A SKY SURVEY OF NEUTRAL HYDROGEN AT λ 21 CM

I. THE GENERAL DISTRIBUTION AND MOTIONS OF THE LOCAL GAS

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[*Manuscript received February* 20, 1961]

Summary

A survey for neutral hydrogen of the whole sky visible from Sydney has been carried out with a multichannel H-line receiver and a 2°·2 aerial beam. A sample of the profiles obtained has been analysed to present the disposition of local hydrogen in terms of three schematic diagrams : (1) the distribution of N_H, the number of hydrogen atoms in a line-of-sight column of 1 cm^2 section, (2) a diagram of representative line half-widths, and (3) the observed distribution of profile peak radial velocities.

Indications were found that the gas is stratified parallel to the galactic plane in general but with some regions of excess density. From the orientation of the N_H contours it is inferred that the local hydrogen may have some correlation with the local galactic magnetic field.

The line profiles away from the Milky Way were mostly single peaked and of half-widths 12–35 km/s, except in some large regions near the galactic poles where wide profiles of half-widths 36–140 km/s were observed. Large-scale grouping of profiles in the range from 12 to 20 km/s occurred, corresponding closely with some of the outstanding features in the N_H distribution.

The peak radial velocity distribution showed evidence of differential galactic rotation at middle and low latitudes and lack of data on distance prevented the complete removal of this effect. However, it was established that in the solar vicinity hydrogen is flowing outwards at a mean radial velocity of +6 km/s in these latitudes near the direction of the galactic centre and anticentre. It is flowing inwards from above and below in high galactic latitudes at a mean velocity of about −6 km/s.

I. Introduction

The whole sky visible from Murraybank (lat. −33°·75), near Sydney, has been observed with a multichannel 21-cm hydrogen line receiver and a wide-beam (2°·2 between half-power points) aerial. Because the hydrogen in the Galaxy is concentrated in a very thin layer, the bulk of these observations pertain to hydrogen close to the Sun, i.e. within a few layer thicknesses. In this paper, intended as the first of a series on the large-scale distribution of neutral hydrogen, the general disposition of gas in the local neighbourhood will be discussed.

Three previous surveys of hydrogen have been reported which include extensive observations away from the galactic plane. Christiansen and Hindman (1952) made pioneer observations to ±50° in galactic latitude. Erickson, Helfer, and Tatel (1959) at D.T.M., Washington, observed hydrogen in latitudes outside ±20°. Recently, Davies (1960) has covered the same region and extended observations to include the sky between ±20°.

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In the present work the disposition of local neutral hydrogen is presented in terms of three schematic diagrams. One is the distribution of N_{H}, the number of hydrogen atoms in a line-of-sight column of 1 cm^2 section, the second is a diagram of sample line half-widths, the variations of which show some correlation with features in the N_{H} contours, and the third is the observed distribution of profile peak radial velocities.

II. Equipment and Observations

Although the equipment has been briefly described elsewhere (McGee and Murray 1959) a short account will be given here in view of recent improvements and modifications.

The receiver is of the conventional double-conversion superheterodyne type switched between the H-line frequency (1420·406 Mc/s) and a reference frequency 2·5 Mc/s above. The figure of merit as an excess noise temperature is about 800 °K. The later stages are split up into 50 channels, most of which are tuned at frequency intervals equivalent to 7 km/s in radial velocity. The outer two channels on each side of the reception band are used as zero line markers. The filters in these channels are 0·5 Mc/s between half-power points and are placed so as to completely fill the two frequency ranges between the first and last of the 7 km/s channels and frequencies $\pm 1\cdot 5$ Mc/s (equivalent to $\sim\pm 320$ km/s) from the central natural line frequency. A complete H-line profile is recorded every 2 min in sidereal time.

Changes to the primary feed of the aerial have improved the beamwidth to 2°·2 between half-power points.

A switched noise source at the vertex of the paraboloid provides a relative intensity calibration for the equipment. Deflections up to 200 °K aerial temperature are possible. It was found that the receiver sensitivity did not alter by more than a few per cent. over the entire survey.

Frequency monitoring depended on comparisons of harmonics of the crystal-controlled local oscillators with signals from WWV. Owing to various deficiencies in signal reception at the long range of WWV the accuracy in terms of radial velocity is restricted to 0·3 km/s. Recently, extensive tests made with a very accurate frequency counter indicate that both local oscillators have frequency stability better than one-tenth of this figure.

Sky observations were taken at meridian transit at intervals of 1° in declination from Dec. $-90°$ to Dec. $+42°$ over periods of 24 hr on each observing position. An H-line profile was evident at almost every point observed. The limit of sensitivity, governed by receiver noise plus inherent interchannel differences in zero level, was set by an r.m.s. fluctuation level of about 0·7 °K on a single profile. More than 95000 profiles were collected during the survey. The reproducibility of each profile selected for reduction was easily checked, in that two profiles in declination and a minimum of four in right ascension coordinates were recorded per aerial beamwidth. Instrumental resolution in both frequency and aerial beam size has produced a lower limit of about 12 km/s in the observed profile half-widths.

III. Treatment of the Data

The diagrams in this paper are based on analysis of a sample from the mass of observations mentioned above. It is intended in succeeding papers to present data based on profiles at intervals of at least one degree in each coordinate. Work on this aspect of the project has been in progress on a large area around the galactic centre and in view of the large-scale features revealed in the intensity and particularly in the radial velocity contours it was decided to study first the gross distributions around the whole sphere. The sample consists of observations made at 2° intervals in galactic latitude along meridians of longitude 30° apart. It was found that all the essential features of the detailed charts remained while localized elements were conveniently eliminated. With the recent completion of preliminary detailed diagrams for the whole survey it has been possible to further check the sampling procedure and make some small corrections that were required in the regions near the galactic plane.

(a) *The H-line Profiles*

The profiles reduced could be divided into three classes. The first and most widely distributed over the sky were those obviously representing local gas: the half-widths were in the range from 12* to 35 km/s, in almost all cases they were single peaked and the values for the peak radial velocities did not exceed ± 12 km/s. The maximum intensity of this class was ~ 50 °K.

Inside $b^{\mathrm{I}} = \pm 10°$ the galactic spiral structure was evident by the appearance of very wide and usually multi-peaked profiles of much greater intensity than elsewhere. The " local " gas was traced across this region by selecting a profile peak whose value was close to that of the single-peaked profiles immediately outside it. The " local " peak was unambiguous in some cases but in others the portion of profile selected as " local " probably contained contributions from more distant gas.

The third class of profile was obtained mainly in low intensity regions at high galactic latitudes. The half-widths ranged from 36 to 140 km/s. Some profiles exhibited two or three fairly definite peaks.

(b) *The H-line Intensities and Quantity of Neutral Hydrogen*

The quantity of local neutral hydrogen is indicated in terms of N_{H}, the number of hydrogen atoms in a 1 cm² line-of-sight column. Values of N_{H} were obtained in the following way. The observed H-line aerial temperatures were converted to brightness temperatures using a statistically established scale between Murraybank and Leiden temperatures. The optical depth of local gas appears to be quite low (profile maximum temperature rarely exceeded 60 °K) so that following from the calculations of Wild (1952) and others we may use the relation

$$N_{\mathrm{H}} = 1 \cdot 84 \times 10^{18} \int_{-\infty}^{\infty} T(v) \mathrm{d}v,$$

* This value is limited by instrumental resolution.

where the numerical factor results from inserting the values for the atomic constants etc., T is the H-line brightness temperature in degrees Kelvin, and v is the radial velocity in kilometres per second. We assume that the integration extends over the local gas only.

