2. Physical State and Dynamical Processes

(J. Lequeux)

A. STRUCTURE AND PHYSICS OF THE INTERSTELLAR MEDIUM (ISM)

It is now clear that the ISM does not consist solely of the classical three components, i.e., molecular clouds, diffuse clouds, and the intercloud medium (H II regions are discussed in section 7 of this Report). High-temperature, low-density components also exist. The role of the transition regions between these components has recently been emphasized, and dynamical processes, including interchange of matter between them and the role of stellar winds and supernova remnants, have been extensively studied. Review papers or general discussions have been given by Field (18.131.115); Salpeter (17.131.143); Kahn (18.131.116, concerning hydrodynamics and MHD); and Heiles (20.156.012, on interstellar magnetic fields). McKee and Ostriker (1975, Astrophys. J. 218, 148) have given a general theory of the ISM including a hot, diffuse component; they emphasize the role of the energy and momentum input from supernovae, the evaporation of cold clouds into the hot medium, and the role of heat conduction.

Reviews on molecular clouds (MCs), mainly observational, have been given by Penzias (18.131.113) and by Thaddeus and Lequeux (in IAU Symposium 75: de Jong and Maeder 20.012.029, pp. 37 and 69). They emphasize the difficulties in deriving from observations the physical parameters and kinematics of MCs. The thermal and chemical balance in MCs has been studied by Clavel et al. (1978, Astron. Astrophys. 65, 435) and Goldsmith and Langer (1978, Astrophys. J. 222, 881: stationary case), as well as by Gerola and Glassgold (1978, Astrophys. J. Suppl., 37, 1: non-stationary case); specific points have been studied by various authors (14.131.085; 17.065.045; 17.065.056; 17.131.084; 18.065.038; 18.131.062; Barnes and Sanqvist, 1977, Astrophys. J. 217, 71; Iglesias, 1978, Astrophys. J. 218, 697; Kwan, 1978, Astrophys. J. 223, 147). It is generally agreed that no exotic source of heating is required, although some may play a role (13.131.040; Hartquist, 1977, Astrophys. J. 217, L45; Elmegreen et al., 1978, Astrophys. J. 220, 853). When there are luminous stars within or close to the cloud, heating of dust by stellar radiation and subsequent heat exchange with the gas is the dominant process (Ryter and Puget, 1977, Astrophys. J. 215, 775; Blair et al., 1978, Astrophys. J. 219, 896). The degree of ionization is very small (Guelin et al., 1977, Astrophys. J. 217, L165, and preprint) and can be accounted for by observed cosmic rays alone (Cravens and Dalgarno, 1978, Astrophys. J. 219, 750). However, numerous observations of radio recombination lines of carbon and sulphur show that these elements can sometimes be ionized by UV radiation from B stars imbedded in MCs or from a nearby H II region. Numbers of papers have been devoted to the excitation of H_2, v=1 in Orion MC1, in planetary nebulae, and in the vicinity of T Tauri stars; this, as well as the molecular "plateau" in Orion, is generally agreed to be due to heating by a shock (Hollenbach and Shull, 1977, Astrophys. J. 216, 419; Kwan, ibid., 713; London et al., ibid., 217, 442; Shull and Hollenbach, 1978, Astrophys. J. 220, 525).

Recent progress in the study of diffuse clouds (DCs) has been made particularly by combining radio, UV and optical observations (e.g., Crutcher, 1977, Astrophys. J. 217, L109; Giovanelli et al., Astrophys. J. 219, 60). The heating of DCs still poses problems, as some may reach temperatures of nearly 1000 K (Lazareff 14.131.039; Dickey et al. 19.131.016 and 1978, Astrophys. J. Suppl. 36, 77). Many studies of heating processes and thermal/ionization balance have been published (13.131.035; 13.131.145; 14.131.144; 17.131.078; Jura 17.131.038; 17.131.080; 17.131.088; 17.131.134; 18.131.270; 19.131.031; De Jong 19.131.051; Joshi and Tarafdar, 1977, Astrophys. Sp. Sci. 49, 199; Draine, 1978, Astrophys. J. Suppl. 36, 595). Heating by photoelectrons ejected from grains seems to give satisfactory results. There is increasing evidence that the degree of ionization in DCs is low (Shaver et al. 17.131.119; 18.131.527). The interaction of external disturbances with DCs has been studied by Hill and Silk (14.131.144; see also 18.131.108), who show that the H_2 observed by Copernicus in front of many hot stars could be produced in a transition-zone H II/DC region; evaporation into a hot medium has been studied by Cowie and McKee (19.131.007; 19.131.127). The effect of stellar winds and supernovae is reviewed below.

The nature of the intercloud medium (ICM), defined as corresponding to very hot neutral hydrogen (10^3 K < T < 10^4 K) (for recent 21-cm observations see 13.131.501; 14.131.039; 14.131.510; Dickey et al., op. cit.), is very much open to question. It appears that the long-standing idea of a uniform ICM bathing the MCs and DCs needs serious revision; most of the space is probably filled with very hot, tenuous gas, so that the 2-component model of the ICM is in difficulty (see, e.g., Shapiro and Field 17.131.112; Scott et al. 19.131.042). The hot H I must be in pockets also containing clouds, between rarefied hot regions, or may even correspond to envelopes of DCs, or small clouds (McKee and Ostriker, op. cit.). Parts of this gas must be ionized by stellar radiation to form low-density H II regions at about 10^4 K (17.131.117; 19.131.004). This picture is consistent with all observations, including recent observations of optical interstellar lines by Hobbs (14.131.155; 17.131.137; 1978, Astrophys. J. 222, 491). A number of papers, however, deal with interpretations of the observations within the classical 2-component models (steady or time-dependent) with the addition of diffuse H II regions produced by isolated O-B stars (see, e.g., 13.131.115; 13.131.116; 14.131.089; 17.131.103; 17.131.109; 18.131.177; 18.131.228). Although comparison of these models with observations should be viewed with caution, they are useful in that they describe basic physical mechanisms which certainly play a role. Other articles that deal with specific mechanisms are 13.131.118; 17.131.042; 19.131.011.

The existence of a very diffuse gas at about 5 x 10^5 K is implied by the Copernicus observations of O VI lines (Jenkins, 1978, Astrophys. J. 219, 845 and 220, 107). However, soft x-ray observations, while being consistent with the existence of this medium, imply also higher-temperature gas, probably in supernova remnant (SNR) shells (17.142.060; 19.142.002; 19.157.004; Sanders et al., 1977, Astrophys. J. 217, 187; review papers by Gorenstein and Tucker 1976, Ann. Rev. Astron. Astrophys. 14, 373, and by Tanaka and Bleeker, 1977, Space Sci. Rev. 20, 815). Whether the O VI gas corresponds to stellar winds of O stars or to the inner parts of SNRs is still unclear, although both may coexist (14.125.033; 19.125.002).

Effects of stellar winds on the neutral ISM have been studied recently for O stars by Weaver et al. (1978, Astrophys. J. 218, 377), and in the cases of T Tauri stars and Herbig-Haro objects by Bohm (1978, Astron. Astrophys. 64, 115), Horedt (ibid., 173), and Schwartz (1978, Astrophys. J. 223, 884). The interaction of SNR shock waves with the ISM has been studied by a number of authors: see, e.g., the reviews by Chevalier (20.125.017), Mufson (14.131.138), Sofue (1978, Astron. Astrophys. 67, 409), and Shull and McKee (preprint). The production of X-rays and cooling of a 10^6 K gas have been investigated by Shapiro and Moore (18.131.024), Raymond et al. (17.062.010), and Smith (19.131.183). The intermediate-temperature, high-velocity gas observed by Cohn and York (1977, Astrophys. J. 216, 408) can be accounted for by radiatively cooling shocks from SNRs or stellar winds (Shull, 1978, Astrophys. J. 216, 414). The more familiar "high velocity clouds" observed close to SNRs (Cohen, 1975, Publ. Astron. Soc. Pacific 89, 626; Jenkins et al. 18.125.021; 19.125.001) or in front of various stars (Drake and Pottasch 19.131.032; Cowie and York, 1978 Astrophys. J. 220, 129 and 223, 876) are likely to be accelerated by SNRs (McKee et al., 1978, Astrophys. J. 219, L23). There is also a feeling that SNRs influence the large-scale structure of the ISM (see, e.g., 13.155.022; 18.131.518). Disruption of MCs by SN explosions is a more controversial subject (Mouschovias 18.062.006; Wheeler and Bash, 1977, Nature 268, 706).

B. THEORY OF STAR FORMATION

With one exception (Tovmasyan, 1977, Astrofizika 13, 131), theories of star formation assume that stars form by condensation and fragmentation of IS clouds (observational aspects of star formation are reviewed in section 10 of this Report). Reviews along these lines have been given by Mestel and Larson (20.012.029, pp. 213 and 249), while Bertout and York (preprint) summarize progress made in Germany. The initial instability of clouds has been investigated by Jura (17.065.057), Kegel and Traving (18.131.002), Weber (18.131.044), and Viala et al. (1978, Astron. Astrophys. 65, 393), while Deissler (18.065.036) considers turbulent clouds, and Monaghan (1978, Mon. Not. Roy. Astro. Soc. 184, 25) studies the thermodynamics of self-gravitating clouds. Mouschovias (17.062.036; 18.062.006) and Mouschovias and Spitzer (18.131.186) study the stability and early evolution of magnetized clouds (see also Sung, 1977, Astron. Astrophys. 60, 393, and 18.065.001). The role of external pressure in decreasing minimum unstable mass has been emphasized by most authors, and it appears that shock waves associated with spiral density waves, SNRs, and stellar winds are efficient in triggering star formation. Important numerical studies of these effects have been carried out by Woodward (18.131.025; preprint), who followed the evolution of a cloud passing through a shock and showed how subsequent collapse occurs. Numbers of papers have dealt with the triggering of star formation, mainly by SNRs, and supporting observational evidence (Elmegreen and Lada 19.152.005; 18.152.004; 19.131.038; Herbst and Assousa, 1977, Astrophys. J. 217, 473; Assousa et al., 1977, Astrophys. J. 218, L13; Elmegreen and Elmegreen, 1978, Astrophys. J. 220, 1051). The further evolution of collapsing clouds has been the subject of many studies too numerous to mention here. Fleck and Hunter (17.065.054), Mouschovias (19.131.008; erratum, 1978, Astrophys. J. 224, 283), and Zasov (1976, Soviet Astron. 20, 664) have studied angular-momentum loss via magnetic braking and showed that it becomes inefficient at some stage, but that collapse is still possible afterwards. Several authors have looked for various types of instabilities which could augment Jean's instability in fragmenting clouds (17.065.052; 17.131.045; 17.131.168; 17.131.015; De Campli and Cameron, 1978, Astrophys. J. 223, 854). A numerical 3-dimensional study of fragmentation and subsequent accretion by fragments has been given by Larson (1978, Mon. Not. Roy. Astron. Soc. 184, 69). Analytical studies of fragmentation yield a minimum mass for stars of about 0.01 $M_\odot$ (Rees 18.065.019; Low and Lynden-Bell 18.131.014; Silk 19.131.101; see also 19.131.130); Silk (19.131.115) and Larson (op. cit.) have tried to obtain theoretically a stellar initial mass function. The collapse of fragments has been studied in general terms by Hunter (1977, Astrophys. J. 218, 834) and Cheng (1978, Astrophys. J. 221, 330), while Disney (17.065.053) and Shu (19.065.044) have criticized some earlier works. New numerical models have been produced by Black and Bodenheimer (17.131.124: rotating clouds) and by Yorke and Krügel (19.131.028: no rotation, but realistic treatment of gas and dust). Evolution has been followed by the latter authors up to the formation of a cocoon (see also Kahn, op. cit., and 19.131.014). It appears that the theory is sufficiently advanced to permit a fruitful comparison with present and future observations. Calculations employing a sophisticated treatment of radiative transfer (18.065.034; Tscharnuter, 1977, Astron. Astrophys. 57, 279) allow one to predict the evolution of the IR emission of protostars and new-born stars (Yorke, 19.131.156; Finn and Simon, 19.133.038); studies of their expected behavior in molecular lines are in progress.

3. Distribution and Motion of the Interstellar Gas: Atomic and Molecular Hydrogen

(H. van Woerden)

Neutral atomic hydrogen (H I) was long considered by far the most important constituent of the interstellar gas. Molecular hydrogen (H_2) is now thought to be dominant in the inner parts of our Galaxy and a major contributor in the solar neighborhood. For practical reasons, H I and H_2 are discussed separately here, but their relationship is mentioned where relevant.

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

A. ATOMIC HYDROGEN (H I)

New 21-cm line surveys have led to almost complete sky coverage, though part of this material is still unpublished.

A southern low-latitude survey at $236° < \ell < 345°$ by Kerr, Harten and Ball (18.155.015) has led to a longitude-velocity diagram along the equator (18.155.017). A new Parkes survey by Kerr and Bowers covers $|b| \leq 10°$ with 0°8 resolution, supplementing the Hat Creek survey by Weaver and Williams (09.157.009). Pöppel, Vieira, Olano and Franco (First Latin American Reg. Astron. Meeting, 1978) are preparing an atlas of $240° < \ell < 372°$, $+3° < b < +17°$, based on observations at Parque Pereyra (Argentina).

Smaller low-latitude regions have been surveyed by Jackson (18.155.016) in Centaurus, by Grayzeck (20.155.055) around $\ell = 122°$ and $b = -15°$, by Mirabel (19.156.016) south of the Galactic center, by Braunsfurth and Rohlfs (Astron. Astrophys. Suppl. 32) at $20° < \ell < 42°$. Burton et al. (20.155.001) surveyed the region $|\ell| \leq 11°$, $|b| \leq 10°$ at high sensitivity (0.08 K rms) out to very high velocities: $|V| \lesssim 500$ km s^{-1}. Colomb and Mirabel (17.131.035) give profiles and column densities in the directions of 23 pulsars. Colomb, Gil and Morras (18.155.050) mapped a region around (300°, -25°).

The Hat Creek high-latitude survey ($|b| > 10°$, $\delta > -30°$) culminated in photographic representations by Heiles and Jenkins (17.155.004). Combination with the Parkes survey at $\delta < -30°$ by Cleary (thesis, Canberra, 1977) led Cleary, Heiles and Halsam (Astron. Astrophys., in press) to a synoptic view of the Galaxy at $|b| > 10°$ for $-90 < V < +70$ km s^{-1}. Colomb, Pöppel and Heiles are preparing photos of H I with $|V| \leq 40$ km s^{-1} for the whole sky at $|b| \geq 10°$, based on a combination of Hat Creek and Parque Pereyra observations; for a preliminary portion, see 19.132.099. Schober (18.155.018) gives maps showing T(V,b) at $|V| < 50$ km s^{-1} from b = -90° to +90° for a number of longitudes. Bystrova and Rakhimov (20.002.034) publish drift scans at declinations between -29° and +40°.

Crovisier, Kazès and Aubry (1978, Astron. Astrophys. 32, 205) have published absorption spectra for 819 sources.

The observations of high-velocity clouds (HVCs) have been reviewed by Giovanelli (IAU Symp. 77) and by Hulsbosch (in IAU Symp. 84: "The Large-Scale Characteristics of the Galaxy").

New searches, out to $|V| = 1000$ km s^{-1} and with detection limits ~0.05 K, have been made by Hulsbosch (Astron. Astrophys. 60, L5, 1978) and by Giovanelli (IAU Symp. 84). Both find many objects with V(LSR) < -200 km s^{-1} in $0° < \ell < 180°$, $-60° < b < 0°$; the highest negative velocities are ~-460 km s^{-1} (around $\ell = 112°$, b = -8°), and are mutually confirmed, as are the very high velocities reported earlier by Wright (11.131.517) and by Cohen and Davies (1975, Monthly Notices Roy. Astron. Soc. 170, 45p). Giovanelli also finds high positive velocities (at $\ell > 180°$, where Hulsbosch has not yet searched) and a new stream in the anticenter region. No new HVCs have been found in the southern high-latitude survey by Cleary.

Detailed studies of individual negative-velocity clouds by Greisen and Cram (17.131.012), Cram and Giovanelli (17.131.090), Davies et al. (17.131.020), Giovanelli and Haynes (19.131.012), and Hulsbosch (1978, Astron. Astrophys. Suppl. 33, 383) show dense cores (velocity width W ~ 7 km s^{-1}, T_b ~ 50 K) in tenuous envelopes (W ~ 25 km s^{-1}). Giovanelli and Haynes (18.131.604) observe similar structure in clouds with high positive velocities. Schwarz et al. (18.131.526) at Westerbork find 3 condensations of 5' diameter and T_b ~ 50 K in a filament in HVC 132+23-211. Cohen and Mirabel (1978, Monthly Notices Roy. Astron. Soc. 182, 395) report a detailed study of HVC 39+4-353. Aitova (19.131.103) claims Hβ emission in OUH 308.

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

The nature and origin of HVCs remains unknown. Eichler (18.131.516) and Giovanelli (19.161.002) have raised arguments against an extragalactic (or intergalactic) interpretation. Haynes (IAU Symp. 84), in a study of several nearby groups of galaxies, finds no isolated intergalactic clouds, though streams of tidal debris are common. Burton and Moore (Astron. J., in press, and IAU Symp. 84) argue that three HVC streams in the anticenter region are connected with a minimum at low velocities; an intergalactic stream impinging on the Galactic disk might be responsible. Oort (1978, in "Problems of Physics and Evolution of the Universe," Publishing House of the Armenian Academy of Sciences, Yerevan, USSR), speculating on the origin of the long "chain A" of HVCs, dismisses many possibilities and finally suggests thermal instabilities in a hot halo.

The Magellanic Stream is the only (former) HVC which may be fairly well understood. Mathewson et al. (19.159.017; 20.159.003; and IAU Symp. 84) and Mirabel et al. (1978, in press) have reported on its small-scale structure. Davies and Wright (19.159.021), Fujimoto and Sofue (17.151.021; 20.159.006; and IAU Symp. 84), and Lin and Lynden-Bell (1977, Monthly Notices Roy. Astron. Soc. 181, 59) have modelled the Stream as tidal debris from the Magellanic Clouds after a close encounter with the Galaxy. Only Lin and Lynden-Bell seem to find the results satisfactory. However, Fujimoto and Sofue (20.159.006; IAU Symp. 84) also raise objections against the primordial model advocated by Mathewson (19.159.017). A later suggestion by Mathewson et al. (20.159.003; IAU Symp. 84) interprets the Stream as the turbulent wake of the Magellanic Clouds on their passage through the halo of the Galaxy; the clouds in the Magellanic Stream would be falling radially into the Galaxy. The relationship of the Magellanic Stream to the HVCs in the northern hemisphere remains a matter of debate (see, e.g., Giovanelli, IAU Symp. 84).

The galactic distribution of neutral atomic hydrogen and of other constituents has been reviewed by Burton (20.155.027). Baker (17.155.018) and Bochkarev and Sunyaev (20.131.115) consider the influence of ionizing background radiation on the outer boundary of the gas disk. Gordon and Burton (18.155.012) and Rots (IAU Symp. 84) discuss the radial gas distributions; Knapp et al. (in press), the H I distribution outside the solar circle. Spiral structure is outlined by Georgelin et al. (IAU Symp. 84) for H II regions, and by Henderson (19.155.033) and Quiroga (20.155.062) for H I; the latter finds a corrugation in the gas layer. Henderson (IAU Symp. 84) presents new data on the warp and thickness of the Galactic disk. Gunn et al. and Jackson et al. (both: IAU Symp. 84) and Sinha (1978, Astron. Astrophys. 69, 227) have re-examined the rotation curve for the Galaxy; best values appear close to Θ_o = 220 km s^{-1}, R_o = 8.5 kpc. Strauss and Pöppel (17.155.013) discuss rolling motions in a spiral arm. Density-wave effects in the structure and motions are considered by Simonson (17.155.003) and by Roberts and Burton (20.131.106).

The distribution and motions of gas in the Galactic center region have been recently reviewed by Oort (20.155.058; see also 1978, Phys. Scripta 17, 175). Burton and Liszt (1978, Astrophys. J. 225, 815) give a simple, tilted-disk model for all the gas at $R < 1.5$ kpc, both with permitted and forbidden velocities. For further discussion of the Galactic center, and of other large-scale features, reference may be made to the Report of Commission 33 and to IAU Symposium 84.

