COMMISSION 14: FUNDAMENTAL SPECTROSCOPIC DATA (DONNÉES SPECTROSCOPIQUES FONDAMENTALES)

Report of Meeting, 22 August 1973

PRESIDENT: A. H. Cook.
SECRETARY: J. G. Phillips.

Silent tribute was paid to two former members lost by death since the 1970 meeting: H. Barrell and M. C. J. Minnaert.

The Draft Report compiled from contributions by the five committees had been distributed to all members of the Commission prior to the meeting. The Draft Report was approved.

President Cook announced that the Commission was taking part in three joint meetings during the course of the General Assembly. One, with Commission 29, was to be on line identification in stellar spectra; a second, with Commission 40, was to discuss data for molecular radio astronomy, a third meeting, with Commissions 4, 31, and 40, was to be a discussion of recommendations of the Consultative Committee for the Definition of the Meter on realization of the Kr-86 wavelength standard of length, and on the value of the speed of propagation of light, the consequences of developments of absorption-stabilised laser sources of standard wavelengths.

Upon recommendation by the Organizing Committee, the following Officers and Committee Chairmen were approved for 1973–76:

President: R. H. Garstang.

Vice-president: W. Lochte-Holtgreven.

Organizing Committee: K. M. Baird, A. H. Cook, S. L. Mandel'shtam, C. Moore-Sitterly, J. G. Phillips, R. Tousey.

Chairmen of Committees:

1. Wavelengths: K. M. Baird.
2. Transition Probabilities: R. H. Garstang,
3. Cross Sections: E. Trefftz,
4. Atomic Structure: W. C. Martin,
5. Molecular Structure: R. W. Nicholls.

President Cook expressed the thanks of the Commission to the retiring members of the Organizing Committee and Committee Chairmen for their loyal service during the past three years.

Looking to the future work of the Commission, the President asked for consideration of the following Statement of Priorities:

'The priorities of work in the fields covered by Commission 14 are determined by the needs of other astronomers, for the aim of Commission 14 is to ensure that data are available by which astronomical observations may be interpreted in physical terms. Thus, there is a continuing need for precise measurements of standard wavelengths so that lines observed in astronomical spectra may be interpreted in terms of spectra of atoms or molecules studied in the laboratory. Until recently, only visible spectra were observed in astronomy, but it may be expected that in the next decade there will be a growing need for standard measurements of frequencies (or wavelengths) of lines in the radio, ultra-violet and X-ray regions of the spectrum. Transition probabilities and cross sections for various processes are needed to interpret physical conditions in astronomical sources, and here again, it is probable that there will be a growing demand for data relating to transitions at energies corresponding to radio, ultra-violet and X-ray spectra.'

In the subsequent general discussion of the above Statement of Priorities, Kessler pointed out that the expectations of the next decade are upon us already, while Martin commented that needs transcend the need for wavelength standards (the charge of Committee 1) and include the need for atomic analyses and wavelength measurements (Committee 4). In a letter read by the President,

https://doi.org/10.1017/S0251107X00031382 Published online by Cambridge University Press

Herzberg asks whether the present committee structure of the Commission is the most appropriate in view of these future needs, while in another letter, Praderie, Malaise and Lamers comment on the serious lack of transition probabilities for lines shortward of 2500 Å, which are of crucial importance for progress in ultra-violet stellar spectroscopy. This latter point was strongly supported by Garstang, who reminded the Commission that quasars shift such ultra-violet lines into the visible part of the spectrum. In the case of molecules, there is a serious lack of microwave identifications and transition probabilities, as well as of data on microwave collisional cross-sections. All these considerations were strongly supported by Seaton, who in a letter stressed the importance of extensions of data into the radio and X-ray regions. In a suggestion to the new Organizing Committee, President Cook urged that it consider within the next year its program for the next General Assembly, to stress these extended needs. In that connection, Kessler urged the Commission to seek more joint input from observational astronomers, possibly through more joint meetings.

On the basis of the above considerations, President Cook presented the following resolution, which was carried:

IMPORTANCE OF SPECTROSCOPIC DATA

The International Astronomical Union,

considering the great advances in astronomical observations throughout the electromagnetic spectrum from radio to X-ray frequencies, and

recognising the crucial importance of reliable numerical values of properties of atoms and molecules, many of which are at present lacking, if the full value and understanding is to be obtained from astronomical observations

urges all who provide financial support for astronomy to support also the measurement and calculation of relevant atomic and molecular properties.

