. J.* **198**, 281) have undertaken a job which had been urgently due for some time. They have calculated synthetic line profiles for one – and for two – component models of the interstellar medium, with variable parameters; comparing these synthetic profiles to observations at latitudes $|b|$ = 2°, 4°, 6°, 8° (Burton and Verschuur, 10.157.003), they find that for a satisfactory representation a two-component model is essential, and determine optimum parameter values for this model. In addition to a number of large-scale galactic parameters, they derive the central density of the intercloud medium (see above), and an estimated cloud diameter: ∿5 pc. More sophisticated models may be desirable, but the present result is a major step forward.

Theoretical developments regarding interstellar temperatures and densities are discussed by Kahn in section 10.

(iii) *Electron densities* – A good review of free electrons outside H II regions is that by Guélin (12.131.133). The best information comes from pulsar dispersion measures and distances, and from the ionization equilibria of heavy atoms.

The most recent compilation of observed properties of pulsars is that by Taylor and Manchester (1975, *Astron. J.* **80**, 794). Recent distance determinations from 21-cm absorption include those by Gómez-Gonzàlez and Guélin (11.141.325), by Gordon and Gordon (1975, *Astron. Astrophys.* **40**, 27), and by Graham *et al.* (1974, *Astron. Astrophys.* **37**, 405); these authors also give references to earlier work. The consensus is that, on average, n_e ∿ 0.03 cm^{-3}; higher values may occur in the inner parts of the Galaxy, and where a line of sight cuts an H II region.

White (10.131.007) derives n_e = 0.03-0.09 cm^{-3} from the ratios of line strengths of Ca I and Ca II; the assumptions made in this type of analysis are criticized by Frisch (12.131.105). Crutcher and Riegel (11.131.054) find 0.05 cm^{-3} from a comparison of H I and Na I lines; Hobbs (11.131.530) uses the line strengths of K I, Na I, Ca II and HI to find n_e ∿ 0.002 n_H.

C. *Structural Features*

In an excellent review, given at *IAU Symposium* **60**, Heiles (12.131.132) collates a variety of data on 'interstellar clouds'. Masses range from 4 $M_\odot$ (cloudlets) to 10^5 $M_\odot$ (big complexes), sizes from 1 to 100 pc, densities from 1 to 100 cm^{-3}, internal motions from 1 to 5 km s^{-1}, and up to 40 km s^{-1} in 'active regions' (expanding shells).

Schwarz and Van Woerden (12.131.535) define clouds by correlating Gaussian profile components in neighbouring points on the sky. Rather than announcing properties for an average or 'standard' cloud, they present *distribution functions* for various observed parameters. Optical depth, diameter, density and mass follow power laws with exponents between –1 and –2. Velocity dispersions fall mostly between 0 and 5 km s^{-1}. Schwarz and Van Woerden also detect 'tenuous clouds' with N_H ∿ 0.05 x 10^{20} cm^{-2}, size 40 x 5 pc, density 0.3 cm^{-3} and mass 10 $M_\odot$ (if at distance 300 pc). The most striking property of their clouds, however, is the *shape*: highly elongated, often filamentary or very irregular. Cox and Smith (11.125.028) have suggested that those shapes might be interpreted in terms of a netwok of tunnels generated in the interstellar medium by supernovae.

Filamentary structures have also been found by Verschuur (11.131.508; 10.131.074); he finds masses of 5 $M_\odot$ per pc along these filaments, and sometimes strong velocity gradients. Fejes and Wesselius (09.155.020) have traced such filaments ('ridges') over many tens of degrees and named them after constellations. Heiles and Jenkins (1976, *Astron. Astrophys.* **46**, 333), in their photos of the sky distribution of hydrogen, show that these filaments dominate the sky at higher latitudes. Several of the longer filaments appear related to the giant radio-continuum Loops and/or local explosions, cf. Subsection F. As emphasized by Heiles (12.131.132), the 'standard' cloud model is at great variance with recent findings; both structure and (presumably) motions appear correlated over large distances, in one, or at most two, dimensions.

Purely *statistical methods* for the analysis of the structure of the interstellar medium have been developed by Baker (09.157.002) and by Mebold, Hachenberg and Laury-Micoulaut (11.131.506). These methods select smooth regions, devoid of obvious cloud structure. The variations of profile about the average describe the turbulence of the intercloud medium, and lead to a determination of its temperature (Subsection B). Baker finds a scale size of 7 pc for the turbulence. Baker (10.155.003) defines 'individual features' as strong local deviations from profile averages (in less smooth regions); he finds two types: kinematical disturbances and hydrogen filaments. Since foreground hydrogen of high optical depth will, through selfabsorption, reduce background profile variations, Baker (11.131.043) has searched for 'deviation defects' and thus detected regions of optically thick hydrogen, notably in Taurus and Perseus.

For the structural features of high-velocity hydrogen, we refer to Subsection H.

D. *Gas and Dust*

Reliable determinations of the *relative amounts of gas and dust* in interstellar space require that the interstellar volumes sampled be closely similar. In recent investigations, this requirement is better fulfilled than in the past.

Knapp and Kerr (12.155.038) and Knapp *et al.* (10.131.062) compare colour excesses $E(B-V)$ of 97 globular clusters with hydrogen column densities, N_H, in their directions. They find a close relation, suggesting a ratio $N_H / E(B-V) = 5 \times 10^{21}$ H atoms cm^{-2} mag^{-1}. This result is in good agreement with the results of Jenkins and Savage (11.113.001) and of Bohlin (1975, *Astrophys. J.* **200**, 42), who compare Ly-α absorption (from OAO-2 and *Copernicus*, respectively) and colour excess in 95 and 37 early-type stars; the average ratios range between 3.6 and 7.5×10^{21}. Knapp (1975, *Astron. J.* **80**, 111) finds a slightly, but not significantly, higher ratio towards 55 elliptical galaxies. Heiles (in press) compares N_H-values from the Berkeley high-latitude survey with the Shane-Wirtanen galaxy counts (some 20000 data points!) and with reddening; he finds no simple relation between any pair of these three extinction indicators: each indicator depends on galactic latitude as well as on the other. Regional variations in the gas/dust ratio have been found by Heiles, and by Seki (10.131.094).

Knapp (11.131.542) has studied neutral hydrogen in 88 *dense dust clouds* – cf. Subsection B. Studies of individual objects include the Coalsack (Kerr, Bowers and Harten, 11.131.541), Khavtassi 713 (Simonson, 09.131.023), the Taurus complex (Heiles and Gordon, 1975, *Astrophys. J.* **199**, 361), NGC 2264 (Minn and Greenberg, 1975, *Astron. Astrophys.* **38**, 81), and two objects in the Perseus Arm (Minn and Greenberg, 1975, *Astrophys. J.* **196**, 161; Höglund and Gordon, 09.131.161). Most of these dust-cloud studies compare H I, H_2CO and (sometimes) OH. In general, most of the gas in dense dust clouds is in the form of H_2.

E. *Hydrogen in Associations, H II Regions, Clusters etc.*

Sancisi (1974, *IAU Symp.* **60**, 115) has found dense, expanding shells (radius $\sim$ 16 pc, thickness $\sim$ 5 pc, expansion velocity 5 km s^{-1}, mass $\sim 10^4$ $M_\odot$) in the *associations* Per OB 2 and Sco OB 2. The stars of the association lie outside the shell, which may be an old supernova remnant, and Sancisi proposes that they formed in the shell, which has been further decelerated since their formation. Sancisi *et al.* (12.131.075) have found strong relationships between H I, OH, CH, H_2 and dust in Per OB 2. Kühn (10.131.092), in an independent study of Ca II and

Na I absorption, H I emission, optical polarization and extinction in this region, concludes that a gas sheet of 15 pc thickness and mass > 1000 $M_\odot$ lies in front of ζ Per.

Bystrova and Rakhimov (1975, *Izv. Spectr. Astr. Obs. Pulkovo* **7**, 70) have surveyed hydrogen in the regions around λ Ori and the association Mon I.

Studies of neutral hydrogen associated with *H II regions* have been made by Bajaja and Garzoli (10.131.130), Crovisier *et al.* (1975, *Astron. Astrophys.* **45**, 97) and Simonson (10.131.163). Fejes (11.131.526) finds a local deficiency in the distribution of neutral hydrogen around α Vir, indicating ionization by this B-star. Goss *et al.* (07.131.004), Radhakrishnan *et al.* (07.131.003), and Caswell *et al.* (1975, *Astron. Astrophys.* **45**, 239) have measured 21-cm absorption spectra for many low-latitude sources.

In the analysis of such observations, it is usually assumed that associated gas should have velocities similar to those of the stars in the H II region or association. However, Minn and Greenberg (09.155.049) and Humphreys and Kerr (12.155.078) find large-scale systematic differences between the kinematics of gas and stars, in agreement with predictions from the density-wave theory.

The structure of an H I–H II boundary was studied theoretically by Macpherson (12.131.517); he finds a possible explanation of the thick H I shells observed.

A great amount of work has been done on *carbon recombination-line radiation* from H I regions. The C II regions are usually associated with dense dust clouds, sometimes bordering on H II regions, sometimes illuminated as a reflexion nebula. Temperatures are often between 5 and 20 K, densities range at least between 10 and 1000 cm^{-3}. Studies published in 1975 include those of M 78 by Brown *et al.* (*Astrophys. J. (Letters)* **195**, L 23), NGC 2023 by Knapp *et al.* (*Astrophys. J.* **196**, 167), NGC 2024 by Mac Leod *et al.* (*Astron. Astrophys.* **42**, 195); among earlier studies, we mention those of Balick *et al.* (11.132.004, Orion A), Brown (10.131.058), Brown *et al.* (12.131.089, ρ Oph), Chaisson (11.131.081, five sources), Chaisson and Lada (11.131.535, Orion A), Dupree (11.131.501, three regions), Gorden (10.131.040), Kerr *et al.* (*IAU Symp.* **60**, 81, ρ Oph), Pedlar and Hart (12.131.033, three regions), and Zuckerman and Ball (11.131.544, three regions).

A variety of *young stellar clusters* have been searched for neutral hydrogen by Tovmassian, Shabhazian and Nersessian (11.153.003–007). Searches in *globular clusters* by Knapp, Rose and Kerr (10.154.022) and by Conklin and Kimble (1975, *Bull. Amer. Astron. Soc.* **6**, 468) have now pushed the upper limits to between 15 and $0.5 M_\odot$, considerably lower than would be expected on the basis of mass loss from evolving stars.

F. *Relationships to Supernova Remnants and Continuum Loops*

Assousa, Balick and Erkes (10.125.047, 048) have searched for neutral-hydrogen shells around *supernova remnants* (SNR). Assousa and Erkes (10.125.038) find an expanding H I shell (V_{exp} = 25 km s^{-1}, mass 3400 $M_\odot$) around HB 21. Knapp and Kerr (12.125.002) and Sato (12.125.032) find a shell of cold hydrogen (radius 40 pc, mass 5000 $\mathfrak{M}_\odot$, V_{exp} ∿ 4 km s^{-1} around W44. Cornett and Hardee (1975, *Astron. Astrophys.* **38**, 157) ascribe the motions of this shell to X-ray or cosmic-ray pressure gradients. In his study of the evolution of SNR, Chevalier (11.125.016) also considers the behaviour of the surrounding dense neutral shell. De Noyer (1975, *Astrophys. J.* **196**, 479), analyzing H I near the Cygnus Loop, finds evidence for an encounter of the SNR with adjacent interstellar clouds, but not for a cool H I shell. The Ori-Gem Loop (Berkhuijsen, 12.125.024) does not appear to be associated with H I. Ariskin (09.131.012) attributes large-scale peculiar motions at longitudes 15°–22° and 45°–60° to a super-supernova explosion 10^7 yr ago.

Claims for possible relations between neutral hydrogen and the *Galactic Loops* had so far been based on undersampled H I surveys. The Berkeley high-latitude survey now allows firmer statements. Heiles and Jenkins (1976, *Astron. Astrophys.* **46**, 333) find a strong relation between the North Polar Spur and filaments of low-velocity hydrogen at higher longitudes, thus confirming work by Berkhuijsen *et al.* (1971) and by Fejes and Wesselius (09.155.020). In agreement with Fejes and Verschuur (09.155.054), Heiles and Jenkins also accept a relationship of H I with Loop III, in particular for the intermediate- and high-velocity clouds at higher latitude. Loop IV may be related with intermediate-velocity hydrogen; no relation is evident for Loop II. Heiles and Jenkins also point out a coincidence of the 'Polar Ridge' of H I (Fejes and Wesselius) with a continuum ridge in Berkhuijsen's map, and of holes in the continuum and hydrogen distributions in Perseus (cf. also Sancisi, 1974, *IAU Symp.* **60**, 115).

The evidence for relationships between H I and some of the Continuum Loops now appears convincing. Baker (12.131.163) finds no strong correlation of H I and continuum emission, but indeed the associated H I is generally located outside the Loops.

G. *Gas at High Latitudes and in the Solar Neighbourhood*

In the low-velocity gas distributed over most of the sky, Lindblad *et al.* (1973) have studied the narrow feature, first isolated by Lindblad in 1967, and interpreted by him as an expanding ring related to *Gould's Belt* of early-type stars and dust clouds. The feature may include the dark clouds in Scorpius-Ophiuchus and Taurus, and the selfabsorbing sheet observed by Heeschen (1955) and by Riegel and Crutcher (07.155.025). Lindblad *et al.* find an expansion age of 60 million years, and an initial expansion speed of 3.6 km s^{-1}; the origin of the expansion may be decompression of gas after passage through a shock wave in the Carina Arm. Burton and Bania (12.155.005) point out that the velocity field attributed to this expanding ring may be well represented as a flow pattern predicted by the linear density-wave theory. A critical difference between the two models only occurs at $270° < l < 360°$, where observations are lacking. Grape (1975, Stockholms Obs. Report No. 9) reports that new observations by Colomb and Turner at Villa Elisa (Argentina) confirm the expanding-ring model. Grape also refines the model into an expanding, doughnut-shaped cloud. Weaver (12.155.049) invokes an inflow of gas from the galactic poles as source of the expansion.