Gosachinskij and Rakhimov (1978, Soviet Astron. 22, 12) find two components, with layer thicknesses 500 and 1500 pc, in the region between the Orion and Perseus arms; the wider distribution dominates between the arms. They further determine (1978, Astron. Zh. 55, 292) the spectrum of cloud masses.

From Copernicus measurements of interstellar Lyα absorption in 100 stars at distances up to several kpc, Bohlin et al. (1978, Astrophys. J. 224, 132) find average hydrogen densities ranging from 0.008 cm^{-3} (toward the Gum Nebula) to 12

cm^{-3} (toward Sco-Oph); the general average is 1.15 atoms cm^{-3} (namely, 0.86 H atoms and 0.143 H_2 molecules). The local gas density is much smaller and may vary with direction: 0.005 ± 0.002 cm^{-3} to HR 1099 at 33 pc (Anderson and Weiler 1978, Astrophys. J. 224, 143), 0.03 ± 0.01 cm^{-3} towards α Aur at 14 pc, 0.20 ± 0.05 cm^{-3} to α Cen at 1 pc (Dupree et al., 20.131.148). Vidal-Madjar et al. (1978, Astrophys. J. 223, 589) suggest that a cloud at less than 1 pc distance is approaching the Solar System. Several measurements of solar Lyα scattered by interstellar H I (Bertaux et al., 17.131.015 and 20.106.014; Adams and Frisch, 19.131.037; Cazes and Emerich, 19.131.158) give a temperature of 10000 ± 2000 K for the local gas and also indicate its flow with respect to the Sun. Hsieh (19.131.057) has emphasized the importance of an out-of-ecliptic mission for such measurements.

From 21-cm absorption spectra of 300 extragalactic sources, Crovisier (1978, Astron. Astrophys. 70, 43) finds a dispersion $\sigma = 5.7 \pm 0.9$ km s^{-1} (in one coordinate) for the "external" motions of interstellar clouds. A similar value is found by Morton (1978, Astrophys. J. 222, 863) from UV absorption lines of neutral atoms in the line of sight to ζ Puppis; the Mg II and Si II ions give $\sigma = 8.5$ km s^{-1}. For the internal motions in clouds, Mebold et al. (1978, Mitt. Astron. Ges. 43, 192), Lockhart and Goss (1978, Astron. Astrophys. 67, 335), and Crovisier and Kazès (IAU Symp. 84) find dispersions between 0 and 3 km s^{-1}. The role of turbulence is discussed by Mebold et al. and by Larson (IAU Symp. 84).

Temperatures of H I clouds have been determined from combinations of absorption and emission profiles by Davies and Cummings (1975, Monthly Notices Roy. Astron. Soc. 170, 95), Lazareff (1975, Astron. Astrophys. 42, 25), Mebold and Hills (1975, Astron. Astrophys. 42, 187), Dickey et al. (1978, Astrophys. J. Suppl. 36, 1), Mebold et al. (1978, Mitt. Astron. Ges. 143, 92), and Roger et al. (1978, Monthly Notices Roy. Astron. Soc. 182, 209). The values range from <15 K (Mebold et al.) to ~1000 K (Dickey et al.); the hotter clouds generally have lower optical depth and higher velocity (cf. also Drake and Pottasch, 19.131.032). Low temperatures are also found from H I self-absorption in dust clouds, and from molecular lines. The UV lines in ζ Oph (Snow 1978, Astrophys. J. 220, L93) give $T < 22$ K, those in ζ Per (Black et al. 1978, Astrophys. J. 224, 448) a 45 K core with a 120 K envelope.

The temperature of the intercloud medium (ICM) was determined by Davies and Cummings (1975), Mebold and Hills (1975), and Hobbs (17.131.137) to be in the range 1500-1800 K. However, Kalberla (1978, thesis, Bonn, and Mitt. Astron. Ges. 43, 230) has pointed out that sidelobe contributions to the measured 21-cm profiles severely affect the determination of ICM emission. York (17.131.050) finds that the gas outside standard clouds may be partly in small clouds.

The hot gas observed in the O VI lines (see Jenkins 1978, Astrophys. J. 219, 845 for a recent survey) represents a third phase in the interstellar gas. In fact, Salpeter (IAU Symp. 84) identifies 7 or 8 phases: molecular clouds (10^3 cm^{-3}, 10 K, $f \sim 0.0004$), standard H I clouds (40 cm^{-3}, 70 K, $f \sim 0.005$), warm clouds (100 - 1000 K), interfaces (>1000 K), a possible intercloud medium (0.2cm^{-3}, 7000 K, perhaps $f \sim 1$), Strömgren spheres (3 cm^{-3}, 10000 K, $f \sim 0.01$), O VI gas (0.0003 cm^{-3}, 3×10^5 K), and coronal gas (10^6 K), with internal density n, temperature T, and filling factor f given in parentheses. Myers (1978, Astrophys. J. 225, 380) and especially Turner (IAU Symp. 84) distinguish several types of dark and molecular clouds, and Myers compiles values of n, T, and mass. Theoretical arguments for a multi-component medium are considered by Jura (17.131.038), Lyon (17.131.103), Shapiro and Field (17.131.112), McKee and Ostriker (20.131.111), and Salpeter (IAU Symp. 84).

Magnetic-field determinations are discussed by Heiles (20.156.012), Turner et al. (18.131.508), and Elmegreen (1978, Astrophys. J. 225, L85).

Very Long Baseline Interferometry (VLBI) work by Dieter, Welch, and Romney (17.131.136) has now brought the smallest scale observed down to 3 x 10^{-4} pc, with a density of 10^5 H atoms cm^{-3}. Structures of scale ∿1 pc are commonly found in aperture-synthesis studies by Greisen (1976, Astrophys. J. 203, 371), Lockhart and Goss (1978, Astron. Astrophys. 67, 355), Schwarz and Wesselius (1978, Astron. Astrophys. 64, 97), and in absorption by Crovisier and Kazès (IAU Symp. 84); smaller scales are rare, according to Greisen (1976) and Dickey and Terzian (1978, Astron. Astrophys. 70, 415). Baker (IAU Symp 84) stresses that the small clouds often form part of long, coherent structures such as filaments or sheets; cf. the alto-cumulus or cirro-cumulus clouds in the Earth's atmosphere.

Filamentary structures are the dominant pattern in observations by Schwarz and van Woerden (12.131.535), Heiles and Jenkins (17.155.004), and by Cleary, Heiles and Haslam (Astron. Astrophys., in press); cf. also the Cetus-Eridanus ridge discussed by Bystrova and Rakhimov (19.132.007). Heiles and Jenkins, and Cleary et al. find correlation of the filaments with optical and radio polarization. The shells discussed by Bajaja et al. (17.131.539), Colomb et al. (19.132.039), and Heiles (18.131.518) may be a related phenomemon. Recently, Heiles (IAU Symp. 84 and Astrophys. J. 1979) has discussed a new class of H I shells, of size ∿1 kpc, mass ∿10^7 $M_\odot$, density ∿0.2 cm^{-3}. These supershells, if attributed to supernovae, would require ejection energies ∿10^{53} erg and have lifetimes ∿10^8 years; the originators may never have been seen, even in external galaxies. A similar energy may be required for the Gum Nebula (Kafatos 1976, Bull. American Astron. Soc. 8, 542).

H I features associated with supernova remnants (SNRs) have been found by Sato and Akabane (17.131.166) around W44, Higgs et al. (18.125.064) near γ Cyg, De Noyer (19.132.010 and 1978 Monthly Notices Roy. Astron. Soc. 183, 187) in IC 443, and by Bystrova (1978, Soviet Astronomical Circular 1014). Correlations with radio-continuum loops are discussed by Heiles and Jenkins (17.155.004) and De Noyer et al. (19.155.019). The interaction of supernovae with the interstellar medium is reviewed by Chevalier (20.125.017). McKee et al. (1978, Astrophys. J. 219, L23) discuss the acceleration of HVCs in SNR. Stecher and Williams (1978, Astron. Astrophys. 67, 115) point out that a supernova flash might ionize H_2, while atomic hydrogen remains neutral; the electrons produced would affect the dispersion measures of pulsars.

Sandqvist et al. (18.131.121) discuss the motions of H I and molecules in dark clouds along Gould's Belt; these may be due to large-scale expansion. Franco and Pöppel (1978, Astrophys. Space Sci. 53, 91) describe a ridge in Sco-Oph, related to Gould's Belt. Cleary et al. (Astron. Astrophys., in press) find a 10^4 $M_\odot$ filament between 250°-10° and 330°-22°, which may be related to the Sco-Cen association; they suggest that infall of gas at the south Galactic pole may be due to collapse of a giant bubble blown by the Gould Belt stars. Bystrova (1978, Astron. Issl. Spec. Astrophys. Obs. Pulkovo, II) and Crutcher (18.131.047) study hydrogen in the Sco OB2 association; Simonson and Van Someren Greve (17.131.141), gas and dust in Cepheus; Sato (19.132.020), H I around the H II region W33.

In several H II regions, Meaburn and collaborators observe large-scale line splitting connected with the interaction of ionized and neutral gas; for a review, see 20.132.016. Lockhart and Goss (1978, Astron. Astrophys. 67, 355) observe H I clouds associated with the Orion Nebula and NGC 2024. Silverglate and Terzian (1978, Astron. J. 83, 1412) find cold H I near several other H II regions. Elmegreen (17.131.109) and Tenorio-Tagle (19.132.009) show that the ionization of standard clouds and of globules in H II regions may take as long as the OB star's lifetime. Dyson (1978, Astron. Astrophys. 62, 269) discusses neutral condensations caused by stellar winds.

The study of recombination lines from cold, predominantly neutral gas has been recently reviewed by Brown, Lockman and Knapp (1978, Annu. Rev. Astron. Astrophys.

16, 445). Papers published since then include those by Rickard et al. (20.131.164), Pankonin and Walmsley (1978, Astron. Astrophys. 67, 129), and Silverglate and Terzian (1978, Astrophys. J. 224, 437). Hill and Hollenbach (1978, Astrophys. J. 225, 390) expect C II recombination lines from a wave of dissociated H_2 surrounding an expanding compact H II region; the dissociation front should also produce strong 21-cm line H I emission (London, 1978, Astrophys. J. 225, 405).

Following several earlier attempts, Kerr et al. (18.131.156) have now found H I in the Coalsack. In several other dense dark clouds H I was studied by Martin and Barrett (18.131.234), Wilson and Minn (19.131.048), and Mattila and Sandell (Astron. Astrophys., in press). Temperatures are below 30 K and the amounts of H I small compared to the extinction; undoubtedly, the bulk of hydrogen is in molecular form.

Heiles (17.131.044) discussed the general correlation of gas and dust on the basis of his high-latitude H I survey, the Shane-Wirtanen galaxy counts, and B-V color excesses. A rediscussion by Burstein and Heiles (1978, Astrophys. J. 225, 40), based on new E(B-V) values for RR Lyr stars and globular clusters, still indicates important variations in the gas/dust ratio. However, as pointed out by Kalberla (1978, thesis, Bonn and Mitt. Astron. Ges. 43, 230; cf. also Baker, IAU Symp. 84), errors exceeding 10^{20} atoms cm^{-2} in the column densities N(H I) are caused by stray radiation received in the antenna sidelobes; such errors may amount to 50% at high galactic latitudes! For reliable determination of the ratio N(H I)/E(B-V), correction for stray radiation will be essential. Apparent variations in the gas/dust ratio may also be caused by neglect of the contribution of molecular hydrogen. The solution is to determine N(H I) and $N(H_2)$ from UV absorption lines. Summarizing Copernicus results for 100 stars, Bohlin et al. (1978, Astrophys. J. 224, 132) find an average $(2N(H_2) + N(H\ I))/E(B-V) = 5.8 \times 10^{21}$ atoms cm^{-2} mag^{-1}, with a spread of a factor 1.5, but ρ Oph gives a ratio of 15×10^{21}. Hence, genuine variations appear to exist.

Burton et al. (1978. Astrophys. J. 219, L67) have measured H I self-absorption features in molecular clouds. The hydrogen has $T_S < 20$ K; its distribution and kinematics correlate with those of CO. Read, using the Cambridge synthesis telescope, finds coincidence of H I and H_2CO in NGC 7538. Myers et al. (1978, Astrophys. J. 220, 864) compare the distributions, temperatures and motions of H I and of various molecules in the ρ Oph cloud.

B. MOLECULAR HYDROGEN (H_2)

This subject has advanced very rapidly, thanks to both ultraviolet (Copernicus) and infrared observations. It was well reviewed, 2 or 3 years ago, by Spitzer (17.131.128) and Jura (18.131.154).

The many lines in the ultraviolet provide the column density $N(H_2)$, temperature and volume density, and the ultraviolet radiation field. As expected from theories of H_2 formation (cf. Spitzer), the ratio $f \equiv 2\,N(H_2)/(2\,N(H_2) + N(H\ I))$ generally varies very strongly with extinction (Savage et al., 18.131.144). Towards ζ Pup, f $= 6 \times 10^{-6}$ only (Morton and Dinerstein, 17.131.057); towards o Per and ζ Per, f = 0.5 - 0.6 (Snow, 17.131.051 and 20.131.047) and probably $f \sim 1$ in dense clouds of $\sim 1000\ cm^{-3}$. For 109 stars, with distances up to several kpc, Savage et al. (20.131.036) obtain an average $\bar{f} = 0.25$. York (17.131.050), Hill and Hollenbach (18.131.108), and Shull and York (19.131.023) find considerable H_2 densities towards stars of little reddening, suggesting that in the "intercloud medium" H_2 occurs in small clouds.

The formation of H_2 molecules has been discussed by Jura (1975, Astrophys. J. 197, 575), Allen and Robinson (18.131.029), Barlow and Silk (18.131.020), Hollenbach et al. (18.064.019), and Tabak (20.131.086); for the intercloud environment, by Hill and Hollenbach (18.131.108) and by Joshi and Tarafdar (20.131.199); for reviews, see Watson (18.131.112) and Dalgarno (20.131.102). The most probable mechanism is

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

H_2 formation by recombination of H I atoms on (possibly graphite) grains, followed by ejection, possibly in an excited state; a gas-phase reaction involving H^- may occur under special conditions.

Population distributions of rotational levels have been calculated by Jura (1975, Astrophys. J. 197, 575), Hill and Hollenbach (18.131.108), and Hollenbach et al. (18.064.019); Green et al. (1978 Astrophys. J. Suppl. 36, No. 4) publish collisional cross-sections. The population ratio of the two lowest rotational levels gives the kinetic temperature; Savage et al. (20.131.036) find for 61 stars with $N(H_2) > 10^{18}$ cm^{-2} a range from 45 to 128 K, with average 77 ± 17 K. Toward ζ Pup, with $N(H_2) = 2.8 \times 10^{14}$ cm^{-2} only, Morton and Dinerstein derive an excitation temperature of 1120 ± 80 K from the higher levels. Volume densities range from 10 to over 1000 cm^{-3} (Jura 1975, Astrophys. J. 197, 575 and 581). The ultraviolet radiation fields sometimes far exceed the general interstellar field, indicating that a cloud is near an early-type star (Jura 1975b). Spitzer and Morton (17.131.049) find high densities and strong fields for H_2 in approaching clouds in front of ζ and κ Ori; these clouds must be thin sheets, possibly caused by shock waves in expanding H II regions or circumstellar winds. Jura (20.131.169) places an H_2 cloud 0.1 pc in front of Maia in the Pleiades and associates it with the well-known reflection nebulae.

Infrared vibrational transitions around 2.1 μm have been detected in the Orion Nebula by Gautier et al. (18.132.004) and mapped by Grasdalen and Joyce (18.132.020) and Beckwith et al. (1978, Astrophys. J. 223, 464). The excitation temperature is ∿2000 K and $N(H_2) \sim 10^{19}$ cm^{-2}. Although UV pumping has been considered as a possible excitation mechanism by Hollenbach and Shull (20.134.006) and Hill and Hollenbach (1978, Astrophys. J. 225, 390), collisional excitation in a shock-heated region appears more likely. Hollenbach and Shull (20.134.006), Kwan (20.131.046), and London et al. (20.134.017) agree on shock velocities of 10 - 20 km s^{-1} and pre-shock densities of 10^5 - 10^6 cm^{-3}; hence, the emission must come from a sheet of $\sim 10^{13}$ cm (=1 AU!) thickness and $\sim 10^{18}$ cm length. Shock models have been elaborated, and compared with UV pumps, by Shull and Hollenbach (1978, Astrophys. J. 220, 525); the shock may be due to stellar wind, an expanding H II region, or to an explosion (Kwan, 20.131.046). Joyce et al. (1978, Astrophys. J. 219, L29), observing with improved velocity resolution, show that the IR emission has the same velocity as a giant molecular cloud. Negative results for corresponding lines at 8150 Å (Traub et al. 1978, Astrophys. J. 223, 140) and 12.3 μm (Young and Knacke 1978, Astrophys. J. 224, 848) indicate a visual extinction $A_v \gtrsim 10$ mag. Khersonskij and Varshalovich (1977, Astron. Zh. Letters 3, 506) estimate the emissivity of rotational lines of HD at 56 and 112 μm wavelength.

On the short-wavelength side of the spectrum, Maccacaro and Sironi (17.131.032) have suggested that H_2 might be detectable by its effects on the soft x-ray spectrum near 25 Å.

So far, there exists no direct information about H_2 on a Galactic scale. Since the excitation of the CO line at 2.6 mm is probably governed by collisions with H_2 molecules, the distribution and motions of CO are generally considered representative. Burton (20.155.027) shows that CO, just as H II regions, γ-ray sources, synchrotron radiation, and supernova remnants, is largely confined to distances R of 4-8 kpc from the Galactic center, while H I extends much farther out. Thus, while in the solar neighborhood H_2 represents only a quarter of the total interstellar hydrogen, at R ∿ 6 kpc it dominates over H I. Also (Burton and Gordon, 18.155.008, 20.155.026 and 1978, Astron. Astrophys. 63, 7), the CO layer is thinner and more clumped; however, the overall kinematics are the same as for H I, and both are depleted at R < 4 kpc. Similar results have been obtained by Scoville et al. (20.155.020) and by Cohen et al. (Astrophys. J. 217, L155; IAU Symp. 84). Yuan and Dickman (IAU Symp. 84) detect CO also in the Perseus Arm. Bania, and Liszt and Burton (both: IAU Symp. 84) discuss CO in the inner parts of the Galaxy.

Estimates of the amount of H_2 in the Galaxy depend critically on saturation corrections for the strong CO line and on assumed abundance ratios. Dickman (1978, Astrophys. J. Suppl. 37, 407) derives a ratio $N(H_2)/N(CO) = (5.0 \pm 2.5) \times 10^5$ by comparison of CO measurements at 2.6 mm and visual extinctions A_V from star counts, assuming that $N(H_2)/A_V$ in dense dark clouds can be obtained from the gas/dust ratio measured elsewhere.

A new possible H_2 tracer is the CH molecule, now well surveyed by Johansson et al. (IAU Symp. 84); its distribution appears similar to that of CO. Much coarser, though of increasing importance, are the observations of gamma rays (Kniffen et al., 20.157.001; Paul, IAU Symp. 84), which may indicate the overall distribution of interstellar gas.

4. Ultraviolet and Visual Interstellar Absorption Lines and the Composition of the Interstellar Gas

(D.C. Morton)

During the past 3 years the Copernicus satellite spectrometer has continued to provide most of the new information on interstellar absorption lines. Some of these results have been reviewed by Spitzer and Jenkins (14.131.114) and more recently by Spitzer (17.131.128). Balloons (14.131.207 and 1978 Publ. Astron. Soc. Pacific 90, 89) have provided some data on Mg I and II, and the TD1 satellite (de Boer and Lamers 1978 Astron. Astrophys.) has measured these ions and Mn II and Fe II. The International Ultraviolet Explorer (IUE) is now giving results for $\lambda > 1150$ Å (Grewing et al. and Dupree et al., Nature 275, 394 and 400). From the ground, high-resolution interferometers and echelle spectrographs have given valuable data on line profiles and extremely weak features. The analysis of lines is becoming more sophisticated through the use of multiple-cloud models to fit the profiles and the inclusion of the hyperfine structure of the transition when appropriate.