A number of items of information were received by the President too late to be included in the Draft Report:

1. *From B. Edlén*

(a) *Precision Measurements of Stellar and Telluric Lines in the Region 6800–7400* Å. *R. and R. Griffin* (*Monthly Notices Roy. Astron. Soc.* **162**, 255, 1973) give a list of wavelengths of 81 stellar and 159 telluric lines in the range 6841–7424 Å determined from high-dispersion spectrograms of Arcturus and Procyon. The random errors are estimated to 0.001 or 0.002 Å, which is a significant improvement over the solar spectrum data of H. D. Babcock and C. E. Moore (The Solar Spectrum, λ 6600 to λ 13495, Carnegie Inst. of Washington, 1947).

(b) *Near Infrared Wavenumber Standards.* A paper by *G. Guelachvili*, to appear in *Optics Communications*, reports wavenumbers in the (2, 0) vibration-rotation band of CO measured in absorption at Laboratoire Aime Cotton in reference to the Krypton 86 primary standard by means of a high information Fourier Interferometer operating in the vacuum. As compared to the best previous measurements the precision is increased by more than a factor of 10. Eight-figure wavenumbers are given for 51 lines from 4149 to 4337 cm^{-1}

2. *Spectroscopic Results of Astrophysical Interest in the U.S.S.R. (1970–1972)*

V. Prokof'ev has submitted the following summary of results:

(A) *Spectra and Energy Levels.* Many experimental and theoretical investigations were devoted to the astrophysically important problem of the spectra of highly ionized atoms in the EUV and X-ray regions.

(a) Measures and new identifications have been made on a number of spectral lines in Al VII to Al XI (1), and S IX to S XIII (2). In addition, the spectra of K XIII to K XV and of Fe XVIII (3) have been obtained using focused laser radiation. Analyses are under way.

(b) Computation of energy levels are essential for interpretation of spectra of highly ionized atoms, where relativistic effects are pronounced. Several methods were used to compute energy levels for S IX to S XII (4); the isoelectronic sequence of Ne (S VII, Cl VIII, Sc XII to Cr XV) (5); resonance lines

https://doi.org/10.1017/S0251107X00031382 Published online by Cambridge University Press

of ions important in solar corona and X-ray, such as He- and Li-like ions with $Z = 8, 10, 12, 16$ and 20, as well as Fe XXIV and Fe XXV (**6**); spectra of the sequence Ti I to Mn IV (**7**); the ions O II, Ne IV, Mg VI and Si VIII (**8**); helium-like ions ($Z \leqslant 6$) using a multiconfiguration approximation (**9**); autoionization levels from Li II through C V (**10**); the ions Ce III, Pr III, Pr IV, Nd X (**11**), and the configuration $1s^2 2s\, 2p^N$ ($N = 1 \ldots 6$) of atoms and ions (**12**).

Energy levels, wavelengths and oscillator strengths have been computed for the transition $3p^4$–$3p^3 4s$ for the sulphur sequence (S I to Cu XIV) (**13**); for the transition $2p^4$–$2p^3 3s$ in the spectra of Co XX, Ni XXI, and Cu XXII (**14**), and for the transition $2p^5$–$2p^4 3s$ of the isoelectronic sequence F I through Cu XXI (**15**). Energy levels have been computed in the configuration $2p^4 3d$ and $2p^4 4d$ for the isoelectronic sequence F I through Mg IV (**16**).

(B) *Oscillator Strengths and Transition Probabilities.* Several standard investigations were in progress of *f*-values and transition probabilities of atoms, ions, and molecules. Relative *f*-values for absorption lines in the Sm I spectra were measured using the hook method (**17**). Absorption line strengths in the spectrum of Procyon, yielded oscillator strengths of many lines of Fe II, Ti II, Cr II, V II, Zr II, La II, Sc II and G II, while the spectra of δ and π Sco as obtained by Morton and Spitzer were used to calculate transition probabilities of the $\lambda 1427$ and $\lambda 1577$ lines of C II. The lifetimes of levels $2p$ and $3p$ of Xe I and $6d(^4F)\, 7s^2P$ of Xe II have been measured (**18**). An experimental investigation of transition probabilities in autoionized series of Ca, Sr, and Be has been carried out (**19**) (**20**). The lifetime of the $2\ \Sigma_4{}^+$ level of the $CO_2{}^+$ ion has been measured as well as the intensities in the first positive band of active nitrogen (**21**).