A contour diagram of N_H is given in Figure 1 on an Aitoff projection using old galactic coordinates (Ohlsson).* The contour interval is $0 \cdot 2 \times 10^{21}$ H atoms cm^{-2}. In the region of the galactic plane indicated by the hatching N_H exceeds $2 \cdot 0 \times 10^{21}$ H atoms cm^{-2} and no data are given because of uncertainties in separating out local gas profiles.

(c) *The H-line Half-widths*

Figure 2 is an attempt to show how the shapes of the profiles vary over the sky. Sample profiles were selected to represent the gas in a latitude range of 10° along the 12 galactic longitudes. The half-width of a profile is indicated at its representative position by a whole number (km/s) and by the length of a rectangle drawn about the l^I meridian. The black portion to the left of a meridian indicates negative radial velocities and the white portion to the right positive velocities. The relative position of the profile peak is given by the arrowhead on top of each rectangle.

(d) *The Radial Velocity of the Gas*

Profile " peak " radial velocities, i.e. the velocities at the points of maximum brightness temperature on the H-line profiles, have been chosen to represent the velocity distribution of the gas. It will be noticed on inspection of the arrowhead positions in Figure 2 that peak and median values would be very close in the greater proportion of profiles. In any case we consider peak velocities a better indication of local gas velocity.

Observed peak values were read from the chart records to an accuracy of 1 km/s. They were corrected to allow for the Earth's orbital motion and the solar motion and are specified relative to the local standard of rest with the aid of Lund Observatory Tables.†

The large-scale distribution of radial velocities of local neutral hydrogen is presented in Figure 3. In the light grey shaded area velocities are positive, in the dark grey shaded areas negative, and in the white, zero. The contour interval is 3 km/s except in the range from $-1 \cdot 0$ to $+1 \cdot 0$ km/s which is classed as zero. The hatched areas along the Milky Way contain velocities exceeding ± 15 km/s. The uncertainty proviso (see Section III (*b*)) applies also to velocities in this region. Low intensity, wide profiles whose peak velocities differed widely between ± 30 km/s approximately were observed in the area north of the broken line XX.

* The symbols for galactic coordinates l and b are being written throughout as l^I and b^I following the convention to distinguish them from the new coordinates.

† Lund Observatory Tables for the conversion of galactic into equatorial coordinates and for the direction cosines in the equatorial system. Based on the Galactic Pole 12^h 40^m ; Decl. +28° (1900.0), corrected for precession to 1958.0. Table for the Reduction of velocities to the local standard of rest. D. A. MacRae and Gart Westerhout. Both published by The Observatory, Lund, Sweden, 1956.

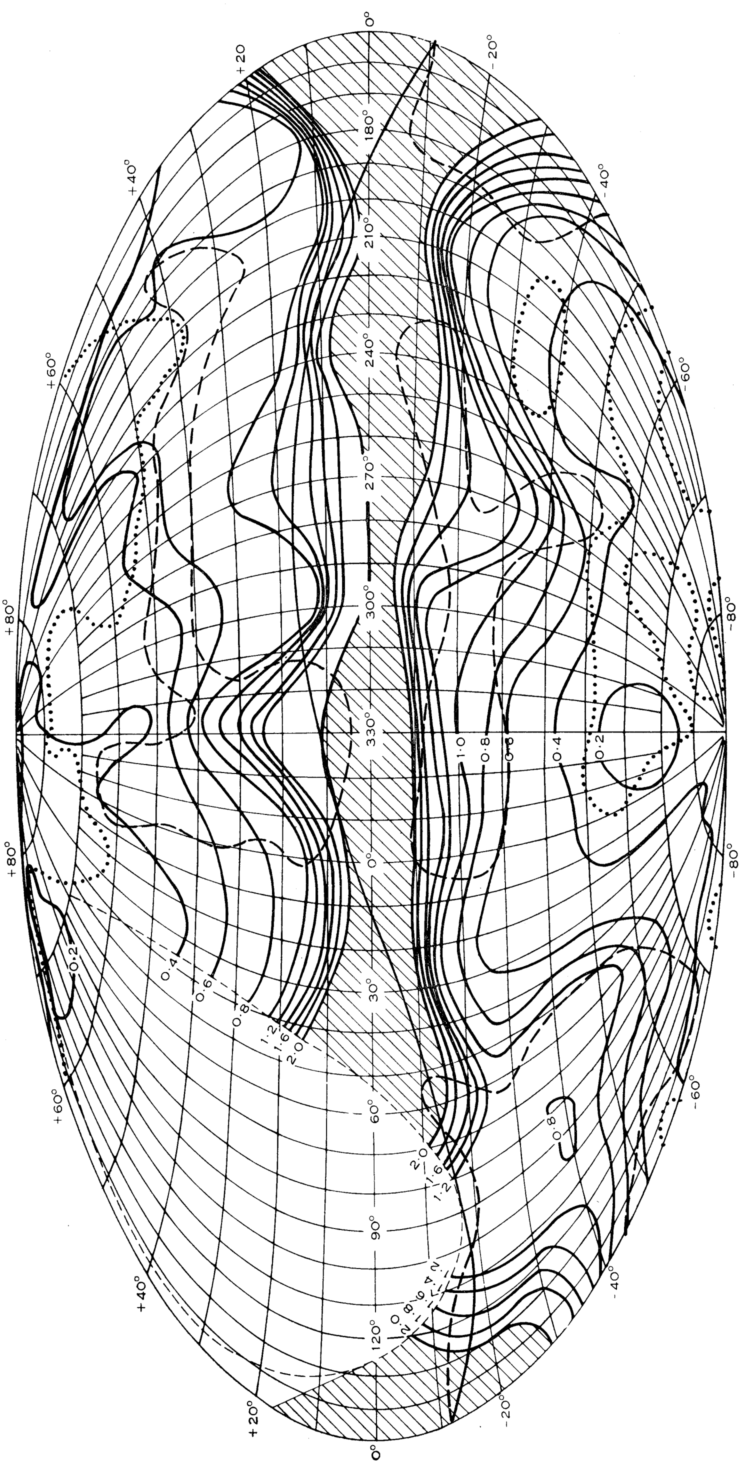


Fig. 1.—The local distribution in N_H, the number of hydrogen atoms/cm² in a line-of-sight column. The contour interval is $0 \cdot 2 \times 10^{21}$ H atoms cm^{-2}. Coordinates: old galactic system (Ohlsson). Projection: Aitoff. The red dashed lines enclose regions where profile half-widths are in the range 12–20 km/s (12 km/s is lower instrumental limit); the red dotted lines enclose regions of profiles exceeding 35 km/s. The unbroken red line is the equator corresponding to an axis parallel to the local galactic magnetic field as derived by Shain.

The present survey information has been augmented by taking velocity values from the Leiden profiles (Muller and Westerhout 1957) in the region $b^{\mathrm{I}}=\pm 10°$, $l^{\mathrm{I}}=45°$ to $l^{\mathrm{I}}=120°$, and by estimating several values from the D.T.M. survey at higher positive latitudes. These regions were not visible from Murraybank.