The properties of *intermediate-velocity gas* ($20 < |V| < 80$ km s^{-1}) at high latitudes were studied by Wesselius and Fejes (09.155.021). They point out that the velocity field of the big complex of 60° diameter and $V \sim -40$ km s^{-1}, centred at $l \sim 210°$, $b \sim +70°$, can be well represented by a 70 km s^{-1} flow coming from $l = 120°$, $b = +40°$; this model modifies an earlier one by Blaauw and Tolbert. Wesselius and Fejes place the complex $z = +70$pc, and believe its flow may be related to the high-velocity clouds, or possibly to an old supernova remnant. They further see this flow as the cause of a prominent 'hole' in the distribution of low-velocity gas, centred at $l \sim 160°$, $b \sim +70°$, close to the pole of Gould's Belt. Takakubo (12.155.069) points out that the gas deficiency in this low-velocity hole is a property of the clouds, not of the intercloud medium, and Seki (10.131.206) finds that the gas/dust ratio in this region is anomalous. Heiles and Jenkins (1976, *Astron. Astrophys.* **46**, 333), in an analysis of intermediate-velocity gas around $l = 260°$, $b = +40°$, find signs of an interaction with a high-velocity stream that may be related to the flow postulated by Wesselius and Fejes.

The 'hole' in the local gas distribution is pronounced also at lower latitudes; Ly-α absorption measurements (see Section 7) give local gas densities much below 0.1 cm^{-3}, i.e. lower than that ascribed to the intercloud medium.

H. *High-Velocity Hydrogen*

This subject has continued to attract much attention. Davies (12.155.067) wrote a good review in 1973; that by Verschuur (1975, *Ann.Rev.* **13**, 257) is, unfortunately, quite biased and polemic. The study by Hulsbosch (1975, *Astron. Astrophys.* **40**, 1) also contains considerable review material.

Several surveys of high-velocity (HV) hydrogen in the northern sky appeared in 1972 (Dieter, 07.157.002 and 07.131.056; Van Kuilenburg, 07.157.001 and 005; Wannier *et al.*, 07.157.008; Davies, 08.155.054); a later addition is that by Hulsbosch (1975). The first survey in the southern sky, by Mathewson, Cleary and Murray (11.159.004), led to discovery of the 'Magellanic Stream' – see below.

The distribution on the sky is dominated by high negative velocities at $b > 0$, especially around $l \sim 120°$; positive velocities are mostly found around $l \sim 270°$ and in the Magellanic Stream. Most of the high-velocity clouds (HVCs) appear in elongated bands or strings, strongly inclined to the galactic equator. Along these strings, great variations in velocity and density occur (Hulsbosch, 1975); their lifetimes must be of order 10^7 yr.

High-resolution studies (Verschuur *et al.*, 07.131.095; Giovanelli *et al.*, 10.131.091; see also Hulsbosch, 1975) have emphasized that most HVCs contain a dense core (velocity halfwidth $W \sim 5-10$ km s^{-1} and a tenous envelope ($W \sim 20$ km s^{-1}). Davies, Buhl and Jafolla (1976, *Astron. Astrophys. Suppl.*) find, for HVC cores in complexes A IV and M II, $W \sim 17$ km s^{-1} and sizes $\sim 0.^{\circ}5$. Greisen and Cram (1976, *Astrophys. J.* **203**), with the NRAO interferometer, find structure of $5'$ scale and $T_b \sim 50$ K in four HVCs. A Westerbork map of HVC 132 + 23 − 210 (Hulsbosch *et al.*, 1976, *Astron. Astrophys.*) shows 3 condensations of $5'$ size in this cloud. Wannier *et al.* (07.157.008) studied the structure of a high-positive-velocity complex.

Minkowski *et al.* (08.132.004) pointed out coincidences in position of HVCs and bright nebulae, but no velocity comparison has yet been made. The possible relationships of HVCs and the Galactic Loops have been discussed in Subsection F above. Observations of high-velocity calcium in the Vela supernova remnant and Gum Nebula are summarized by Morton in Section 7 of this Report.

Comparisons of HVCs and IVCs (intermediate-velocity clouds) are made by Wesselius and Fejes (09.155.021) and Davies *et al.* (1976). Distances of IVCs, ranging from 70 pc to 1 kpc, have been found by comparison of 21-cm and K-line profiles (Rickard, 07.131.054; Wesselius and Fejes, 09.155.021; Hulsbosch, 1975, quoting observations by Wallerstein and by Herbig). However, for HVCs no direct distance determinations are yet available.

The nature and origin of HVCs remains a matter of controversy. Oort (1966–1970; for references see Hulsbosch, 1975) interprets them as the result of interaction of infalling intergalactic gas with galactic gas in the Halo or outskirts of spiral arms. Davies (07.155.038, 08.155.054) and Verschuur (09.155.005), following and extending earlier work by Habing (1966), see the HVCs as offshots or high-z extensions of the outermost galactic spiral arms. The appearance of most HVCs in elongated bands, possibly merging with spiral arms at low latitudes (cf. also Hulsbosch, 1975) supports this view, and Hulsbosch and Oort (09.155.006) agree that it may be correct for HVCs at lower latitudes. However, the high-b HVCs do not easily fit into this picture, and Davies sees these as tidal relics of a Galaxy - Magellanic Clouds encounter, now falling into the Galaxy; the encounter would also be responsible for the warp of the Galaxy, and for the high-z extentions of the outer arms (cf. Hunter and Toomre, 1969). Hulsbosch and Oort emphasize that high-b HVCs show no continuity with low-b arms, and especially that the erratic variations of column density N_H and velocity V within extended HVC complexes are signs of an interaction of two media. In this connection, the correlation between N_H and V found by Silk and Siluk (09.131.039) in HVCs around $l = 115°$, $b = +15°$ appears significant. Hunt (1975, *Monthly Notices Roy. Astron. Soc.* **173**, 465) has made extensive calculations of the accretion of intergalactic gas (of various temperatures) by the galactic disk.

There certainly are HVCs of different sorts. The unusual cloud first found near the south galactic pole by Dieter (1965) and Hulsbosch (1968), then traced northward as a long filament in rigid motion by Wannier and Wrixon (07.157.011), is now known as the 'Magellanic Stream' (Mathewson *et al.*, 11.159.004); it extends along a great circle to the Magellanic Clouds and, with considerable scatter in position and velocity, beyond. This object is clearly related to the Magellanic Clouds, hence extragalactic. It may well be a tidal tail of the Small Magellanic Cloud, but it is unclear whether the Large Cloud or the Galaxy is responsible. However, the run of velocity along the Stream suggests a hyperbolic Kepler orbit with perigalacticon at about 50 kpc (Mathewson *et al.*, 11.159.004). For this and other reasons, Mathewson (1976, *Quarterly J. Roy. Astron. Soc.*) now rejects a tidal origin of the Stream and sees it, together with the Magellanic Clouds, as the result of fragmentation and partial condensation of a large, elongated gas cloud in the Local Group. Within the Stream, he finds six elongated clouds, containing $10^7 - 10^8$ solar masses of hydrogen, and rotating at about 20 km s^{-1}, indicating total masses of $10^{8.5}$ $M_{\odot}$. The properties of these clouds are similar to those of dwarf-irregular galaxies, and searches are being made for optical emission.

The Magellanic Stream almost follows the supergalactic equator, as do most galaxies in the Local Group, and many of the HVCs (De Vaucouleurs and Corwin, in press). In the Sculptor Group and elsewhere, Mathewson, Cleary and Murray (1975, *Astrophys. J.* **195**, L 97) also found galactic tails and intergalactic hydrogen aligned along the supergalactic equator. Thus, Mathewson (1976, *Quarterly J. Roy. Astron. Soc.*) now considers all high-velocity clouds as extragalactic condensations of intergalactic gas in the Local Group.

Several clouds of extremely high velocity have recently been found: one near M33 by Wright (11.131.517), one near M31 by Davies (1975, *Monthly Notices Roy. Astron. Soc.* **170**, 45p), an isolated one by Cohen and Davies (1975, *Monthly Notices Roy. Astron. Soc.* **170**, 23p). While the last one may be related to the Magellanic Stream, the other two might belong to their neighbouring galaxies. But whatever the truth for these and other special objects, the subject of high-velocity clouds is now clearly, at least partly, connected with that of intergalactic matter.

7. ULTRAVIOLET AND VISUAL INTERSTELLAR ABSORPTION LINES AND THE COMPOSITION OF THE INTERSTELLAR GAS

(D. C. Morton)

Since mid 1972 there has been a remarkable increase in the measurements of interstellar absorption lines and the determination of abundances. Fabry-Pérot interferometers and high-resolution scanners, as well as the traditional coudé spectrographs, have been used on ground-based telescopes; while balloons, rockets, and satellites with improved spectral resolution have opened the far-ultraviolet region where most ions have their resonance absorption lines. In space the most useful instruments have been the UV spectrometers on the ESRO TDIA satellite for $2060 \leqslant \lambda \leqslant 2870$ Å (de Jager *et al.*, 11.034.001) and on the NASA *Copernicus* (OAO-3) orbiting telescope for $912 \leqslant \lambda \leqslant 3200$ Å (Rogerson, Spitzer *et al.*, 09.114.121). Spitzer and Jenkins (1975, *Ann. Rev.* **13**, 133) have reviewed many of the new results in more detail than will be possible here. This report, covering publications and preprints since July 1972, will summarize the various surveys of particular interstellar atoms or molecules from either the ground or space and will describe several studies that have combined all the available data on certain stars.

All abundance ratios will be quoted by number with the notation O VI/H I etc, and the solar element abundances used as standards usually have been adopted from Withbroe (06.073.034). Morton and Smith (11.022.009) have compiled a list of wavelengths, oscillator strengths, and radiation damping constants for most atomic lines likely to be absorbed in the interstellar gas, and Morton and Dinerstein (1976, *Astrophys. J.* **204**) have listed the same quantities for all the relevant Lyman and Werner lines of H_2. Astrophysical measurements have been used by de Boer and Morton (1974, *Astron. Astrophys.* **37**, 305) and de Boer *et al.* (11.022.028) to provide additional *f*-values for C I, Mn II, and Fe II. Frequently it is necessary to derive the curve of growth for an ion to obtain its abundance. Nachman and Hobbs (09.131.182) have discussed the risks due to the use of only doublet ratios of saturated lines; however, Morton (1975, *Astrophys. J.* **197**, 85) has demonstrated how an empirical curve of growth can be derived for several ions that likely have the same velocity distribution. Furthermore, de Boer (1974, Groningen *Proefschrift*), Crutcher (1975, *Astrophys. J.* **200**, 625), Gómez-Gonzàlez and Lequeux (1975, *Astron. Astrophys.* **38**, 29), and Spitzer and Morton (1976, *Astrophys. J.* **204**) have used high-resolution visible scans to help in fitting multiple-cloud models to profiles.

A. *Surveys of Particular Atoms and Molecules*

Bohlin (1975, *Astrophys. J.* **200**, 402) obtained average neutral hydrogen densities of $0.01 \leqslant n_{\mathrm{H\,I}} \leqslant 2.5$ atoms cm^{-3} from the Ly-α profiles in the *Copernicus* spectra of 40 OB stars between distances of 60 and 1100 pc. The densities are particularly low towards Orion, Canis Major, and Puppis, where there is little reddening and considerable H II, while the highest values occur in Perseus, Ophiuchus, and Scorpius, confirming the earlier analysis of rocket and OAO-2 spectra by Savage and Jenkins (07.131.030). An abrupt increase of $n_{\mathrm{H\,I}}$ with distance around 160 pc in the last two constellations indicates the presence of a thin dense sheet covering tens of degrees. From averages for 10 reddened stars with strong H_2 lines, Bohlin

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concluded that a typical cloud has $N_H/E_{B-V} = 5.4 \times 10^{21}$ hydrogen nuclei cm^{-2} mag^{-1}, similar to 6.2×10^{21} derived by Jenkins and Savage (11.113.001) from lower resolution Ly-α data, and 5.1×10^{21} by Knapp and Kerr (10.131.062) from the 21-cm emission towards globular clusters. Ryter, Cesarsky, and Audouze (1975, *Astrophys. J.* **198**, 103) and Gorenstein (1975, *Astrophys. J.* **198**, 95) found 6.8×10^{21} and 6.6×10^{21}, respectively, from the absorption of soft X-rays. Closer to the Sun, $n_{H\ I}$ has been derived from the absorption superposed on the chromospheric Ly-α emission in K, G, and F stars. Moos *et al.* (11.114.072) found $0.02 \leqslant n_H \leqslant 0.1$ cm^{-3} over the 11 pc to α Boo; Dupree (1975, *Astrophys. J.* **200**, L27) found 0.01 cm^{-3} over 14 pc to α Aur; and Evans, Jordan, and Wilson (1975, *Monthly Notices Roy. Astron. Soc.* **172**, 585) found 0.015 cm^{-3} over 3.5 pc to α CMi. If a uniform neutral intercloud medium exists, $n_{H\ I} \lesssim 0.01$ cm^{-3}. When comparisons with the optical absorption lines are required, useful 21-cm emission profiles from the directions of specific stars have been published by Grayzeck and Kerr (11.131.532) and Beintema (1975, Groningen *Proefschrift*).