Improvements and additions continue to be made to the necessary oscillator strengths and sometimes even to the laboratory wavelengths for interstellar lines. Morton (1978 Astrophys. J. 222, 863) has tabulated the latest data for atomic lines, and more recently Lugger et al. (1978 Astrophys. J. 224, 1059) have used Copernicus observations to obtain oscillator strengths for many N I lines. Morton and Dinerstein (17.131.037) have calculated wavelengths and oscillator strengths for most of the H_2 lines likely to appear in far-UV spectra. New f-values have been determined for OH 1122 Å (Ray and Kelly 14.022.073, Chaffee and Lutz 19.131.072), CH^+ 4233 Å (Erman 19.022.022), and H_2O 1240 Å (Smith and Parkinson 1978 Astrophys. J. 223, L127).

The Sun remains the most useful basis of comparison for abundances. A re-analysis of C, N, and O relative to H by Lambert (1978 Monthly Notices Roy. Astron. Soc. 182, 249) resulted in little change for these elements in standard compilations such as that prepared by Withbroe (06.071.021). However, the Sun may not be representative of all parts of the interstellar gas. Pagel et al. (1978 Monthly Notices Roy. Astron. Soc. 184, 569) have pointed out that new data on optical line widths and radio recombinations indicate that temperature fluctuations may not be significant in the central part of Orion, and hence one correction to abundances can be omitted. The O/H ratio is Orion is about half that in the Sun. On the other hand, the Sun may be the best standard for elements that can be strongly depleted in the gas between the stars. Olthof and Pottasch (14.132.041) found evidence that the Fe/H ratio in the Orion Nebula is about 1/20 that in the Sun.

A. SURVEYS OF PARTICULAR ATOMS AND MOLECULES

The local density of H I has been obtained from Copernicus observations of the interstellar absorption superposed on the Lα emission from nearby stars. A summary of the data on five stars by Dupree et al. (20.131.148) shows that the nearby gas is rather clumpy with the average n(H I) ranging from 0.03 ± 0.01 cm^{-3} towards α Aur (14 pc) to 0.20 ± 0.05 cm^{-3} towards α Cen A (1.3 pc). The detection of photons from the hot white dwarf HZ 43 (60 pc) shortward of 670 Å shows that n(H I) ≈ 0.02 in that direction (18.126.020; 19.126.004). Variations between 0.008 or less for β CMa and 12 cm^{-1} for ρ Oph over larger distances were obtained by Bohlin (14.131.043) and Bohlin et al. (1978 Astrophys. J. 224, 132) from the Lα absorption in hot stars. Freeman et al. (19.131.165) failed to detect He I at 548 Å in the direction from which the interstellar medium approaches the Sun. They concluded that n(He I) < 0.004 cm^{-3}, which is consistent with a low H I density if He/H has its cosmic value of about 0.1. The H I velocity components are usually lost in the saturated Lyman lines, but Giovanelli et al. (1978 Astrophys. J. 219, 60) were able to make useful comparisons with visible and UV lines towards several stars using high signal-to-noise 21-cm profiles.

D I absorption has also been detected in the *Copernicus* profiles. According to the summary of nine stars by Dupree et al. (20.131.148), D/H ranges between 0.24 x 10^{-5} for α Cen A to 3.9 x 10^{-5} for α Aur with data extending as far as μ Col at 1060 pc. However, within the estimated errors D/H = (1.8 ± 0.4) x 10^{-5} would be consistent with all stars except α Cen A, where the D I line is unusually weak. Although there is no evidence for variations in D/H when the average is taken over 100 pc or more, the low ratio for α Cen A raises the question of whether some of the D has been produced since the Big Bang by synthesis or spallation. Vidjal Madjar et al. (1978 Astrophys. J. 223, 589) have proposed that the anisotropy in nearby O and B stars produces a selective radiation force in the unsaturated D I lines that accelerated D I relative to H I in the direction of $\ell = 90^{\circ}$, enhancing the D I towards α Aur and depleting it towards α Cen. Jenkins and Shaya (1978 Bull. Am. Astron. Soc. 10, 465) surveyed the C I lines in 30 stars and found a steep increase of the C I column density with that of H I and H_2, presumably because the increasing extinction of light with λ < 1100 Å reduces the ionization of carbon.

Lugger et al. (1978 Astrophys. J. 224, 1059) investigated the N I lines in ten stars, including both reddened and unreddened ones. Although the column density of hydrogen nuclei ranged from 21.2 to 19.0 dex cm^{-2}, the depletion of N I was relatively small, varying from 0 to 0.64 dex. The detection of the weak intersystem lines of N I at 1159.8 Å (Lugger et al.) and O I at 1355.6 Å (Zeippen et al. 20.022.064) will permit the determination of column densities when stronger lines are saturated.

York (19.131.067) studied the O VI absorption in four stars along with some data on C IV and N V. The ionization equilibrium requires kinetic temperatures between 2.8 x 10^5 and 7 x 10^5 K. In the spectroscopic binary λ Sco the O VI lines remained stationary, indicating that they do not originate in gas directly associated with the B1.5 IV star. A more extensive O VI survey in 72 stars by Jenkins (20.131.097; 1978 Astrophys. J. 219, 845 and 220, 107) shows no evidence of correlation with the properties of the stars. The line widths increase with distance, apparently due to multiple clouds which average about 6 kpc^{-1} each with N(O VI) ≈ 10^{13} cm^{-2}. The interstellar O VI lines are entirely different from the much broader P Cygni absorption profiles because of the stellar wind, as shown for example in a plot for ζ Pup (17.114.303). McKee and Ostriker (20.131.111) have proposed that the O VI originates in the conductive interfaces between clouds and an intercloud medium heated to 5 x 10^5 K by supernovae.

Towards HD 153919, Dupree et al. (1978, submitted to *Nature*) found ratios of C IV/Si IV and N V/Si IV consistent with the photoionization model by McCray et al. (19.131.011) but significantly smaller than in the interstellar bubble calculated by Weaver et al. (20.064.037 and 1978 Astrophys. J. 220, 742).

The Mg II doublet at 2800 Å and the Mg I line at 2852 Å have been observed in several stars with balloon-borne spectrographs using either photographic recording (14.131.207; 14.131.143; 17.131.118; 20.131.183) or a TV sensor (1978 Publ. Astron. Soc. Pacific 90, 89). Mg II also has been measured in six stars within 27 pc by Copernicus (1978 Astrophys. J. 220, L97); in the case of α Leo the equivalent widths are about twice those obtained with the balloons. The lines are saturated in many of the stars, making the column densities uncertain when derived from simple curves of growth or from the assumption that Mg is distributed like Na I or Ca II. De Boer and Lamers (1978 Astron. Astrophys.) reported equivalent widths of Mg I, Mg II, Mn II, and Fe II obtained with the TD1 S59 satellite, but in some cases the values are smaller by a factor of two compared with those obtained by Copernicus and IUE.

Jura and York (1978 Astrophys. J. 219, 861) have surveyed the lines of Cl I, Cl II, and P II with Copernicus. They concluded that Cl is depleted by a factor of three or less depending on what is adopted for its cosmic abundance, and P is depleted by a factor of two or three, in contrast with the large depletions found for Fe. Since Fe and P should have the same condensation temperature, these observations favor the growth of grains in the general interstellar gas rather than by condensation in regions where T ≃ 1200 K. Savage and Bohlin (1978 Astrophys. J.) have determined depletions of Fe II in 55 stars ranging from -0.1 to -2.5 dex.

A new form of interstellar gas has been identified by Cohn and York (20.131.042) in the profiles of C II, C III, N II, and Si III, where there are features with $|V_{LSR}| > 20$ km s^{-1}. Some Orion stars have components of C III and Si III between -80 and -120 km s^{-1}. The ionization can be explained by collisions in a gas with temperatures between 2 x 10^4 and 10^5 K, possibly resulting from radiatively cooling shocks due to SNR or stellar winds (Shull 20.131.043). Cowie and York (1978 Astrophys. J. 220, 129; 223, 876) have presented additional data and found that most of the material lies between 20 and 60 km s^{-1} in components which can also be seen in Ca II.

High-resolution ground-based observations have extended our knowledge of interstellar Li I, Na I, K I, Ca II, and Ti II. Vanden Bout et al. (1978 Astrophys. J. 221, 598) measured the Li I absorption lines at 6708 Å in ζ Per and ε Aur. An estimate of the ionization correction for ζ Per indicates the Li has about half the abundance found in carbonaceous chondrites.

Hobbs has continued his PEPSIOS scans of Na I, K I, and Ca II, both for stars of minimal reddening (14.131.155; 17.131.137) (1978 Astrophys. J. 222, 491; Publ. Astron. Soc. Pacific 90, 301) and for others (17.131.006; 1978 Astrophys. J. Suppl. 38). Beintema (14.131.199) has published an extensive set of Ca II profiles ranging over ± 70 km s^{-1} and has compared them with 21-cm emission. Crutcher has observed the weak Na I lines at 3302 Å (14.131.156) and the weak K I line at 4044 Å (1978 Astrophys. J. 219, 72), permitting the determination of column densities where the stronger lines are saturated. Jura (17.131.145) has shown that H_2/Na I does not vary much among clouds, while Na I/Ca II does because of varying amounts of Ca in grains.

The hyperfine structure in the Na I D_1 and D_2 lines was resolved for the first time by Wayte, Wynne-Jones, and Blades (1978 Monthly Notices Roy. Astron. Soc. 182, 5p). In α Cyg they found one cloud component with b = 0.38 km s^{-1}, corresponding to a kinetic temperature of 200 K. It is important to remember such low internal velocities can exist when analysing saturated profiles. Stokes and Hobbs (18.131.049) and Stokes (1978 Astrophys. J. Suppl. 36, 115) have observed Ti II at 3384 Å with an echelle scanner in 68 stars. The depletion of Ti ranges from 0.1 to 2.9 dex but is well correlated with Ca at four times the solar ratio of Ti/Ca.

The Copernicus investigations of H_2 have been considerably extended in several papers, including a survey of column densities in J"= 0 and 1 by Savage et al. (1977

Astrophys. J. 216, 291), measurements of J" = 1 lines in the directions of five stars with low reddening by York (17.131.050), and an analysis of the velocity components in several stars by Spitzer and W.A. Morton (17.131.049). This last paper showed that the more negative velocities had higher rotational temperatures. The H_2 results have been summarized by Spitzer (17.131.128).

Crutcher and Watson (17.131.013) found the OH absorption line at 3078 Å in ζ Oph and ο Per, and Snow (17.131.053; 14.131.090) detected the UV line at 1222 Å in ζ Oph and possibly in ο Per. In both stars the derived column densities show serious discrepancies, probably due to the adopted f-values. Chaffee and Lutz (19.131.072) measured OH lines at 3078 and 3082 Å in ζ Per. Crutcher and Watson (18.131.128) failed to detect NH towards ο Per. Since both NH and OH should form at about the same rate on grains, the severe lack of NH implies that the molecules form in the gas phase. NaH was not found in ζ Oph and σ Sco (20.131.062).

C_2 absorption from J" = 2 at 10139 and 10148 Å has been detected in VI Cyg 12 by Souza and Lutz (20.131.040) and at 8761 Å in ζ Oph by Chaffee and Lutz (1978 Astrophys. J. 221, 191). In addition, absorption from J" = 0 at 2313 Å at the 40 level has been reported by Snow (1978 Astrophys. J. 220, 193), but his derived upper limit in the column density is a factor 2.7 below the Chaffee-Lutz detection, probably due to an incorrect f-value.

A catalogue of stars with the diffuse interstellar bands at 4430, 5780, 5797, and 6284 Å has been prepared by Snow, York, and Welty (19.131.102). New observations have been published for 4430 by Walborn (1977 Publ. Astron. Soc. Pacific 89, 765), for 5780 by Savage (17.131.096) and Schmidt (1978 Astrophys. J. 223, 458), for both 5780 and 5707 by Danks and Lambert (17.131.001), for 6379 and 6614 by Welter and Savage (20.131.014), and for 4430, 5780, and 5797 in ten stars around ρ Oph by Snow and Cohen (17.131.075). Walborn found an unusually strong 4430 line in HD 97950, the central star of NGC 3603. A search from 1114 to 1450 Å at 0.2 Å resolution by Snow, York, and Resneck (1977 Publ. Astron. Soc. Pacific 89, 758) revealed only one possible diffuse band at 1416 Å. Correlations between 4430 and the broad UV absorption band at 2200 Å have been found by Nandy and Thompson (14.131.115) and Dorschner, Friedemann, and Gurtler (19.131.121; 20.131.014), but the groups disagree on the strength and the correlation. Sneden et al. (1978 Astrophys. J. 223, 168) found that the diffuse bands do not correlate well with visual and IR extinctions, suggesting that the grains producing these extinctions are not the source of the bands.

B. ANALYSIS OF INDIVIDUAL LINES OF SIGHT

Zeta Oph continues to receive attention as a bright star shining through several interstellar clouds, including at least one with a density exceeding 10^3 H nuclei cm^{-3}. Black and Dalgarno (20.131.068) have used the analysis of the visual and UV absorption lines by Morton (13.131.045) to model the main cloud as two components with a temperature and total hydrogen density of 100 K and 500 nuclei cm^{-3} in an outer part and 22 K and 2500 cm^{-3} in a core. Crutcher (14.131.108) has attempted a resolution of the visual line profiles into five components and pointed out their importance in the analysis of strong lines. Zeippen et al. (20.022.064) found that oxygen towards ζ Oph is depleted between -0.50 and -0.25 dex, although de Boer (preprint) obtained -0.12 from fitting the wings of the OI profile at 1302 Å. Snow and Meyers (1978 preprint) have decomposed the ζ Oph profiles of Mg II, P II, Mn II, and Fe II into components at heliocentric velocities of -14.4, -17.5, and -29.2 km s^{-1} with b = 2.5, 3.0, and 4.0 km s^{-1} respectively. Although the cloud at -29.2 km s^{-1} has less than 1% of the hydrogen, it contains half of the Fe II, and all four elements occur with approximately solar abundance ratios.

Wright and Morton (1978 Astrophys. J. 226) detected rotationally excited HD in the spectrum of ζ Oph and concluded that it is consistent with the model of Black and Dalgarno. Crutcher (17.131.151) measured the CO radio emission from clouds towards ζ Oph and o Per. Smith et al. (1978 Astrophys. J. 220, 138) analysed the UV CO lines and derived a one-component model. Towards ζ Oph the radio and optical CO lines agree in velocity and width with each other and with H_2 and the strongest neutral atomic lines, but CH^+ is in a different cloud. Morton (1978 Monthly Notices Roy. Astron. Soc. 184, 713) has found that 23 of the 47 unidentified UV lines in ζ Oph are due to C I, four others can be attributed to H_2 or HD, and one is spurious.

The far UV lines in the reddened stars o and ζ Per have been investigated by Snow (14.131.090; 17.131.051; 20.131.047), and the atomic and molecular lines in ζ Per between 3060 and 3390 Å have been observed by Chaffee and Lutz (19.131.072). A model for the main ζ Per cloud has been developed by Black et al. (1978 Astrophys. J. 224, 448). Like ζ Oph, a cold core is required with a temperature of 45 K and hydrogen density of 267 nuclei cm^{-3} surrounded by a region at 120 K and $100 cm^{-3}$. The visible lines in ρ Oph have been discussed by Hobbs (14.131.053) and Crutcher (18.131.047). In the Carina nebula, complex structure was found in the Ca II lines by Walborn and Hesser (14.131.015) with velocities ranging from -196 to +103 km s^{-1}.

In less obscured directions, the Copernicus data on γ Ara have been analysed by Morton and Hu (14.131.157), and high-velocity lines towards ζ Ori have been discussed by Drake and Pottasch (19.131.032). Jenkins, Silk, and Wallerstein (18.125.021; 19.125.001) have studied the UV lines in four stars associated with the Vela SNR, and Morton and Bhavser (1979 Astrophys. J. 227) have examined the lines in the spectrum of γ Vel. Also in the Gum Nebula, Morton and Dinerstein (17.131.037) and Morton (1978 Astrophys. J. 222, 863) have published analyses of all the H_2 and atomic lines towards ζ Pup. Shull and York (19.131.023, 025, 036) have investigated the far UV lines towards the unreddened stars μ Col, HD 28497, and HD 50896.

5. Interstellar Grains

(B. Donn)

Observational and experimental research appear to be the most significant areas of recent progress. Theoretical investigations and conclusions are subject to uncertainties arising from our lack of knowledge concerning the characteristics of grains and their physical and chemical properties; however, current work should improve the basis for theoretical analysis and interpretation.

Several useful reviews and symposium proceedings have appeared since the IAU Report of 1976. Those dealing predominantly with grains are: Wickramasinghe and Morgan (17.012.001); Huffman (20.131.177); Salpeter (20.131.158); Andriesse (20.131.035); and Greenberg (Physics and Astrophysics of Cosmic Grains: Erice Summer School on Infrared Astronomy, in press). Two compendia treat interstellar and interplanetary grains, for which a physical relationship appears likely: "The Dusty Universe" (17.012.027), and "Cosmic Dust" (McDonnell 1978). The book "Protostars and Planets" (Gehrels 1978) and accompanying special issue of Moon and Planets contain many significant papers on the properties, formation, and interactions of grains. Other reviews and conference proceedings have material relevant to the subject; IAU Symposium proceedings and the Annual Reviews of Astronomy and Astrophysics are especially valuable.

The ultraviolet albedo and phase function have been determined from a number of investigations with conflicting conclusions. Lilley and Witt report increasing albedo from 2000 to 1500 Å with a more symmetric scattering at shorter wavelengths (Astrophys. J. 222, 909, 1978). Henry et al. report little large-angle scattering (Astrophys. J. 222, 902, 1978), while Morgan (Astron. Astrophys., in press) and Morgan et al. (Monthly Notices Roy. Astron. Soc. 185, 371, 1978) find little or no

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increase of albedo for λ less than 2000 Å. From observations of Merope, Andriesse et al. (Astron. Astrophys. 54, 541, 1977) tend to confirm the results of Lilley and Witt.

A theoretical study of scattering by reflection nebulae has been made by Jura (20.131.169). Observational results for the visible spectrum are given in several papers, e.g., 14.132.037, 062 and Shah (Astron. Nach. 298, 319, 1977).

Infrared observations and their interpretation are reviewed by Ney (20.131.059). A summary of stellar and nebular infrared results appears in a review by Merrill ("Interaction of Variable Stars with Their Environment", IAU Coll. 42, p. 446). Carbon-star spectra appear in 20.114.028 and observations of ice and silicate absorption in clouds in 18.131.031. Unidentified emission features are described by Russell et al. (20.135.011). Many other papers on infrared observations relevant to grain research are indexed in the various journals.

Gillette et al. (14.131.162) conclude that laboratory silicates cannot account for the ratio of extinction to the 10 μm band intensity. Many minerals, as well as Brudersheim meteorite material, fail to account for the 2000 Å feature, according to work of Egan and Hilgeman (14.131.037). Bussoletti and Zambetta (18.022.026), Day (14.131.024), Dorschner et al. (17.131.129; 20.131.195; Astr. Nach. 298, 279, 1977; see also 14.131.192; 14.105.028) have published measurements of extinction or infrared-band absorption.

Various species of carbonaceous material have been proposed as interstellar grains and examined by Hoyle, Wickramasinghe and colleagues (20.131.023, 096; Nature 270, 701, 1977; and Astrophys. Space Sci. 53, 489, 1978, work which claims to account for the near-infrared interstellar spectrum). Other proposals appear in 20.131.026, 190. Observations of circumstellar emission from M stars and carbon stars show that both silicate and carbonaceous grains form.

Many minerals and related species were studied in the infrared by Rose (unpublished Univ. of Minnesota thesis). Magnetite as an interstellar grain constituent was discussed by Landaberry and Magakhar (20.131.179). The temperature-dependence of graphite scattering is reported in 14.131.168 and that of silicates in the far ultraviolet by Lamy (Icarus 34, 68, 1978).