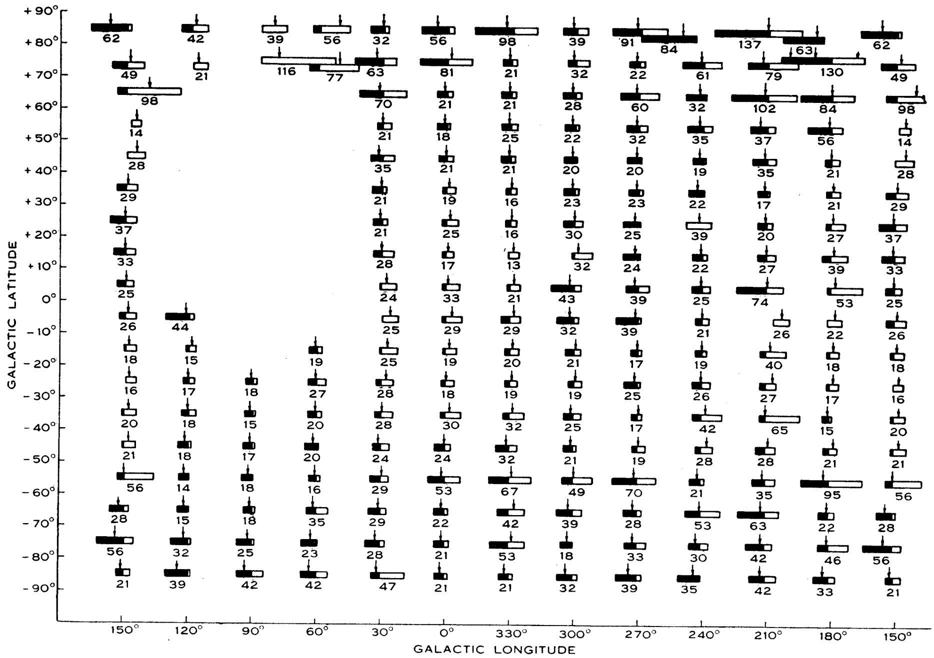


Fig. 2.—Hydrogen line half-widths. The length of each rectangle is proportional to the half-width in equivalent radial velocity; negative values are represented by the black portion to the left of the meridian line, positive values by the white on the right. The whole number beneath each rectangle is the half-width in km/s. The arrowheads denote the relative position of a profile peak.

IV. Comparison with Other Large-scale Surveys

The D.T.M. survey is based on profiles observed at intervals of 10° in both galactic longitude and latitude outside $|b^{\mathrm{I}}|=20°$; in the Jodrell Bank survey profiles were observed at 5° intervals.

A comparison of some of the amounts of neutral hydrogen recorded by the three surveys in the overlapping region has been made in Table 1. The D.T.M. data had to be taken from a rather small diagram and converted to N_{H} by an approximate factor quoted by the authors. In the table the D.T.M. values are consistently lower than the Murraybank N_{H} by an average $0 \cdot 2 \times 10^{21}$ units, the Jodrell Bank values show no systematic differences from ours except in the galactic plane region. The last two columns of Table 1 compare D.T.M. average radial velocities around parallels of latitude with corresponding Murraybank figures. In addition, individual radial velocities of the latter two surveys were compared. One hundred and fifteen pairs of values were available. The D.T.M.

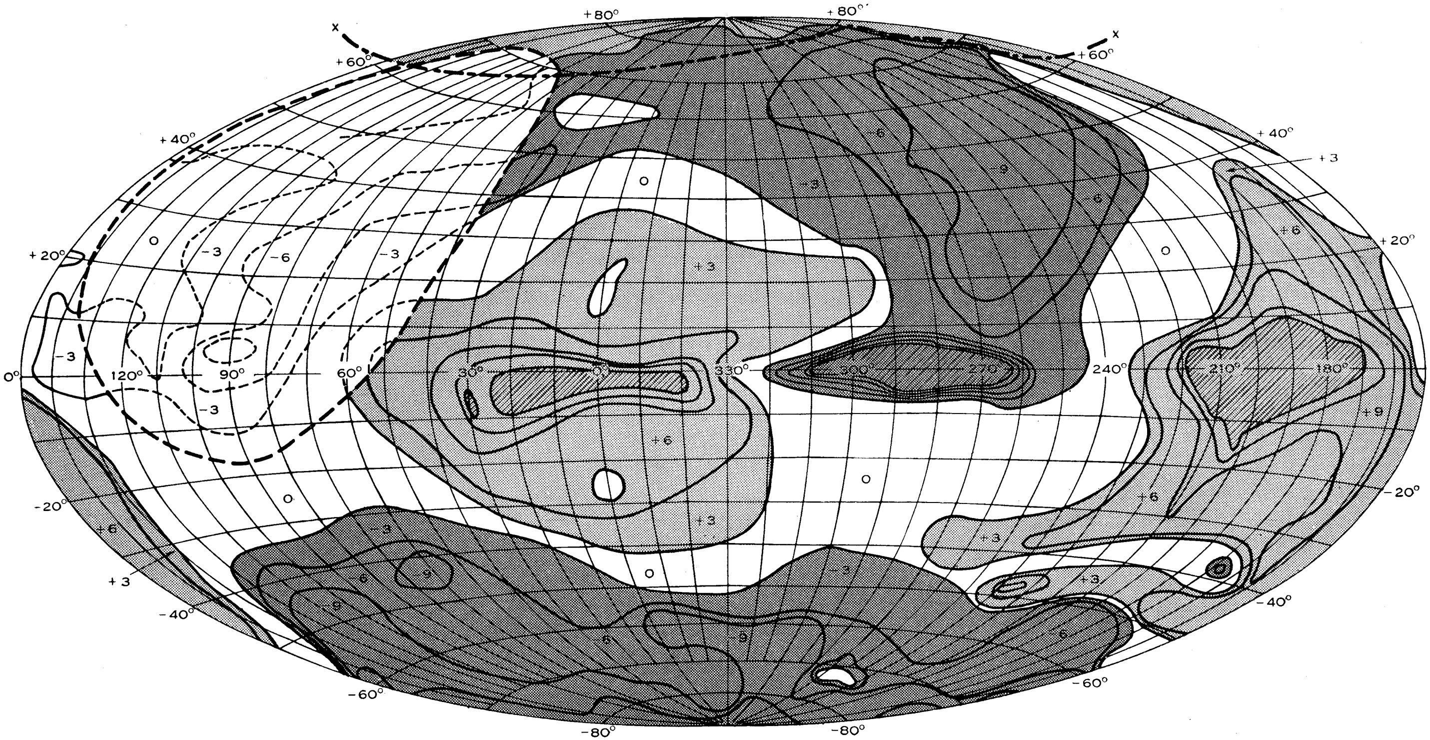


Fig. 3.—The distribution of H-line peak radial velocities. The contour interval is 3 km/s. Coordinates : old galactic system (Ohlsson). Projection : Aitoff. Light grey shading denotes regions of positive velocity, dark grey shading negative velocities, and white denotes zero velocity (-1, 0, $+1$ km/s).

value at a point was estimated from their radial velocity–galactic longitude diagrams. 30% of the pairs agree exactly, 31% had a | 1 | km/s difference, 18% a | 2 | km/s difference. The overall means were equal.