Rogerson and York (10.131.289) and York and Rogerson (1976, *Astrophys. J.* **203**) found that D/H lies between 0.45×10^{-5} and 3.6×10^{-5} with an average of 1.8×10^{-5} towards 5 stars with distances between 80 and 1060 pc. An upper limit on B/D in two cases suggests that the D was formed during the initial big bang rather than in supernovae, and hence that the present density of the universe is not sufficient to close it.

Li I has been detected towards ζ Oph and 55 Cyg by Traub and Carleton (10.131.045) and Vanden Bout and Grupsmith (11.131.002), with column densities of 2.3×10^9 and 1.7×10^{10} cm^{-2} respectively. Boesgaard (12.131.004) failed to find Be II in the spectra of 24 stars, but in no case was the limit on Be/H less than the solar value of 1.1×10^{-11}. Morton, Smith, and Stecher (11.131.094) obtained upper limits for B II in the directions of ζ Oph and λ Ori A; in the case of ζ Oph B/H $< 0.75 \times$ the cosmic abundance of 1×10^{-10} that Boesgaard *et al.* (12.114.147) found in the atmosphere of α Lyr.

Jenkins and Meloy (12.131.117) and York (12.131.118) discovered O VI absorption lines in the spectra of several stars, with widths somewhat greater than the other interstellar lines. These authors have interpreted this O VI, along with the absence of N V and S IV, as evidence for a component of the interstellar gas with a temperature between 2×10^5 and 2×10^6 K. Cox and Smith (11.125.028) have suggested that supernovae produce the hot gas, while Castor, McCray, and Weaver (1975, *Astrophys. J.* **200**, L107) have proposed that the O VI originates in the shock-heated interstellar gas swept up by the wind from each hot star.

There has been no extensive survey of the Na I D lines since Hobbs (02.131.007) published his high-resolution profiles. However, de Boer and Pottasch (11.131.051) compiled new and old measures of the UV doublet and pointed out the abundance underestimate that can occur when the saturated D lines are used without consideration of the much weaker UV lines. Surveys of K I λ 7699 have been completed by Lutz (12.131.029) and Hobbs (11.131.035, 12.131.013), who have shown that the column density N(K I) is well correlated with N(Na I), N(H I), and E_{B-V}, but not with N(Ca II), and that the K I profile often reveals the densest clouds much better than the saturated Na I D lines. Shulman, Bortolot, and Thaddeus (12.131.094) detected the very weak K I doublet $\lambda\lambda$ 4044, 4047 in ζ Oph. White (10.131.007) measured the Ca I line in 10 stars and obtained upper limits for 9 more. Since the publication of the profiles of the Ca II K line by Marschall and Hobbs (07.131.061), the most important new data on this ion are the profiles by Beintema (1975, Groningen *Proefschrift*). In addition, Chu-Kit (09.155.003) and Rickard (11.131.021) have measured K-line radial velocities for many southern stars. Wallerstein and Goldsmith (11.131.008) analysed new and old observations of Ti II and concluded that Ti is depleted in the gas by factors of 10 to 200. The elusive Fe I lines were found in ζ Oph by Shulman *et al.* (12.131.094) and in ζ Per and *o* Per by Chaffee (11.131.090). During the period covered by this summary, additional ground-based measures of Na I, K I, Ca II, or Ti II in selected stars have been reported by Scholz (08.114.117), Cohen (10.131.208; 12.131.061; 1975, *Astrophys. J.* **197**, 117), Chaffee (11.131.090; 1975, *Astrophys. J.* **199**, 379), Hobbs (09.114.038; 1975, *Astrophys. J.* **200**, 621), Balogna (1975, *Mem. Roy. Astron. Soc.* **78**, 51), Walborn and Hesser (1975, *Astrophys. J.* **194**, 535), and de Boer and Pottasch (12.114.120).

Determination of the abundances of Li, Na, K, and Ca requires estimates of the electron density n_e and radiation field to give the contributions from the unobservable Li II, Na II, K II, and Ca III. Often n_e is obtained from Ca I/Ca II or similar ratios based on the UV lines, but if the neutral and ion are concentrated in different clouds, only limits on n_e can be derived. As an alternative, Jura (1975, *Astrophys. J.* **200**, 415) assumed that the neutrals were concentrated with the H_2 and used the physical conditions derived from the rotational populations of the molecule to indicate that Na and K are not significantly depleted towards several stars with $E_{B-V} \leqslant 0.10$, while Ca is ∿ 1% solar.

Boksenberg *et al.* (08.131.085) measured the UV lines of Mg I and Mg II in 6 stars with a balloon-borne spectrograph. However, their column densities may be in error because they assumed that both ions are distributed over the various clouds like Ca II, which often is highly depleted.

The early *Copernicus* observations of H_2 and HD by Spitzer, Drake *et al.* (09.131.065), Spitzer and Cochran (10.131.212), and Spitzer, Cochran, and Hirshfeld (1974, *Astrophys. J. Suppl.* **28**, 373) have been discussed in the review by Spitzer and Jenkins. Since that time York (1976, *Astrophys. J* **204**) has reported H_2 towards 5 stars with $E_{B-V} \leqslant 0.03$ and concluded that some of the neutral gas must be in small clouds about 30 pc thick and denser than 0.3 atom cm^{-3}. Towards several more reddened O-type stars, Spitzer and Morton (1976, *Astrophys. J.* **204**) found multiple components, one of which was strongest for the lowest rotational levels, and the others were stronger for the higher levels and always at more negative velocities. The latter absorptions could originate in clouds ∿ 0.02 pc thick with n_H ∿ 10^3, located some 20 pc from the star and compressed behind a shock front due to an expanding H II region or a supernova remnant. Castor, McCray and Weaver (1975, *Astrophys. J.* **200**, L107) have proposed that the interstellar gas swept up by the wind from such a star would have a thin outer layer of H_2.

There have been new ground-based measurements of CH, CH^+, and CN by Scholz (09.114.117), Hobbs (09.153.007, 09.131.054), Frisch (07.131.071), Cohen (10.131.208; 1975, *Astrophys. J.* **197**, 117), and Chaffee (11.131.090; 1975, *Astrophys. J.* **199**, 379). The last author showed that the velocities of CH and CH^+ differ by 1 km s^{-1} in four Ophiuchus stars, as expected from the proposals by Black and Dalgarno (10.131.278) and Watson (11.131.063) that CH must be formed from CH^+ where H_2 is plentiful, with the result that CH and CH^+ cannot be in the same region. Vanden Bout (08.114.075) detected $^{13}CH^+$ in ζ Oph and deduced $^{12}C/^{13}C$ = 75(+25, −15), consistent with limits obtained by Hobbs (07.131.138) for other stars. Hobbs (09.131.139) failed to detect CO^+ λ 4250 in 14 stars.

Jenkins *et al.* (09.131.066) and Snow (1975, *Astrophys. J.* **201**, L21) have discussed the CO lines in several stars and estimated upper limits for many other molecules that might be expected at UV wavelengths. Snow (preprint) has detected OH λ 1222.071 in ζ Oph; a recent calculation of the *f*-value by Ray and Kelly gives $N(OH) \approx 10^{14}$ cm^{-2}.

B. *Analysis of Individual Lines of Sight*

Following the initial *Copernicus* surveys of 5 reddened stars by Morton *et al.* (09.131.063) and 4 unreddened stars by Rogerson, York *et al.* (09.131.064), all the UV and visual interstellar lines have been analysed together in some detail for several specific stars to determine the properties of the absorbing regions. The most extensive information exists for the reddened star ζ Oph, for which Morton (12.131.529; 1975, *Astrophys. J.* **197**, 85) has deduced column densities for one or more ions of H, Li, C, N, O, Na, Mg, Al, Si, P, S, Cl, Ar, K, Ca, Ti, Mn, Fe, Ni, Cu, and Zn, as well as the molecules H_2, HD, CH, CH^+, CN, and CO. The abundances of S and Zn are almost solar while the other elements are depleted by various amounts down to the extreme of 2×10^{-4} solar for Ca, presumably due to the formation of grains, though Greenberg (11.131.067) has noted that the missing C, N, and O exceed what can be accounted for in some theoretical grain models. Spitzer and Jenkins have reviewed the various mechanisms of grain formation or destruction that might produce the observed variation of depletion from element to element, particularly the correlation with condensation temperature first discussed by Field (11.131.038). More recently Snow (1975, *Astrophys. J.* **202**) has noted a possible correlation of increasing depletion with increasing cloud density and decreasing ionization potential of the

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first ion of each element. Such a pattern could occur if the grain sticking coefficient increases with a decrease in this potential, which influences many other properties of an atom. However, the high abundances of Li, Na, and K require special consideration, and the problem remains that C, N, O, and Ar sometimes are more depleted than S.

Depletion patterns similar to ζ Oph have been observed in other reddened stars such as ξ Per (Gómez-Gonzàlez and Lequeux, 1975, *Astron. Astrophys.* **38**, 29), γ Ara (Morton and Hu, 1975, *Astrophys. J.* **202**), and o Per (Snow, 1976, *Astrophys. J.* **205**). The investigations of ζ Pup and γ^2 Vel in the Gum Nebula by de Boer *et al.* (08.114.116), de Boer and Pottasch (10.131.093), Grewing *et al.* (10.119.001), and Burton, Evans, and Griffin (12.131.082) have revealed underabundances of many elements though S again is near normal. Jenkins, Silk, and Wallerstein (preprint) examined HD 74455 and 75821 behind the Vela supernova remnant and found one set of lines near 0 km s^{-1} relative to the LSR with depletions like ζ Oph, and another set at -180 and -90 km s^{-1} in the respective spectra with normal abundances of C, N, O, Mg, Si, S, and Fe, probably as a result of grain evaporation by the shock. Thackeray and Warren (08.132.027) found additional Ca II velocity components in these two stars, and Thackeray (11.132.021) has further mapped the Ca II velocity field in the Gum Nebula by measuring seven more stars. The unreddened stars ($E_{B-V} \leqslant 0.03$) β Cen, λ Sco, and α Vir discussed by York (*Astronaut. Res.* 1973; 1975, *Astrophys. J.* **196**, L103) and York and Kinahan (preprint), respectively, also have S approximately solar and depletions of Mg, Al, Si, Ca, Mn, and Fe, but probably not as much as towards ζ Oph. The relative populations of higher ion states such as C III and N II towards these unreddened stars are not consistent with a uniform neutral intercloud medium heated by the observed X-ray background. Sheets or small clumps of H I seem more likely, as suggested by the H_2 lines already mentioned. The data do permit the heating of a uniform, low-density H I gas by cosmic rays, but these seem to be ruled out by the presence of HD in some clouds according to the calculations of Black and Dalgarno (10.131.086), O'Donnell and Watson (12.131.006), and Jura (12.131.012).

Steigman, Strittmatter, and Williams (1975, *Astrophys. J.* **198**, 575) have suggested that the UV interstellar absorption lines arise mainly in shells around the observed stars. These authors considered the absorption in a standard Strömgren sphere and a surrounding transition region where there is some residual hydrogen ionization, as well as the absorption in a shell of interstellar gas swept up by the star's wind. In both cases the models are consistent with several of the observed ion abundances, but seriously in error for others, including some of the new results for ζ Oph. Nevertheless it is possible that regions associated with the star could account for all of the observed N II and some of the C II, N I, O I, Mg II, Si II, etc., in which case the depletions must be even greater along the rest of the path, where the majority of the H I is located. Steigman *et al.* have proposed that saturated shell lines could hide saturated components originating in the general interstellar medium, where they assume that the velocity dispersion is smaller so that the concealed column density can be considerably larger. However, there is no convincing evidence for a lower turbulent velocity there than in the H II region and the transition zone. If the saturated lines do conceal much of the material, it is not clear why the relatively strong S II lines always give abundances near normal. Also the column densities of Mg II and Fe II often were determined from weak lines with little saturation, and Si II sometimes depended in part on very strong lines whose damping wings would be effective if the number of absorbers were increased by a factor of 10.

8. INTERSTELLAR MOLECULES

(B. J. Robinson)

The present review is based on microwave ($\lambda > 1$ mm) information about interstellar molecules; the ultraviolet observations are summarized by Morton in the preceding contribution. Relationships between molecules and dust are discussed by Lynds in the following contribution. For problems of formation of molecules, we refer to the review by Dalgarno (1975). A bibliography of review papers is given at the end of the present report; a complete bibliography of papers on interstellar molecules is to appear in the Report of Commission 40.