Theoretical calculations for spherically stratified graphite grains were made by Wickramasinghe (14.131.028), and for heterogeneous grains by Bohlen and Wickramasinghe (20.061.044). Absorptive properties for core-mantle grains were calculated by Aannestad (14.131.028); for spheres with nonisotropic refractive indices, by Wang and Greenberg (17.063.037); and for grains with resonant impurities, by Purcell and Shapiro (19.131.100). Consequences of defects in crystalline grains and of particle irradiation are discussed by Drapatz and Michel (19.131.095), Day (19.022.011), and Czyzak et al. (18.131.022).

The existence of crystalline grains, particularly of terrestrial minerals, has been questioned by Donn (18.131.105), who outlined a kinetic treatment of grain formation. Condensation experiments by Day and Donn (Astrophys. J. 222, 145, 1978; Science, Oct. 1978) yielded non-equilibrium condensates supporting this conclusion and showed how data needed for astronomical calculations may be obtained. An experimental condensation program now in progress at the University of California, San Diego will also supply basic data; see Arnold ("Comets, Asteroids, and Meteorites", Delsemme, ed., Univ. of Toledo 1977, p. 519), and Stephens and Kothari (Moon and Planets, in press).

Theoretical treatments of grain formation have been carried out by several authors. Salpeter (17.131.143) reviewed formation and destruction in supernovae and planetary nebulae; other papers are: 17.131.027; 14.131.190; 14.133.022, 026; and

Shields (Astrophys. J. 219, 559, 1978). Clayton (in "Protostars and Planets") examines supernovae formation in some detail. Novae shells containing infrared-emitting grains serve as cosmic laboratories where the initiation and development of condensation may be observed. Grain formation in novae envelopes has been studied by Clayton and Hoyle (17.124.002), Clayton and Wickramasinghe (18.124.002), Gallagher (19.124.002, containing an extensive reference to observations), and Yamamoto and Nishida (Prog. Theor. Phys. Japan 57, 1939, 1977).

A detailed discussion of grain formation based on nucleation theory was developed by Yamamoto and Hasegawa (Prog. Theor. Phys. Japan 58, 816, 1977). The destruction and growth of grains has been investigated by Barlow (Monthly Notices Roy. Astron. Soc. 183, 367, 397, 417, 1978). Papers on grain destruction, mainly sputtering, include 17.131.158; 18.131.188; 20.131.016; and Draine and Salpeter (1979a,b in preparation); see also Lanzerotti et al. (Nature 272, 431, 1978), Onaka and Kamijo (Astron. Astrophys. 64, 53, 1978), and Draine (Astrophys. J. 229, 1979: chemisputtering of graphite). Consequences for heavy-element depletion are given in 14.131.142; 19.131.017; and by Duley and Millar (Astrophys. J. 220, 124, 1978). Effects of grain collisions are discussed by Hayashi and Nakagawa (17.131.170) and in 18.131.032. Novel structures are predicted in 19.131.054, 082.

Simplified treatments and assumptions of thermodynamic equilibrium have been criticized by Donn in the papers noted and in "Protostars and Planets." Application of these results to the origin of dust in η Car has been given by Andriesse et al. (Monthly Notices Roy. Astron. Soc., in press). A protoplanetary source of grains has been proposed by Mendis et al. (14.107.015). This leads to a developing area, the relation between interstellar and primordial solar-system solids: see Cameron (17.012.027); Lattimer et al. (Nature 269, 116, 1977); Falk et al. (Nature 270, 700, 1977); Margolis (Moon and Planets); and a series of papers by Clayton listed in his "Protostars and Planets" paper. Penetration of grains into the present Solar System has been examined by Levy and Jokipii (18.131.207) and by Greenberg (14.131.137).

The temperature fluctuations of small grains have been studied by Gail and Sedlmayr (14.131.098), Purcell (17.131.144), and Seki and Yamamoto (Prog. Theor. Phys. Japan 59, 1142, 1978). Temperatures for iron grains reaching 133 K were calculated by Tabor (20.131.197) and for graphite by Aiello et al. (20.131.202). Aiello et al. (20.131.001) calculated temperature distributions and infrared emission for dust clouds using experimental refractive indices for silicates.

Iguchi (14.131.045) concluded that below 20 K saturated molecules form on grains and that above 50 K unsaturated species occur. In a series of papers, Allen and Robinson (13.131.005; 18.131.029; 19.131.045) developed a model of molecule formation on small grains and calculated the time-dependence of the composition of dense clouds. Abadi et al. (18.131.107) considered absorption and catalyses for very porous grains. Pickles and Williams (20.131.203) modeled steady-state formation rates on grains and found surface properties to be unimportant. Barlow and Silk (18.131.020) concluded that recombination on graphite is the principal source of H_2; later (20.131.015) they found that H+O above 60 K yielded H_2CO. Duley and McCullough (19.131.015) reported laboratory investigations of simulated grain materials and found evidence that absorption of interstellar molecules will yield molecular ions. Duley and Millar (Monthly Notices Roy. Astron. Soc., in press) found that metal-oxide grains may be effective catalysts for molecules. In a theoretical study, Hunter and Watson (to be published) found desorbed H_2 molecules to have about 0.2 eV translational energy and average rotational state above J=7. Schmoluchowski, in an ongoing study, concludes that on amorphous H_2O with volatile impurities, H atoms cannot move freely and H_2 recombination will be very low.

Photoelectric heating of interstellar gas by grains was considered by Barlow and Silk (20.131.015), Jura (17.131.038), de Jong (19.131.052), and Draine (Astrophys. J. Suppl. 36, 595, 1978). Gail and Sedlmayr (14.130.030) and Simons

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(14.131.155, 006) calculated charge-distribution functions, relaxation times, and some consequences of grain charge. Effects of grain radioactivity were investigated by Yanagita (20.131.200).

Power-law grain-size distributions to fit the extinction curve, using combinations of grain composition, were reported by Mathis et al. (20.131.074). Polarization presented some difficulties. Hong and Greenberg (Astron. Astrophys., in press) claim to fit visible extinction and polarization with an exponential distribution of dielectric particles. Witt (Publ. Astron. Soc. Pacific 89, 750, 1977) and Greenberg (18.131.208) conclude that a bimodal distribution is needed to explain high ultraviolet albedo. Andriesse (Astron. Astrophys. 16, 169, 1978) suggests that the infrared observations of M17 can be explained by temperature fluctuations to 150 K for 10 Å grains (Platt particles). Large grains are proposed for the Orion nebula by Rowan-Robertson (14.131.019); Breger also proposes large grains to explain the wavelength dependence of polarization of some Orion stars (19.131.125). The infrared interpretation has been criticized by Andriesse (17.132.005).

Breger (17.131.052) surveyed over 200 stars near the Orion nebula for polarization. Polarization of Galactic center sources at 3-13 μm was measured by Capps and Knacke (to be published), who propose aligned silicate grains in a minimum field of 5×10^{-4} Gauss. Polarization is an increasingly active field, and many other observational papers on linear polarization, interstellar birefringence, and circular polarization, together with theoretical investigations, are listed in the references cited earlier. In work recently completed, Purcell examines the effects of suprathermal rotation on interstellar grain alignment; in a companion paper, Spitzer and McGlynn examine the consequences for grain alignment of torque reversal arising from grain-surface changes. Hong and Greenberg (Astron. Astrophys., 1978) studied consequences of polarization reversal due to strong optical resonances.

Snow et al. (20.131.109) conclude that observations of diffuse bands are as consistent with a molecular origin as with a grain origin. Duley reports research on the origin of diffuse bands based on grain composition and structure (14.131.049; 20.131.189). Polarization measurements of the 6284 Å band in HD 183143 were made by Fahlman and Walker (14.131.027).

Investigations of the relation between grains and far-infrared or millimeter radiation appear in 14.131.014, 035, 050; 18.131.126; 20.131.013; 20.132.027; and 20.133.010, 013, 014. A report on a balloon observation of far-infrared emission from the Galactic plane by Maihara et al. will also be published. At the other extreme, Lingenfelter and Ramaty (19.131.010) have examined possible gamma-ray lines from interstellar grains.

The interstellar extinction curve and ratio of total absorption to extinction are still active fields, and numerous papers are to be found in the usual sources. The same is true for research on dust distribution and regional characteristics. A detailed study of dust in globular clusters was made by Kanagy and Wyatt (Astrophys. J. 83, 779, 1978). Dust emission from envelopes around late-type stars yielding information on grains was studied by Jones and Merrill (18.064.034) and Tsuji (to be published).

A subject that has become active rather recently is the laboratory study of ultraviolet effects on ice mantles, notably by Greenberg and associates (17.131.024; also, Fourth IAU Regional Meeting, 1978, to be published). Allamondola and Norman propose fluorescent line emission from icy mantles to explain the unidentified infrared-emission features in nebulae (Astron. Astrophys. 63, L23, 66, 1978).

The question of intragalactic dust has been treated by Wesson (18.131.222), who places limits determined by the isotropy of the microwave background. Abadi and

Edmunds (19.161.004) used galaxy counts and obtained an optical depth of 0.09 ± 0.01 associated with intragalactic hydrogen clouds. Margolis and Schramm (19.161.006) estimated optical depths around clusters of galaxies to be ∿0.1.

6. Interstellar Molecules

(M. Morimoto)

A. NEW MOLECULES, SEARCHES, AND IDENTIFICATIONS

Two ionic molecules, HCO^+ (14.131.052; 17.131.111; 18.131.061, 225) and N_2H^+ (14.131.091; 17.061.019), were positively identified, and the long chain molecules HC_5N through HC_9N (17.131.116; Kroto et al., Astrophys. J. 219, L133; Broten et al., Astrophys. J. 223, L105) were discovered. These achievements were the results of intensive theoretical, laboratory and observational efforts and have provided highly useful information on interstellar chemistry. Two molecules with NO bonds were also detected. The detection of methane (20.131.178) was announced briefly, but as of this writing neither a full account of the supporting observations nor confirming observations have appeared in the literature. New molecules discovered or identified in the reporting period are listed in the following table:

NO	Turner preprint, NRAO
HNO	20.131.077
C_3N	19.022.015, 016
H_2CCO	19.131.073
HC_5N	see text
HC_7N	see text
NC_9N	see text
C_2H_5CN	20.131.149
N_2H^+	see text
HCO^+	see text
C_2	20.131.040

Other unsuccessful searches are reported in 18.131.060, 127; 19.131.114; and Hollis et al., Astrophys. J. 219, 74.

The J=3→2 line of CO (870 μm) was detected, extending the "radio" spectral observations to sub-mm wavelengths (18.131.259; 19.131.193; 20.131.094). The 183-GHz water emission line was detected from an airborne observatory (18.132.043). Theoretical (14.131.021, 116; 18.131.017; Kroto et al., Astrophys. J. 219, 886; Barrett, Astrophys. J. 220, L81; Wilson, Astrophys. J. 220, 737 and 739) and laboratory (14.022.089; 14.131.204; 18.022.018; 18.131.026, 152) studies of molecular structure and energy levels were carried out to predict new line frequencies. Large numbers of unidentified molecular lines are believed to have been detected, but frequencies and/or other important information are not available in the literature. Optical observations yielded discovery of C_2 (20.131.040) and other negative results (18.131.128; 19.131.163; 20.131.062).

B. ISOTOPE REPLACEMENTS

Many new isotope replacements of known and newly found molecules were discovered: $H^{13}CO^+$ (18.131.061), which provided a clue for its identification; $HN^{13}C$ (18.131.033); ^{17}OH (18.131.015); DCO^+ (18.131.111); ^{30}SiO (20.131.066); DNC (20.131.030, 049, 054); $H^{15}NC$ (20.131.031); N_2D^+ (20.131.151); $H_2{}^{18}O$ (Philips et al., Astrophys. J. 222, L59); and NH_2D (Turner et al., Astrophys. J. 219, L43; Kuiper et al., Astrophys. J. 219, L49). The detection of CH_3NHD was reported (19.131.039), but following observations (Broten et al., preprint, ARO) showed no spectral line at the specified frequency. Observations were also made of already discovered species (14.131.062, 087, 169, 170, 171; 17.131.040, 055, 115, 125, 179;

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18.131.067, 163, 239, 179, 282; 19.131.040, 047, 050, 097, 145, 146, 147, 148, 149; 19.155.002; 20.102.051; 20.131.053, 117, 122; Watson et al., Astrophys. J. 222, L145; Whiteoak and Gardner, Monthly Notices Roy. Astron. Soc. 183, 67p; Turner preprint, NRAO).

Observations of these isotope lines are often believed to provide direct information on nuclear abundances in the Universe; however, the line intensity is not necessarily proportional to isotopic abundance. One must bear in mind the possible major effects of line excitation and optical depth, on the one hand, and of chemical fractionation (e.g., 19.131.151) on the other. Many of the observations mentioned above have been influenced by the former effect, and nearly all of them by the latter. In particular, a dramatic concentration of deuterium in the molecular phase is now apparent (e.g., 18.131.111; 20.131.191; Turner preprint, NRAO). Consideration of these effects makes it increasingly evident that there is a large-scale gradient in isotopic abundance in the Galaxy, in the sense that ^{13}C is more abundant near the Galactic center than in the disk, whereas the reverse is true for deuterium (e.g., Penzias, Comm. Astron. Astrophys., fall 1978). Interpretations of these results in terms of Galactic chemical evolution have also been suggested (18.131.200; 18.064.046; 19.131.167; 20.131.060).

C. INTERSTELLAR CHEMISTRY

There are now three strong lines of evidence that gas-phase reactions play an important role in the production of interstellar molecules: 1) two ionic molecules, HCO^+ and N_2H^+, regarded as important products of ion-molecule reactions, are very abundant; 2) chemical fractionation is known to occur among isotopes in molecules; and 3) extensive mapping observations (19.131.021, 035; Tucker and Kutner, Astrophys. J. 222, 859) support ion-molecule reactions. Calculations of molecular parameters relevant to reactions appear in 14.022.059; 14.131.176; 17.131.175; 18.131.021. Those involving radiative processes appear in 18.022.002, 115; 18.131,030; 19.022.023; Smith and Adams, Astrophys. J. 220, L87. Rates of individual reactions have been studied both theoretically (14.022.084; 14.131.122; 17.131.174; 18.131.274; 19.131.064, 093, 113) and in the laboratory (14.022.063; 14.131.132; 17.022.062; 18.022.037, 104; 18.131.045; 19.022.063; 20.022.033; 20.131.029; Mitchell and McGowan, Astrophys. J. 222, L77).

One of the most important (but least well known) of the environmental parameters figuring in initial chemical reactions is the electron density, or ionization rate. Observations of heavy-element recombination lines appear able to yield electron densities in the vicinity of early-type stars, but not within dense clouds, where most of the reactions take place (e.g., 17.131.106). On the other hand, an upper limit of e/H smaller than 10^{-8} has been deduced from molecular-line observations (see 20.131.095 for DCO^+/HCO^+ and 20.131.151 for N_2D^+/N_2H^+). Chemistries involving the preceding reactions and employing known, calculated, and/or assumed constants, together with various parameters, have been worked out (14.131.146; 17.131.146; 18.131.001, 063, 145; 19.131.031, 034; 20.131.124, 193; Herbst, Astrophys. J. 222, 508).

Numbers of works devote special attention to a single element or species and pursue its chemistry, e.g., CH^+ (14.131.023); oxygen (17.131.121); H_2O (18.131.149); Poly-C_2H_2 (18.131.285); CH_4 (19.131.055); Si (19.131.070); N (20.131.204); NO (Loew et al., Astrophys. J. 219, 458), and CO (Liszt, Astrophys. J. 222, 484). Herbst et al. (19.131.161) consider observable and unobservable molecules related through a simple reaction and consider abundance estimates of the latter; examples are given of protonated ions, such as N_2H^+ vs. N_2. However, it has become evident that some of the important reactions have longer time scales than the dynamical time scale of a contracting cloud (14.131.085, 177; 17.131.107; 20.131.063).

The chemical evolution and structure of molecular clouds (MCs) has received recent attention (17.131.045, 064; 18.131.148, 187; 19.131.117, 166; 20.131.076;

Suzuki et al., Prog. Theor. Phys. 56, 111; Liszt, Astrophys. J. 222, 484; de Jong, Liège Symp. 1977; Gerola and Glassgold, Astrophys. J. Suppl. 37, 1). The formation of molecules, especially CO, has been found to have considerable influence on cloud dynamics and evolution through cooling (14.131.045; 20.131.196; Sabano and Kannari, Proc. Astron. Soc. Japan 30, 77; Goldsmith and Langer, Astrophys. J. 222, 881). Molecular formation in shock waves has also been also studied (19.131.196; Elitzur and Watson, Astrophys. J. 222, L141; Saito and Deguchi, preprint, Tokyo Astron. Obs.). In addition, reactions on grain surfaces have been considered as mechanisms for molecule formation (14.131.145, 180; 17.131.024, 087; 18.131.206, 190, 270; 19.131.045, 056; 20.131.015, 166). The abundances of interstellar molecules have further been compared with those of cometary molecules (20.131.032). Despite these efforts, an overall understanding of interstellar chemistry still lies in the future.

D.EXCITATION AND FORMATION OF RADIO SPECTRAL LINES

Transition probabilities, collisional cross sections, and other molecular parameters relevant to spectral-line excitation have been calculated for CO (14.131.150, 187; 17.131.113); CO and HD (14.131.048); OH (14.022.073; 18.131.056; 20.131.037, 203; Guibert et al., Astron. Astrophys. 66, 395); H_2CO (14.022.044, 054; 17.131.175; 19.131.186); and other molecules (14.131.105, 188, 189; 17.022.096; 18.131.236; 19.131.030, 033, 177; 20.131.022; Dwivedi et al., Astrophys. J. Suppl. 36, 573; Green and Chapman, Astrophys. J. Suppl. 37, 169). Similar laboratory work has been done for H_2CO (20.022.073) and other molecules (17.022.097; 19.022.022; 20.022.009, 054). The formation of molecular lines has been studied for CO (14.131.001; 17.063.007; 18.131.054, 057, 146, 243; 19.131.005, 112; 20.131.216; Kuiper et al., Astrophys. J. 219, 129) and for other molecules (14.131.119; 18.131.005, 150, 237, 245; 20.131.150; Schneps et al., Astrophys. J. 221, 124; Kwan et al., Astrophys. J. 223, 147).

E. RADIO SPECTRAL-LINE OBSERVATIONS

Molecular-line observations serve as a probe of dense, cold gas in our own Galaxy and in other galaxies. Numbers of molecular objects have been observed in various spectral lines, and activity in this field continues to be very high.

(1) Surveys

Many extensive surveys have been carried out, e.g., for CH (18.131.028, 041; 20.131.059, 181; Johansson et al., in IAU Symp. No. 84: "The Large-Scale Characteristics of the Galaxy"); OH (19.131.155); CO (20.155.025); $J=2\to1$ of CO (19.131.179); NH_3 (20.131.165); SO (Gottlieb et al., Astrophys. J. 219, 77); CS (Gardner and Whiteoak, Monthly Notices Roy. Astron. Soc. 183, 711); and HC_3N (17.131.094). CO line surveys in the Galactic plane have revealed the global H_2 distribution in the Galaxy (14.131.016, 117; 17.131.114; 18.131.199; 18.155.008, 012).

(2) Dust Clouds and Reflection Nebulae

Dust clouds have been most extensively studied in the CO lines (14.131.056), 118, 124, 160, 173, 548; 17.131.009, 017, 169; 18.131.036, 110, 123, 129, 147, 201, 214, 238, 278; 19.131.006, 049, 080, 162, 194; 20.131.129; Dickinson, Astrophys. J. Suppl. 37, 407; Lada and Reid, Astrophys. J. 219, 95). Studies of H_2CO absorption (14.131.011, 123, 136; 17.131.030; 18.131.068, 121, 140, 141, 185; 19.131.074), NH_3 (19.131.128, 129, 173; Ho et al., Astrophys. J. 221, L117), OH (14.131.136; 17.131.014, 019, 030, 070; 20.131.020; Mattila et al., Astron. Astrophys., in press), and cyanpolyene (19.131.190; 20.131.085; Little et al., Monthly Notices Roy. Astron. Soc. 183, 45p and 805) were also completed. Further studies including these and other lines appear in 14.131.002, 141, 159; 17.131.054, 056; and 18.131.121, 158. Martia and Barrett (Astrophys. J. Suppl. 36, 1) observed dust globules in CO, CS, NH_3, H_2CO, and OH lines and found evidence of the beginnings of collapse. Myers et al. made mappings of the ρ Oph cloud in H_2CO, H I, OH, NH_3, and CO lines and revealed its structure (Astrophys. J. 220, 864).