TABLE 1

SAMPLE COMPARISONS OF N_H AND AVERAGE RADIAL VELOCITIES OBTAINED BY D.T.M. (E), DAVIES (D), AND MURRAYBANK (M) SURVEYS

	N_H (10^{21} H atoms cm^{-2})												Velocities Averaged Around Parallels of b (km/s)	
l^{I}	330°			30°			150°			210°				
b^{I}	E	D	M	E	D	M	E	D	M	E	D	M	E	M
+5	—	4·0	2·3	—	4·0	2·9	—	6·0	5·7	—	3·0	1·6	—	+0·0
+10	—	3·0	2·0	—	2·1	2·0	—	2·8	3·5	—	1·8	1·0	—	+0·3
+20	1·6	2·4	1·8	1·0	1·2	1·0	1·0	1·8	1·4	0·8	1·0	0·9	0·0	−0·6
+30	0·8	1·5	1·4	0·7	0·6	0·7	0·7	1·0	0·7	0·6	0·6	0·8	−2·2	−1·3
+40	0·6	1·0	1·0	0·2	0·5	0·5	0·2	0·7	0·5	0·6	0·6	0·9	−1·9	−2·4
+50	0·4	0·7	0·5	0·1	0·3	0·4	0·1	0·3	0·5	0·5	0·6	0·8	−4·0	−4·0
+60	0·3	0·6	0·4	0·1	—	0·3	—	—	0·5	0·3	0·6	0·9	−6·1	−2·2
+70	0·2	0·3	0·4	—	—	0·3	—	—	0·5	0·2	0·3	0·7	−3·0	−3·4
l^{I}	90°			30°			150°			210°				
−5	—	3·8	—	—	6·0	3·1	—	4·0	5·0	—	3·5	2·6	—	+3·3
−10	—	2·0	2·0	—	3·2	1·4	—	2·5	3·0	—	2·0	2·2	—	+2·6
−20	0·8	0·9	0·8	0·8	1·3	0·9	1·4	1·7	1·9	—	0·5	0·8	+3·8	+3·1
−30	0·3	0·9	0·5	0·6	0·6	0·9	1·0	1·6	1·9	—	0·6	0·5	+2·3	+3·1
−40	0·4	0·6	0·4	0·3	0·6	1·0	1·0	0·9	1·0	0·5	0·6	0·4	+0·6	−0·5
−50	0·4	0·6	0·5	0·6	0·6	0·9	0·4	0·8	0·6	0·5	0·3	0·3	−3·7	−3·0
−60	0·4	0·4	0·5	0·5	0·6	0·7	0·4	0·7	0·4	0·5	—	0·3	−6·0	−5·3
−70	0·3	0·3	0·4	0·4	0·4	0·3	0·5	0·3	0·4	0·3	—	0·3	−5·2	−6·0
−80	0·2	—	0·4	0·2	—	0·4	0·2	—	0·3	0·2	—	0·3	−6·8	−8·2

V. RESULTS AND DISCUSSION

(*a*) *The* N_H *Distribution*

(i) *Features*.—A number of large-scale features are prominent in the N_H contour diagram of Figure 1. In the northern galactic hemisphere two spurs dominate; one from the Scorpius-Ophiuchus region near the galactic plane to latitude +65° is spread over some 45° in longitude. The ridge is at first centred about $l^{I}=327°$ but moves towards $l^{I}=0°$ as latitude increases. References to Figure 2 will show that almost the whole spur is characterized by profiles in the half-width range 12–20 km/s. Areas containing profiles in this range have been indicated by the broken red lines in Figure 1. Such evidence would point to a compact complex of hydrogen clouds. Large dust clouds have been observed in the lower latitudes of this same region and, if association of dust and hydrogen is assumed, the region must be fairly close to the Sun—of the order of 150 parsecs distant.

The second spur develops from about $b^{\mathrm{I}}=+40°$ in Sextans and extends along $l^{\mathrm{I}}=210°$ to $b^{\mathrm{I}}=75°$. It is a region of broader profiles (>35 km/s half-widths which are found within areas indicated by the red dotted lines in Fig. 1). No optical feature seems to be associated with this spur.

In southern latitudes a weaker ridge begins from about $b^{\mathrm{I}}=-15°$, $l^{\mathrm{I}}=265°$ and shifts to $l^{\mathrm{I}}=240°$ as it reaches $b^{\mathrm{I}}=-60°$. An area some 20° wide about the centre line is one of the narrow width profiles (12–20 km/s).

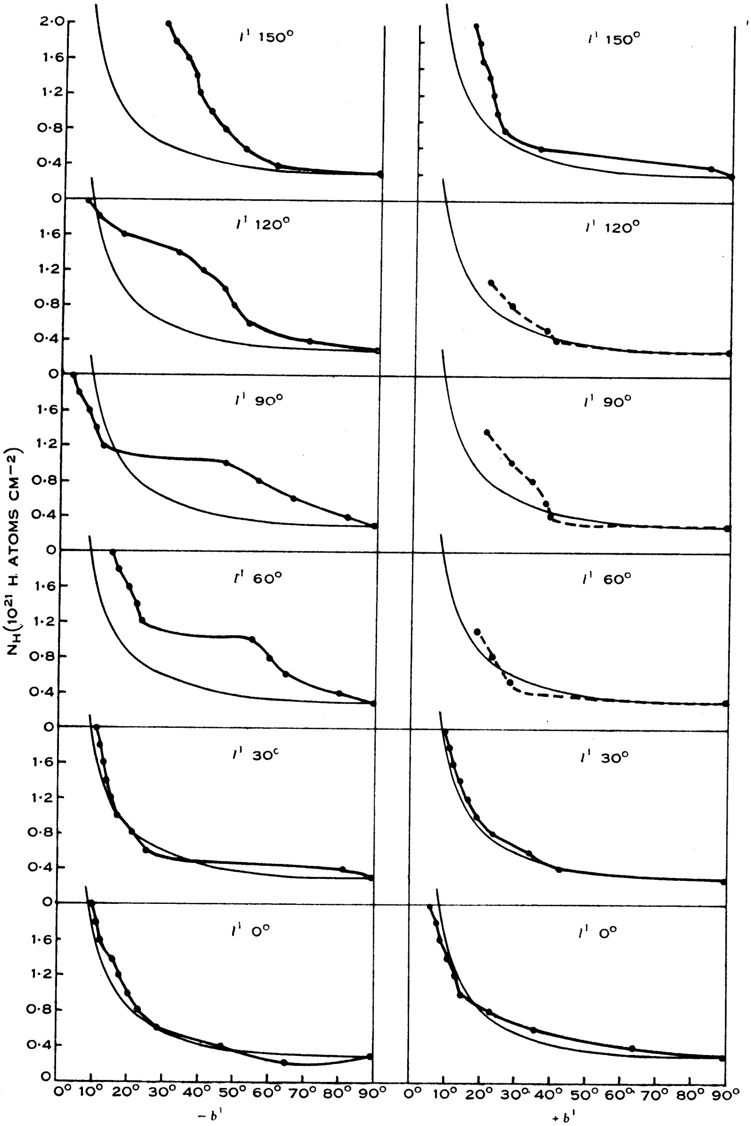
The outstanding feature of the N_{H} diagram is in the Gemini-Taurus-Orion region with a continuation over a large area including Triangulum, Andromeda, and Pisces. The longitude range is approximately $l^{\mathrm{I}}=180°$ back to $l^{\mathrm{I}}=60°$ and the latitude $b^{\mathrm{I}}=+20°$ to $b^{\mathrm{I}}=-80°$. As the broken red line again shows, most of the region south of $b^{\mathrm{I}}=-10°$ exhibits profiles in the 12–20 km/s range. However, it could well be that here are two separate regions. The gradient of N_{H} contours in the $l^{\mathrm{I}}=130°$ vicinity is associated with a sudden change in radial velocities (see Fig. 3). This phenomenon was remarked in the earlier observations of the Taurus-Orion cloud.

The N_{H} contours fall to minima in both hemispheres at places away from the galactic poles. The northern minimum is centred on $l^{\mathrm{I}}=105°$, $b^{\mathrm{I}}=+72°$ with values below $0 \cdot 2\times10^{21}$ H atoms cm^{-2}, the southern minimum centre is approximately at $l^{\mathrm{I}}=335°$, $b^{\mathrm{I}}=-65°$, with similar N_{H} values. It is interesting to note that the mean longitudes of the major northern spur and the southern minimum and the northern minimum and the major southern spur are approximately the same.