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Table 1. Interstellar molecules observed at radio frequencies 1973-1975

No. of atoms	Molecule: Name	Molecule: Formula	Transition	Frequency (GHz)	Emission or absorption	Sources where detected: Sgr B2	Ori A	Other	Reference
2	CH radical	CH	$^2\Pi_{1/2}, J=1/2, F=0-1$	3.263 794	E	*	*		*Nature*
	CH radical	CH	$^2\Pi_{1/2}, J=1/2, F=1-1$	3.335 481	E&A		*	> 120	**246**, 466,
	CH radical	CH	$^2\Pi_{1/2}, J=1/2, F=1-0$	3.349 193	E		*		1973.
2	–	NS	$^2\Pi_{1/2}, J=5/2-3/2$ (c)	115.155	E	*			*Astrophys. J.*
			$^2\Pi_{1/2}, J=5/2-3/2$ (d)	115.555	E	*			**200**, L 147,
									L 151, 1975.
2	Sulphur	SO	1_2-1_1	13.04.38	E	*			
	monoxide		2_2-1_1	86.093 94	E		*		
			3_2-2_1	99.299 85	E	*	*	5	*Astrophys. J.*
			2_3-1_2	109.3	E		*		**184**, L 59,
			4_3-3_2	138.178 60	E	*	*	2	1973.
2	Silicon	SiS	$J=5-4$	90.771 85	E	*		IRC+10216	*Astrophys. J.*
	Sulphide		$J=6-5$	108.924 64	E	*		IRC+10216	**199**, L 47, 1975.
3	Ethynyl	C_2H	$N=1-0$, $JF=\frac{3}{2}2-\frac{1}{2}1$	87.317 05	E	*	*	12	
	radical		$JF=\frac{3}{2}1-\frac{1}{2}0$	87.328 70	E	*	*	11	*Astrophys. J.*
			$JF=\frac{1}{2}1-\frac{1}{2}1$	87.402 10	E		*	5	**193**, L 115,
			$JF=\frac{1}{2}0-\frac{1}{2}1$	87.407 23	E		*	5	1974.
3		HCO	$J=3/2-1/2, F=2-1$	86.670 55	E	–	–	3	*BAAS*, 7, 540, 1975.
3		N_2H^+	$J=1-0$, $F=1-1$	93.171 88	E				*Astrophys. J.*
			$F=2-1$	93.173 78	E	*	*	21	**193**, L 83, 89,
			$F=0-1$	93.176 13	E				1974.

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Table 1. (Continued)

No. of atoms	Molecule: Name	Molecule: Formula	Transition	Frequency (GHz)	Emission or absorption	Sources where detected: Sgr B2	Ori A	Other	Reference
3	Sulphur dioxide	SO_2	$8_{17}-8_{08}$	83.688 074	E	*	*		*Astrophys. J.* **198**, L 81, 1975.
			$8_{35}-9_{28}$	86.639 100	E		*		
			$7_{35}-8_{26}$	97.702 352	E		*		
5	Cyanamide	NH_2CN	$4_{13}-3_{12}$	80.504 60	E	*			*Astrophys. J.* **201**, L 149, 1975.
			$5_{14}-4_{13}$	100.629 50	E	*			
7	Methylamine	CH_3NH_2	$2_{02}-1_{10}$ (A_a)	8.777 38	E	*	*		*Astrophys. J.* **191**, L 135, L 139, 1974.
			$5_{15}-5_{05}$ (a)	73.044 07	E	*	*		
			$4_{14}-4_{04}$ (s)	86.074 44	E	*	*		
			$2_{02}-1_{01}$ (a)	88.669 58	E	*			
7	Vinyl cyanide	CH_2CHCN	$2_{11}-2_{12}$	1.371 56	E	*			*Astrophys. J.* **195**, L 127, 1975.
7	Cyanodia-cetylene	HC_5N	J=1–0	2.662 87	E	*			NRC preprint
			J=4–3	10.650 643	E	*			
			J=8–7	21.301 247	E	*			
8	Methyl formate	$HCOOCH_3$	$1_{10}-1_{11}$ (A)	1.610 249	E	*			*Astrophys. J.* **197**, L 29, 1975.
			$1_{10}-1_{11}$ (E)	1.610 906	E	*			
9	Dimethyl ether	$(CH_3)_2O$	$2_{02}-1_{11}$	4.119 67	E	*			*Astrophys. J.* **191**, L 79, 1974; **201**, L 149, 1975
			$2_{11}-2_{02}$	31.106 20	E		*		
			$5_{23}-5_{14}$	80.539	E	*			
			$2_{20}-2_{11}$	86.226 728	E		*		
			$6_{06}-5_{15}$	90.938 099	E		*		
9	Ethyl-alcohol	C_2H_5OH	$6_{06}-5_{15}$	85.265 46	E	*			*Astrophys. J.* **196**, L 99, 1975.
			$4_{14}-3_{03}$	90.117 51	E	*			
			$5_{15}-4_{04}$	104.808 58	E	*			

A. *New Molecules*

At the time of the last Report the discovery of complex organic molecules at microwave and mm wavelengths was in full flood. The rate of discovery eased for a period, but during 1975 the rate has quickened again as a direct result of an improved 3 mm-λ receiver on the Kitt Peak 11 m telescope. Table 1 lists the 15 new molecules announced in 1973–75. Two of these molecules have 9 atoms (dimethyl ether and ethanol) while the heaviest found are methyl formate, sulphur dioxide and cyanodiacetylene.

Two unexpected lines have been identified (by computation) as N_2H^+ and C_2H. A large number of unidentified mm-wave lines have been found, but no announcements of their frequencies have been made pending attempts at identification. It is likely that many of them will be lines of species that are transient under laboratory conditions, akin to CH, CN, C_2H, N_2H^+, HNC, HCO, HCO^+, CH_2S, CH_2NH, so that their rest frequencies are extremely difficult (if not impossible) to measure. For example, years of effort to measure the microwave transitions of CH were unsuccessful, and finally the ground-state triplet was detected and identified astronomically. However, the identification of U 90.7 with HNC has finally been confirmed by three laboratory groups.

Many new lines of known molecules have been found, too many to be listed here. The number of known lines is now close to 200; half the lines have $\lambda \leqslant 4$ mm. The highest-frequency transition, the $J = 2$-1 line of CO at 230 GHz, was observed in 6 sources with the Kitt Peak 11-m and Lick 3-m telescopes, one of a number of cases where mm-wave receivers have been used on optical telescopes. The 230-GHz line was found to be optically thick, like the $J =$ 1-0 line at 115 GHz.

B. *Structure of Dense Molecular Clouds*

The Orion molecular cloud (MC1), associated with the Kleinmann-Low nebula, has been mapped at many wavelengths, as listed in Table 2. Collisional excitation of the 2-mm lines implies total densities higher than 10^7 cm^{-3}, with kinetic temperatures presumably higher than the value of 80 K measured for the CO envelope. These figures imply Jeans' masses of less than 10 $M_\odot$, suggesting marked gravitational instability. However, the observed velocity distribution shows no clear evidence for contraction of the cloud. The CO observations show slight rotation of the cloud, but this would only support a few percent of the mass of 6×10^4 $M_\odot$. The large widths of CO emission lines may be due to the presence of moderate-amplitude hydromagnetic waves, with $B_0 \geqslant 40$ μG. Inorganic molecules in the direction of the K-L nebula show a wide profile base ($\Delta V \approx 30$ km s^{-1}).

Detailed and extensive mapping of the Sgr B2 molecular cloud in the lines of CO, CS and H_2CO shows that the cloud has a dense core (diameter 6 pc, $n_{H_2} \approx 5 \times 10^4$ cm^{-3}, $A_v \approx 10^3$) and a very large envelope (diameter 45 pc). The total mass of the cloud is 3×10^6 $M_\odot$. The kinetic temperature is 20 K, suggesting near-thermal equilibrium between the grains and the H_2.

Table 2. Observations of Orion molecular cloud (MC1)

Molecule	Transition	Frequency (GHz)	Cloud size (arc min)	Inferred total density (cm^{-3})	Inferred total mass ($M_\odot$)	Reference
CO	J=1–0	115.271	20 × 10	10^3 to 10^4	6×10^4	*Astrophys. J.* **193**, L41, 1974.
CO	J=2–1	230.538	20 × 10	2×10^3		*Astrophys. J.* **186**, L19, 1973.
HCN	J=1–0	88.632	9 × 5	10^5		*Astrophys. J.* **190**, 545, 1974.
CS	J=2–1	97.981	9 × 6	} $> 4 \times 10^5$	}	*Astrophys. J.* **196**, 709, 1975.
CS	J=3–2	146.969	11 × 5			
H_2CO	$1_{01}-0_{00}$	72.838	6 × 3	$\geqslant 10^6$		*Astrophys. J.* **196**, 719, 1975.
CH_3OH	J=3–2, ΔK=0	145.1	< 1	10^7 to 10^8		*Astrophys. J.* **183**, L27, 1973.

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Extended regions of CO $J = 1\text{-}0$ emission have been found in the direction of 32 H II regions and 5 SNR. In the H II regions the CO emission has optical depths of 20 to 120 and is larger in spatial extent than the radio continuum emission, but the CO maxima are related to the continuum peaks and to IR sources. Detailed CO maps of dark clouds (such as the ρ Oph cloud) have been made.

Maps of CS and/or HCN emission have been made for many H II regions or regions containing IR sources, including W3, W 12, M 17, W 51, the W 75 region, NGC 1999, NGC 2024 and NGC 2264. If the HCN is excited by collisions with neutral particles at a density of 10^5 cm^{-3}, the total cloud masses are 10^4 to $10^{5.5} M_{\odot}$.

Aperture synthesis maps of the 6-cm H_2CO absorption in W3, Sgr A and Sgr B2 have been made with angular resolution of 20″. These show no small-scale structure in the molecular clouds, which have dimensions of minutes of arc and are large compared to the size of the continuum sources.

The 1667-MHz OH absorption of Sgr A and Sgr B2 has been synthesized with an angular resolution of 3.′25. The absorption was found to be produced by a small number of separate clouds.

Two rough surveys of CO $J = 1\text{-}0$ emission with a 65″ beam were made along the galactic plane (at $b = 0°$ for $350° < \ell < 90°$ sampled each 1° and for $10° < \ell < 200°$ sampled each 5°). They showed, as would be expected, a distribution very similar to that of the H II regions: there is a strong maximum of CO emission for $4 < R < 8$ kpc, and very little CO for $R > 10$ kpc or $R < 4$ kpc (except for the major CO concentration at the centre of the Galaxy). The abundance of CO relative to H I decreases smoothly from $R = 2$ to $R = 10$ kpc.

C. *New Molecular Clouds*

A number of new molecular clouds have been discovered, either associated with H II regions and IR sources or with diffuse dark clouds. The new dense clouds are rich in diatomic and triatomic molecules, as listed in Table 3. None of them have shown the chemical richness of the remarkable cloud associated with Sgr B2.

Table 3. Some new molecular clouds

Region	Cloud diameter	Molecules seen	Comments	Reference
M 8	4′	CO, HCN, H_2O, H_2CO	near Herschel 36	*Astrophys. J.* **182**, L11, 1973.
near M 17	6′	CO, CS, SO, HCN, H_2O, NH_3, H_2CO		*Astrophys. J.* **189**, L35, 1974.
IC 1396	4′	CO, CS, SO, HCN	Elephant's trunk	*Astrophys. J.* **195**, 75, 1975.
L 1646	10′ (CS)	CO, CS, HCN	R-association	*Astrophys. J.* **199**, 79, 1975.
Orion MC2	6′ (CO)	CO, CS, HCN, HNC, N_2H^+, U89.2, NH_3, H_2O	IR cluster 12′ NE of trapezium	*Astrophys. J.* **191**, L121, 1974
ρ Oph	8′ (CS)	OH, CO, CS, SO, U87.3, H_2CO		*Astrophys. J.* **189**, L135, 1974.
NGC 1333	7′ × 4′	CO, CS, HCN, NH_3, H_2CO	contains H-H objects, T-Tauri stars and IR sources	*Astrophys. J.* **194**, 609, 1974.
M 78	8′	HCN, H_2CO	contains H-H objects, T-Tauri stars and IR sources	*Astrophys. J.* **194**, 609, 1974.
Mon R2 association	1° (CO)	OH, CO, CS, HCN, H_2O, H_2CO	reflection association	*Astrophys. J.* **194**, L103, 1974.
R CrA	2°	CO, CS, SO, H_2CO	dark nebula	*Astrophys. J.* **194**, L103, 1974.

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D. *Stellar Envelopes*

Molecular-line observations are yielding valuable data on temperature, densities, kinematics and abundances in the envelopes expelled from stars. Maser emission (OH, H_2O, SiO) from envelopes around long-period variable stars is discussed in Section H. Another important class is represented by the obscured late-type carbon star IRC+10216. Emission lines from CO, CN, CS, SiO, SiS, HCN, C_2H and HC_3N have large widths (24 km s^{-1}) which strongly suggest expansion of the envelope. The cloud size is $\leqslant 40''$ for HCN and about 2′ for CO. If the molecules are excited by infrared radiation from the central star, the mass of the envelope is about 0.03 $M_\odot$. Similar carbon stars are IRC+00352, +30219 and +40540. Envelopes have also been detected around stars of relatively early spectral type in CRL 618 and CRL 2688.

CO has been detected in planetary nebulae (*Astrophys. J.* **201**, L85, 1975).

E. *Models for Dense Molecular Clouds*

In dense clouds the abundant molecules have high optical depths, and there has been a major breakthrough in interpreting some basic problems of cloud structure that have been with us for a decade (since dense OH clouds were observed at the galactic centre). The recent progress has resulted from the application of theories of radiative transfer developed for optically-thick stellar atmospheres (e.g. Sobolev, *Moving Envelopes of Stars*, Harvard, 1960).

The major problems encountered in understanding dense molecular clouds are:

(a) Molecular species with very different optical depths (e.g. $^{12}C^{16}O$, $^{13}C^{16}O$, $^{12}C^{18}O$) have line profiles of similar shape.

(b) Different molecules with high optical depths show different brightness temperatures (compare CO, HCN and CS in Orion-MC1).

(c) The molecular line widths are about two orders of magnitude greater than the thermal widths. If the line widths were produced by turbulence, it would be highly supersonic and need a large energy source to balance the rapid damping. (See *Astron. Astrophys.* **36**, 465, 1974).

Scoville and Solomon (*Astrophys. J.* **187**, L67, 1974) and Goldreich and Kwan (*Astrophys. J.* **189**, 441 1974) have assumed that the line widths are produced by large-scale velocity gradients (such as contraction) at speeds V_c much greater than the thermal velocity V_t. When the optical depth τ is large, local photon trapping occurs and only a fraction $\beta \approx 1/\tau$ of the photons escape from a zone of dimension V_t/V_c x the cloud size. The photons which escape from this zone escape completely from the cloud, because of the gradient of velocity. Thus we can see right into the clouds even though $\tau \gg 1$.