(3) Spiral-Arm H II/MC Complexes

The Orion complex has been thoroughly studied (14.131.005, 006, 013; 17.131.120; 18.131.109, 132, 162, 218; 19.131.012, 022, 164; 20.131.048; 20.133.002). Vibrationally excited HC_3N was detected in a KL object (18.131.215). Among other molecular complexes studied were W49 (19.131.063; 20.131.058), the DR21 region (18.131.257; 19.131.022, 111; Dickel et al., Astrophys. J. 223, 840), M17 (18.131.284; 19.131.013), NGC 6334 (20.131.061; 20.132.026), and W3 (18.131.533; Ho and Barrett, Monthly Notices Roy. Astron. Soc. 183, 93p). These and other sources have also been discussed in 14.131.159; 17.131.133; 17.132.003; 18.131.238; 19.131.022, 071, 195; 19.132.005; 20.131.110, 129; Elmegreen and Elmegreen, Astrophys. J. 219, 105; Elmegreen and Lada, Astrophys. J. 219, 467; Blair et al., Astrophys. J. 219, 896; Elmegreen and Elmegreen, Astrophys. J. 220, 510; Elmegreen et al., Astrophys. J. 220, 853; Zeilik and Lada, Astrophys. J. 222, 896; and Lucas et al., Astron. Astrophys. 66, 155. From these observations, the H II/MC complexes appear to be regions of successive star formation, and an overall physical picture seems ready to emerge (e.g., 19.131.063, 164; Dickel, Astrophys. J. 223, 840).

(4) Maser Sources and Circumstellar Molecular Clouds

With respect to OH lines, there have been recent searches and new sources detected (14.131.133, 147, 196; 19.131.091, 141; 19.133.005; 20.131.118; Fix and Weisberg, Astrophys. J. 220, 836; Elitzur, Astron. Astrophys. 62, 305; Bowers, Astron. Astrophys. Suppl. 31, 127; Astron. Astrophys. 64, 307); observations of sources in H II regions (14.131.163; 19.131.154; 19.141.074; 20.131.152, 157) and of stellar sources (18.122.038; 18.131.281; Rosen et al., Astrophys. J. 222, 132; Fix, Astrophys. J. 223, L25); and interferometric studies (18.131.095; 19.122.165; 19.131.009, 098; Reid and Muhleman, Astrophys. J. 220, 229) for ground-state transitions. Studies of excited-state lines appear in 14.131.026; 17.131.126; 19.131.142; and Weinberg, Astron. Astrophys. 66, 431. Theoretical and interpretative work appears in 14.131.022, 125, 151; 17.131.004, 108, 163; 19.022,010; 19.131.079, 160; 20.131.083; Elitsur and de Jong, Astron. Astrophys. 67, 323; and Salem and Middleton, Monthly Notices Roy. Astron. Soc. 183, 491.

Recent work on H_2O masers includes searches and new sources (14.131.092, 121; 14.141.628; 17.131.043, 047, 098, 147, 161; 19.131.092, 110, 188; 20.131.057); monitoring of time variation (14.131.058; 19.131.132, 191; 20.131.028, 128; 20.132.039); interferometer measurements (17.131.099; 18.131.258, 614; 19.131.024, 159; 20.131.018; Foster et al., Astrophys. J. 221, 137; Rosen et al., Astrophys. J. 222, 132; Genzel et al., Astron. Astrophys. 66, 13); analyses of velocity structure (17.131.003; 18.131.176; 19.131.123; 20.131.003, 090); other observational studies (14.131.003, 201; 18.131.217; 20.131.137; Elmegreen and Lada, Astrophys. J. 219, 467; van Blerkom, Astrophys. J. 223, 835); and theoretical and interpretive studies (18.131.013, 122; 20.131.021; 20.133.017), including work relating to OH masers (14.131.046, 057; 17.131.039).

The SiO v=3 maser line has been detected by Scalise et al. (Astron. Astrophys. 65, L7). Other SiO work includes general surveys and monitoring (14.022.056; 19.131.204; 20.131.002, 071; 20.131.099; Dickinson et al., Astron. J. 83, 36); observations of Ori A (18.131.198; 20.131.075) and of variable stars (14.131.017; 18.122.060; 19.122.155; 20.122.108); and a study of pumping mechanisms (17.061.044). Work on maser action in other lines has included studies of methanol (14.131.018; 20.131.212) and HC_3N (18.131.130). Various models, theories, and interpretations for interstellar masers have been proposed (14.131.103; 17.131.061, 069, 173; 18.131.003, 050, 114, 196, 197; 19.003.045; 19.131.133, 192; 20.131.038, 209).

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

Additional recent work has been reported on circumstellar MCs, on mass loss in stars, and on infrared (IR) sources. In IRC+10216, lines of SiS, SiO, and HC_3N (14.131.008) and of CO (14.141.623, 633; 17.131.046) have been observed, and the physical picture of an expanding envelope has become clear. HC_3N (20.131.027) and HC_5N (20.122.006) have been observed in W Hya. Zuckerman et al. (19.131.018) found circumstellar CO emission in 9 out of 73 evolved stars. Other IR sources have been studied in OH, H_2O, CO, HCN, CS, and HC_3N lines (14.141.601, 617, 618, 623, 628, 644; 17.141.616, 617, 621, 626; 18.141.634; 19.133.003; 20.133.001, 002). The large mass-loss rate in these IR stars (17.131.043; 17.141.616, 617) suggests that they are proto-planetary nebulae. Other studies appear in 19.131.178, 182; 20.064.044; and in Lambert and Vanden Bout, Astrophys. J. 221, 854.

(5) Molecular Clouds Associated with Supernova Remnants

The CO line has been mapped in IC443, the Cygnus Loop (19.125.013; 20.125.005), in W44 (19.131.080; 20.135.045), and in W28 (18.131.151). OH absorption was also observed in W44 (14.131.149).

(6) The Galactic Center

Molecular clouds in this region have been studied very intensively, but the information obtained is still fragmentary. Surveys have been carried out in NH_3 (14.131.086), in OH (14.131.133; 17.131.042; 18.131.042), and in CO (19.155.017; Inatani et al., preprint, Kisarazu Tech. Coll.; Burton and Liszt, preprint, NRAO). From the CO survey, Burton and Liszt proposed a rotating and expanding disk model.

The highly interesting and complex object Sgr B2 has received much attention by radio astronomers. Line profiles, column densities, etc. of a relatively small number of spectral lines appear in 14.131.029, 164; 17.131.041, 091, 120; 18.131.066, 162; 19.131.144, 171; and 20.131.027. Scoville et al. (14.131.104) made mappings in the CO, ^{13}CO, CS, and H_2CO (2-cm) lines and developed a core-halo model with a mass of 3 x 10^6 $M_\odot$. McGee et al. (14.131.120) found four separate velocity components from observations of the 9.1 GHz line of HC_3N. Churchwell et al. (19.131.047) observed ^{13}CO replacements of HC_3N and found that the $H^{13}CCCN$ line is about twice as strong as replacements at other sites. Andrew et al. (Astron. Astrophys. 66, 437) observed the CH line and found 6 or 7 separate components. Avery et al. (submitted to Astrophys. J.) observed HC_5N and compared intensities of a number of rotational transitions with equilibrium calculations to derive a core-halo model.

The Sgr A molecular cloud was surveyed in HCN by Fukui et al. (20.131.215), who found a size of 26' x 8' in ℓ and b and estimated its mass at 3 x 10^6 $M_\odot$; they also surveyed this object in the HCO line (preprint, Tokyo Astron. Obs.).

(7) Extragalactic Objects

CO lines have been detected in several spiral galaxies (14.131.148; 14.158.009, 010; 19.158.053, 063; Morris and Lo, Astrophys. J. 223, 803). A scan of M31 (20.158.057) showed that the CO line arises from the dusty regions on the inner sides of the spiral arms. Other molecular lines observed include H_2O (19.131.051; 20.158.100; Huchtmeier, Astron. Astrophys. 64, L21); HCN and CS (19.158.111); and OH and H_2CO (17.158.028; 17.159.001; 18.159.003; 19.158.130).

7. H II Regions

(M. Peimbert)

A. INTRODUCTION

A considerable amount of effort has been devoted to the study of H II regions in the past three years. Catalogues, reviews, and works of general interest include: the proceedings of a symposium on H II regions and related topics (Wilson and Downes 18.012.026); a review by Flower (18.132.015) on physics of fully ionized regions; an Hα photographic atlas and catalogues of the northern Milky Way by Dubout-Crillon (17.131.541) that reveal 85 new regions of faint emission; an Hα catalogue of the nebular complexes of the Large and Small Magellanic Clouds compiled by Davies, Elliot and Meaburn (17.159.001); a catalogue of relative emission-line intensities observed in planetary and diffuse nebulae developed by Kaler (18.133.008); reviews of the physical parameters of M8, M16, M17, M20, and M42 carried out by Goudis (14.132.012; 17.131.520; 17.131.536; 17.131.537); and a radial-velocity study of optically discovered H II regions by Crampton et al. (1978 Astron. Astrophys. 66, 1), from which they confirm the existence of another arm, between 90 and 112 degrees, beyond the Perseus arm. The following discussion reviews representative papers on physical conditions, evolution, gradients, the nucleus of our Galaxy, and extragalactic H II regions.

B. PHYSICAL CONDITIONS

The number of papers dedicated to the determination of the electron density and the emission measure (EM) of H II regions has been substantial. From radio data it is possible to derive the EM and the root-mean-square density N_e(rms) along the line of sight (e.g., 17.131.527; 17.141.052; 19.132.037; 19.132.038; 1977 Astron. Astrophys. 60, 233; 1977 Astron. Astrophys. 61, 377; 1978 Astron. Astrophys. 63, 325; 1978 Monthly Notices Roy. Astron. Soc. 183, 119, 435). Balick and Brown (17.131.538) carried out an unsuccessful search of sub-arc-second structure and concluded that there is a minimum size in the bright-structure distribution of H II regions of the order of 1/30 pc. Optical observations are hampered by reddening, and most of the electron-density determinations are derived from forbidden lines (e.g., 19.134.015); however, there are a few determinations of EM and N_e(rms) based on the Balmer lines (e.g., Peimbert et al. 14.131.531; Tamura 18.132.017; Reynolds and Ogden 1978 Astrophys. J. 224, 94). Kippenhahn and Krügel (17.116.002) have found that, for a rapidly rotating O star, the polar radius of the associated H II region might be up to 1.6 times the equatorial radius for a constant-density nebula.

To determine the chemical composition of an H II region, as well to obtain information about its degree of ionization and its energy balance, it is essential to determine accurately the electron temperature T_e. Up to now the most accurate method to determine T_e has been provided by forbidden-line ratios in the optical region. Because of the relatively higher T_L/T_C ratio for H56α and H66α, and the relatively lower baseline distortion caused by interference of the signal (which is proportional to T_C), the most accurate T_e values derived from radio data are those by Berulis et al., Pauls and Wilson, and Wilson et al. (18.131.579; 1977 Astron. Astrophys. 60, L31; 1978 Astron. Astrophys.); their values are a few hundred degrees smaller than those derived optically for the Orion Nebula (19.134.015). Perrenod et al. (1977) from radio observations obtained a temperature gradient in the Orion Nebula with T_e increasing outwards, in agreement with the optical results by Bohuski et al. (11.133.010), but in disagreement with radio observations by Pauls and Wilson (op. cit.) and by Pankonin et al. (1978 Astron. Astrophys.), as well as with the more accurate optical results by Peimbert and Torres-Peimbert (19.134.015), which do not show such a gradient. The result by Perrenod et al. might be explained by systematic errors in the radio reductions, as discussed by Lockman and Brown (1978 Astrophys. J. 222, 153). Gibbons (17.132.001) from the line profiles of Hβ and [O III] λ5007 Å has obtained similar temperatures to those derived from the ratio of auroral to nebular lines of O III in the Orion Nebula; these T_e values are obtained under the assumption that Hβ and the [O III] lines originate in the same volume elements, which is not the case because of the presence of O^+ along the line of sight.

Abundances in H II regions in the solar neighborhood may be compared with those in H II regions at different distances from the Galactic center, with extragalactic H II regions, and with models of Galactic chemical evolution. There have been several abundance determinations based on optical data (Thomsen 14.131.158; Tamura 18.132.017; Peimbert and Torres-Peimbert 19.134.015; Hawley 1978 Astrophys. J. 224, 417; Talent and Dufour 1978 Bull. Am. Astron. Soc. 10, 406; Pagel 1978 Monthly Notices Roy. Astron. Soc. 183, 1p). The He/H abundance ratio for the Orion Nebula is very accurate, and the values for C, N, O, Ne, S, and Ar are very similar to those of the Sun; on the other hand, Fe is underabundant by an order of magnitude (Olthof and Pottasch 14.132.041).

Abundances derived from forbidden lines are affected by temperature variations along the line of sight. A promising new field to improve the accuracy of the abundance determinations is provided by the observations of fine-structure transitions in the far infrared (like those of Ne II, Ne III, S II, S III, S IV, O III); these lines are not temperature-sensitive, but rather density-sensitive. Some of these lines have been detected in the Orion Nebula and elsewhere (Baluteau et al. 18.132.026; Melnick et al. 1978 Astrophys. J. 222, L137; Moorwood et al. 1978 Astrophys. J. 224, 101). Moorwood et al. find excellent agreement between the [O III] 88.35 μm observations and the predictions by Simpson (13.131.518); however, the [S III] 18.7 μm/33.4 μm ratio is considerably larger than the value predicted by Simpson, indicating a larger density. This density, together with the [O III] 88.35 μm line observations, yields an oxygen abundance in excellent agreement with the optical results by Peimbert and Torres-Peimbert (19.134.015).

Another important physical condition is the ionization structure. Several ionization-structure models emphasizing different aspects have been elaborated: shadowed regions from the central star (Mathis 18.132.003); the effects of stellar metal opacity (Balick and Sneden 18.131.514); the influence of the star, the gas density, and its chemical composition (Stasinska 1978 Astron. Astrophys. 66, 257; 1978 Astron. Astrophys. Suppl. 32, 429); analysis of ionization correction formulae (Grandi and Hawley 1978 Publ. Astron. Soc. Pacific 90, 125); the stellar temperature (Köpen 1978 Astron. Astrophys. Suppl.); and the effects of weak shocks (Brand and Mathis 1978 Astrophys. J. 223, 161). The results of Grandi and Hawley and of Stasinska are somewhat different from those of Balick and Sneden, particularly for the S and N ionization correction factors; most of the discrepancy is presumably due to the computing procedure.

Considerable effort has been devoted to the study of dust in H II regions. Barlow (1978 Monthly Notices Roy. Astron. Soc. 183, 367, 397, 417) has made an extensive study of the destruction and growth of dust grains in interstellar space; according to his review, ices and graphite grains are mostly destroyed in H II regions, while iron particles are not. These results are in agreement with the observed atomic abundances in the Orion Nebula. There are other reviews on: the presence of dust in H II regions; formation and destruction of dust grains; and observations, location, and nature of the dust responsible for the infrared emission (Isobe 20.132.015; Salpeter 20.131.158; Panagia 19.132.022). Different aspects of dust presence in H II regions have been considered by several authors (e.g., Zeilik 17.131.508; Sarazin 17.131.518; Smith 17.131.524; Moorwood and Feuerbacher 17.131.525). From observations of the Ne II 12.8 μm line and the nearby continuum, Aitken et al. (19.132.018) find that, in the compact core of G333.6-0.2, dust is depleted. Rodriguez and Chaisson (1978 Astrophys. J. 221, 816), by comparing high-radiofrequency and far-infrared observations of several H II regions, conclude that strong dust depletion, if present, is confined to an inner fraction of the

Strömgren radius. Several models have been made to study the effects of dust on the structure of H II regions (Balick 14.133.022; Natta and Panagia 18.131.501; Dana and Petrosian 18.132.007; Sarazin 19.132.002; Aannestad 1978 Astrophys. J. 220, 538; Panagia and Smith 1978 Astron. Astrophys. 62, 277; Perinotto and Picchio 1978 Astron. Astrophys. 68, 275).

C. EVOLUTION

Manfroid has modeled in detail the evolution of an H II region during the first 1.5 million years (17.064.049; 19.132.032; 1977 Astron. Astrophys. 61, 437); he has also studied the spectrum of recombining H II regions (17.131.506; 18.131.520). The existence of high-density condensations of neutral and ionized gas, dense ionized shells, and ionization fronts inside H II regions has been studied by several authors (Hawarden and Brand 17.131.533; Becklin et al. 18.132.005; Tenorio-Tagle 19.132.009 and 1977 Astron. Astrophys. 61, 189; Danks and Manfroid 1977 Astron. Astrophys. 56, 443; Dyson 1978 Astron. Astrophys. 62, 269). Dyson (19.064.053) has studied the effect that stellar-wind bubbles have in H II regions located on the edges of massive neutral clouds (see also Pişmiş 1978 IAU Symp. 83, in press; McCray 20.12,011, p. 35). Pişmiş and Hasse (18.131.606) have studied a triple emission nebula in Orion in which each of the components seems to be at a different evolutionary stage.

There is a group of H II regions called "ring nebulae," which have a WN star in their centers; these stars are evolved objects that have lost a substantial amount of mass and that have atmospheres composed mostly of helium and nitrogen. Work on physical conditions in these objects has been carried out by Malov (18.132.001), Israel and Felli (18.132.002), Sabbadin et al. (19.134.026), Pişmiş et al. (1977 Rev. Mex. Astron. Astrophys. 2, 209), and Parker (1978 Astrophys. J. 224, 873). Parker finds for NGC 6888 an N/H overabundance by a factor by three to four relative to normal H II regions, while Peimbert et al. (1978 Astrophys. J. 220, 516) and Talent and Dufour (1978 Bull. Am. Astron. Soc. 10, 406) also find an N/H overabundance in NGC 2359.

D. GALACTIC GRADIENTS

Churchwell and Walmsley (13.131.515), from radio recombination-line surveys, reported the presence of an electron temperature gradient. Corroboration and extension of this result from radio observations was achieved by several groups (Viner et al. 18.131.546; Churchwell et al. 1978 Astron. Astrophys.; Wilson et al. 1978 Astron. Astrophys.; Lichten et al. 1978 Astrophys. J.). Lockman and Brown (1978 Astrophys. J. 222, 153) argue that the gradient in T_e across the Galaxy is not unambiguously established through recombination-line observations because of systematic effects in the commonly used reduction procedures; however, optical results appear to confirm the presence of a T_e gradient (Peimbert et al. 1978 Astrophys. J. 220, 516; Hawley 1978 Astrophys. J. 224, 417; Talent and Dufour 1978 Bull. Am. Astron. Soc. 10, 406).

Churchwell et al. (1978 Astron. Astrophys.) obtain the distribution of He^+/H^+ across the disk of the Galaxy; the He^+/H^+ increase from 14 to 9 kpc is attributed to a He/H abundance gradient, while the decrease for smaller galactocentric distances is attributed to selective absorption of He^+ ionizing photons by dust. On the other hand, Lichten et al. (1978 Astrophys. J.) do not find a significant correlation between He^+/H^+ and distance.

Sivan (17.155.040) was the first to obtain an N^+/S^+ abundance gradient. Subsequent work on N/H, O/H, He/H, and C/H gradients (Peimbert et al. 1978 Astrophys. J. 220, 516; Hawley 1978 Astrophys. J. 224, 417; Talent and Dufour 1978 Bull. Am. Astron. Soc. 10, 406) has been reviewed elsewhere (Peimbert, in IAU Symp. 84: "The Large-Scale Characteristics of the Galaxy").