In the area of theoretical calculations, perturbation theory has been invoked to calculate the asymptotic expansion of $1/z$ for the transition probabilities of resonance lines of atoms (**22**). Theoretical calculations have been carried out on oscillator strengths for excited states of helium-like systems (**23**); singlet and triplet transitions of Sr (**24**); Cd (**25**); Be and Ba (**26**); electric dipole transitions $1s^2 2s\, 2p^{N+1}$–$1s^2 2s^2 2p^N$ of Be, B, C, N, O and F (**27**); the transitions $3d^3 4p$–$3d^3 4s$ and $3d^4 4p$–$3d^5$ in Cr II (**28, 29**).

(C) *Collisions between Atoms, Molecules and Electrons.* Laboratory measures have been made of excitation cross-sections in singlet and triplet lines of He I by electron impact (**30**), as well as the excitation functions for resonance lines of Ca I and Ba I (**31**); Ba II and Sr II (**32**); N III (**33**); the absolute values of the ionization cross-sections by electron impact for Mg, Ca, Sr, and Ba (**34**), and the excitation cross-sections of lines of Xe II by impact of He and Xe in metastable states (**35**). The photoabsorption cross-section of barium vapor was measured near the ionization limit (**36**).

In the case of molecules, the formation of excited particles in He^+–CO collisions has been studied, as well as electron impact effective cross-sections of excitation of bands of CO and CO^+ (**37**), $CO_2{}^+$ (**38**), NO (**39**) and OH (**40**).

Theoretical calculations of excitation cross-sections have been carried out for the transition $2s^2 2p^2$–$2s\, 2p^3$ in C I, N II and O II, and for $2s^2 2p^2$–$2s^2 2p\, 3s$, $2s^2 2p\, 3p$ in C I (**41**). Semiempirical formulae have been developed for ionization cross-sections of atoms and molecules by electron impact (**42**), and other semi-empirical methods were invoked to calculate photoionization cross-sections of levels $3s$, $4s$, $5s$ and $3p$ of Na (**43**). Formulae have been derived for the calculation of the excitation cross-sections of atoms by electron impact (**44**); good agreement is found for the S–P dipole transition in H, He and Na and for the transition $4s^2$–$4p^2$ of Ca.

(D) *Other Studies.* The profile of the $2p_{10}$–$5d_5$ line of ^{86}Kr has been studied and corrections applied to its nominal wavenumber (**45**). The Stark-broadening of lines of the ions Si II and Si III has been calculated, and the resonance broadening of Lα has been studied experimentally (**46**). A general theory of Stark-broadening of hydrogen lines has been developed within the framework of the one-electron approximation, leading to a general analytic expression for the complete line contour (**48**).

3. *Report from the Centre for Research in Experimental Space Science-York University*

The following has been abstracted from a report submitted by *R. W Nicholls*:

(A) *Intensity Measurements on Molecular Spectra.* Intensity measurements were completed on CO_2^+ spectra of importance in the spectrum of Venus (**49**), and a definitive set of band strengths have been obtained for the C_2 Swan system (**50**). Absolute absorption intensity measurements have been completed on the Cameron system of CO (**51**), the NO beta system (**52**), the O_2 Herzberg bands (**53**) and continua (**54**). The absolute absorption oscillator strengths of the O_2 Atmospheric Band system have been recently measured at high resolution, but not yet published. The 'hook' method of interferometric spectroscopy was used to measure band oscillator strengths for the NO Gamma system (**55**), and the NO Beta system (**56**); the potential precision of the method has been recently extended by about three orders of magnitude (**56, 57**). Shock tube techniques have been used to measure the absolute band strengths of the CN Red and Violet systems (**58, 59**), and a study has been completed of the intensity distribution in the B–X system of SO.