Dr. W. C. Erickson has called the authors' attention to the fact that his estimated minimum (personal communication) of the D.T.M. survey and the northern minimum here agree exactly and that the position, $l^{\mathrm{I}}=105°$, $b^{\mathrm{I}}=+72°$, is the pole corresponding to the plane of the general magnetic field in the solar vicinity given by the late G. A. Shaĭn (1957). Noting systematic deviations of the position angles of the planes of preferential vibrations of stellar light, Shaĭn found that the local galactic magnetic field was inclined at an angle of 18° to the galactic plane. He had hoped to be able to compare the magnetic field plane with the distribution of local gas clouds. The plane is shown in red on Figure 1 cutting the galactic plane at $l^{\mathrm{I}}=15°$ and $l^{\mathrm{I}}=195°$. There does not seem to be sufficient evidence to come to any conclusions except that this plane fits the gas distribution very much better than the so-called Local System plane with its pole at $l^{\mathrm{I}}=170°$, $b^{\mathrm{I}}=+74°$.

(ii) *The Variation of* N_H *with* b.—The variation of N_{H} with galactic latitude was studied to provide information on the nature of the hydrogen distribution. If the gas is stratified parallel to the galactic plane the observed N_{H} should vary as the cosecant of the latitude.

N_{H} is plotted against b^{I} at each of 12 galactic longitudes in Figure 4. A reference value of $N_{\mathrm{H}}=0 \cdot 3\times10^{21}$ H atoms cm^{-2} was taken for $|b^{\mathrm{I}}|=90°$. A cosecant curve has been drawn from this point for comparison with each observed N_{H} curve. It can be seen that the N_{H} values tend to conform to the cosecant



(a)

Fig. 4 (*a*).—The variation of N_H with galactic latitude at a number of galactic longitudes between 0° and 150°. The fine line curve in each is a cosecant curve ($N_H = | 0 \cdot 3 \times 10^{21}$ cosec $b^I |$).

distribution with some departures which are positive in most cases. We are led to the conclusion, then, that the local distribution is substantially horizontally stratified and that embedded in it is a number of concentrations of gas. The N_H values in the regions towards the north and south galactic poles appear normal in spite of the rather wider profiles observed in the high northern latitudes.

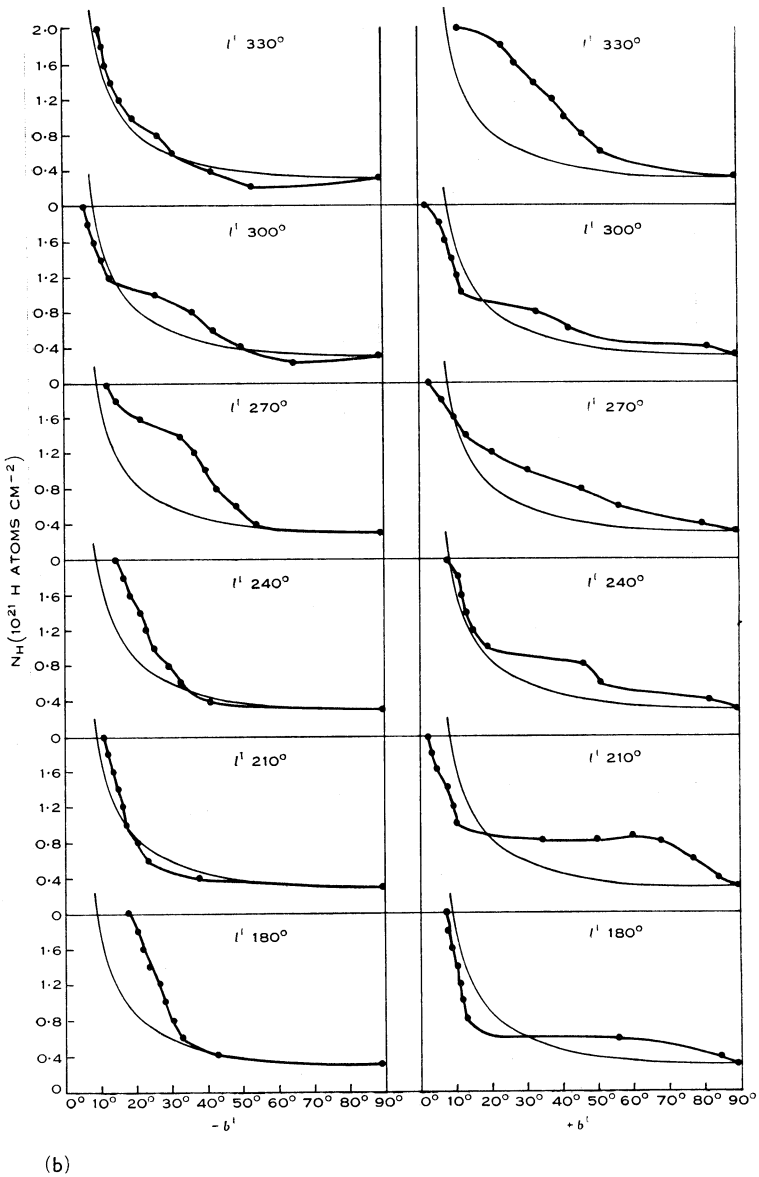


Fig. 4 (*b*).—The variation of N_H with galactic latitude at a number of galactic longitudes between 180° and 330°. The fine line curve is a cosecant curve ($N_H = | 0 \cdot 3 \times 10^{21} \operatorname{cosec} b^I |$).

The departures from horizontal stratification are illustrated in Figure 5 in which ΔN_H (the departure of the experimental N_H value from the cosecant distribution value) is plotted on a polar projection. The greater part of the local region is seen to be stratified, while features mentioned in earlier discussion emerge as areas of excess N_H. The region in Gemini-Taurus-Orion and the

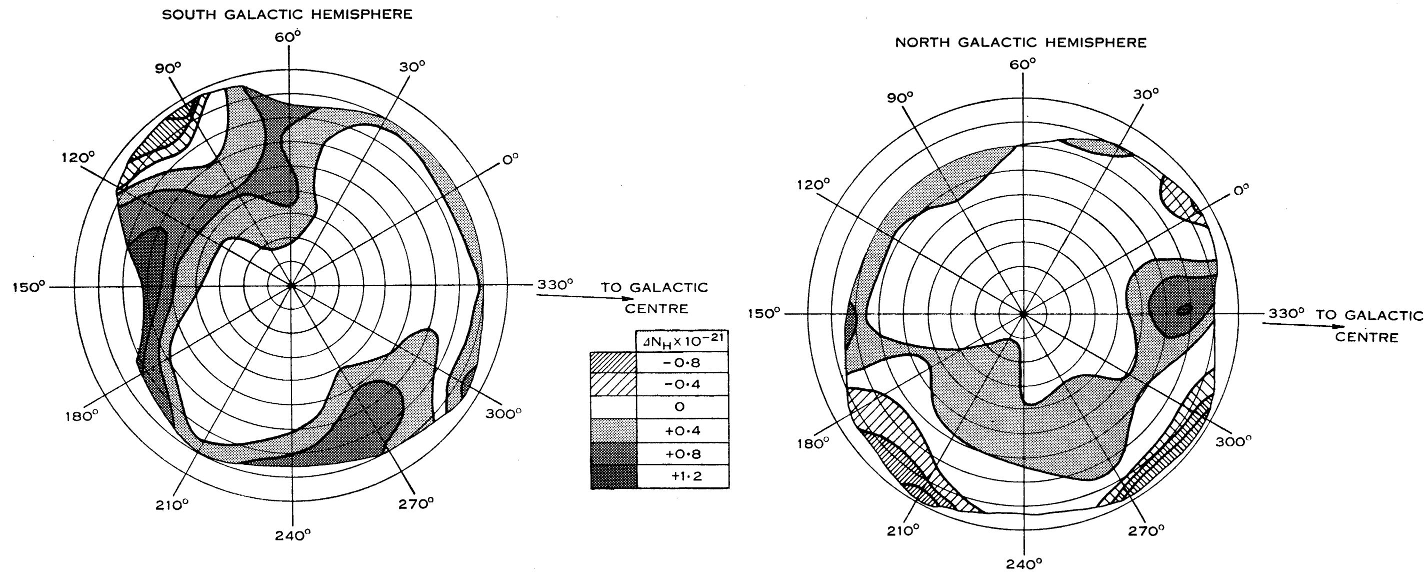


Fig. 5.—The distribution of ΔN_{H}, the departures of the observed N_{H} from a theoretical N_{H} cosecant b^{I} distribution. The hatched areas denote negative departures.