E. NUCLEUS OF THE GALAXY

Mezger and Pauls (IAU Symp. 84) have reviewed radio and infrared observations of the H II regions near the nucleus of the Galaxy. From observations of the [Ne II] 12.8 μm line by several groups (Aitken et al. 17.131.502; Willner 1978 Astrophys. J. 219, 870; Wollman et al. 17.155.023 and 1978 Astrophys. J., in press) it has been found that the Ne/H ratio is normal or overabundant. The He^+/H^+ ratio in nuclear giant H II regions is extremely low (Mezger and Smith 17.131.514; Churchwell et al. 1978 Astron. Astrophys.; Lichten et al. 1978 Astrophys. J.). Recent discussions by Chaisson et al. (1978 Astrophys. J. 221, 810) and Thum et al. (1978 Astron. Astrophys. 64, L17) on Sgr B2 indicate that He/H $\gtrsim$ 0.10, in agreement with a previous suggestion by Mezger and Smith (17.131.514). According to Mezger and Pauls, the giant H II regions near the Galactic center show LTE T_e values higher than those in spiral-arm H II regions, arguing against an increased metal abundance in the center of the Galaxy. On the other hand, Rodriguez and Chaisson (1978 Astrophys. J.), from radio recombination lines, the [Ne II] 12.8 μm observations, and a model for Sgr A West, find that T_e = 5000 ± 1000 K and obtain an overabundance of Ne/H by roughly a factor of four.

F. EXTRAGALACTIC H II REGIONS

Reviews on galaxies of the Local Group and on interstellar abundances in external galaxies have been presented by Courtès (20.132.018) and Webster (20.158.068). A review on the H II regions in the Magellanic Clouds has been written by Dufour (1976 Earth and Extraterr. Sciences 2, 245), and abundance determinations in H II regions of the Magellanic Clouds have been made by Aller et al. (1977 Proc. Natl. Acad. Sci. 74, 5203), Dufour and Harlow (1977 Astrophys. J. 216, 706), and Pagel et al. (1978 Monthly Notices Roy. Astron. Soc.).

Andrillat and Collin-Souffrin (17.158.111) have obtained abundances and physical conditions in the nucleus of NGC 3310. Hawley and Grandi (1977 Astrophys. J. 217, 420) have observed [S III] lines in NGC 604 and discuss the presence of N/S gradients in different galaxies. Shields and Searle (1978 Astrophys. J. 222, 821) and Hawley (1978 Astrophys. J. 224, 417) have computed He/H, O/H, and N/H gradients across M101. Recent results on abundance gradients in M33 and M101 have been derived by several authors (1978 Kwitter and Aller, 1978 Sedwick and Aller, 1978 Rayo and Torres-Peimbert; private communications). Alloin et al. (1978 Astron. Astrophys.) have computed O/H and N/H distributions in a large number of galaxies.

8. Planetary Nebulae

(G.S. Khromov)

A. MONOGRAPHS, CATALOGUES, AND REVIEW PAPERS

The most important publication of the reporting period is the proceedings of IAU Symposium 76 on planetary nebulae (Terzian 1978); this work, containing numerous reviews and original results, will be identified as PN76 throughout the present section of the Report. Among other works one may note those by M. Perinotto (Mem. Astron. Soc. Ital. 47, 177, 1976), L. Aller (18.133.041), G. Khromov (20.012.011, p. 86), and particularly the valuable catalogue of spectrophotometric data by J.B. Kaler (18.133.008). A useful list of revised positions of 345 planetary nebulae has been published by D. Milne (18.133.025).

B. DISCOVERIES AND MISIDENTIFICATIONS

Lists summarizing new discoveries and either possible or definite misidentifications of planetary nebulae since 1967 have been compiled by Kohoutek (PN76, 47), Acker and Maracot (Astron. Astrophys. Suppl. 30, 217, 1977), and R. Weinberger (ibid. 30, 335, 1977). New surveys and studies of selected objects are numerous (14.133.018, 028, 044; 18.133.042; 19.135,001; Astron. Astrophys. Suppl.

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

30, 343, 1977 and 14.132.008; 14.133.030, 042; 17.131.542; 17.133.005, 007, 020; 18.133.029, 034; 19.135.006, 016, 022; 19.135.028; Inf. Bull. Var. Stars n 1300, 1977; Astron. Zh. Letters 4, 16, 1978; Astrophys. J. 221, 151, 1978). The total number of known planetary nebulae has increased by 150-300 objects in the last decade, depending on the classification criteria applied.

C. PLANETARY NEBULAE IN OTHER GALAXIES

Important searches for planetary nebulae in neighboring galaxies have been carried out by H. Ford, G. Jacoby, and D. Jenner (14.158.189; 18.131.515; 19.135.011; PN76, 19), and by J. Danziger et al. (PN76, 63). In the nine closest galaxies some 366 planetary-like objects have been discovered, most of them in M31. These data may be used for preliminary discussions of the role of planetary nebulae in the chemical evolution of galaxies. New studies of planetary nebulae in the Magellanic Clouds have been published by Webster (17.133.002; 18.133.045; 19.135.013; and PN76, 11) and Sanduleak et al. (PN76, 64). These studies have suggested differences in spatial distribution and chemical composition between objects in the Small Magellanic Cloud and those in the Large Magellanic Cloud. However, since the data on chemical composition are controversial (17.133.004, 025; 19.135.002, 030), it appears safer to conclude that there are no pronounced abundance differences among planetary nebulae in the LMC, SMC, and the Galaxy.

D. GALACTIC PLANETARY NEBULAE

The distribution of planetary nebulae in our own Galaxy has been studied by Cahn and Wyatt (Astrophys. J. 210, 508, 1976; PN76, 3) and by Alloin et al. (17.133.014). Their estimates for the total number of these objects in the Galaxy range from 4×10^3 up to 5×10^4, an uncertainty due largely to uncertainties in distance scales (see the review by Liller, PN76, 35). An interesting study of the orbits of Galactic planetary nebulae has been published by Peralta (Astron. Astrophys. 54, 79, 1977 and 64, 127, 1978).

Some authors maintain that there exist several subsystems of the Galactic planetary nebulae (PN76, 167, 215; 19.135.025; and others). This idea would appear to merit further careful study, as its basis does not yet seem to be firmly established (18.133.033; PN76, 66; Bull. Astron. Inst. Czechosl. 26, 248, 1975; Astron. Astrophys. 63, 341, 1978; Astron. J. 82, 468, 1978). There have also been attempts to use planetary nebulae to study Galactic extinction (17.131.164; 18.131.272; 19.135.008); these results are somewhat unreliable because of uncertainties in the distances to the nebulae. The same uncertainty afflicts some interesting attempts to trace the influence of the planetary nebulae and their nuclei upon the interstellar medium and the chemical evolution of the Galaxy (PN76, 339, 341).

E. SPECTROPHOTOMETRY, PHYSICAL CONDITIONS, AND ABUNDANCES

Important observations of ultraviolet radiation from 1200 to 2400 Å for several dozen planetary nebulae have been published by Gurzadian (14.133.002; PN76, 76), Bohlin et al. (14.133.031; PN76, 121), and Pottasch et al. (19.135.008). There have also been theoretical studies of this problem (Mem. Astron. Soc. Ital. 47, 313, 1976; 17.132.022); observation and theory are in good accord (PN76, 93; 19.135.005).

Spectrophotometric observations of planetary nebulae are characteristically numerous: Kaler (18.133.002, 008); Barker (Astrophys. J. 219, 914, 1978); Torres-Peimbert and Peimbert (Rev. Mex. Astron. Astrophys. 2, 13, 1977); Kostjakova (18.133.048); Kaler et al. (17.133.006); Kondratjeva (14.133.023); Webster (14.133.024); and others (e.g., Astrofizika 11, 249, 1975; 13.133.006, 032; 14.133.001, 027; 17.131.521; 17.133.018, 021, 024, 027; 18.133.001, 013, 014, 028, 031; 19.135.009, 018, 020, 032; Publ. Astron. Soc. Pacific 89, 261, 1977; Astron. Astrophys. 60, 147, 1977; Astrophys. Sp. Sci. 48, 437, 1977; Soviet Astronomical Circular No. 947, 3, 4, 1977; Compt. Rend. Acad. Sci. Paris 48, 437, 1977; Astrofizika 13, 437, 1977; Astrophys. J. 209, 108, 1976 and 221, 851, 1978; Astron.

Astrophys. 63, 279, 1978; PN76, 122, 123, 165, 166). Some authors have analyzed the precision and approach of optical spectrophotometry of the planetaries (17.133.023; Proc. Sternberg State Astron. Inst. Univ. of Moscow 47, 222, 1976; PN76, 71). The averaged observed planetary-nebula spectrum has been published by Khromov (Astron. Zh. 53, 762, 1976).

Most of the data on the physical parameters of nebular matter are provided by a theoretical analysis of the optical spectrum. The most recent progress in the theory of elementary processes in nebulae is reviewed by Seaton (PN76, 171) and by Dalgarno (PN76, 139); new collisional parameters for some important ions are reported by Pradhan (18.022.029) and by Garstang and Robb (PN76, 159). The theories of recombination-line and forbidden-line spectra, and of resonance-radiation transfer, have also been refined (17.132.023; 18.131.016; 18.133.004; Monthly Notices Roy. Astron. Soc. 178, 101, 1977 and 180, 57p, 1977). Several other publications treat the determination of N_e and T_e in individual objects by traditional methods (17.133.011, 019; 18.131.016; 13.133.024; 14.133.025; PN76, 164).

There have also appeared unprecedented numbers of new results on the chemical composition of planetary nebulae (17.155.012; 19.135.002, 012, 024; Astrophys. J. 219, 559; 220, 193; 221, 145, 1978; PN76, 215, 235, 245, 246, 247). It is now becoming evident that reliable abundances can be obtained only through the use of detailed theoretical models constructed with the aid of empirical spectrophotometric data. Detailed reviews of the problem of theoretical modelling, together with abundance data, have been published by Harrington (PN76, 151) and Keys and Aller (Publ. Astron. Soc. Pacific 89, 618, 1977). Numerous specific models have also been described (14.133.004; 17.133.001; 19.135.026; Astron. Astrophys. 61, 247, 1977; Astrophys. J. 219, 565, 1978; PN76, 121, 161, 354, 357). Considerable progress in this area was achieved after charge-exchange processes and density gradients were included by Bohlin et al. (Astrophys. J. 219, 575, 1978), Harrington and Marionni (17.133.022), and Pequignot et al. (Astron. Astrophys. 63, 313, 1978). However, data on abundances in planetary nebulae are still rather controversial (see the summary in PN76, 230). It seems reasonable to conclude that the certain overabundance of oxygen is probably the only chemical peculiarity of planetary nebulae of which we can presently be sure.

F. RADIO AND INFRARED EMISSION

Recent radio observations of planetary nebulae, including recombination-line observations, are relatively scarce and have not substantially changed our present ideas about these objects (14.131.534; 14.141.151; 17.131.532; 17.133.017; 18.133.009, 021; 18.031.204; 18.141.031; PN76, 127, 327; Monthly Notices Roy. Astron. Soc. 182, 723, 1978; also a review, PN76, 111). Among the more interesting results are the detection by Mufson et al. (14.133.015, 021) of CO emission from NGC 7027 and the probable detection of H_2 emission from the same object by Treffers et al. (Astrophys. J. 209, 793, 1976).

New measurements of IR continuum radiation from planetary nebulae have been reported by Mosely and Harper (PN76, 124), Cohen and Barlow (14.133.029), and others (14.113.045; 18.133.046; 19.135.004, 018; Monthly Notices Roy. Astron. Soc. 181, 233, 1977). The fine structure of the IR emission spectrum has also been further studied (14.135.005, 014; 17.131.529; 18.133.015, 036; 19.133.012; 19.135.013; Astrophys. J. 217, L149, 1977; PN76, 125, 126, 127). The goal of these studies is a determination of the composition and physical properties of the dust particles; however, the results are of questionable reliability (see the review by Rank, PN76, 103; also 13.133.020; 17.133.013; 19.135.008, 010; Astron. Astrophys. 63, L23, 1978).

Our understanding of the IR emission from planetary nebulae is still rather primitive. It is generally believed that this radiation is emitted by heated dust (of unknown composition), that the dust is probably mixed with ionized gas, and that the partial mass of the dust is small (14.133.022; 18.133.006; PN76, 275, 281, 292). The dust is thought to be heated by direct and scattered ultraviolet radiation, but the details of the IR and UV energy balances are not yet clear (see also 18.133.024; 19.135.014). The dust appears to cool quite rapidly with nebular expansion (14.133.009).

G. SPATIAL STRUCTURE AND DYNAMICS

Advances in observational technique have drawn renewed attention to the structure and dynamics of planetary nebulae. Of prime importance are recent monochromatic images of many nebulae by Reay, Coleman, Worswick, Phillips et al. (18.133.003; 19.135.015, 019; Astron. Astrophys. 61, 695, 1977; PN76, 163-4; see also 14.133.019; 18.133.039; 19.135.018; PN76, 289, 291), together with a number of high-resolution radio images (13.133.008, 026; 17.133.009, 010; 19.135.007). Of similar importance are new studies of inner dynamics in planetaries by Johnson (18.133.005) and others (18.133.037; Astrophys. J. 216, 776, 1977; Monthly Notices Roy. Astron. Soc. 181, 475, 1977; 182, 13, 1978; PN76, 290). Relevant to further theoretical work are papers by Cudworth (14.133.007), who confirmed the random spatial orientation of the axes of planetary nebulae, and by Khromov (18.132.012) and Perinotto (Astron. Astrophys. 60, 443, 1977), who discuss inner density gradients in the nebulae.

Numbers of authors have attempted to explain the shape, structure, and internal dynamics of planetary nebulae (14.133.026; 17.133.008, 012, 015; 18.133.018; Astron. Astrophys. 59, 91, 1977; PN76, 251, 263, 292; Astrofizika 14, 307, 1978). A general theoretical approach is still lacking, but a simple description of nebular dynamics may be obtained within the framework of an isothermal expansion of a cloud of hot gas, as noted by Khromov (18.133.030).

H. CENTRAL STARS

Evidence is mounting that the nuclei of some planetary nebulae are binaries (19.119.006; 19.135.023; PN76, 207, 209; Astron. Astrophys. 61, 761, 1977); however, this fact does not appear to be crucial to an understanding of the planetary-nebula phenomenon.

Spectral studies of planetary nuclei are highly valuable and are growing in number; see Aller (18.133.011; 19.135.021), Lutz (14.133.035; Astron. Astrophys. 60, 93, 1977; PN76 185, 212), Heap (13.133.007; 19.135.029; Astrophys. J. 215, 864, 1977), and Y. Andrillat (18.114.029). New determinations of the temperatures of a number of central stars, by classical methods but with modern observational data, have also been published (Astrophys. J. 210, 843, 1976; 215, 864, 1977; 220, 887, 1978). In addition, Pilugin and Khromov (Astron. Zh., in press) have calculated Zanstra H and He temperatures for the nuclei of 168 nebulae.

Recent observations of the ultraviolet spectra of 40 planetary nuclei have been published by Pottasch et al. (Astron. Astrophys. 62, 95, 1978; see also 14.133.006). These have presented new opportunities for the empirical testing of model nebular atmospheres (14.064.042, 053; for earlier work, see the review by Hummer in PN76; also PN76, 210; Astrophys. J. 220, 541, 1978). This work has also reopened the debate on the possible variability of the central stars of some objects (19.122.058; 19.123.038; PN76, 209, 211).

I. ORIGIN AND EVOLUTION

This challenging problem has received the attention of many authors. Pottasch et al. (PN76, 211) and Khromov (Astrofizika, in press) have published revised H-R diagrams for the nuclei of planetary nebulae. The spatial density of nebulae in the Galaxy has been studied by Cahn and Wyatt (18.133.023), Smith (18.133.032), Weidemann (PN76, 353), Khromov (Astrofizika, in press), and Alloin et al. (17.133.014).

Great effort has also been expended in attempts to determine the evolutionary precursors of the planetary nebulae. One group of workers is searching for these among the peculiar BQ[] stars; e.g., Ciatti and Mammano (13.114.030, 333; 18.114.332; Astron. Astrophys. 61, 459, 1977; see also 13.133.019; 18.122.063; 18.114.316; 19.065.050; 19.114.328; J. Roy. Astron. Soc. Can. 71, 386, 1977; Inf. Bull. Var. Stars n 13, 17, 1977; PN76, 325, 326, 327, 328, 357; Publ. Astron. Soc. Pacific 90, 36, 1978). Another group argues that they must be sought among the IR stars with CO emission, such as some of the IRC, CRL, and NML objects; see Zuckerman et al. (17.141.616; 19.131.018; PN76, 305; Astrophys. J. 220, 53, 1978; see also 17.141.617; 18.141.614; Monthly Notices Roy. Astron. Soc. 181, 61p, 1977). Only time can tell the outcome of this rivalry.

There have also continued to be published various competing mechanisms and scenarios for the evolution of the nebular precursors, for the ejection of the nebulae, and for the future fate of the nuclei (14.065.128; 14.133.020; 17.064.015; 18.122.088; 18.126.016; 19.122.188; PN76, 247, 323; Astrophys. Sp. Sci. 51, 135, 1977; Astrophys. J. 219, 125, 1978; Monthly Notices Roy. Astron. Soc. 182, 97, 1978); see also reviews by Shaviv and Pachinsky (PN76, 195, 201). Because of the complexity of the problem, as discussed in the realistic review of Roxburgh (PN76, 295), there seems little justification for choosing one theoretical approach over another at the present time.

9. Supernova Remnants

(L.A. Higgs)

Great progress has been made in the last few years in the study of supernova remnants (SNRs), largely owing to the development of sophisticated computer models for evolving remnants and to the improved sensitivity and spatial resolution of observational instruments in all regions of the electromagnetic spectrum. Several good reviews of various aspects of SNR evolution have recently been written. Kahn (17.125.032) has outlined the general physics of SNR evolution, Culhane (19.125.026) and Gorenstein and Tucker (20.142.040) have reviewed studies of soft X-ray emission from SNRs, and Chevalier (20.125.017) has written an excellent review of the interaction of the supernova blast with the interstellar medium (ISM).

Large numbers of theoretical papers, dealing mainly with the evolution of SNRs, have recently appeared. Useful coordinate transformations for self-similar adiabatic (Sedov) models have been given by Newman (20.125.029), while Bollea and Cavaliere (17.062.002) have computed the X-ray bremsstrahlung radiation for such models. Solinger et al. (14.125.034) have suggested, however, that thermal conductivity makes isothermal models more relevant to real SNRs. On the other hand, Isenberg (20.125.010) and co-workers (18.062.056; 20.062.050, 063; 20.125.031) have shown that real SNRs probably cannot be well represented by any self-similar model, adiabatic or isothermal. Cowie (19.125.044) has numerically modelled SNRs allowing for thermal conduction in a two-fluid model (differing ion and electron temperatures), and Itoh (20.125.032) has computed the X-ray emission for a two-fluid model.

Considerable work has been done on the effects of instabilities and inhomogeneities in the expansion. Chevalier (14.125.017) has developed a model in which the ejecta knots produced by Raleigh-Taylor instabilities early in the remnant's history (Chevalier and Klein, Astrophys. J. 219, 994, 1978) heat the ISM by conversion of their kinetic energy into thermal energy. The thermal instability that arises behind the shock in the late radiative phase of SNR evolution has been modelled by Falle (14.125.002). The dynamical effects on an interstellar cloud overrun by a supernova blast have been studied by Dyson and Gulliford (14.125.043). McKee et al. (Astrophys. J. 219, L23, 1978) have investigated the acceleration of interstellar clouds by the passage of an SNR shock in order to explain high-velocity filaments in old remnants. The evaporation of clouds in the interior of an SNR has been considered by McKee and Cowie (19.131.127). The dynamics of SNRs in very late stages of evolution have been treated by Sofue (Astron. Astrophys. 67, 409, 1978) with application to the filamentary structure of S 147.