(B) *Wavelength Measurements and Structure Studies on Molecular Spectra.* A new study has been completed of the vibrational and rotational structure of the visible and near I–R ammonia spectrum (**60, 61**). The strongest feature at 6450 Å has been assigned to 5 ν_1, other vibrational assignments have been newly made and the 6450 Å band has been rotationally analyzed. A new vibrational analysis has been performed on shock-excited band systems of YO.

(C) *Identification Atlas of Molecular Spectra.* Atlases 8 and 9 on CN Red and CN Violet respectively have been issued (**62, 63**).

(D) *Synthetic Spectra.* The synthetic spectrum computer program SPECT III has been further refined to produce realistic emission, absorption and atmospheric transmission profiles.

(E) *Theoretical Studies.* A major study of line strength (Hönl-London) factors has been completed by Whiting (**64**), the prime result of which is a computer program for evaluation of any Hönl-London factor for any degree of coupling. The routine production of diatomic Franck-Condon factors has continued, and a series of Spectroscopic Reports to distribute them has been instituted (**65, 66, 67, 68, 69**). A new method has been developed for the computation of polyatomic Franck-Condon factors, and recent results have been published for CO_2^+ (**70**). The mathematical basis of the *r*-centroid approximation has been worked out (**71**); these ideas have been extended to polyatomic molecular transitions (**72**).

(F) *Atmospheric Absorption Coefficients.* A modification of the SPECT III computer program is being used to study realistic absorption coefficients of atmospheres (**73**).

(G) *Interpretative Work.* The recent discovery by Brewer *et al.* of an unusual absorption band at 30–60 km was identified as NH; spectroscopic and chemical evidence was put forward to explain the occurrence of stratospheric NH (**74**).

4. *From the Division of Quantum Metrology, National Physical Laboratory, Teddington, United Kingdom*

G. H. C. Freeman and *Vera P. Matthews* have used their vacuum Michelson Interferometer (**75**) for detailed studies of a few of the Hg^{198} UV lines from two r.f. standard lamps, at 1 and 3 torr (nominal) argon carrier gas pressure. The green line was used as a working internal standard. The procedure of interferometer scanning has been described elsewhere (**76**). Comparisons are made with previous work of Rowley (**77**) and Kaufman (**78**). From the visibility curves the line shapes and widths can be obtained. Their results indicate that for all the lines, except λ185 nm, the width at half intensity is approximately 10^{-6} of the wavelength, with those from the higher pressure lamp being 10% to 20% wider. The λ185 nm line is self reversed under all conditions. These results, together with temperature shift of the wavelength, have been discussed in detail.

5. *Additional Reports submitted at the Meeting*

(A) *K. L. Andrew* reported on the status of his research on argon. Interferometer measures were made of an argon tube cooled by liquid nitrogen at path lengths of 6, 30, 50 and 80 meters. Andrew presented a computer printout of results for 80 lines.

(B) *R. H. Garstang* reported that G. W. Wares has been using a shocktube method to obtain absolute transition probabilities of Mg I, Mg II, and the α-system of TiO, while M. Huber has employed the hook technique to derive transition probabilities for 107 lines of Fe I.

(C) A recent KPNO publication (Contrib. No. 559) describes the solar photospheric spectrum. 14624 lines are measured between 2918 Å and 9000 Å on their photographs with a probable error of ± 0.0001 Å.