extension into Pisces are prominent, as is the Scorpius-Ophiuchus spur at the lower latitudes. The feature in south latitudes near $l^{\mathrm{I}}=270°$ is more accentuated in this representation. There are no obvious striations related in direction to the local spiral arm, which, if they had existed, would have been evident using this projection.

(iii) *Estimation of Gas Density in the Solar Vicinity*.—Our observations do not include an indication of distance and consequently cannot, without arbitrary assumptions as to distribution along the line-of-sight, yield density. However, Schmidt (1957), using the results of the extensive low latitude observations at Leiden, has derived a distribution of hydrogen in a direction perpendicular to the galactic plane. Assuming that our observations, including those at high latitudes, refer to the same distribution, we can use this model, together with our evidence of stratification and well-established values of N_{H}, to calculate the local gas density.

TABLE 2

MEAN VALUES OF N_{H} AROUND PARALLELS OF GALACTIC LATITUDE

b^{I}	$N_{\mathrm{H}}\times 10^{-21}$ (H atoms cm^{-2})	$N_{\mathrm{H}} \sin b^{\mathrm{I}}$	b^{I}	$N_{\mathrm{H}}\times 10^{-21}$ (H atoms cm^{-2})	$N_{\mathrm{H}} \sin b^{\mathrm{I}}$
+85°	0·37	0·370	−85°	0·33	0·330
+75°	0·40	0·386	−75°	0·33	0·318
+65°	0·50	0·454	−65°	0·36	0·326
+55°	0·55	0·450	−55°	0·46	0·376
+45°	0·62	0·439	−45°	0·64	0·450
+35°	0·81	0·465	−35°	0·85	0·488
+25°	0·93	0·393	−25°	1·10	0·465
+15°	1·24	0·322	−15°	1·62	0·420
+ 5°	2·68	0·233	− 5°	2·85	0·248
Means (excluding last entry)		0·41			0·40

Mean values of N_{H} around parallels of galactic latitude are given in Table 2. If the hydrogen were stratified horizontally the values of $N_{\mathrm{H}} \sin b$ would equal N_{H} for $b^{\mathrm{I}}=90°$ and would be constant for all values of b^{I}. We have therefore tabulated $N_{\mathrm{H}} \sin b^{\mathrm{I}}$ also, and, excluding the value at 5°, which is dubious for reasons given above, the values do not vary much. This is to be expected from the appearance of Figure 5 but the numerical evaluation gives a more representative value of N_{H} for a vertical column through the Galaxy. Thus, if we restrict attention to the regions within about 30° of the galactic poles, the values of N_{H} are about $0\cdot 40\times 10^{21}$ H atoms cm^{-2} to the north and $0\cdot 33\times 10^{21}$ H atoms to the south and imply that the Sun is a little to the south of the halfway position. If we extend consideration to 75° from the poles, thus including some of the clouds mentioned earlier, the values become $0\cdot 40\times 10^{21}$ H atoms cm^{-2} for both north and south.

Davies (1960) from his own observations found N_{H} values higher in the south than in the north and concluded that the Sun lay about 20 pc north of the galactic plane. The discrepancy seems due to averaging over different areas of sky : for example, we do not see the northern low intensity region near $l^{\mathrm{I}}=90°$, Davies does not see the southern low intensity region near $l^{\mathrm{I}}=300°$. We have tried including relevant values from the other two surveys, but results indicate that the Sun lies at the centre of the hydrogen layer within the observational uncertainty.

A mean value of N_{H} of $0 \cdot 35 \times 10^{21}$ H atoms cm^{-2} in the directions $b^{\mathrm{I}}=\pm 90°$, in conjunction with Schmidt's shape for the distribution (determined unfortunately for other parts of the galactic disk) leads to a derived density near the Sun of $0 \cdot 46$ H atoms/cm³. This may be compared with Westerhout's (1957) value for the mean density at the Sun's distance from the galactic centre of about $0 \cdot 5$ H atoms/cm³.

(b) *Profile Shape*

The half-widths of the sample profiles in Figure 2 range from 12 to 140 km/s. The outstanding piece of information supplied by this diagram is the large-scale grouping of similar profiles. Profiles in the range 12–20 km/s were arbitrarily designated as " narrow ". Their deployment has been shown by the broken red lines superimposed on the N_{H} contours in Figure 1. It has already been remarked that the dominant features of the N_{H} distributions are regions of narrow profiles.

The red dotted lines in Figure 1 outline the regions of " wide " profiles—again arbitrarily chosen for half-widths greater than 35 km/s. The northern galactic polar cap has profiles of mean half-width 70 km/s and values up to 137 km/s. Some of these profiles have two and three peaks. In the south the mean half-width is 50 km/s with the maximum 95 km/s.

An interesting question has arisen concerning the value of these wide half-widths. Dr. Erickson (personal communication) has suggested that most of the local gas profiles are not in fact Gaussian in shape but are cusp-like, having broad wings with comparatively narrow, central sections. The broad wings may be due to some background of well-dispersed hydrogen—not necessarily in the galactic disk. Thus, when measuring half-widths for low intensity profiles where any " central sections " tend to be confused with noise, the value will be relatively much wider than for a profile whose maximum temperature is above, say, 10 °K.

A number of samples were chosen at random from the profiles used in the present results and divided into groups of half-width 12–35 km/s and 36–140 km/s. " Overall width ", meaning widths read between the estimated zero intensity points of the profiles, i.e. greater than about $0 \cdot 5$ °K, were measured and means taken for each group.

In the 12–35 km/s group the mean half-width was 24 km/s and the mean overall width 112 km/s. The ratio of half to overall width is $0 \cdot 22$. For the 36–140 km/s group the corresponding results are 80, 186 km/s, and $0 \cdot 44$. These figures would point to the existence of such an effect but it is not the whole story. More of this type of data are being collected to make a closer study of the broad low intensity contribution.

However, in spite of the above, there seems little doubt that the " wide " profiles are wider by at least a factor of two. The reason for their existence in a distribution of local gas remains unanswered at present. A number of possible explanations come to mind. Firstly, the areas of wide profiles may be simply large diffuse clouds, the north one fortuitously overlaying the galactic polar cap. If, in fact, some association exists between the local galactic magnetic field and the disposition of neutral gas in the spiral arm a reason exists for more diffusion in these areas. Against this, a gradation in profile widths with increasing latitude may be expected in such a case and none has been detected.

Again, it is known that clouds of gas may oscillate in the z-direction about an equilibrium position in the plane. Thus, a greater velocity spread might well be observed from high latitudes were the aerial to intercept radiation from a number of clouds in different phases of this motion.

