PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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Introductory Remarks

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Introductory remarks

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The recognition that interstellar space is filled with an exceedingly tenuous gas goes back to a paper by Eddington in 1926 in which he showed that the stationary Ca^+ and Na lines observed in distant stars are due to Ca^+ ions and Na atoms present in the space between the stars. The discovery of further atoms and of the first molecules was made possible by the development of high-dispersion spectrographs for stellar spectroscopy, especially the Coudé spectrograph at Mount Wilson Observatory. Dunham & Adams (1937*a*, *b*) observed with this instrument, in addition to absorption lines of interstellar Ti^+, K and Fe, three very sharp lines at 4300.31, 4232.58 and 3957.74 Å†, which they could not identify. It was Swings & Rosenfeld (1937) who pointed out that the first of these lines coincides with the $R_2(\frac{1}{2})$ line of the well known CH band at 4315 Å. This line is the only line in this band that comes from the lowest rotational level ($J = \frac{1}{2}$ of the $^2\Pi_{\frac{1}{2}}$ component). In this way the first interstellar molecule was tentatively identified. This identification was brilliantly confirmed when three further lines of CH in the 3870 Å band were predicted to arise from the lowest rotational level by McKellar (1940) and were observed in the spectrum of ζ Ophiuchi by Adams (1941). In addition, three lines of CN belonging to the 3883 Å band were predicted by McKellar and observed by Adams, showing that CN in the $N = 0$ as well as the $N = 1$ level is present in the interstellar medium. McKellar (1941) from the observed intensity ratio estimated a temperature of 2.3 K, the first hint (if we had understood it at the time) of the existence of the 3 K radiation.

This work left open the question of the nature of the two relatively strong lines at 4232.58 and 3957.74 Å and two additional lines observed by Adams in 1940 at 3745.33 and 3579.04 Å. All four lines were identified to be due to CH^+ by laboratory experiments (Douglas & Herzberg 1941, 1942; Douglas & Morton 1960). Again they are the lines (R(0)) that come from the very lowest rotational level of the ground state.

It took 22 years after this identification of CH^+ before the next molecule, namely the OH molecule, was identified, this time by radioastronomical methods (Weinreb *et al.* 1963). Subsequently, as you all know, a large number of molecules were identified by radio methods. In view of this important development it is sometimes forgotten that the first interstellar molecules were discovered by optical means. Even now there is a considerable need for further optical work to establish the presence of molecules that do not have an electric dipole moment and are therefore not amenable to detection by radio methods. Two such molecules have indeed been identified in the last 10 years. One is H_2, the most abundant molecule by far in the interstellar medium. Figure 1 shows a spectrum obtained by the Princeton group (Spitzer *et al.* 1973) with the aid of the Copernicus satellite, in the neighbourhood of 1100 Å; it shows clearly one of the strong H_2 absorption bands. For comparison, a spectrum obtained in the laboratory and reduced to the same scale is shown. In this case, because of the slow

† $1 Å = 10^{-10}$ m $= 10^{-1}$ nm.