Each collisional excitation is reproduced from τ to 3τ times by photon scattering before the photon escapes (depending on the geometry). Only those spontaneous emissions which give rise to a photon which escapes from the cloud contribute to the net transfer of population between levels. The ratio of the rates of radiative and collisional equilibration is then proportional to $\beta|\mu|^2/n_{H_2} \propto T_{ex}/n_{H_2}.n_m$ when $\tau \gg 1$, compared to $|\mu|^2/n_{H_2}$ when $\tau \ll 1$; here T_{ex} is the rotational excitation temperature, n_{H_2} the density of hydrogen molecules, n_m the density of the observed molecule and $|\mu|^2$ the square of its dipole moment. When n_m/n_{H_2} is small, T_{ex} (and so the observed intensity) is much less than the kinetic temperature even though $\tau \gg 1$.

The photon-trapping model in a collapsing cloud has been used to explain the relative intensities of CO, CS and SiO lines in the W 51 molecular cloud and to match the CO and HCN profiles for the Orion-MC1 (*Astrophys. J.* **196**, 473, 1975). The model also shows that the relative intensity of isotopic species is not a measure of the isotopic abundances (see *Astrophys. J.* **199**, 69, 1975).

It appears that the gas can be cooled by CO and HD line emission at a rate faster than the collapse rate. Thus the work done in compressing the gas as the cloud collapses is not adequate to maintain the cloud temperature. It has been suggested that the cloud temperature is maintained by IR sources which heat the dust, which then heats the gas.

The radiative-trapping models seem very plausible, but have been criticized because the observed velocities give no obvious hint of large-scale collapse (or other large-scale motions such as rotation). However, more computations are needed to see the effect on line profiles of gradients of density, kinetic temperature and velocity (*Astrophys J.* **196**, 473, 1975).

Circumstantial evidence for collapse and fragmentation is provided by the presence in the massive molecular clouds of O and B stars, far-IR sources, compact H II regions, and OH and H_2O masers. But the rate of collapse in the models is too high to be consistent with the observed rates of star formation.

F. *Galactic Centre Kinematics*

CO observations of the galactic centre (heavily undersampled despite evidence of fine-scale structure) have been extended to cover the longitude range $\ell < 360°$ and the negative-velocity range. The observations have not given credence to the model of an expanding and rotating *ring* of molecules, which had been inferred from OH and H_2CO absorption measurements. A double spiral has been suggested as a possible alternative model.

G. *Molecules in External Galaxies*

Absorption and/or emission by molecules has been observed in a number of galaxies in the last three years, as listed in Table 4.

Table 4. Molecules observed in external galaxies

Galaxy		Molecules observed	References
NGC	Messier		
224	M 31	CO	c
253	–	OH, CO, H_2CO	a, b, c, f
1068	M 77	CO	d
3034	M 82	CO, $^{13}C^{16}O$	b, c
4945	–	OH, H_2CO	a
5055	M 63	CO	c
5128	–	H_2CO, OH	g
5194	M 51	CO	c, d
5236	M 83	CO	d
LMC	–	CO, H_2CO, OH	e, g

a. *Nature*, **247**, 526, 1974.
b. *Astrophys. J.* **199**, L75, 1975.
c. *Astrophys. J.* **199**, L79, 1975.
d. Thesis, L.J. Rickard, Chicago
e. *Monthly Notices Roy. Astron. Soc.* **173**, 69p, 1975.
f. *Monthly Notices Roy. Astron. Soc.* **173**, 77p, 1975.
g. *Monthly Notices Roy. Astron. Soc.* (in press)

The best-studied system is NGC 253, one of the dustiest galaxies in the Hubble Atlas. The continuum source in the nucleus is absorbed by OH and H_2CO, whose profiles reveal kinematics remarkably similar to those of the nucleus of our own Galaxy. Similar expansion and contraction velocities are found in the OH and H_2CO absorption in the nucleus of NGC 4945. In NGC 253 the CO emission covers a higher velocity range than the OH or H_2CO absorption.

H. *Molecular Masers*

All centimetric emission lines from molecules show departures from thermodynamic equilibrium which suggest weak maser amplification of the continuum background. But the term 'maser' refers specifically to those cases where strong amplification produces lines with very high brightness temperatures.

I. *SiO Masers*

The biggest surprise in the last three years was the discovery of maser emission identified with excited vibrational states of SiO associated with long-period variable stars. Transitions observed to be masering in SiO are:

$v = 1$ state				$v = 2$ state			
$J = 1\text{-}0$	ν	=	86.243 GHz	$J = 1\text{-}0$	ν	=	42.821 GHz
$J = 2\text{-}1$	ν	=	43.122 GHz				
$J = 3\text{-}2$	ν	=	129.363 GHz				

The $J = 1\text{-}0$, $v = 0$, $J = 2\text{-}1$, $v = 2$ and $J = 1\text{-}0$, $v = 3$ maser transitions have not been detected. No maser action has been seen for CO ($J = 1\text{-}0$, $v = 1$) or for HCN ($v = 1$ l-doublet).

SiO masers have been found associated with Orion A and the following long-period variables:

o Cet	WX Ser	RR Aql
NML Tau	U Her	NML Cyg
VY CMa	VX Sgr	R Cas
R Leo	R Aql	S Per
R Hya	R LMi	U Ori
W Hya	χ Cyg	RX Boo
S CrB		

Many of these stars show OH and H_2O maser emission. A high-sensitivity H_2O survey has detected all but four of them. The radial-velocity separation between the two SiO emission peaks is somewhat less than that of the corresponding H_2O emission, suggesting that the expanding SiO ring is closer to the star.

The $J = 1\text{-}0$ transitions in both the $v = 1$ and $v = 2$ states of SiO have been observed to be time-varying in Orion A, *o* Cet and R Cas. About 20% circular polarization has been measured in Orion A and W Hya.

II. *OH Masers*

Many new OH sources of the OH/IR type (associated with long-period variables) have been found. None of these are visible optically and few have been found in the infrared. *VLBI* observations indicate component sizes $>0\overset{\prime\prime}{.}1$ arc (typically 5×10^{14} cm). The detailed structure of the 1612-MHz OH emission from VY CMa has been determined by interferometry at Jodrell Bank; it is similar to the structure found earlier for NML Cyg, and is interpreted as radial expansion away from the central star. The 1665/1667-MHz emission from VY CMa comes from a region much smaller than the 1612-MHz emission.

New types of satellite OH emission have been found. Extended ($\approx 30'$) sources of unpolarized 1720-MHz emission are seen in the direction of W 41, W 43, W 51, 3C 123 and 3C 353. At 1612 MHz extended (5 to 15′) unpolarized sources have been found associated with OH 316.8−0.1, 327.3−0.6, 329.1−0.2, 330.9−0.2, 330.9−0.3, 333.4−0.4, 337.8−0.2, 337.8−0.3 and 337.9−0.5. Highly circularly-polarized 1720-MHz emission was found associated with the pre-main-sequence star V1057 Cyg, and similar emission has been observed in the direction of VV Ser, IC 2087 and LK Hα 321. No H_2O emission was seen in V1057 Cyg.

Absorption has been observed for the first time in the rotationally excited $^2\Pi_{3/2}$, $J = 5/2$ state for W3, G267.9−1.1, G291.3−0.7, G327.3−0.5 and G0.55−0.85.

More close associations between 1665-MHz OH masers, compact H II regions and IR condensations have been found as a result of accurate interferometer positions for the OH emission and sensitive synthesis maps in the continuum. Many of the compact H II regions have diameters $\leqslant 0.1$ pc and emission measures of 10^8 cm^{-6} pc. An interesting case is ON1, where a

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compact H II region is seen in isolation from any extended H II region or IR sources (but in a region where CO, CS and HCN are found). For about a third of OH masers no compact H II region or IR condensation is present. Many compact H II regions are not accompanied by OH emission, which is thought to have a lifetime of about 10^4 years early in the development of the H II region.

OH absorption of the extragalactic sources 3C 123, 3C 353 and 3C 391 shows optically-thin main lines with excitation temperature ≈6 K (for 3C 123). The excitation temperatures of the satellites are anomalous because of pumping which inverts the 1720 MHz transition.

III. *H_2O Masers*

Many more H_2O masers have been found, associated with H II regions, with IR objects and with heavily-reddened, late M stars.

Most H_2O masers are *not* coincident with compact H II regions, but about half have a discrete IR source nearby. The H_2O masers may develop at an earlier stage than the OH masers. H_2O emission has been detected from regions near a number of Herbig-Haro objects (e.g. HH-1, HH-9, a group in NGC 1333).

W49 was long thought to be unique amongst H_2O masers in having components shifted far ($\Delta V \approx 200$ km s^{-1}) from the central velocity. Recently similar, though less extreme, high-velocity components (with $\Delta V \approx 50$ km s^{-1}) have been found in Orion A, H_2O 327.3–0.4, 331.0–0.2, 331.5–0.1, NGC 6334A, Sgr B2, M17, H_2O 34.3+0.1, W 51 and NGC 7538. Radhakrishnan, Goss and Bhandari (1975, *Pramana* **5**, 51) suggest that these large *frequency* shifts are due to stimulated Raman scattering; results for the 11 sources above do not support this suggestion.

Single-dish mapping of the distribution of H_2O emission at different radial velocities in Orion A, Sgr B2 and W75S has shown that the sources spread over an area tens of seconds of arc across. *VLBI* measurements have shown that the spread of the OH emission in these sources is only a few seconds of arc, as is found from *VLBI* for the H_2O emission in W49A.

Linear polarization up to 50 percent is found in a quarter of H_2O masers. Circular polarization is less than 1 percent, as expected from the small Landé g factor for the 22-GHz H_2O transition.

IV. *Masering in CH*

Although OH mases strongly, the Onsala observations of CH show extremely weak inversions of the 9 cm triplet (optical depths ≈ –0.001). Near dense H II regions the inversion of the F = 1-1 line is quenched but the satellite lines remain inverted.

V. *Masering in CH_3OH*

The series of 25-GHz emission lines of CH_3OH in Orion A have clearly been shown to be masering. The observations reveal multiple sources of sizes less than about 10″ with brightness temperatures in excess of 800 K. When examined with high spectral resolution, each line is composed of at least six separate components, with symmetry about the central, strong feature. The intensities have varied by a factor of three in a time interval of a few months.

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9. INTERSTELLAR GRAINS

(B. Lynds)

There has been much new and exciting work published on the subject of interstellar grains – for example, the confirmation of the existence of a characteristic extinction hump in the ultraviolet (4.6 μ^{-1}) and the absorption band at 10 μ; the clear evidence that there is a correlation between regions rich in certain molecules and in dust; the evidence for the existence of dust in H II regions and in circumstellar shells; the suggestion that intergalactic dust exists; the continued excellent laboratory work on various candidates for interstellar grain material; and some outstanding theoretical work on the interrelation between interstellar and intergalactic grains and their environments.

Several fine *review papers* have been published; Aannestad and Purcell (10.131.066) have compiled an excellent bibliography. A review of textbook quality was written by Wickramasinghe and Nandy (09.131.211), while Wesson (11.131.015) has presented an interesting discussion of cosmogonical and cosmological aspects of interstellar grains in his review. *IAU Symp.* **52** (10.012.022) was devoted to discussions of interstellar dust and related topics. Greenberg and Hong (12.131.140) have published quantitative discussions of the chemical composition and distribution of interstellar grains.

The most significant new aspect of the *extinction curve* is the very pronounced extinction hump which peaks at about $\lambda^{-1} = 4.6\,\mu^{-1}$ (2175 Å). Savage (1975, *Astrophys. J.* **199**, 92) has presented interstellar extinction curves over the wavelength region 1800–3600 Å for 36 stars, which are mostly confined to the brighter OB associations. He reports that every extinction curve exhibits a broad extinction hump and the strength of the feature correlates well with $E(B-V)$. Code (1975, *Bull. Am. Astron. Soc.* **7**, 249) has reported that the largest variations in the extinction curves occur shortward of 1500 Å. Viotti and Lamers (1975, *Astron. Astrophys.* **39**, 465) have concluded that the normalized extinction curves for different stars are not the same. Nandy and Thompson (*Astron. Astrophys.*, in press) have studied the variation of the extinction in the wavelength range of 2740 to 1350 Å using data obtained with the ESRO TD1 satellite. They found that the mean extinction curve derived separately for three separate galactic regions does not show longitude dependence. These and other authors conclude that separate particles are needed to produce the general scattering and the 2200 Å absorption band. Friedmann and Dorschner are continuing an analysis of the correlations of the equivalent widths of the λ 2200 Å band with other interstellar features. Greenberg and Hong (12.131.140) have stated that the continued rise in extinction beyond $\lambda^{-1} \sim 6\,\mu^{-1}$ can only be produced by solid particles whose sizes are characterized by radii of the order of or less than 10^{-6} cm. York *et al.* (09.131.067) show that this rise continues to 1000 Å. Isobe (10.131.147) has shown that mixtures of graphite core-ice mantle grains with large and small mean size and graphite grains provide good fits to the extinction curve, and Wickramasinghe and Nandy have stated that the observed profile of the 2200 Å feature is consistent with extinction by polydispersions in shape of small graphite spheroids. 'Dirty' ice grains cannot reproduce the UV extinction hump (Aannestad and Purcell (10.131.066)). It is possible that the absorption feature may be produced by silicate grains; and Andriesse and de Vries (11.131.005) suggest that the far ultraviolet scattering may be produced by interstellar radicals (Platt's particles) having a plausible size distribution.