The possibility that the wide profiles are due to hydrogen from the galactic corona, say, is not considered likely since the half-width increase is only of the order of three to one, the overall width three to two. A much greater dispersion is expected from the randomly moving and presumably highly dispersed gas clouds of the corona. Further, we should expect to see wide profiles even better at intermediate latitudes, where the longer, oblique paths should yield higher intensities.

(*c*) *The Radial Velocity Distribution*

(i) *The Observed Distribution.*—The striking feature of the observed distribution of peak radial velocities (Fig. 3) is the large-scale grouping of velocities of similar sign and magnitude. Two regions of positive velocity, one centred approximately on $l^{\mathrm{I}}=10°$ and the other on $l^{\mathrm{I}}=190°$, extend to galactic latitudes of $\pm 40°$ and over longitude ranges of more than 90° each. Regions of negative velocity lie between these at low latitudes. The high latitudes are characterized by negative velocities ; the southern cap is completely occupied by approaching gas down to $b^{\mathrm{I}}=-40°$, the northern cap has approaching gas, together with a sector of diffuse gas of various velocities. Considerable regions between the four main features are occupied by gas at zero velocity. Some of the observed velocities in the hatched regions have magnitudes up to 34 km/s. The velocities of the purely local gas outside $|b^{\mathrm{I}}|=10°$ are restricted to about ± 12 km/s, except for the one " irregular " region centred on $l^{\mathrm{I}}=150°$ approximately and extending from $b^{\mathrm{I}}=+40°$ to $b^{\mathrm{I}}=+90°$. It has wide profiles and higher peak velocities (up to ± 30 km/s).

Some of the features of this distribution, e.g. the alternating positive and negative velocity regions along the galactic equator, are clearly associated with differential galactic rotation, but it would be of great interest if, in addition, a general flow pattern could be recognized. Here again, owing to the lack of a measure of the distance to the observed hydrogen we cannot assign a particular velocity to be expected in a given direction due to differential galactic rotation. We can make an estimate based on the current rotational model after assuming that the peak of the H-line profile should originate in a region not more than a given distance from the galactic plane.

The standard formula for the radial velocity due to differential galactic rotation of an object at a short distance r from the Sun is

$$v_g = rA \sin 2l' \cos b^{\mathrm{I}},$$

where v_g is the radial velocity in km/s ; r is the distance from the Sun in kiloparsecs ; A is Oort's constant, taken as 19·5 km/s/kpc ; $l' = (l^{\mathrm{I}} - l_0^{\mathrm{I}})$, l^{I} is galactic longitude, $l_0^{\mathrm{I}} = 327°{\cdot}5$, the l^{I} of the galactic centre ; b^{I} is galactic latitude.

We assume a model in which the main concentration of local gas, giving rise to the profile maximum, is not more than 0·11 kpc from the galactic plane. This is the distance at which, according to Schmidt, the density has fallen to half its maximum value.

Curves of v_g against l^{I} at a number of galactic latitudes between $\pm 4°$ and $\pm 60°$ are sketched in grey in Figure 6. Observed radial velocity–galactic longitude curves have been superimposed in black at each latitude in the figure.

(ii) *Discussion of the Velocity Curves*.—Two quite definite results emerge from a study of Figure 6. The first comes from the fact that the amplitude of the model differential galactic rotation curve becomes less than 1 km/s at latitudes above $|b| \sim 50°$. This means that the values of the observed velocities in the high latitudes are effectively not influenced by differential rotation. The means of the negative velocities down to $|b^{\mathrm{I}}| \sim 40°$ (shown in dark grey in Fig. 3), are $-5{\cdot}6$ km/s in the northern hemisphere and $-6{\cdot}1$ km/s in the south.

In the second case, no matter how inaccurate the model may be, the differential rotational velocity must pass through zero at the longitudes of the galactic centre and anticentre ($l^{\mathrm{I}} = 327°{\cdot}5$ and $147°{\cdot}5$ respectively). Thus any observed departures at these points or differences in sign between the two curves cannot be due to differential rotation. In the direction near $l^{\mathrm{I}} = 327°{\cdot}5$ positive velocities of mean value $+4{\cdot}5$ km/s occur at all latitudes between $b^{\mathrm{I}} = \pm 30°$ and in $l^{\mathrm{I}} = 147°{\cdot}5$ positive velocities of mean value $+6$ km/s at latitudes $-4°$ to $-50°$. The mean velocity in the northern latitudes of $l^{\mathrm{I}} = 147°{\cdot}5$ is approximately zero. These parts of the observed curves in Figure 6 are emphasized by thick segments.

We can conclude, then, that neutral hydrogen is flowing in towards the Sun from above and below in latitudes $|b^{\mathrm{I}}| = 90°$ to $|b^{\mathrm{I}}| \sim 40°$, at all longitudes, at approximately 6 km/s. The gas is flowing away from the solar vicinity in low and middle latitudes in directions centred on $l^{\mathrm{I}} = 327°{\cdot}5$ and in southern latitudes on $l^{\mathrm{I}} = 147°{\cdot}5$ at approximately the same speed.

Finally, the longitudes of the maximum velocities of the observed curves in Figure 6 have a tendency to be shifted with respect to the fixed longitudes of the stationary points of the model curves as galactic latitude increases. The $l^{\mathrm{I}} = 282°{\cdot}5$ maximum (negative velocity) has moved from that value by some 30°, to a lower longitude, at latitudes $\pm 32°$. On inspection of the other maxima it is found that values initially at $l^{\mathrm{I}} = 102°{\cdot}5$ in $\pm b^{\mathrm{I}}$, at $l^{\mathrm{I}} = 192°{\cdot}5$ in $+b^{\mathrm{I}}$ decreased in l^{I}, at $l^{\mathrm{I}} = 12°{\cdot}5$ in $-b^{\mathrm{I}}$ remained much the same, and at $l^{\mathrm{I}} = 192°{\cdot}5$ in $-b^{\mathrm{I}}$ increased in l^{I} with increasing galactic latitude. This effect may be an indication of a shearing of the gas as distance from the galactic plane increases.

(iii) *Estimate of the Mass of Hydrogen Inflow.*—If $0 \cdot 46$ H atoms/cm^3 be accepted as a reasonable average density for the gas in the neighbourhood of the Sun responsible for the peaks in the profiles, the rate of inflow over the galactic