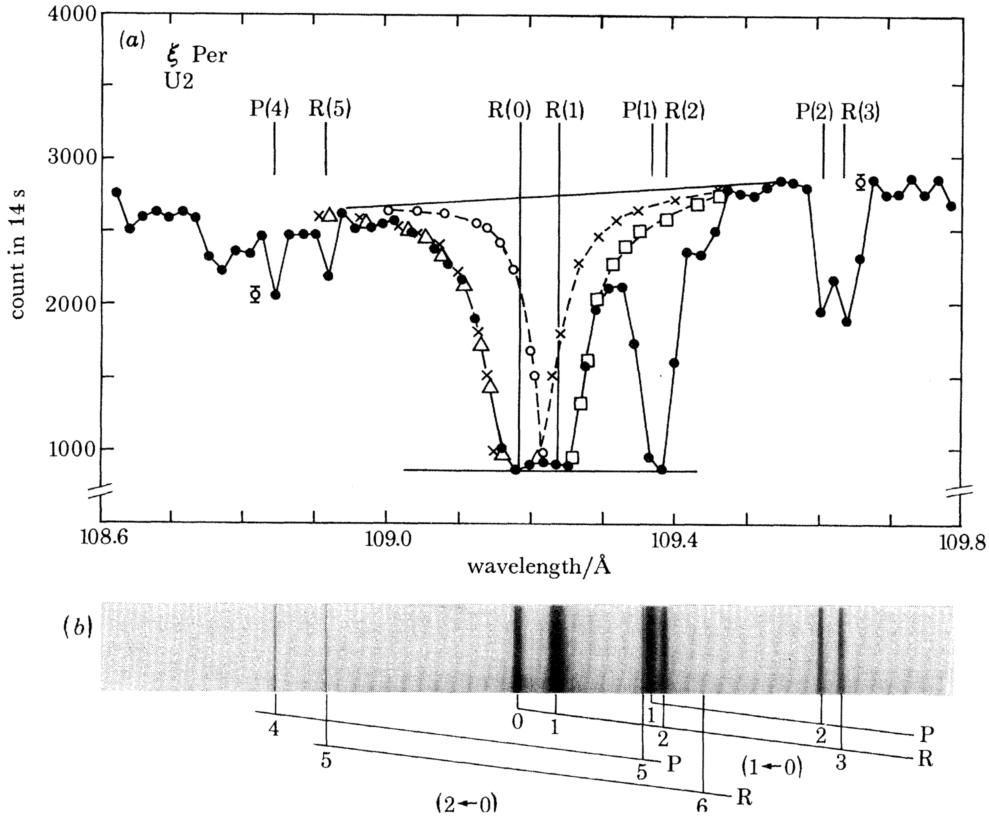

FIGURE 1. H_2 absorption near 1090 Å in interstellar space (*a*), after Spitzer *et al.* (1973), and in the laboratory (*b*).

conversion of *ortho*- into *para*-hydrogen and the slow rotational relaxation even within one of the modifications, not only the R(0) line appears but several higher lines as well. Because of the high abundance of H_2, the isotopic molecule HD has also been observed by the Princeton group (Drake 1974; Morton 1975).

The second homonuclear molecule recently observed by optical methods is the C_2 molecule (Souza & Lutz 1977; Chaffee & Lutz 1978). Here the lowest rotational lines in two bands of the Phillips system have been clearly observed. It seems very likely that a number of other molecules that have no dipole moment, like CH_3, CO_2 and N_2, will eventually be observed by optical methods.

An important recent observation has been the detection in the Orion nebula of the quadrupole spectrum of hydrogen in emission: first the rotation–vibration spectrum (Gautier *et al.* 1976) and more recently the pure quadrupole rotation spectrum (Beck *et al.* 1979; Knacke & Young 1980). It seems very likely that the emission of these quadrupole lines is caused by strong shock waves. A good deal of theoretical work on this mechanism is being done at present (see the paper by Dalgarno in this symposium). It is reasonable to assume that other emission features may be found in the infrared or visible or ultraviolet regions that result from these interstellar shock waves.

Attempts to observe the infrared spectrum of H_3^+ in interstellar clouds have been made by Oka. If, as is generally assumed, H_3^+ ions are present, they will eventually recombine with electrons (unless they undergo ion–molecule reactions before this happens). The recombination