REFERENCES

1. Kononov Eh. Ya., Koshelev K. N: 1970, *Opt. i Spektrosk.* **29**, 217; Kononov Eh. Ya., Koshelev K. N., Ryabtsev A. N.: 1971, *Opt. i Spektrosk.* **30**, 996.
2. Podobedova L. I., Kononov Eh. Ya., Koshelev K. N.: 1971, *Opt. i Spektrosk.* **30**, 394.
3. Bojko V. A., Vojnov Yu. P., Gribkov V. A., Sklizkov G. V.: 1970, *Opt. i Spektrosk.* **29**, 1023.
4. Safronova U. I., Ivanova A. N., Rabinkina N. V.: 1971, *Opt. i Spektrosk.* **31**, 496.
5. Safronova U. I., Lezhava E. A.: 1972, *Opt. i Spektrosk.* **32**, 233.
6. Vajnshtejn L. A., Safronova U. I.: 1972, *Kratkie soobshcheniya po fiz.* No. 3, 40.
7. Bogdanovichjus P. O., Vizbarojte J. J.: 1971, Instit. Fis. i Matemat. Akad. Nauk Lit. S.S.R. VINITI No. 2805–71.
8. Kantseryavichyus A. Yu., Shadzhyuvene S. D.: 1971, *Lit. fiz. sbornik* **11**, 769.
9. Kavetskikh V. I., Kaminskas V. A.: 1971, *Lit. fiz. sbornik* **11**, 197.
10. Balachov V. V., Lipovetskij S. S., Pavlichenkov A. V., Palyudov A. N., Senashenko V. S.: 1971, *Vestn. Moskov. Univ. Fiz. i Astron.* **12**, 65.
11. Shadzhyuvene S. D., Surgajlene R. T., Ripskite P. V., Bogdanovichyus P. A., Karaziya R. I.: 1970, *Lit. fiz. sbornik* **10**, 873.
12. Kuplyauskis Z. I., Lazauskas V. M., Yutsis A. P.: 1971, *Lit. fiz. sbornik* **11**, 191.
13. Gruzdev P. F.: 1970, *Opt. i Spectrosk.* **28**, 615.
14. Gruzdev P. F.: 1971, *Zh. prikladnoj spektrosk.* **14**, 1100.
15. Gruzdev P. F.: 1971, *Opt. i Spektrosk.* **30**, 525.
16. Gruzdev P. F., Loginov A. V.: 1972, *Opt. i Spektrosk.* **33**, 3.
17. Komarovskij V. A., Penkin N. P., Nikiforova G. P.: 1971, *Opt. i Spektrosk.* **29**, 220.
18. Karimov R. G., Klimkin V. M.: 1971, *Izv. VUZ, Fiz.*, No. 3, 24.
19. Kozlov M. G., Startsev G. P.: 1971, *Opt. i Spektrosk.* **30**, 575.
20. Basiev T. T., Malakhov Yu. I., Tsys' S. N.: 1971, *Opt. i Spektrosk.* **30**, 421.
21. Pavlovskaja E. N., Yakovleva A. V.: 1971, *Opt. i Spektrosk.* **30**, 365.
22. Khristenko S. V., Vetchinkin S. I.: 1971, *Opt. i Spektrosk.* **31**, 503.
23. Safronova U. I., Ivanova A. N., Kharitonova V. N.: 1970, *Opt. i Spektrosk.* **28**, 585.
24. Zilitis V. A.: 1970, *Opt. i Spektrosk.* **29**, 821.
25. Zilitis V. A.: 1972, *Opt. i Spektrosk.* **31**, 161.
26. Zilitis V. A.: 1970, *Opt. i Spektrosk. Uchenye zapiski Latv. Univers. Riga*, 15.
27. Nashlenas Eh. P., Kaminskas V. A., Yutsis A. P.: 1971, *Lit. fiz. sbornik* **11**, 203.
28. Kuzmitskite L. L., Ushpalis K. K.: 1971, *Lit. fiz. sbornik* **10**, 201.
29. Kuzmitskite L. L., Ushpalis K. K., Dembavskajte A. V.: 1970, *Lit. fiz. sbornik* **10**, 213.
30. Smirnov Yu. M., Sharonov Yu. D.: 1971 *Opt i Spektrosk.* **30**, 1001.
31. Aleksakhin I. S., Zapesochnyj I. P., Garta I. I., Starodub V. P.: 1971, *Opt. I Spektrosk.* **30**, 1178.
32. Bejtman I. Ya., Vajnshtejn L. A., Dronov A. P., Kudzyavtsev E. M.: 1970, *Zh. Eksperim. Teor. Fiz.*, **59**, 1991.
33. Smirnov Yu. M., Sharonov Yu. D.: 1972, *Opt. i Spektrosk.* **32**, 624.
34. Vajnshtejn L. A., Ochkur V. I., Rakhovskij V. I., Stepanov A. M.: 1971, *Zh. Eksperim. Teor. Fiz.* **61**, 511.
35. Bochkova O. P., Tolmachov Yu. A.: 1972, *Opt. i Spektrosk.* **32**, 827
36. Kozlov M. G., Startsev G. P.: 1970, *Opt. i Spektrosk.* **28**, 1217.
37. Koppe V. T., Koval' A. G., Danilevskij N. P., Popova L. I., Fizgeer B. M.: 1971, *Zh. Eksperim. Teor. Fiz.* **61**, 906.
38. Koval' A. G., Koppe V. T., Danilevskij N. P., Popova L. I.: 1972, *Opt. i Spektrosk.* **32**, 1037.
39. Povch M. M., Skubenich V. V., Zapesochnyi I. P.: 1972, *Opt. i Spektrosk.* **32**, 1044.
40. Sushanin I. V., Kishko S. M.: 1971, *Opt. i Spektrosk.* **30**, 580.
41. Poshyunajte N. P., Lyash A. V., Bolotin A. B.: 1970, *Opt. i Spektrosk.* **29**, 799.
42. Krasavtsev L. M., Krinberg I. A.: 1971, *Issledovanija po geomagn. aeron. fiz. Solntsa*, No. 16, 182.