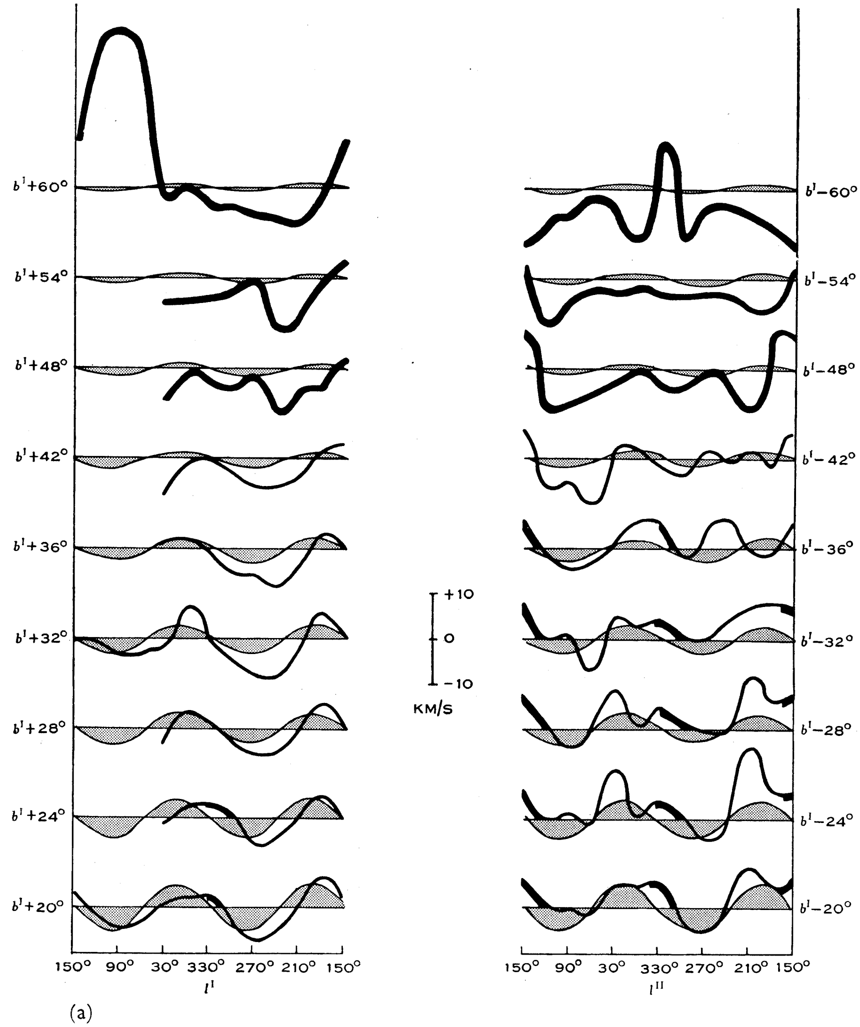


Fig. 6 (*a*).—Radial velocity as a function of galactic longitude. Observed velocities are the black curves; predicted velocities due to differential galactic rotation at points $0 \cdot 11$ kpc above and below the galactic plane ($v_g = 0 \cdot 11 \times 19 \cdot 5 \sin 2l' \cos b^{\mathrm{I}} \cot b^{\mathrm{I}}$) are shown in grey. Thick segments indicate definite discrepancies between observation and simple differential rotation.

polar caps at the mean velocity 6 km/s is $0 \cdot 7 \times 10^{-7} M_{\odot}$ per year per square parsec. This estimate is admittedly rather approximate but it shows that if such inflow is common over large areas of the galactic disk it would represent a highly significant item in the dynamics of the Galaxy.

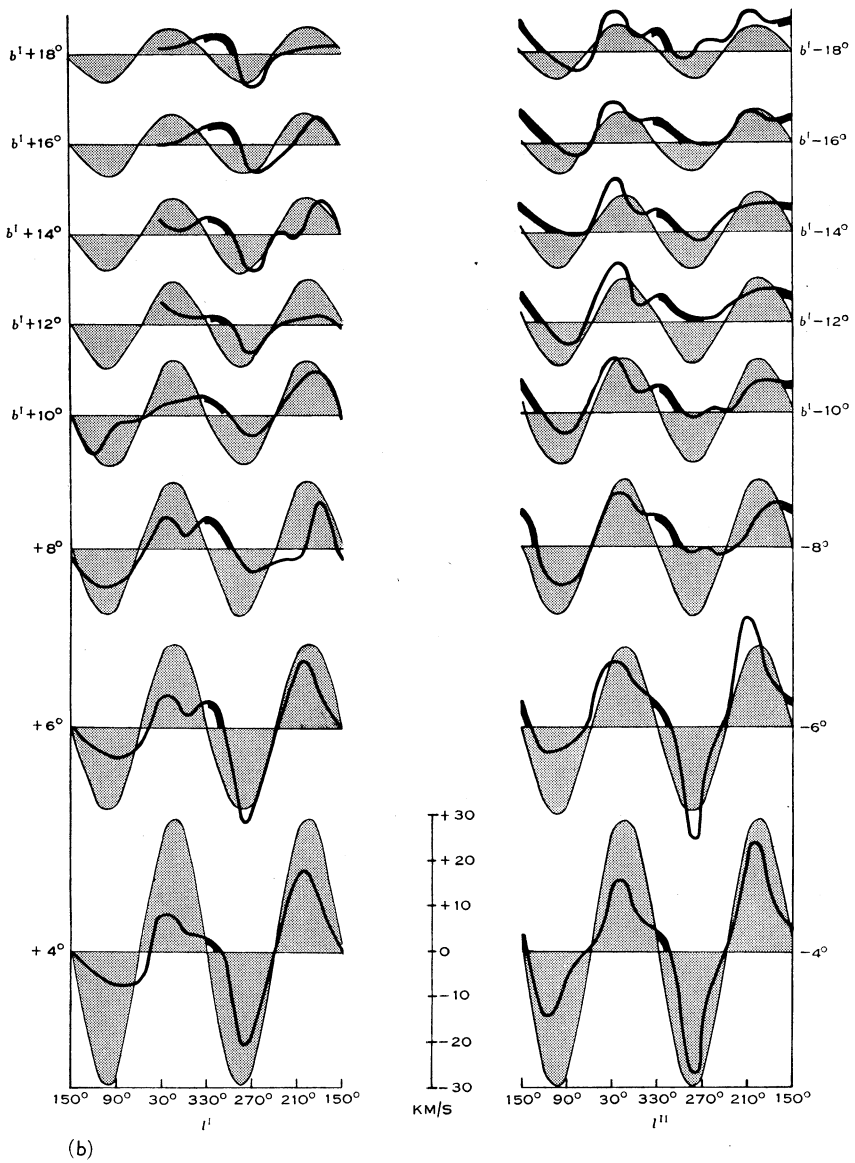


Fig. 6 (*b*).—For explanation see Figure 6 (*a*).

VI. Conclusion

Indications have been found that the local neutral hydrogen has a general horizontal stratification in which regions of excess density occur. The gas does not appear to be correlated closely with the so-called Local System, but the possibility exists that its disposition is in some way connected with the local galactic magnetic field.

The line profiles observed away from the Milky Way were generally single peaked with a range in half-width of 12–35 km/s. Wide profiles (36–140 km/s) were consistently observed in large regions near the galactic poles. Large-scale grouping of profiles into the comparatively narrow range 12–20 km/s occurred corresponding closely with outstanding features of the N_{H} distribution. This fact pointed to the compact nature of such large local complexes as the Scorpius-Ophiuchus spur and the Taurus-Orion region.

The peak radial velocity distribution was characterized by the simplicity of arrangement—two large regions of positive velocity in low and middle galactic latitudes were separated by negative velocity areas. The galactic polar caps down to $|b^{\mathrm{I}}| \sim 40°$ showed a great predominance of negative velocities. Part of this pattern is due to differential galactic rotation but two definite facts emerged from the observations: hydrogen is flowing away from the Sun at about 6 km/s in the directions of the galactic centre and anticentre in low and medium latitudes and is streaming in from above and below in latitudes $|b^{\mathrm{I}}| = 90°$ to $|b^{\mathrm{I}}| \approx 40°$ at about 6 km/s. The maximum radial velocities involved in these motions are $\sim \pm 12$ km/s. The complete flow pattern could not be determined from the present investigations.

VII. Acknowledgments

The authors would like to express sincere appreciation of the very considerable help and encouragement received from Dr. J. L. Pawsey in the preparation of this paper. He has always been most enthusiastic about the advantages of a wide-beam aerial in a sky survey of this nature.

We have benefited from many discussions with colleagues from the Radiophysics Laboratory and Mt. Stromlo Observatory.

Finally, we gratefully acknowledge the major contribution made by Miss Janice Milton in the original reduction of the data.

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