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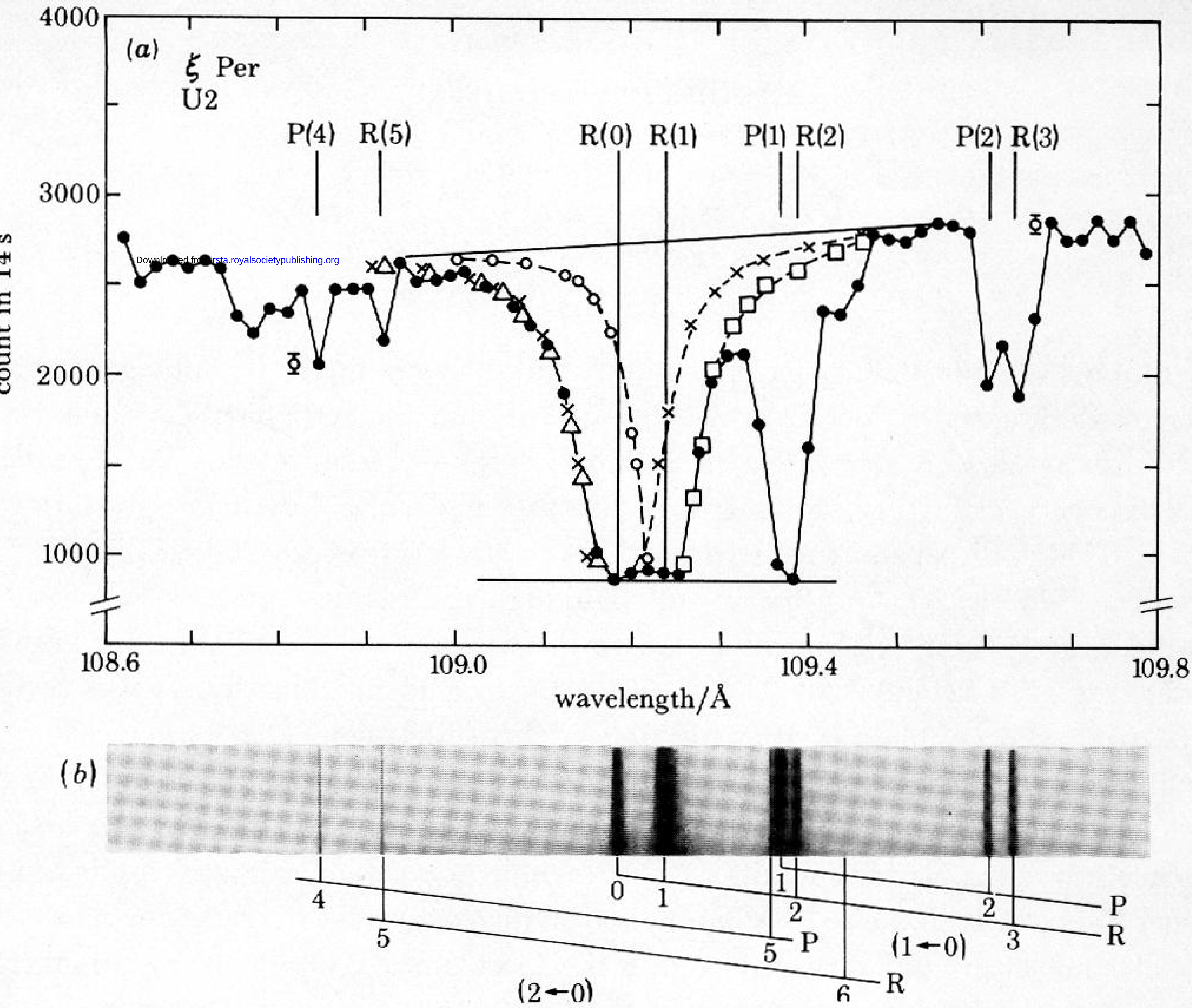
with electrons will lead to the formation of Rydberg states of H_3 and, after cascading to the lowest of these, to predissociation into H_2+H, that is, we have dissociative recombination. In the laboratory the Rydberg spectrum of H_3 has recently been observed in the visible and infrared regions (Herzberg 1979; Dabrowski & Herzberg 1980; Herzberg & Watson 1980; Herzberg *et al.* 1981). These same emissions must occur from interstellar clouds and should be observable. Similarly, in view of the likely presence of NH_4^+ one should look for the Rydberg spectrum of NH_4, which has recently been observed in the laboratory (Herzberg 1981).