43. Zilitis V. A.: 1970, *Opt. i Spektrosk.* **29**, 617.
44. Vajnshtein L. A., Vinogradov A. V.: 1970, *J. Phys.* **B3**, 1090.
45. Batarchukova N. R., Kartashev A. I., Ptitsina E. A.:1970, *Trudy metrolog. Inst. S.S.S.R.*, No. 114 (174), 5.
46. Skidan V. V., Shrejder E. Ya.: 1971, *Opt. i Spektrosk.* **28**, 627.
47. Kobzeev G. A.: 1971, *Opt. i Spektrosk.* **30**, 199.
48. Lisitsa V. S., Sholin G. V.: 1971, *Zh. Eksperim. Teor. Fiz.* **61**, 912.
49. McCallum J. C., Nicholls R. W.: 1972, *J. Phys.* **B5**, 1417.
50. Danylewych L.: Ph. D. thesis, York University.
51. Hasson V., Nicholls R. W.: 1971, *J. Phys.* **B4**, 681.
52. Hasson V., Nicholls R. W.: 1971, *J. Phys.* **B4**, 1769.
53. Hasson V., Nicholls R. W.: 1971, *J. Phys.* **B4**, 1778.
54. Hasson V., Nicholls R. W.: 1971, *J. Phys.* **B4**, 1789.
55. Farmer A. J. D., Hasson V., Nicholls R. W.: 1972, *J. Quant. Spectr. Rad. Transfer* **12**, 627.
56. Farmer A. J. D., Hasson V., Nicholls R. W.: 1972, *J. Quant. Spectr. Rad. Transfer* **12**, 635.
Hasson V., Farmer A. J. D., Nicholls R. W.: 1972, *J. Phys.* **B5**, 1241.
57. Hasson V., Farmer A. J. D., Nicholls R. W., Anketell J.: 1972, *J. Phys.* **B5**, 1248.
58. Arnold J. O., Nicholls R. W.: 1972, *J. Quant. Spectr. Rad. Transfer* **12**, 1435.
59. Arnold J. O., Nicholls R. W.: 1972, *J. Quant. Spectr. Rad. Transfer* (in press).
60. McBride J. O. P., Nicholls R. W.: 1972, *J. Phys.* **B5**, 408.
61. McBride J. O. P., Nicholls R. W.: 1972, *Canadian J. Phys.* **50**, 93.
62. Brocklehurst B., Seel R. M., Hébert G. R., Nicholls R. W.: 1971, CRESS, York University.
63. Brocklehurst B., Seel R. M., Hébert G. R., Nicholls R. W.: 1972, CRESS, York University.
64. Whiting E. E., Paterson J. A., Kovacs I., Nicholls R. W.: 1972, *J. Mol. Spectr.*
65. McCallum J. C., Jarmain W. R., Nicholls R. W.: 1970, CRESS Spectr. Report No. 1.
66. McCallum J. C., Nicholls R. W.: 1971, CRESS Spectr. Report No. 2.
67. McCallum J. C., Jarmain W. R., Nicholls R. W.: 1972, CRESS Spectr. Report No. 3.
68. McCallum J. C., Jarmain W. R., Nicholls R. W.: 1972, CRESS Spectr. Report No. 4.
69. McCallum J. C., Jarmain W. R., Nicholls R. W.: 1972, CRESS Spectr. Report No. 5.
70. McCallum J. C., Nicholls R. W.: 1971, *J. Phys.* **B4**, 1096.
71. Nicholls R. W.: 1972, *Chem. Phys. Letters* (in press).
72. McCallum J. C., Nicholls R. W.: 1971, *J. Phys.* **B4**, 1096.
73. Cann H. W. P., Nicholls R. W.: 1972, *J. Atmos. Sci.* (in press).
74. Nicholls R. W.: 1972, *Nature* (in press).
75. Freeman G. H. C.: 1972, *Optics Commun.* **4**, 66. 4th E.G.A.S. (Amsterdam) abstracts, paper 25.
76. Terrien J.: 1967, *J. Physique* **28**, C2-3 to C2-10.
Terrien J.: 1954, National Physical Laboratory Symposium No. 11 on Interferometry pp. 437–456.
Rowley W R. C., Hamon J.: 1963, *Rev. Optique* **10**, 519.
77. Rowley W. R. C.: 1962, Comité consultatif pour la définition du mètre (CCDM). Comité international des poids et mesures, Paris, Gauthier-Villars.
78. Kaufman V.: 1962, *J. Opt. Soc. Am.* **52**, 866.