The turbulent amplification of magnetic fields in SNR shells has been discussed by Chevalier (19.062.019), and Shirkey (Astrophys. J. 224, 477, 1978) has numerically modelled the radio evolution of young remnants, assuming such amplification. (The radio evolution of extremely young SNRs has been treated by Marscher and Brown, Astrophys. J. 220, 474, 1978). The related problem of the acceleration of cosmic gas in SNR shells has been discussed by Chevalier (19.125.017) and Bell (Monthly Notices Roy. Astron. Soc. 182, 443, 1978). Berezinsky and Prilutsky (Astron. Astrophys. 66, 325, 1978) have commented on the gamma-ray emission expected from pion decay in SNR shells. Dopita (19.065.054) has presented diagnostic diagrams for the optical emission from shocks, and Shull and McKee (preprint) have modelled shocks with special emphasis upon the transfer of ionizing radiation. Raymond and Smith (20.022.113) have calculated soft X-ray spectra for conditions appropriate to SNRs.

The temperatures in old SNRs have been discussed by Kahn (18.125.001), and the injection of hot gas into the ISM by old remnants has been modelled by Smith (19.125.002) and McKee and Ostriker (20.131.111). Jones (14.125.033) has concluded that 80% of the ISM should consist of hot, low-density tunnels produced by SNRs.

Many papers have dealt with the Crab Nebula. Shklovskij (18.134.001) has commented on the peculiarities of the Crab, and Chevalier (19.125.027) has questioned its classification as Type I. The injection mechanism for the relativistic particles in the Crab is the subject of papers by Dobrowolny and Ferrari (17.141.322), Peterson (18.125.042), Shklovskij (19.134.030), and Usov (Astron. Zh. Letters 3, 396, 1977). The diffusion of these particles has been discussed by Wilson (14.143.018), Cocke (14.134.007), Weinberg and Silk (17.134.003), and Wolff and Novick (18.134.010). Ionization conditions and abundances in the Crab filaments have been considered by Contini et al. (20.134.002; Astron. Astrophys. 68, 443, 1978) and Bychkova and Bychkov (20.125.001).

Cosmic-ray production in Cas A by second-order Fermi acceleration in turbulent vortices has been studied by Chevalier et al. (18.143.004; Astrophys. J. 222, 527, 1978). Kundt (19.125.012) has commented that Cas A may have a binary system at its center.

The study of SNRs in the highest energy ranges (gamma rays) is still relatively new, and most observations to date have been of the pulsar-associated Crab and Vela remnants. Observations of the Crab have been reported by Walraven et al. (14.142.165), Thompson et al. (19.142.708), and others (19.134.011, 012; 19.142.713, 734). Leventhal et al. (19.134.010; 20.134.008) have reported a possible 400-keV spectral line, which may arise from the pulsar. Observations of the Vela region have been discussed by Bennett et al. (18.142.001). Lamb (Nature 272, 429, 1978) has reported on positional coincidences of three COS-B sources with SNRs.

With the advent of satellites such as Copernicus, Ariel V, and SAS-3, much new information on the X-ray structure and spectra of SNRs has been obtained. The Crab Nebula has, of course, been extensively studied. The size of the hard X-ray source surrounding the pulsar has been determined, mainly by lunar occultations, by Wolff et al. (14.142.136, 137; 17.134.001) and others (14.134.006; 14.142.164; 17.142.215). Dolan et al. (20.142.036) have determined the spectrum of this source, and Weisskopf et al. (18.134.005) have observed its polarization, confirming its synchrotron nature. A more extended, thermal component has been observed and discussed by Toor et al. (18.134.003), Charles and Culhane (19.142.005), and

Kestenbaum et al. (20.134.005). The effects of the ISM on X-rays observed from the Crab have been discussed by several authors (17.131.032; 19.131.174; 20.131.113).

Charles et al. (19.125.009) have analysed the X-ray emission from Cas A. The spectra of this and of Tycho's SNR have been observed by Davison et al. (17.125.021) and indicate two-component thermal models. Searches for X-ray line emission from Cas A have been made by Pravdo et al. (17.125.022) and Kestenbaum et al. (Astrophys. J. 222, 537, 1978), with only the iron line at 6.7 keV being detected. Catura and Acton (18.125.007) have reported on the X-ray structure of Puppis A, and Zarnecki et al. (Astrophys. J. 219, L17, 1978) have found that a two-component thermal model is needed for this remnant also. Zarnecki and Culhane (19.125.020) have detected the 0.65-keV O VIII line in Puppis A, while Moore and Garmire (17.125.020) observed the low-energy spectrum of the Puppis and Vela SNRs. The latter has also been observed by Smith (Monthly Notices Roy. Astron. Soc. 182, 39p, 1978). The X-ray structure and spectrum of IC 443 has been determined by Shulman et al. (17.142.024), Malina et al. (18.125.016), and Parkes et al. (19.125.021). A low-energy map of the Cygnus Loop has been given by Gronenschild et al. (17.132.018). Observations supporting the hypothesis that the North Polar Spur is an old SNR have been reported by Cruddace et al. (18.142.029) and Hayakawa et al. (19.157.005). Borken and Iwan (20.142.075) interpret this feature as a reheated SNR.

X-rays from the probable remnants of the AD 1006 and AD 185 supernovae have been detected and discussed by Winkler and Laird (17.125.011), Naranan et al. (19.125.018), and Winkler (19.125.003; Astrophys. J. 221, 220, 1978). Other remnants detected include G287.8-0.5 (Becker et al. 18.142.092), W44 (Gronenschild et al., Astron. Astrophys. 65, L9, 1978), and the new remnant in Cygnus (Snyder et al., Astrophys. J. 222, L13, 1978). X-ray surveys of several SNRs are reported by Zarnecki et al. (14.142.064) and others (14.142.059; 17.125.016; 19.142.134). Naranan et al. (18.142.057) have postulated the existence of an old SNR to account for X-ray emission in Eridanus, and Epstein (20.159.008) has hypothesized that LMC X-1 may be an SNR. From X-ray data, Clark and Culhane (17.125.023) have derived initial blast energies for several remnants.

A corresponding increase in the number of optical studies of SNRs may be noted. New spectra of the filaments in the Crab Nebula have been obtained by Chevalier and Gull (14.134.002), Wyckoff et al. (17.134.004), and Davidson and Humphreys (18.134.004); Davidson (Astrophys. J. 220, 177, 1978) has discussed spectra of the fainter outer regions which show a high helium abundance. Trimble (19.131.176) has unsuccessfully searched for excess extinction around the Crab Nebula. Kamper and van den Bergh (18.125.059) have studied the proper motions of the fast-moving filaments and slowly moving flocculi in Cas A. From image-tube spectra of several of these, Kirshner and Chevalier (20.125.013; Astrophys. J. 219, 931, 1978) find the latter to be overabundant in helium. Van den Bergh and Kamper (20.125.021) have shown that proper-motion studies of Kepler's SNR indicate the presence of circumstellar material overtaken by the supernova shock. A search by Reynolds and Ogden (Astrophys. J. 220, 172, 1978) for a "fossil Strömgren sphere" around the Tycho SNR was unsuccessful. Spectra of the filaments of this remnant (Kirshner and Chevalier, Astron. Astrophys. 67, 267, 1978) have been interpreted as showing these to be the result of an initial interaction with interstellar clouds. From sulphur line ratios, Canto (20.125.020) has estimated initial energies and ambient ISM densities for several remnants.

Kirshner and Taylor (18.132.008) and Doroshenko and Lozinskaya (Astron. Zh. Letters 3, 541, 1977) have optically detected the high-velocity gas between the denser filaments in the Cygnus Loop. Woodgate et al. (20.134.029) have derived the radial distribution of [Fe XIV] emission in this remnant. The Monoceros Loop has been studied in interstellar absorption features (Wallerstein and Jacobsen 18.125.002; Cohen 20.131.185) and by narrow-band photography (Kirshner et al., Astron. Astrophys. Suppl. 31, 261, 1978; Davies et al., Astron. Astrophys. Suppl.

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31, 271, 1978). Ultraviolet interstellar absorption features associated with the Vela SNR have been discussed by Jenkins et al. (18.125.021; 19.125.001), and Elliott et al. (17.125.024) have presented Hα photographs of this remnant and of the Vela SNR. Reynolds (17.125.029) has proposed that the Gum Nebula is a reheated SNR. Goudis and Meaburn (Astron. Astrophys. 62, 283, 1978) have compared optical features of Puppis A with the radio data.

Interferometric observations of several SNRs have been made, and interpreted in terms of shocks in inhomogeneous media, by Lozinskaya and colleagues (17.125.005; 18.125.052; 20.134.003; Astron. Astrophys. 64, 123, 1978). Similarly, Sabbadin, D'Odorico and co-workers have obtained spectra of a large number of possible SNRs with the goal of separating SNRs from H II regions (17.125.019; 18.125.014; 18.132.013; 19.125.042). They have also discussed the apparent under-abundance of nitrogen in LMC remnants (18.125.057; 18.159.002). Spectrographic and/or photographic observations of LMC remnants have also been made by Dopita and co-workers (18.125.019; 19.125.037), Danziger and Dennefeld (17.125.007; 18.125.003), Dufour (17.133.025), and Lasker (20.125.027; Astrophys. J. 223, 109, 1978). Absolute photometry of remnants in the LMC have been reported by Greve and van Genderen (19.125.067). Jones (14.159.003) has suggested that optical observations of LMC remnants would be useful in calibrating a radio surface brightness versus diameter (Σ-D) relation.

Optical detections of radio remnants have been reported by van den Bergh (18.125.009; Astrophys. J. 220, L9 and 171, 1978; preprints) and Longmore et al. (20.125.018). Kirshner and Fesen (Astrophys. J. 224, L59, 1978) find that the recently discovered knots in one of these, 3C 58, are slow moving, thus resembling Kepler's SNR, whereas the radio object resembles the Crab. Possible new SNRs were detected optically by Gull et al. (19.125.051) in Cygnus and by Meaburn and Rovithis (20.125.028) in the southern sky. Kumar (Astrophys. J. 219, L13, 1978) has found a remnant in an open cluster; he has also found seven in M 31 (18.125.013), while D'Odorico et al. (Astron. Astrophys. 63, 63, 1978) have identified three in M33.

Supersynthesis techniques and improved receivers have greatly increased the radio data on SNRs. New millimeter observations of the Crab have been reported by Werner et al. (19.134.028) and Zabolotnyj et al. (Astron. Zh. Letters 4, 13, 1978). Lunar-occultation observations of the Crab have been described by Altunin et al. (17.134.005), while Matveenko (14.134.003) has commented on flaring in its 8-cm emission. Swinbank and Pooley (preprint) have recently produced a very detailed 2.7-GHz map of the Crab. The anomaly in the flux density of Cas A at 38 MHz has been confirmed by Read (19.141.002; 20.141.076), who has suggested that it was a radio flare. Baars et al. (20.141.048) have reanalysed the absolute spectrum of Cas A, and Stankevich (Astron. Zh. Letters 3, 349, 1977) has discussed its time variation. A new 3-mm map of Cas A has been made by Dickel (preprint). Bell (19.141.117) and Dickel and Greisen (preprint) have determined the motions of radio knots in this remnant and find motions much slower than those of the fast optical knots.

Lunar-occultation observations of Kepler's SNR (and the Crab) have been reported by Velusamy and Sarma (20.125.015), and Strom and Sutton (14.125.014) have presented a synthesis map of Kepler's SNR. The radio structure of the Cygnus Loop at 25 MHz has been discussed by Abranin et al. (20.156.003). New radio maps of many other individual SNRs (possible or probable) have been made by numerous observers (14.125.035; 17.141.057, 092; 18.125.012, 036; 19.125.005, 015, 022, 028, 050; 20.125.008; 20.141.047, 053, 130; Astron. Astrophys. 62, 13, 1978; 66, 77, 1978). These include observations of the Crab-like remnants 3C 58, G21.5-0.9, and G292.0+1.8; of G78.2+2.1, formerly known as the γ Cygni SNR and now found to be much larger than previously assumed; of G127.3+0.7, in the direction of an open cluster; and of G127.1+0.5, centered on a compact source. Observations of the latter are given by Shaffer et al. (Astron. Astrophys. 68, L11, 1978). New maps of CTA 1

(Sieber et al., preprint), G74.9+1.2 (Weiler and Shaver, preprint) and G65.2+5.7 (the new Cygnus remnant) (Reich et al., preprint) have also been produced. Surveys of a number of remnants have been made by Clark et al. (14.125.044, 046) and others (14.125.039, 045; 14.141.101; 17.125.009; 18.125.039). Milne and Dickel (18.125.075) and others (14.125.010, 027; 19.125.016) have reported on the radio polarization of many SNRs. Low-frequency observations of 14 SNRs have been made by Dulk and Slee (14.125.001). Observations (mainly non-detections) of extremely young extragalactic SNRs have been reported by Allen et al. (17.158.060) and by Brown and Marscher (Astrophys. J. 220, 467, 1978).

Distance estimates for various possible SNRs have been obtained from 21-cm hydrogen-line observations by Caswell et al. (14.141.146), Kazès and Caswell (19.125.049), Sato (20.125.016; 20.141.162), and Goss and Mebold (20.142.045). The expanding H I shells around W44 and HB21 have been discussed by Jones (14.125.012) and Turner et al. (18.131.508); Colomb and Dubner (preprint) have found a possible shell around G261.9+5. Neutral hydrogen associated with IC 443 has been observed by DeNoyer (19.132.010; Monthly Notices Roy. Astron. Soc. 183, 187, 1978). Heiles (18.131.518; preprints) has commented on the large H I shells which fill most of the interstellar volume and are presumably related to old, very energetic supernova remnants. The possibility of star formation having been induced in two associations by large expanding shells has been proposed by Assousa et al. (20.152.003, 006).

Radio recombination lines in the directions of several SNRs have been studied by Pankonin and Downes (17.125.008) and Cesarsky (18.131.004). Observations of CO emission from clouds near four SNRs have been reported by Kodaira et al. (19.131.080), Cornett et al. (19.125.013), Wootten (20.131.045), and Scoville et al. (20.125.005).

Clark (17.124.025) has presented evidence against a correlation, proposed earlier, between the z-distance of an SNR and its radio spectral index. The general distribution of SNRs within our Galaxy and within other galaxies has been discussed by Henning and Wendker (14.125.050) and Vettolani and Zamorani (19.125.019), and the population of SNRs in the Magellanic Clouds has been analyzed by Clarke (17.125.002). The Σ-D relation has been the subject of comments by Smith (14.125.009) and has been recalibrated by Clark and Caswell (17.125.001). (Sabbadin, in 19.125.014, concluded that there were systematic errors in the latter study.) Recently, Caswell (Proc. Australian Astron. Soc. 3, 130, 1977) has discussed the z-dependence of SNR surface brightness, and he and Lerche (preprint) have also done this employing a new catalog of SNRs. Shklovskij (19.125.010) has commented on the physical reasons for observed Σ-D correlations.

From historical studies, Clark and Stephenson (19.125.045) have concluded that fewer than 20% of galactic supernovae leave long-lived remnants. Weiler and Panagia (preprint) have discussed whether Crab-like remnants are all short-lived. Stephenson et al. (20.125.003) have confirmed the identification of the AD 1006 remnant. A possible association of pulsars with three SNRs (other than the Crab and Vela) has been proposed by Morris et al. (Astron. Astrophys. 68, 289, 1978).

Finally, the formation of interstellar grains in the initial stages of remnant formation has been discussed by Simons and Williams (17.131.027), Falk et al. (20.107.029), and Lattimer et al. (Astrophys. J. 219, 230, 1978), while Dopita (19.125.034) has commented on the destruction of grains in SNRs.

Clearly, the high-resolution X-ray observations soon to be provided by the HEAO-2 satellite, together with the increasing use of sophisticated hydrodynamic computer codes to model the expansion of inhomogeneous remnants into an inhomogeneous ISM, will, in the next few years, lead to a much greater understanding of SNRs. Perhaps the puzzling physical differences between the Crab-like remnants and shell remnants will shortly be resolved.

https://doi.org/10.1017/S0251107X00010993 Published online by Cambridge University Press

10. Star Formation

(B. Zuckerman)

Observational research pertinent to star formation has remained one of the most vigorously pursued areas of astronomy since Field reviewed the subject three years ago in the 1976 Reports on Astronomy. Recent conference proceedings that are especially germane include: "H II Regions and Related Topics" (Wilson and Downes 18.012.026); IAU Symposium 75 (de Jong and Maeder 20.012.029); proceedings of the Massive Molecular Clouds Workshop at Gregynog, Wales (in press; for a summary, see Edmunds 20.011.002); and the volume "Protostars and Planets" (Gehrels 1978). These are referred to below as Books 1, 2, 3, and 4, respectively.

The overall picture of star formation that has emerged leads from the very large scale ($\sim$1 kpc) to the very small scale ($\sim$ 1 AU). Four scale lengths are apparent. The first is related to a global galactic phenomenon, possibly spiral density waves, and may be seen most clearly in other galaxies. For our Milky Way, Bash et al. (17.131.114; 20.155.015) have modeled the distribution of molecular clouds behind a two-arm spiral pattern. Typical time and length scales for this stage are 3 x 10^7 years and 1 kpc. (An alternative view, favored by some astronomers, is that giant molecular clouds "live" for much longer times and are therefore not associated with spiral arms.) The building blocks of the global distribution are giant molecular cloud complexes and their accompanying OB associations. Typically, these cloud complexes have masses $\sim 10^5$ $M_{\odot}$, largest dimensions $\sim$100 pc, and lifetimes as recognizable entities $\lesssim 10^7$ years (Blitz, Book 3; Stark and Blitz, Astrophys. J., in press). The complexes are separated by $\sim$ 600 pc locally, and probably by less in the molecular ring that lies between 4 and 8 kpc from the Galactic center.

Most massive stars of type O and B, as well as some lower-mass stars, form as members of clusters located near the edges of large molecular clouds. Typically these incipient clusters have molecular masses 10^3-10^4 $M_{\odot}$, lifetimes $\lesssim 10^6$ years, dimensions $\sim$ 1 pc, and separations 1-10 pc (Zuckerman, Book 1, p. 360; Kutner et al. 18.131.109; Elmegreen and Lada 19.152.005; Lada et al., Astrophys. J., in press). Each of these clusters then fragments into stars, the most massive of which is often (but not always) of O or B type. This last stage of fragmentation is apparent as a clustering of OH and H_2O masers, infrared sources, and compact H II regions. Typical times scales are $\lesssim 10^5$ years; length scales are $\sim$ 0.1 pc for the overall dimensions of the group and 1-100 AU for individual maser and infrared sources (Genzel and Downes et al. 20.131.137; 1978 Astron. Astrophys. 66, 13; and Astron. Astrophys., in press; Werner et al. 20.131.069; Habing, Book 1, p. 156).

Whereas the 10^3 $M_{\odot}$ clusters referred to above tend to cluster together in relatively localized regions of the giant molecular complexes (see discussion below), low-mass stars (e.g., of solar type) are probably able to form almost anywhere in the giant complexes (e.g., Smith et al. 1978 Astron. Astrophys. 66, 65; Elmegreen, Book 4, and references therein).

The preceding discussion outlines the overall observational picture. References below contain details and highlight areas of controversy.

Both the 10^5 $M_{\odot}$ cloud complexes and the 10^3 $M_{\odot}$ incipient clusters are generally gravitationally bound. It was argued, in 1974, that they are generally in free-fall collapse, where, for a uniform density, V $\sim$ r; this would explain nicely the broad (supersonic) linewidths and general absence of self-reversed profiles observed in CO and other molecules. At present, however, there is little agreement on the cause of the supersonic linewidths. Unimpeded free-fall collapse makes stars too rapidly; furthermore, CO self-reversal is now apparent in some profiles, implying that in such clouds collapse velocities are small with respect to other less ordered

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motions, or V is proportional to $r^{-\frac{1}{2}}$ rather than to r, or expansion rather than collapse is occurring, or some combination of these (Milman 14.131.056; Baker 18.131.057; Snell and Loren 19.131.005; White 19.131.020; Leung and Liszt 13.131.054 and 20.131.150; Leung and Brown 19.131.112; Ho et al. 19.131.128 and 1978 Astrophys. J. 221, L117; Elmegreen and Lada 18.131.284; Lada 19.131.013; Fallon et al. 20.131.092; Lequeux, Book 2, p. 69; Deguchi and Fukui 20.131.216; Martin and Barrett 1978 Astrophys. J. Suppl. 36; Myers et al. 1978 Astrophys. J. 220, 864; Kwan 1978 Astrophys. J. 223, 147). Magnetic fields (Mouschovias, Books 2 and 4) and rotation (Field, Book 4; Heiles and Katz 17.131.022; Clark et al. 19.131.162; Martin and Barrett 1978 Astrophys. J. Suppl. 36, 1) have been considered as possible mechanisms to support clouds against collapse. (However, rotation cannot account for broad CO linewidths observed along a given line of sight.)