Finally I should like to recall to you the problem of the diffuse interstellar lines. Most astronomers take it for granted that these 'lines' are produced by the interstellar dust grains. For many years I have favoured the idea that they are due to interstellar molecules. Diffuseness of molecular bands may be produced by three causes: (1) unresolved rotational structure, (2) predissociation, (3) internal conversion. I have emphasized in the past the second alternative but this does imply the difficulty of providing a sufficiently fast formation process since the very act of observation leads to dissociation of the molecule. Douglas (1977) has pointed out that carbon chains as observed in the microwave region by the Ottawa group may have diffuse absorption bands in the visible region which are diffuse because of the third mechanism. The recent work of Wdowiak (1980) lends considerable support to Douglas's interpretation but a conclusive identification is still to be accomplished.

References (Herzberg)

Adams, W. S. 1941 *Astrophys. J.* **93**, 11.
Beck, S. C., Lacy, J. H. & Geballe, T. R. 1979 *Astrophys. J. Lett.* **234**, L 213.
Chaffee, F. H., Jr & Lutz, B. L. 1978 *Astrophys. J. Lett.* **221**, L 91.
Dabrowski, I. & Herzberg, G. 1980 *Can. J. Phys.* **58**, 1238.
Douglas, A. E. 1977 *Nature, Lond.* **269**, 130.
Douglas, A. E. & Herzberg, G. 1941 *Astrophys. J.* **94**, 381.
Douglas, A. E. & Herzberg, G. 1942 *Can. J. Res.* A **20**, 71.
Douglas, A. E. & Morton, J. R. 1960 *Astrophys. J.* **131**, 1.
Drake, J. F. 1974 *Proc. R. Soc. Lond.* A **340**, 457.
Dunham, T., Jr & Adams, W. S. 1937*a* *Publ. Am. astr. Soc.* **9**, 5.
Dunham, T., Jr & Adams, W. S. 1937*b* *Publ. astr. Soc. Pac.* **49**, 26.
Eddington, A. S. 1926 *Proc. R. Soc. Lond.* **111**, 424.
Gautier, T. N., Fink, U., Treffers, R. R. & Larson, H. P. 1976 *Astrophys. J. Lett.* **207**, L 129.
Herzberg, G. 1979 *J. chem. Phys.* **70**, 4806.
Herzberg, G. 1981 *Faraday Discuss. chem. Soc.* (In the press.)
Herzberg, G., Lew, H., Sloan, J. J. & Watson, J. K. G. 1981 *Can. J. Phys.* **59**, 428.
Herzberg, G. & Watson, J. K. G. 1980 *Can. J. Phys.* **58**, 1250.
Knacke, R. F. & Young, E. T. 1980 *Astrophys. J. Lett.* **242**, L 183.
McKellar, A. 1940 *Publ. astr. Soc. Pac.* **52**, 187, 312.
McKellar, A. 1941 *Publ. Dom Astr. Obs.* **7**, 251.
Morton, D. C. 1975 *Astrophys. J.* **197**, 85.
Souza, S. P. & Lutz, B. L. 1977 *Astrophys. J. Lett.* **216**, L 49.
Spitzer, L., Drake, J. F., Jenkins, E. B., Morton, D. C., Rogerson, J. B. & York, D. G. 1973 *Astrophys. J. Lett.* **181**, L116.
Swings, P. & Rosenfeld, L. 1937 *Astrophys. J.* **86**, 483.
Wdowiak, T. J. 1980 *Astrophys. J. Lett.* **241**, L 55.
Weinreb, S., Barrett, A. H., Meeks, M. L. & Henry, J. C. 1963 *Nature, Lond.* **200**, 829.



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