Joint Meeting of Commissions 14 and 40, 25 August 1973

CHAIRMEN: D. S. Heeschen, A. H. Cook.

SPECTROSCOPIC DATA FOR THE INTERPRETATION OF RADIO FREQUENCY RADIATION FROM MOLECULES

The purpose of the joint meeting of the two Commissions was to explore what data were needed for the interpretation of astronomical observations of radiation from molecules and to see how far the needs were met by existing data or by laboratory or theoretical work at present under way. It appeared that a great deal more information from experimental and theoretical sources was required.

Dr B. J. Robinson discussed some current problems of identification of molecules which required more experimental determination of transition frequencies, pointing out that the recent high rate of discovery of new molecules was in part a consequence of the many frequencies that had been measured by spectroscopists, but that most simple molecules for which frequencies were known had been found or looked for. An outstanding problem was that of lines observed in astronomical sources which could not at present be attributed to any molecules; the main ones had frequencies of 89.189, 90.664 and 85.4 GHz, the first two being prominent in a number of sources and the last in Sgr B2. Although the corresponding molecules were not so far identified, some indications of their properties could be obtained from comparisons of maps of the emissions with those from known molecules. A second problem was that of transient molecules which, with brief lives in laboratory apparatus were difficult to study, but which might be quite stable in the conditions of the interstellar medium. An associated problem was that of molecules with very low vapour pressure, again difficult to study in the laboratory. Thus no molecules incorporating the relatively abundant magnesium had been detected, possibly because the vapour pressure is too low to enable transition frequencies to be measured in the laboratory. A final problem is that of frequencies of astronomical sources which are inconsistent with laboratory measurements.

Dr B. E. Turner said that the use of interstellar molecules as probes of physical conditions and processes in interstellar clouds is hampered by the lack of basic laboratory data. Two basic areas of research are involved: the study of the excitation of interstellar molecules and a determination of their abundances and ambient physical conditions; and a study of formation and destruction of these molecules.

The excitation of interstellar molecules is poorly understood because the nature of the interaction of molecules with radiation and with neutral particles is largely unknown. Regarding neutral particles (H_2 primarily), we need to know both the selection rules for collisional interaction and the total cross sections. Only if the interaction is pure dipole-dipole in nature will the excitation temperature of the molecules be a well behaved monotonically increasing function of the particle density, varying from the background radiation temperature at low densities to the kinetic temperature at high densities. If higher moment-induced moment interactions are important (leading to collisional selection rules $\Delta J = \pm 2, \pm 3, \ldots$) then the excitation temperature of the lower rotational levels can greatly exceed the kinetic temperature, or it can be negative, for even the simplest diatomic molecules. Abundances and physical conditions can be derived in these cases only if the detailed nature of these interactions is known. The laboratory technique of double resonance spectroscopy, recently applied to NH_3 and CH_3OH, seems best able to attack these problems, but much more detailed experiments are needed on these and other molecules.