Coyne (10.153.028) has reviewed the observations concerning the nature of *birefringence* in the interstellar medium. Mavko *et al.* (11.131.042) have reported the discovery of structure in the polarization curve – a 'hump' at 4000 Å and a broad depression between 4200 and 5000 Å. Michalsky *et al.* (11.131.003) reported the first detection of interstellar circular polarization in stars later than spectral class A, and Stokes *et al.* (11.131.121) found evidence of circular polarization in 13 of 84 bright stars observed.

Using the Crab Nebula as a background source of linearly polarized light, Martin and Angel (12.131.103) have investigated the birefringence by measurements of circular polarization. Lundin at Uppsala Observatory is constructing a polarimeter designed to study the correlation between separation and polarization of nearby stars.

The *alignment mechanism* for interstellar grains is continuing to be investigated by Shah (07.131.050) and Cugnon (10.131.159). Dolginov (11.131.014) has shown that alignment by corpuscular streams, particularly stellar winds, can be efficient and he also suggests that in the non-equilibrium interstellar plasma alignment would be possible because of temperature anisotropy in the magnetic field.

In a series of papers, Martin (08.131.001, 08.131.003, 11.131.039) has discussed the physical processes influencing grain alignment and has emphasized the relationships between circular and linear polarization and extinction. Shapiro (1975, *Astrophys. J.* **201**, 151) has reported on the polarization and extinction properties of magnetic dust grains.

Measurements of surface polarimetry of the Milky Way have been reported by Staude *et al.* (10.155.045) and by Wolstencroft (10.155.043). Staude *et al.* conclude that the Milky Way is linearly polarized by $p = 1-2\%$ and that eleven regions may show circular polarization.

Herbig (1975, *Astrophys. J.* **196**, 129) has summarized current data on the diffuse *interstellar bands* in the region 4400–6850 Å and he presents arguments that the material is a constituent of the very small grains (radius ∿ 300 Å) which are believed to be responsible for the far-ultraviolet extinction. Hayes *et al.* (10.131.154) have indentified a broad-band structure of the interstellar extinction curve having a characteristic size of several hundred Angstroms. Savage (1975, *Bull. Am. Astron. Soc.* **7**, 260) has discussed his high-resolution profiles of narrow diffuse features at 5780, 5797, and 6379 Å.

Several authors [Wu, 08.131.104; Isobe, 09.131.135; Manning, 08.131.110; Duley, 12.131.177; and Dempsey and Wickramasinghe (1975, *Astrophys. Space Sci.* **34**, 185)] have prepared models of grains which contain molecules giving rise to some of the diffuse interstellar bands.

Nandy and Thompson (*Monthly Notices Roy. Astron. Soc.*, in press) have found a close correlation between the λ2200 feature and the diffuse band λ 4430. Dorschner (1975, *Astrophys. Space Sci.* **34**, 39) found correlations between the equivalent widths of λ 2175 and λ 5578 and λ 5780.

An important result of infrared extinction observations has been the discovery of strong absorption bands in the 10 μ region. These observations are reviewed by Aannestad and Purcell (10.131.066). It has been suggested that the absorption is due to silicates. Smith (1975, *Astrophys. Space Sci.* **34**, 49) has reviewed the recent observations of dust in H II regions. The dust may be observed directly by emitted IR radiation and by scattered stellar radiation. Persson *et al.* (1975, *Bull. Am. Astron. Soc.* **7**, 429) reported observations of the 10 μ features in 22 Southern H II regions and noted that the strength of the feature ranges from apparent emission to deep absorption.

Gillett *et al.* (1975, *Bull. Am. Astron. Soc.* **7**, 428) have presented evidence that the ice-to-silicate ratio is strongly anisotropic.

Witt and Lillie (09.155.082) have reported on OAO-2 observations of the *diffuse galactic light* in the 1500–4200 Å region. They conclude that the measurements suggest a wavelength-dependent albedo with a minimum around 2200 Å and a rapid increase toward values near unity at wavelengths shortward of 2000 Å. Mathis (10.155.075) has numerically solved the equation of transfer for a 'spiral arm' and has tabulated models having various values of $\tilde{\omega}$ and g. Morgan, Thompson, and Nandy are studying the background radiation observed from the UV telescope in the TD1 satellite.

Pipher (10.155.047) has presented rocket measurements of galactic background at 100 μ which she suggests is due to thermal grain emission.

Although this review should not concern itself with *circumstellar grains*, many of the papers published on this subject are direct contributions to the understanding of the nature of interstellar grains. The report of the 17th International Colloquium on Astrophysics at Liège (09.012.003) contains discussions of the condensation nuclei for interstellar grains. Stein and Ney (12.061.035) have shown that the angular size of dust shells surrounding stars can lead to information about the optical properties of grains. Lefèvre (1975, *Astron. Astrophys.* **41**, 437) has discussed thermionic emission from hot grains. Horedt (10.131.081) has discussed the implication of the segregation of grains in the presence of gravitational and drag forces on the formation of stars. Nandy and Wickramasinghe (10.131.021) considered the extinction and scattering properties of grains associated with T-Tauri stars. Burke and Silk (11.131.086; 11.131.087) have studied the basic physics of dust grains in a hot gas with special application to supernovae and η Carinae. Pecker and his colleagues are studying the sorting of atomic species of dust grains of different sizes during the galactic evolution (*Astron. Astrophys.* **18**, 253, 1972 and **35**, 7, 1974).

Baschek *et al.* (12.131.114) have discussed the *infrared emission* of dust heated by randomly-distributed stars. Caroff *et al.* (10.131.068) have shown that the far-infared emission from grains sets a lower limit to grain temperature. Harwit *et al.* (07.131.098) have suggested that dust grains heated by Ly-α have temperatures of the order of 40° and emit radiation at 100 μ. Ryter and Puget (1975, *Bull. Am. Astron. Soc.* **7**, 428) have suggested that the far-infrared emission on a galactic scale is produced by interstellar dust. Bussoletti *et al.* (1975, *Astrophys. Space Sci.* **34**, 191) have computed the absorption efficiency of dust particles in the IR for silicates and graphite grains.

Panagia (1975, *Astron. Astrophys.* **42**, 139) has discussed the effect of a temperature range on the emissivity of grains. Using middle-IR data ($\sim$ 10 μ) he argues that the dust mass inside H II regions has been underestimated and that the dust/gas ratio turns out to be similar to the interstellar medium.

Leung (1975, *Astrophys. J.* **199**, 340) has developed a numerical method for solving the problem of radiation transport in dense interstellar clouds and uses it to determine the grain temperature distribution inside such dark clouds. He finds that pure silicate grains attain low temperatures ($T < 7$ K for $\tau = 5$). Leung (preprint) has also constructed models to study the IR emission from clouds associated with H II regions.

Durand (09.131.178) has shown that transition radiation emitted by dust grains subjected to bombardment by relativistic electrons is not a source of diffuse galactic X-rays and that it can be important only under very special circumstances. Gorenstein (12.131.158) has also discussed the scattering of cosmic X-rays by grains.

Snyder (10.131.180) has reviewed the problem of the distribution of interstellar molecules and concludes that the evidence is growing that interstellar dust grains have an important role in molecular formation and destruction and, in turn, that molecules probably are the best tool for the quantitative analysis of the grain composition.

In a two-part definitive paper, Aannestad (09.131.110 and 111) has studied the *formation of molecules* employing catalytic surface reactions on interstellar grains, first for normal H I clouds and secondly in interstellar shocks.

Merrill *et al.* (1975, *Bull. Am. Astron. Soc.* **7**, 429) has reported that molecular clouds show an absorption feature at 3.07 μ which they attribute to absorption by cold ices. They also reported observations of a feature due to cold silicate material. Dickman (1975, *Bull. Am. Astron. Soc.* **7**, 265) has completed a study of CO in dark clouds and Myers (1975, *Astrophys. J.* **198**, 331) has discussed the molecule-dust correlations in the dark cloud Khavtassi 3 and has concluded that predictions based on ion-molecule reactions give better consistency than abundances based on molecular formation on grain surfaces. (Studies on the formation of complex molecules by means other than atom-grain encounters are not reviewed in this section.) Watson and Salpeter (07.131.128) have discussed molecule formation on interstellar grains and Salpeter and Watson (10.131.181) found that the abundances determined through formation on grain surfaces give a fit for CO but not for formaldehyde. Duley (10.131.020) has considered the effect of fluctuation of grain temperatures on hydrogen atom recombination on grain surfaces. Stecher and Williams (12.131.010) have re-examined the Bates and Spitzer theory for molecular formation (specifically CH and CH^+) on grains, and Iguchi, *et al.* (11.131.139) have discussed the formation of molecules on the surface of grains. Schutte (09.022.043) has discussed the formation of molecular hydrogen on cold surfaces and Lee (1975, *Astrophys. Space Sci.* **34**, 123) has discussed the influence of grain mantles on the formation of H_2 on grain surfaces.

Allen and Robinson (1975, *Astrophys. J.* **195**, 81) have considered the heating of a grain by the energy liberated when a chemical bond is formed between two atoms on a grain and the subsequent radiative recooling, which may liberate the adsorbed volatile. They calculate the time scales for molecular desorption from a grain for OH and CO for four different grain compositions.

Wickramasinghe (1975, *Monthly Notices Roy. Astron. Soc.* **170**, 11P) has discussed the possibility that formaldehyde molecules condense on silicate grains as polyoxymethylene whiskers, freezing a significant fraction of the O and C atoms onto the grains.

Greenberg (11.131.067) has reported that the depletion of O, C, and N is greater than can be accounted for by accretion on grains.

Moorwood and Feuerbacher (1975, *Astrophys. Space Sci.* **34**, 137) have discussed the importance of *grain charge* on the growth and motion of grains in H II regions. Feuerbacher *et al.* (09.131.056; 10.131.233) have calculated the equilibrium potential for grains subject to UV radiation and plasma, and Wesson (10.131.023) has worked on the accretion mechanism, incorporating electrostatic interactions. Bartkus and Kazlauskas (12.131.036) have discussed the influence of nearby transits of charged particles on the Coulombian friction of grains.

Spitzer's method to calculate the charge of grains has been extended by Gail and Sedlmayr (1975, *Astron. Astrophys.* **41**, 359). Wickramasinghe (11.131.076) has calculated the electron charge and acceleration of supra-thermal grains expelled from cool stars and Hayakawa (1975, *Astrophys. Space Sci.* **34**, 73) has suggested that drifts of the interstellar medium may be caused by dust grains expelled from stars.

Several papers have been published related to the *growth and destruction of grains.* Bibring *et al.* (12.131.197) discuss the aging of grains and the 'sticking' process in the solar nebula; Carusi *et al.* (1975, *Astrophys. Space Sci.* **33**, 369) have studied grain accretion processes in a protoplanetary nebula; Salpeter (12.065.015) reviewed 'dying stars and reborn dust'; and Komarnitskaya (08.131.131) discussed the capture of interstellar dust. Lefèvre (12.131.162) has calculated the time scale for which coagulation of grains in the ρ Oph cloud would be important. De Jong and Kamijo (09.131.151) have included the effects of low-energy cosmic rays in considering the growth and destruction of grains.

Simons and Williams (1975, *Astrophys. Space Sci.* **32**, 493) have discussed the spontaneous coagulation of grains. Duley (11.131.017) concluded that, if grain temperatures are below 20 K in dense clouds, the grain mantles will be composed primarily of solid CO. Czyzak and Santiago (10.131.064) have reviewed the justification for the existence of graphite grains.

Leung (1975, *Astrophys. J.* **199**, 340; *Bull. Am. Astron. Sci.* **7**, 428) is studying the *physics of dense interstellar dust clouds*, including radiation transport, gas and grain temperatures and emergent continuum radiation. Witt and Stephens (12.131.069) have made Monte Carlo calculations of the surface brightness of dark nebulae and Harwit (12.131.045) has discussed the propagation of far infrared radiation through a dust cloud. Myers (12.131.184) found that 3 of 35 dust clouds surveyed at 5 GHz showed emission.

Carrasco *et al.* (09.131.164) has reported on interstellar dust in ρ Oph; Carrasco *et al.* (09.131.084) discussed extinction and polarization in dust clouds and Hopper and Disney (12.131.034) have discussed the alignment of interstellar dust clouds.

Brand (1975, *Astrophys. Space Sci.* **33**, 231) has shown that segregation of dust to the center of dense clouds can occur from photodesorption from dust grains by an anisotropic radiation field, and Arshynova (07.131.125) has examined the redistribution of dust by encounters with hot stars.

The effects that grains have on the physical condition of interstellar clouds have been studied by Kudo (12.131.097), Watson (08.131.020; 10.131.177), Hayakawa (12.131.160), Lyon (1975, *Bull. Am. Astron. Sci.* **7**, 419) and Seki (10.131.206).

Hayakawa (10.142.080) has studied the scattering of X-rays by grains and has suggested that the velocities of *dust grains in metagalactic space* may be responsible for cosmic rays of relatively high energies and also for diffuse X-rays by interaction with cosmic black body radiation.

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Chiao and Wickramasinghe (08.158.054) have suggested that charged dust grains may be driven out of the galactic disk along magnetic field lines by radiation pressure, resulting in a significant amount of intergalactic extinction. Wickramasinghe *et al.* (1975, *Astrophys. Space Sci.* **35**, L9) have prepared a dust model for the cosmic microwave background, and Wesson (1975, *Astrophys. Space Sci.* **36**, 363) has suggested that silicates could produce the microwave background radiation.