Observations and implications of magnetic fields in dark clouds are considered by Vrba et al. (18.131.267; 19.131.106; and Book 4); Mouschovias (19.131.008); Brown and Marsher (19.131.062); Scalo (19.131.075); Troland and Heiles (19.132.031); Nakano (20.131.033); Hartquist (20.131.065); Guelin et al. (20.131.095); Watson et al. (1978 Astrophys. J. 222, L145); and Langer (Astrophys. J., in press).

Bok globules may or may not be objects that will soon give birth to new stars. The situation is reviewed by Bok (20.131.184) and by Dickman (19.131.134). Most of the small globules near H II regions are probably left-over gas that was not incorporated into existing stars, rather than gas that is presently collapsing to form new stars (but see Tenorio-Tagle 19.132.009). The situation for the isolated globules is not so clear (Schmidt 14.131.034; Dickman 14.131.118; Martin and Barrett 14.131.141; Milman 19.131.006; Rickard et al. 19.131.074; Brand and Zealey 1978 Astron. Astrophys. 63, 345; Martin and Barrett 1978 Astrophys. J. Suppl. 36, 1). A particularly interesting globule is the Thumbprint Nebula in Chamaeleon (Fitzgerald et al. 18.131.052; Brooks et al. 18.131.141).

Apparently, small isolated portions of molecular clouds can lose their internal energy and form low-mass stars, but the formation of high-mass (O and B) stars requires external assistance in the form of an excess pressure generated by expanding H II regions (Zuckerman, Book 1, p. 360; Lada 19.131.013; Elmegreen and Lada 19.152.005), supernovae blast waves (Ogelman and Maran 18.152.004; Schwartz 19.131.038; Herbst and Assousa 20.152.003; Lada et al. Book 4), cloud-cloud collisions (Loren 18.131.110), stellar winds (Weaver et al. 20.064.037), or a spiral density wave (Woodward 18.131.025). The observational motivation for introducing these sources of external pressure is to explain the association of regions where massive stars are now forming with existing H II regions and/or supernovae remnants, and, in addition, the tendency of massive stars to form near the edges of molecular clouds. In particular, one finds that, in a large molecular cloud complex, active formation of massive stars at a given time is localized in a very small fraction of the total volume of the complex (Zuckerman, Book 1, p. 360; Lada et al., Book 4, in press).

The Orion Nebula and its related molecular cloud continues to be the most studied region of star formation in the Milky Way. Studies have been carried out in the infrared continuum (Guedin and Mitrofanov 14.141.631; Werner et al. 17.132.007; Ward et al. 17.141.622; Westbrook et al. 18.141.609; Dennison et al. 19.133.035 and 19.134.021; Pipher et al. 1978 Astrophys. J. 219, 494; Beichmann et al. 1978 Astron. Astrophys. 62, 261; Gull et al., Astrophys. J., in press), in infrared lines (especially the 2 μm lines from H_2) (Gautier et al. 18.132.004; Forrest et al. 18.132.011 and 18.132.012; Russell et al. 19.133.009; Erickson et al. 19.133.011; Kwan 20.131.046; Schull and Hollenback 20.134.006 and 1978 Astrophys. J. 219, 877 and 220, 525; London et al. 20.134.017; Joyce et al. 1978 Astrophys. J. 219, L29 and 220, 156; Hall et al. 1978 Astrophys. J. 223, L47; Traub et al. 1978 Astrophys. J. 223, 140; Beckwith et al. 1978 Astrophys. J. 223, 464 and Astrophys. J., in press; Moorwood et al. 1978 Astrophys. J. 224, 101; Hippelein and Munch 1978 Astron.

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Astrophys. 68, L7; Young and Knacke 1978 Astrophys. J. 224, 848; Melnick et al., Astrophys. J., in press), in the radio continuum (Martin and Gull 17.131.531; Chikada et al. 17.131.545; Fukui and Iguchi 19.132.019; Thum et al. 1978 Astron. Astrophys. 65, 207), in radio recombination lines (Ahmad 17.132.016; Kuiper and Evans 1978 Astrophys. J. 219, 141; Boughton 1978 Astrophys. J. 222, 517; Jaffe and Pankonin, Astrophys. J., in press; Pankonin et al. Astron. Astrophys., in press; and Kutner et al., Astrophys. J., in press); in OH, SiO, and H_2O maser lines (Zuckerman and Palmer 14.131.006; Moran et al. 20.131.075; Genzel and Downes 20.131.090; and Hansen et al. 20.131.152); and in other molecular lines (Evans et al. 14.131.013 and Astrophys. J., in press; Kutner et al. 18.131.109 and 19.131.164; Barrett et al. 18.131.218; 19.131.012 and 1978 Astrophys. J. 224, L23; Zuckerman et al. 18.132.016; Kwan and Scoville 18.132.025; Phillips et al. 10.131.022; 20.131.094 and 20.133.002; Morris et al. 20.131.048; Fallon et al. 20.131.092; Kuiper et al. 1978 Astrophys. J. 219, 129; Wilson et al., Astron. Astrophys., in press; and Waters et al., Astrophys. J., in press).

The molecular clouds, H II regions, and infrared sources near W3 and W3 (OH) have continued to receive special attention in reviews by Mezger et al. (14.131.530 and 20.133.011) and in a series of papers by Hughes, Vallée and Viner (17.131.517; 19.132.033; 1978 Astrophys. J. 222, L27 and 223, L97; and Astron. Astrophys., in press). Other investigations have been carried out in the infrared (Fazio et al. 14.141.629; Furniss et al. 14.141.629; Beetz et al. 18.131.501; Westbrook et al. 18.141.609; Willner 19.133.029; and Hackwell et al. 1978 Astrophys. J. 221, 797); in the radio continuum (Harris et al. 17.131.504 and 17.131.532; Harten 17.131.507; Wellington et al. 17.131.516; Wendker and Altenhoff 19.132.004; and Rholfs et al. 20.132.031); in radio recombination lines (Pankonin 19.131.108; Rickard et al. 20.131.164; and Jaffe et al. 1978 Astrophys. J. 223, L123); in OH and H_2O maser lines (Mader et al. 14.131.046; Forster et al. 20.131.018; and Haschick et al. 20.132.039); and in other molecular lines (Rickard et al. 14.131.026; Crovisier et al. 14.131.163; Wilson et al. 1978 Astron. Astrophys. 63, 1; Winnberg et al. 1978 Astron. Astrophys. 66, 431; Ho and Barrett 1978 Monthly Notices Roy. Astron. Soc. 183, 93p; and Lada et al., Astrophys. J., in press).

References to Orion and W3 are usually omitted in the following compilations.

Individual massive protostars and young stars are studied in OH and H_2O maser lines and in infrared and radio-continuum emission. The hope is to place all of these sources in a proper evolutionary sequence. Therefore, accurate positional information is essential. Position correlations have been studied by Forster et al. (1978 Astrophys. J. 221, 137) and Evans et al. (Astrophys. J., in press). Accurate single-antenna and interferometer positions for the maser sources have been obtained by Mader et al. (14.141.046 and 1978 Astrophys. J. 224, 115); Downes et al. (14.131.136); Genzel, Downes et al. (18.131.217; 18.131.510; 20.131.090; 20.131.090; 1978 Astron. Astrophys. 66, 13 and Astron. Astrophys., in press); Evans et al. (17.131.132); Walker et al. (19.131.024 and Astrophys. J., in press); Johnston et al. (19.131.159); Moran et al. (20.131.075); Forster et al. (20.131.018); Mathews et al. (20.132.013); and Hansen et al. (20.131.152).

Additional studies of OH masers (Rickard et al. 14.131.026; Knapp and Brown 17.131.039; Knowles et al. 17.131.126; Davies et al. 20.131.083; Caswell et al. 20.131.118; Reid and Muhleman 1978 Astrophys. J. 220, 229) and H_2O masers (Schwartz and Buhl 14.131.092; Lo et al. 14.131.121; White and Little 14.141.628; Knowles and Batchelor 17.131.003 and 1978 Monthly Notices Roy. Astron. Soc. 184, 107; Morris and Knapp 17.131.047 and 17.131.147; Kaufmann et al. 17.131.512 and 20.131.057; Gammon 18.131.502; Lada et al. 18.131.509; Cato et al. 18.131.512; Scalise and Schaal 19.131.110; Campbell 1978 Publ. Astron. Soc. Pacific 90, 262; Cesarsky et al. 1978 Astron. Astrophys. 68, 33; Blitz and Lada, Astrophys. J., in press; and Blair et al., Astrophys. J., in press) were carried out towards various regions of star formation. High-velocity H_2O emission (Goss et al. 17.131.503 and 20.131.003;

Heckman and Sullivan 17.131.543; Morris 18.131.176; Walker et al. 19.131.024; Boyd 19.131.123; Fernandez and Reinisch 1978 Astron. Astrophys. 67, 163), maser time variations (Little 17.131.047 and 20.131.128; Gammon 18.131.502; Gruber and de Jager 18.131.504; Sullivan and Kerstholt 18.131.524; Pankonin et al. 19.131.154; Little et al. 20.131.028; Haschick et al. 20.132.039; Burke et al., Astrophys. J., in press), and the Zeeman effect (Chaisson and Beichman 14.131.007; Lo et al. 14.131.158; Knapp and Brown 17.131.039; Moran et al. 1978 Astrophys. J. 224, L67; Knowles and Batchelor 1978 Monthly Notices Roy. Astron. Soc. 184, 107) all received special attention.

Summaries of and models for the maser emission have been given by Shmeld et al. (18.131.013); Moran (19.131.089); Burdyuzha et al. (20.131.209); Genzel et al. (1978 Astron. Astrophys. 66, 13); Elitzur and de Jong (1978 Astron. Astrophys. 67, 323); and Elmegreen and Morris (Astrophys. J., in press).

Infrared observations related to star formation have been reviewed by Werner et al. (20.131.069), Wynn-Williams (Book 2, p. 105), and Fazio (19.133.022). Infrared studies of individual sources are reported in the following papers: Zeilik et al. (14.131.503; 17.131.508; 20.132.019; and 1978 Astrophys. J. 222, 896); Pipher, Soifer et al. (14.131.508; 17.131.018; 18.131.522; 18.131.565 and 19.132.044); Gillett et al. (14.131.514); Emerson et al. (14.132.009); Thum and Lemke (14.141.607); Kleinmann et al. (14.141.624 and 1978 Astrophys. J. 221, L77); Sibille et al. (17.131.515); Andriesse and Vries (17.141.605); Harper et al. (17.141.615); Thompson et al. (17.141.625 and 18.141.620); Wilner (17.141.630); Clegg et al. (17.141.637); Sato et al. (17.141.638); Merrill et al. (18.131.031); Strom et al. (18.131.037; 18.131.038; 18.131.040 and 18.131.124); Vrba et al. (18.131.039); Persson et al. (18.131.517); Beckwith et al. (18.141.605); Westbrook et al. (18.141.609); Chini et al. (19.131.083); Harvey et al. (19.132.003; 19.133.031; and 1978 Astrophys. J. 219, 891); Aitken et al. (19.132.018); Wynn-Williams et al. (19.132.026; 19.133.003; and 1978 Monthly Notices Roy. Astron. Soc. 183, 237); Hefele et al. (19.132.028 and 1978 Astron. Astrophys. 66, 465); Ward et al. (19.132.030); Cohen and Frogel (19.133.001); Dyck et al. (19.133.022; 19.133.024; and 1978 Astrophys. J. 220, L49); Simon et al. (19.133.006); Frogel et al. (19.133.014); Wright et al. (19.133.025 and 20.133.007); Ryter and Puget (20.131.013); Jordan et al. (20.133.006); Gatley et al. (1978 Astrophys. J. 220, 822); Dain et al. (1978 Astrophys. J. 221, L17); Melnick et al. (1978 Astrophys. J. 222, L137); Tokunaga et al. (1978 Astrophys. J. 224, L19); Elias (1978 Astrophys. J. 224, 453 and 857); Thronson et al. (1978 Astron. J. 83, 492); Puetter et al. (Astrophys. J., in press); Rank et al. (Monthly Notices Roy. Astron. Soc., in press); and Rowan-Robinson et al. (Astron. Astrophys., in press).

Models for infrared cocoon stars have been calculated by Kwan and Scoville (17.141.629 and 18.141.610); Cochran and Ostriker (19.131.014); Yorke and Krugel (19.131.028); Yorke (19.131.156); Finn and Simon (19.133.008); and Bedijn et al. (1978 Astron. Astrophys. 69, 73).

The association of molecular clouds and ionization fronts (bright rims) and related objects is clearly important in the picture of star formation outlined above. Observations and discussions of such interactions are given by: Blair et al. (14.131.056 and 1978 Astrophys. J. 219, 896); Lada et al. (17.131.009; 17.132.003; 19.131.013; and 1978 Astrophys. J. 219, 95); Sherwood and Dachs (17.131.097); Knapp et al. (17.131.133); Baars and Wendker (17.131.540); Mufson and Liszt (19.131.063); Loren (19.131.126 and (20.131.167); Dickel et al. (20.131.061); Evans et al. (20.131.076); Gardner and Whiteoak (20.132.026); Rieu and Pankonin (20.134.013); Elmegreen et al. (1978 Astrophys. J. 219, 105 and 467 and 220, 510 and 853); Lucas et al. (1978 Astron. Astrophys. 65, 155); and Arny and Bechis (Astron. Astrophys., in press).

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General observations or discussions of molecular clouds and/or H II regions associated with star-forming regions are given by: Kutner and Tucker (14.131.002); Werner et al. (14.131.025); Myers and Ho (14.131.123); Encrenaz et al. (14.131.124); Gottlieb et al. (14.131.159); Gardner and Whiteoak (14.131.509); Balick and Brown (17.131.538); Righini et al. (18.131.018); Plambeck et al. (19.131.068); Matsakis et al. (19.131.111); Baud (19.132.005); Knapp et al. (19.132.020); Schwartz et al. (20.131.165); Sargent (20.131.168); Gillespie et al. (20.132.002); Clark and Johnson (1978 Astrophys. J. 220, 500); Schneps et al. (1978 Astrophys. J. 221, 124); Rodriguez and Chaisson (1978 Astrophys. J. 221, 816); Churchwell et al. (1978 Astron. Astrophys. 67, 139); Little et al. (1978 Monthly Notices Roy. Astron. Soc. 183, 805); and Blitz (Book 3).

Compact H II regions are discussed in the following references (most describe radio-continuum synthesis observations): Downes et al. (14.131.136 and Astron. Astrophys. Suppl., in press); Brown and Zuckerman (14.131.548); Harris (17.141.601 and 18.141.611); Viner et al. (18.131.546); Israel (18.131.548; 19.132.037; 20.132.003 and 20.132.021); Myers (18.131.019); Pişmiş and Hasse (18.131.606); Chaisson (19.131.087); Mezger et al. (19.132.023 and 20.131.144); Matthews et al. (20.132.013; 1978 Astron. Astrophys. 63, 307, and Astron. Astrophys., submitted); Shaver (20.132.014); Israel and Felli (1978 Astron. Astrophys. 63, 325); Birkinshaw (1978 Monthly Notices Roy. Astron. Soc. 182, 401); Scott and Harris (1978 Monthly Notices Roy. Astron. Soc. 182, 657); Goss et al. (1978 Astron. Astrophys. 65, 307); Shaver and Danks (1978 Astron. Astrophys. 65, 323); Panagia et al. (1978 Astron. Astrophys. 68, 265); Lobert and Goss (1978 Monthly Notices Roy. Astron. Soc. 183, 119); Scott (1978 Monthly Notices Roy. Astron. Soc. 183, 435); and Gilmore (1978 Ph.D. Thesis, University of Maryland).

Radio recombination lines from regions of star formation (e.g., the ρ Oph dark clouds) have been studied by: Cesarsky et al. (17.131.092; 18.131.125; 19.132.011); Pankonin and Walmsley et al. (17.131.106; 19.132.008; 1978 Astron. Astrophys. 64, 333 and 67, 129); Knapp et al. (17.131.123 and 17.131.519); Kazès et al. (20.132.005); and Falgarone et al. (1978 Astron. Astrophys. 65, L13).

After the onset of nuclear reactions in their interiors, some young stars may be detected optically as, for example, Herbig-Haro (HH) objects embedded in dark cloud material and later as T Tauri, Ae and Be stars, etc. (Strom, Book 2, p. 179). Most extended HH objects appear to be associated with spatially displaced protostellar objects such that the HH objects are simply reflection nebulae (Strom 19.131.086) or are clouds shocked by strong stellar winds (Schwartz 1978 Astrophys. J. 223, 884 and Böhm 1978 Astron. Astrophys. 64, 115). In more point-like objects, such as HH 1 and 2, the exciting star may be embedded in the HH object itself (Schmidt and Vrba 14.132.031; Böhm et al. 17.132.004; Schwartz 17.132.020), so that, in general, HH objects seem to come in two forms: emission and reflection (Gyulbudaghian 14.132.060). Additional observations of HH objects have been carried out optically (Allen et al. 14.141.608; Munch 19.134.005; Dopita 1978 Astron. Astrophys. 63, 237 and 1978 Astrophys. J. Suppl. 37, 117) and in H_2O maser lines (Lo et al. 17.131.043; Rodriguez et al., Astrophys. J., in press). Finally, Beckwith et al. (1978 Astrophys. J. 223, L41) report 2 μm H_2 emission towards T Tauri.

11. Appendix

(G.B. Field)

The presentation of this Report was made possible not only by the generous reviewing efforts of its writers, but also through the cooperation of the many members of Commission 34 and others who submitted supporting statements of relevant research to them. Unfortunately, not all such statements were received in time to permit incorporation into the various sections of the Report. It is the purpose of this Appendix to call attention to work that may not have been thoroughly considered above; as only the briefest summary can be given here, details are best sought directly from the authors themselves.

Note should first be taken of the many recent and substantial Soviet contributions to the study of the interstellar medium that, often through lack of rapid translation, have not become sufficiently known to scientists elsewhere. Numbers of these contributions in the areas of gas distribution and motion, planetary nebulae, and supernova remnants are mentioned in sections 3, 8, and 9 of the present Report. However, much additional work has also been published on the subjects of interstellar grains and dust, interstellar molecules, physical conditions and dynamics, H II regions, distribution and dynamics of the interstellar gas, and compact H II regions and molecular sources. A detailed list of these and related works has kindly been prepared by G. Khromov (Astronomical Council, Academy of Sciences of the Soviet Union, Moscow). In addition, a variety of photometric and spectroscopic studies of nebulae and the interstellar medium has been carried out by D.A. Rozhkovskij and colleagues at the Astrophysical Institute of the Academy of Sciences, Kazakhstan SSR at Alma Ata. Lists of both sets of publications are also available from the office of the President of Commission 34 (Center for Astrophysics, Cambridge, Massachusetts).

H. Dickel (Sterrewacht, Leiden) has prepared a supplementary list of publications dealing with supernova remnants, the Cygnus X Region, molecular clouds, H II regions, and related topics; some of these publications are referenced in the relevant sections of the present Report. Further reports were received from P. Pişmiş (Observatorio Astronomico Nacional, Mexico City), treating internal motions and non-isotropic mass loss in H II regions; from A. Peraiah (Indian Institute of Astrophysics, Bangalore), concerning hydrogen-line formation in planetary nebulae; from Y. Andrillat (Observatoire de Haute Provence, Forcalquier), describing numerous spectroscopic observations of planetary nebulae in the near-infrared; from G. Courtès (Laboratoire d'Astronomie Spatiale, CNRS and l'Observatoire de Marseille), listing numbers of publications on H II regions and other topics; and from J.-C. Pecker (Institut d'Astrophysique, Paris), summarizing work on ionization structure. Pecker has also obtained preliminary results dealing with the dynamics of H II and star-forming regions.

G. B. FIELD
President of the Commission.