Mattila (1975, *Astron. Astrophys.*, in press) and Rozhkovskij and Matyagin (1975, *Trudy Astrofiz. Inst. Alma Ata* **25**, 3) have attempted to identify the 'extragalactic' component of the diffuse galactic light.

Laboratory and numerical calculations of the *optical properties of possible grain materials* have continued. Wickramasinghe (09.003.124) has published light-scattering functions for small particles with applications in astronomy. Greenberg (10.131.189) has reviewed some scattering problems of interstellar grains. Purcell and Pennypacker (10.131.225) have described a method for calculating scattering and absorption cross sections for dielectrics of arbitrary shape. Watson (10.063.059) has investigated photoemission yields for small spheres. Duley (10.131.018) has shown that several parameters describing certain interstellar grains cannot be predicted from the bulk properties of an assumed grain material.

Laboratory work on the indices of refraction of various substances has continued. Egan and Hilgeman (12.131.059; 1975, *Bull. Am. Astron.* **6**, 433) discussed enstatite, troilite, bronzite, augite, bytownite, basalt, and the Bruderheim meteorite. Day (10.131.250; 12.131.041; 1975, *Astrophys. J.* **199**, 660) studied small amorphous quartz and olivine spheres. Steyer and Huffman (10.131.251) reported on olivine; Fullerton and Huebner (09.131.083) on ice-coated silica grains; Zaikowski *et al.* (1975, *Astrophys. Space Sci.* **35**, 97) on several phyllosilicates, and Knacke and Thompson (09.063.048) on silicates.

Friedemann and Dorschner are conducting experiments to determine the IR bands of cosmic dust.

Day *et al.* (12.061.007), in a quantitative study of silicate extinctions, conclude that silicates have an almost negligible effect in producing extinction in the visible region of the extinction curve, although Day (12.131.041) suggests a possible identification of the 10 μ 'silicate' features.

Morgan and Nandy (12.131.159) have discussed the IR bands of small silicate spheroids. Aannestad (1975, *Astrophys. J.* **200**, 30) has discussed the absorptive properties of silicate core-mantle grains and concludes that other types of particles must account for the UV extinction as well as much of the visible.

Morgan and Nandy (12.022.002) have reported that refractive indices exhibit large experimental uncertainties. Willis *et al.* (10.131.172) have studied optical and photoemissive properties of graphite grains. Wickramasinghe *et al.* (12.063.038) have discussed the size-dependent complex refractive indices of graphite spheres; Day and Huffman (09.131.133) have measured the extinction efficiency of graphite smoke in the 1200–6000 Å region. Manning (08.131.086) has discussed the anionic species of Fe, and Codina-Landaberry *et al.* (12.131.150) reported on the linear polarization produced by Fe and FeO grains. Cameron (10.131.196) has suggested that carbonaceous chrondites may be collections of interstellar grains.

Anders *et al.* (12.131.062) have performed *laboratory experiments* which suggest that interstellar molecules may originate by catalytic reactions on grain surfaces. Floyd *et al.* (10.131.277) have reported experiments to measure radiation-induced reactions in solid acetelene which simulate processes occurring in condensed gas mantles of grains. Breuer (10.131.187) has shown that irradiation of adsorbed simple gases leads to the formation of rather complex molecules.

McCullough *et al.* (10.131.176) reported on a study of molecules generated from the radiation-induced polymerization of C_2H_2 at 55 K. They suggest that C_6H_6 may be an important constituent of interstellar grains.

Bar-Nun (1975, *Astrophys. J.* **197**, 341) has demonstrated experimentally that CO and most of the hydrocarbons will evaporate from graphite grains. Day (10.131.173) has discussed the thermal accommodation coefficient of graphite.

Greenberg and Yencha (10.131.182) have described photochemical experiments on simulated interstellar material. The results indicate the presence of numerous organic molecules. They conclude that complex products will be produced at temperatures of 10 K or less with efficiencies which make the process astronomically important.

10. PHYSICAL STATE AND DYNAMICAL PROCESSES

(F. D. Kahn)

Much progress has been made in the study of the energy balance of the interstellar medium. In particular it has become clear that stellar winds and supernova explosions are very important in determining the temperature and distribution of the gas.

The *thermal and ionization balance* was investigated by Bochkarev (08.131.106) and by Beysekova and Bochkarev (09.131.061). They found that the heating and ionization of the ISM were more easily accounted for in terms of soft cosmic-ray particles than in terms of X-rays. They also pointed out that a large fraction of the interstellar volume would be disturbed by recent supernova explosions.

But Steigman, Kozlovky and Rees (12.131.053), who considered the ionization of matter in cool H I regions, found that diffuse X rays (with photon energies above 0.3 keV) would make a noticeable contribution, even in the presence of other sources of ionization. Meszaros (12.131.005) described a model of the intercloud medium, where ionization below 24.58 eV is produced by UV photons, and found satisfactory agreement with observation. Grewing and Walmsley (11.131.006) found that X-ray heating can maintain a temperature of up to 5000 K in the intercloud medium, at a density of 0.2 cm^{-3}. But Penston (11.131.012) points out that new UV observations from *Copernicus* imply a heating rate in clouds that is much higher than had hitherto been assumed. The UV radiation field has also been calculated by Terzian (*Astrophys. J.* **193**, 93, 1974) and by Jura (*Astrophys. J.* **191**, 375, 1975). Jura (*Astrophys. J.* **197**, 575 and 581, 1975) has based quantitative models for the physical conditions in interstellar clouds on his UV radiation field and on *Copernicus* results. Further contributions to this subject were made by Bergeron and Souffrin (*Astron. Astrophys.* **25**, 1, 1973 and **36**, 27, 1974).

General reviews of the problems of heating and ionization sources were given by Silk (11.131.520), and by Dalgarno and McCray (08.131.072).

These papers concern mainly the gas in the galactic disk. The gas at great heights above the plane was studied by McCray and Buff (08.131.006). The ambient pressure there is lower and it turns out that a hot phase, with $T \geqslant 3 \times 10^5$ K, should occur.

The *effect of stellar mass loss* on the ISM was described by Dyson and de Vries (08.132.005) and by Dyson (09.132.009) who calculated, in particular, the speeds that would be maintained in the shocked interstellar gas around the source of the wind. Basu (09.131.198) pointed out that considerable kinetic energy would be given to the interstellar medium by giant and supergiant mass loss. The amount may be comparable, in his view, with that derived from UV radiation by early type stars. Observations have also indicated the importance of stellar winds. Deharveng (10.132.045) noted that the splitting of the [N II] λ 6584 line in Orion extends over large regions and must arise from a system of motions that is more widespread than can be explained in terms of the evaporation of gas from globules buried in the nebula. In another paper (12.131.509) she described an expansion, with speed 30 km s^{-1} in NGC 3199. This nebula surrounds a WR star, whose mass ejection may be the cause of the motion.

Smith (09.132.027) has observed gas motions in the central cavity of the Rosette Nebula and finds that they result from the ejection of mass by the stars within the nebula, at a rate of some 10^{-5} $M_\odot$ yr^{-1}. Harris and Wynn-Williams (preprint, 1975) have recently made a map of the fine structure of W3 at 5 GHz. The compact H II region (part A) of this nebula shows a distinct central hole. The most likely explanation is again that there is a stellar wind blowing from the exciting star(s).

The general problem of the stellar-wind interaction has been reconsidered by Castor, McCray and Weaver (*Astrophys. J.* **200**, L 107, 1975). Mass ejected from an early-type star will blow bubbles in interstellar space, with typical radius 30 pc, particle density 10^{-2} cm^{-3} and temperature 10^6 K. The bubbles may be surrounded by a compressed layer of H_2. The column density of O VI detected by observations from *Copernicus* (see below) agrees with the amount calculated in this paper.

Various new results have come from observation by means of the *21-cm line* of hydrogen. Hachenberg and Mebold (11.131.546) have divided the intercloud medium into cells and then separated the velocity dispersion of the different cells from the typical internal velocity dispersion within the individual cells. From the latter quantity they find that the gas kinetic temperature is T_k = 5000 ± 1200 K. Davies and Cummings (*Monthly Notices Roy. Astron. Soc.* **170**, 95, 1975) have observed the 21-cm line in absorption on the background sources Vir A, Cyg A and Cas A. Their analysis reveals spin temperatures T_s for the H in various clouds in the range 600–8000 K, and gas kinetic temperatures T_k in the same range. There is some evidence that T_k increases with height above the galactic plane.

Berkhuijsen (12.125.024) has used the 21-cm line to map the Origem Loop, an old *supernova remnant* in the Anticentre. She finds that it has a radius of 60 pc, expansion speed 20 km s^{-1} and age 10^6 yr. The loop has the structure of a shell, whose thickness is about 0.43 times as large as its inner radius.

Verschuur (10.131.074) has drawn attention to a striking ridge, seen at 21 cm in the range $\ell \sim 180° - 200°$ near $b = -50°$, which is associated with a neighbouring Hα filament, and he wonders whether there is a supernova remnant nearby. In another paper (11.131.508) he points out that neutral gas regions often have a small-scale structure that is more ordered than has been suggested. Clouds frequently have a filamentary form, and contain some 10 $M_\odot$ within 3 pc diameter, or within a similar length of a filament.

Siluk and Silk (12.131.040) have noted that the ratio Na I/Ca II is dependent on the velocity of the clouds where it is measured. Low values of the ratio are associated with high speeds relative to the local standard of rest. These regions may well be associated with supernova remnants.

But Sofue (09.155.067) has found a correlation that suggests a connection between loop structures and dense interstellar gas along spiral arms. In another paper (12.155.012) he, and Hamajima and Fujimoto, provide evidence against the association of loops with supernova remnants.

Observations on board *Copernicus* have produced the most important collection of results on the nature of the interstellar medium, cf. Section 7 above.

Spitzer and Jenkins give an account, with many references, in Vol. **13** of *Ann. Rev. Astron. Astrophys.* (1975). Among individual results, Morton (*Astrophys. J.* **197**, 85, 1975) has analysed the spectrum in the range λλ 980–1420 Å, as seen in absorption against ζ Ophiuchi. He finds strong depletion (up to factor 4000) for most elements in the interstellar gas. The material is strongly concentrated into clouds, where $n_H \sim 10^4$ cm^{-3}, typically. The temperature range is 19–115 K, the clouds have small thickness, about 0.05 pc, but a large lateral extent, up to 25 pc. In another paper he and de Boer (*Astron. Astrophys.* **37**, 305, 1974) find that $n_H \sim 220-660$ cm^{-3}, from an analysis of C I lines, and $n_H \sim 10^4$ cm^{-3} from a study of C^+, They again find a small value for the cloud thickness. York (12.131.118), and Jenkins and Meloy (12.131.117), discuss the O VI absorption lines, and set upper limits on the strength of N V, Si IV and S IV lines. The O VI must arise in regions where 2×10^5 K $< T < 2 \times 10^6$ K, and $n_H \geqslant 10^{-3}$ cm^{-3}. The gas there is probably in pressure equilibrium with the background medium. On the other hand large velocity shifts are observed, up to 90 km s^{-1}. These regions may be associated with later stages in the evolution of a supernova remnant.

York (preprint, 1975) has investigated the distribution of H_2, along lines of sight with little reddening. It tends to occur in small clouds but there is also a diffuse component. In the case of material between us and the star HD 28497, rotational temperatures in the H_2 seem to be larger than 1050 K, possibly as high as 2200 K.

The *propagation of cosmic rays* is affected by inhomogeneities in interstellar space. These occur on a wide range of linear scales, either as mirror points in a magnetic field, typically separated by tens of parsecs, or on a microscale, of the order of 10^{12} cm. The diffusion of cosmic rays has been considered by Holmes (11.143.002), McIvor and Skilling (11.143.005) and by all three authors jointly (11.143.026). If supernovae produce the cosmic rays (and this is no longer regarded as certain), then we should observe at Earth the output from some 2000 separate outbursts at any one time. This would be equivalent to about 10% of all the supernovae that occur in the Galaxy within the typical c.r. lifetime of 10^6 yr.

Cesarsky and Audouze (11.143.001) find that the chemical composition of very-high-energy cosmic rays is consistent with the leaky-box model for their confinement.

The broadening of pulses from pulsars gives some statistical information on the fluctuations of the electron density in interstellar space (on a length scale of 10^{12} cm, or so). In this way it is related to the problem of cosmic-ray confinement. Williamson (11.131.022) notes that the pulsar data indicate that either the electrons themselves, or the locations where the plasma is much disturbed, are confined to comparatively small regions.

Finally Cesarsky (preprint 1975) points out that low-energy cosmic rays are prevented from diffusing away from their hypothetical sources (in supernovae) by the small-scale plasma irregularities. They therefore cannot fill the non-ionized portions of interstellar space with suprathermal 2-MeV particles, as the well-known theory requires.

Taken together all these results indicate very strongly that a definite connection exists between supernovae (mainly) and stellar winds (partly), on the one hand, and the detailed structure, temperature and state of ionization of the interstellar medium on the other.

There has also been some work on some *other possible physical effects*. Wickramasinghe (08.131.030) finds that fast dust grains may be expelled from stars at several thousand km s^{-1}, and may later deposit much heat in the clouds where they are stopped. Hayakawa (12.131.160) invokes fast-moving grains for the production of ionization in the ISM. No one seems though to have considered whether the Alfvén wave mechanism, which prevents the free diffusion of cosmic rays, will not also hold back the dust grains, since these are likely to carry an electric charge. If so they will couple most effectively with the gas surrounding the star where they originate, and will produce an effect which is indistinguishable from that of a stellar wind.

11. STAR FORMATION

(G. B. Field)

The study of star formation remains a primarily theoretical topic, but in the reporting period, a number of observational techniques, including high-resolution radio interferometry of compact H II regions, infrared studies from 2 to 400 μm, and microwave and millimeter-wavelength studies of interstellar molecules, developed data about regions where stars are apparently forming. So far, these data have had only a minor impact on theoretical studies, but one hopes that the impact will grow in the near future. IAU Symposium No. 75 on Star Formation, to be held in September 1976 at Geneva, Switzerland, will encourage this impact.

Several *review articles* are of interest. McNally (08.065.133) and Kahn (12.065.115) have written general reviews, while Larson has reviewed the theory of protostars (10.131.065 and 12.065.181). Strom, Strom, and Grasdalen have reviewed young stars in dark clouds (*Ann. Rev. Astron. Astrophys.* **13**, 187, 1975), and Strom (08.064.065) has also. Zuckerman and Palmer have reviewed radio studies of interstellar molecules which relate closely to star formation (12.131.074). A review by Litvak of coherent molecular radiation (12.131.073) is also of interest.

In general, both the theory and the interpretation of observations have been based on the premise that stars form by condensation of the interstellar medium. This view is disputed by Mirzoyan (08.065.150), who argues that the evidence is better explained by expansion from a denser state.

Most studies envision the birth of stars in dense interstellar clouds, so a necessary antecedent to star formation is the formation of such clouds in the galaxy. P. Biermann (11.065.003) takes the view, that star clusters form from clouds, but that stellar associations form from a tenuous intercloud medium. Pikel'ner (08.151.022) discusses the role of spiral shock waves in forming dense clouds, as does Shu (11.151.060). Talbot and Arnett (10.065.106) and Talbot

(11.155.025) argue that the process of star formation must depend on the abundance of heavy elements which cool the gas enough to permit contraction. Searle, Sargent, and Bagnuolo (09.065.016) and Searle (09.065.134) consider the operation of star formation in other galaxies.

What can one say, observationally and theoretically, about the *properties of dense clouds* where star formation takes place? Stein, McCray, and Schwarz (08.065.092) argue theoretically that such clouds form directly via a thermal instability in gas which has been heated by a supernova radiation burst; Sabano (09.061.031) stresses the role of thermal instability when atomic hydrogen combines to form H_2. Crutcher, from his study of OH emission from a dust cloud, concludes that this cloud is rotating, and must have contracted from a more normal interstellar cloud (10.131.004). Hopper and Disney (12.131.034) study the orientation of observed dark (and presumably dense) interstellar clouds, and conclude, contrary to previous work, that they are aligned parallel to the galactic plane, and not in any relation to the direction of the local magnetic field. Their best fit to the data is achieved by thin sheets parallel to the galactic plane. Appenzeller (12.131.113), on the other hand, finds from his study of the polarization of starlight in Barnard's Loop that the Loop is best explained as a condensation of gas lying in a 'magnetic pocket,' as predicted theoretically by Parker and by Pikel'ner.

Kudo (12.131.097) shows from a study of the cooling mechanisms that dark clouds will cool to approximately 10 K. Presuming that magnetic fields and rotational effects will be less effective than gas pressure in providing support against gravity, Taff and Van Horn (12.065.007) examine the pulsational modes of clouds modelled as bounded isothermal spheres, calculating the parameters at which gravitational collapse sets in. It is this collapse which is presumed to initiate star formation.

Although there is reason to doubt that magnetic fields and rotation can be ignored in following the collapse of interstellar clouds, a number of theoretical studies do so, in order to avoid the severe problems in treating them. Larson (09.131.019) follows up on Hoyle's theory of fragmentation of collapsing clouds by introducing probability considerations to explain the mass spectrum of fragments. Arny and Weissman (09.065.103) also follow the fragmentation theory, addressing an earlier criticism by Layzer, that even if fragments formed, they would be destroyed by mutual collisions during the collapse of the cluster of fragments. According to their study, the collapse 'bounces' at a larger radius than estimated by Layzer, with the result that many fragments escape destruction. Both de Jong, Chu, and Dalgarno (*Astrophys. J.* **199**, 69, 1975) and Leung (*Astrophys. J.* **199**, 340, 1975) study the cooling and heating processes in dense clouds with a view to evaluating the pressure which supports them.

A lively debate is underway as to the proper interpretation of the doppler widths of molecular lines observed in dark clouds. Goldreich and Kwan (11.131.091) propose that the best interpretation is that the cloud is collapsing, as might be expected from theoretical analysis of the gravitational stability of the clouds (if magnetism and rotation are ignored). Linke and Wannier (12.132.034) see evidence for both gravitational contraction and rotation in the Orion molecular cloud, while both Lada *et al.* (12.131.195) and Zuckerman and Evans (12.131.090) argue that the line widths are smaller than predicted by gravitational collapse. On the other hand, Lucas (12.131.157) concludes that turbulent broadening also fails to explain the data. Loren, Peters, and Vanden Bout (12.131.169) also address this problem. Harvey *et al.* (12.131.110) and Davies (12.131.144) conclude from studies of OH maser sources that the individual subclouds responsible for the maser emission have masses from 0.5 to 50 $M_\odot$, just in the range expected for individual stars.

Rotation and magnetic fields are expected to be significant factors in the dynamics of dark clouds. Masheder, Booth, and Davies (11.131.023) give evidence from OH observations that fields in very compact clouds surrounding young stars are of the order of 10^{-3} G; Chaisson and Beichman (*Astrophys. J.* **199**, L39, 1975) also find evidence for such large fields in Orion. Clark and Johnson (12.131.017) claim even larger fields from Zeeman splitting of millimeter-wavelength lines. These measurements seem to imply that the magnetic flux is frozen in as the cloud collapses. A number of theoretical papers discuss the effects of magnetism and rotation on collapse. Bisnovatyj-Kogan, Ruzmaikin, and Sunyaev (09.065.009) propose that even in the absence of a frozen-in magnetic field (as might have been the case for the first generation of stars in the galaxy), turbulence will induce a field through dynamo action. This field transmits the angular momentum of collapsing stars to the surrounding medium, permitting star formation to proceed. Ingvarson (09.131.134) studies the collapse of a magnetic cloud, including pressure and rotation as well. His results show that the magnetic field leads to highly nonspherical collapse, as expected. He also studies ambipolar diffusion through the field, and fragmentation in the cloud. Wright (09.065.157) considers the development of pinch instabilities in a collapsing magnetic cloud, showing that flux can be destroyed in the process of forming stars. Nakano (09.065.004) and Ferraioli and Virgopia (10.065.027) also study the joint effects of magnetism and rotation. Virgopia (09.065.140) derives the relation between angular momentum and mass for newly-formed stars. According to Gillis, Mestel, and Paris (11.065.019), the transmission of the angular momentum of a collapsing cloud to the surrounding medium by Alfvén waves is not powerful enough to substantially reduce the effect of rotation on collapse.

Safranov (10.107.012) studies the problem of viscous transport of angular momentum in a rotating disk, as do Lynden-Bell and Pringle (12.065.020), while Genkin and Safranov (*Astron. Zh.* **52**, 306, 1975) show that there is gravitational instability in a rotating disk of finite thickness, for waves longer than 8 times the characteristic thickness of the disk. Black and Bodenheimer (*Astrophys. J.* **199**, 619, 1975) study the collapse of rotating clouds using a new numerical technique, and find a tendency to form ring structures, as had Larson (07.065.076) earlier. McNally (*Mem. Soc. Roy. Sci.* Liège 6, 479, 1975) also studies collapse of rotating clouds, but in the absence of pressure forces. Clement (12.065.160) develops a technique for solving Poisson's equation in axisymmetric systems which is suitable for rotating bodies.

There is a gap between the studies alluded to above, where the scales are at least astronomical units, and the *studies of protostars proper*, where opacity effects are important because of much higher densities. Work of the latter type follows the pioneering studies of Larson (02.065.036 and 02.065.037) and Narita, Nakano, and Hayashi (03.065.085), which are reviewed in (10.131.065). These studies both found that, in the absence of magnetic fields and rotation, collapse forms a core of high temperature which accretes the outer infalling matter through a shock wave. The disagreements in detail between the two models are addressed by Hayashi (Evolution Stellaire avant la Séquence Principale, 15th Liège Symposium, p. 127, 1970) and Larson (Yale University Observatory preprint, 1974), as well as in independent studies by Kondo (*Publ. Astron. Soc. Japan* **27**, 215, 1975) and Westbrook and Tarter (*Astrophys. J.* **200**, 48, 1975). The latter authors carry out calculations using the initial conditions both of Narita *et al.* on the one hand, and of Larson on the other, and elucidate the differences. They also confirm the discovery of Larson and Starrfield (05.065.122) that in massive stars, the radiation pressure due to the high luminosity of the core stops the accretion of the outer layers and ejects them from the star, thereafter forming a compact H II region as a result of the ultraviolet light of the hot newly-formed star. Appenzeller and Tscharnuter (11.065.015) also find that a massive protostar (60 $M_\odot$) ejects a shell (43 $M_\odot$).

Kolesnik and collaborators study the problem of protostar collapse in some detail (09.065.177, 11.065.044, 12.065.090).

Among the authors who consider theoretically the *development of the compact H II region* formed around massive stars, are Baglin *et al.* (10.065.110), Berruyer (11.065.013), and Kahn (12.065.128). Kahn shows that the thermalized (infrared) radiation from the gas and dust near the star which is being heated by the star itself is sufficient, in view of the opacity provided by the dust, to drive out the outer parts of the shell at high speed. According to Edmunds and Wickramasinghe (12.065.030) the radiation pressure in this type of event is capable of separating the dust from the gas, driving out the former preferentially, and removing the heavy elements which would otherwise have been incorporated into the star.

Although one imagines that complicating factors like centrifugal force would drastically modify these results (as in Larson, (07.065.076), where a ring formed), the concept of a dense region of gas and dust around a new-born star, heated and ionized by the hot star within, has been a fruitful one for the interpretation of radio and infrared observations. That such a compact H II region would be a powerful infrared source, because the ultraviolet light is ultimately absorbed by dust and reemitted as infrared, was predicted by Davidson and Harwit as long ago as 1967 (*Astrophys. J.* **148**, 443). A large number of observational papers appear to support this idea, including infrared studies by Stein (08.131.093), Cohen (10.113.052), Wynn-Williams and Becklin (11.131.527), Wynn-Williams, Becklin, and Neugebauer (11.131.523), Gatley *et al.* (12.141.607), and others. Capps and Dyck (08.114.020) show that the infrared emission in the 8–14 μm band is polarized, strongly suggesting emission by dust, while Gammon, Gaustad, and Treffers (08.114.019), among others, identify a feature in the infrared spectrum which they attribute to silicates, again confirming the dust hypothesis. Deharveng (12.131.524) studies Hα emission knots in regions of star formation, but the great opacity due to dust in these regions greatly inhibits optical observations. Radio observations of free-free emission from the compact H II regions around the young stars therefore provide a powerful tool, as do the observations of maser lines of molecules like OH and H_2O. According to de Jong (10.022.004), the dense regions near protostars are theoretically suitable as H_2O maser sites, and indeed OH (and hence H_2O) masers are observed at such sites according to Habing *et al.* (12.131.522). Morris *et al.* (12.141.603) discuss the relevance of millimeter-wavelength molecular lines to protostars. A number of authors, including Kudo (08.131.071) and Strelnitsky (10.131.221), consider measer pumping in such a situation; Strelnitsky, Sunyaev, and Varshalovich (08.131.078) argue that abnormal abundances may be required for the masers to work.

As the star settles down to the *main sequence*, it loses its direct connection with interstellar matter, so only a few representative references will be quoted in this field. Herbig (09.065.144) calls attention to a star which is only $1-2 \times 10^5$ yr old, but is apparently now past the T Tauri stage, while Strom, Grasdalen, and Strom (12.141.602) argue from infrared and optical observations that Herbig-Haro objects are precursors to T Tauri stars. Schwartz (*Astrophys. J.* **195**, **631**, 1975) adduces evidence that the nebulae associated with T Tau and with Herbig-Haro stars are excited by strong stellar winds.

A number of studies have identified *regions of active star formation*. Strom *et al.* (*Astrophys. J.* **196**, 489, 1975) discuss M 78 in this context, and Grasdalen, Strom, and Strom (10.131.059) show that the ρ Oph cloud contains many stars which can be seen only at 2 μm wavelength because of the high dust opacity. These stars are presumed young because of their location. Encrenaz (11.131.095) shows from CO study of the ρ Oph cloud that the density is extremely high ($>10^5$ cm^{-3}), so that the cloud is presumably collapsing. This picture is pursued by Brown *et al.* (12.131.089), who show from C^+ recombination lines in the cloud that it must contain B stars in order to ionize the carbon. Vrba *et al.* (*Astrophys. J.* **197**, 77, 1975) discuss the whole situation in the ρ Oph cloud further.

Considerable study has been made of the Orion molecular cloud, and its relation to the young stars presumably born from it, see Gatley *et al.* (09.132.028), Werner *et al.* (12.132.011), Gerola and Sofia (*Astrophys. J.* **196**, 473, 1975), and Zuckerman and Palmer (*Astrophys. J.* **199**, L35, 1975).

In conclusion, the theoretical work on collapse of clouds to form stars is beginning to be more realistic, but it is still far short of permitting direct comparisons with observation. However, the knowledge that young stars are often found in dust clouds, that these clouds are dense enough to be collapsing, and in some cases appear to be doing so, and that young massive stars appear to be embedded in compact H II regions as predicted by the theory, is encouraging. It appears that further observational work, which stresses kinematical relationships wherever possible, and theoretical work, which stresses the calculation of collapse with realistic parameters, will permit greater scientific understanding of star formation in the future.

H. VAN WOERDEN
President of the Commission

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