Regarding the interaction of interstellar molecules with radiation, much more information is needed on the precise positions of potential curves for electronically excited states, and on oscillator strengths for transitions from these states to the ground state. Rates and wavelengths for photodissociation and photoionization depend on these parameters, as do the rates for certain possible formation mechanisms such as indirect radiative association by inverse predissociation. In some cases, interstellar molecules may even be pumped by interaction with radiation involving these states. In the infrared, the problem is solely with uncertain line strengths for vibrational transitions, but these are crucial since radiation at these wavelengths (2–350 μ) is likely to affect significantly the excitation of molecules that are observed to occur preferentially near strong infrared sources. The 2.8 μ vibrational transition of OH has played a prominent role in theories of the anomalous excitation of interstellar OH, although its strength is highly uncertain.

Interstellar molecules are destroyed primarily by photodissociation (in clouds of low density) and by adsorption onto dust grain surfaces and possibly dissociation by cosmic rays (in clouds of high density). A good start has been made on the photochemistry of several of the more complex interstellar molecules, but little has been done on diatomic species, which, because they are observed primarily in low-density clouds, are the species most likely affected by radiative destruction. Questions of adsorption rates of various molecules on surfaces are almost completely unanswered, although in dense clouds these rates are important in determining relative molecular abundances. Various 'rules' of surface chemistry need to be tested, such as that physical adsorption but not chemiadsorption can proceed on contaminated surfaces, that chemisorption but not physical adsorption requires appreciable activation energy, and that physical adsorption is very similar in mechanism to the condensation of a vapor on the surface of its own liquid. Virtually nothing is known of the dissociation and ionization rates of molecules by interaction with high-energy particles.

Interstellar molecules are presently thought to be formed by several processes including radiative association, neutral gas exchange reactions, ion-molecule reactions, surface reactions, and possibly even under LTE conditions, for example in pre-solar nebulae. Radiative association, which is relevant primarily to diatomic molecules observed optically in low-density clouds, has highly uncertain rates which have undergone many drastic revisions recently. The most important, and uncertain, rates, involve direct radiative association of CH^+, from which CH, CN and CO are formed by exchange reactions. Other molecules, such as OH, CN, CO, NO, C_2 may form by inverse predissociation but rates for these processes are equally uncertain.

Ion-molecule reactions appear best able to explain observed abundances and patterns of interstellar molecules in both low and high density clouds. Among types of ion-molecules reactions that need further study are those of the form $A^+ + H_2 \rightarrow AH^+ + H$ (particularly $A \equiv O$, OH, CN), and those reactions involving C^+ with a large variety of small molecules (NH, CH, H_2O, NH_2, NH_3, HCN, H_2CO and others). All gas-phase reactions, whether initiated by radiative association or ion-molecule reactions, also involve neutral exchange reactions, and many of these, of particular importance, are unstudied such as $CH + X \rightarrow CX + H (X \equiv N, C, O)$ and similar reactions involving OH and CO.

The problems of formation of molecules on surfaces are too numerous to cite here. In particular, the products formed depend strongly on whether the surfaces are saturated (i.e. contain a layer of relatively unreactive molecules such as H_2O, NH_3, CH_4) or not. In conjunction with a strong theoretical approach, well-designed laboratory experiments might be able to suggest whether interstellar grain surfaces are saturated or not, and hence offer a qualitative idea of what types of molecules may preferentially be formed, and whether the rates are adequate. Such progress will probably also require definite observational information on the presence or absence of sources of UV radiation inside dense molecular clouds, the temperature, and the density of both gas and grains. Present experiments on surface catalysis have not adequately simulated the expected interstellar conditions, either with regard to the surfaces used, or in the choice of initial gas phase species. A severe difficulty, deduced theoretically, seems to be that of desorbing molecules from the surfaces at very low temperatures, once they have formed. Experiments on desorption by UV and infrared radiation, as well as energetic particles, are greatly needed. Experiments on isotope separation and the separation of ortho-para forms of molecules such as NH_3, H_2, and H_2CO by adsorption at low temperatures are also required to determine whether some of the isotope and ortho-para anomalies observed in interstellar molecules are indicative of a direct role played by interstellar grains.

Dr D. R. Johnson described work of the microwave laboratory at the National Bureau of Standards in three different areas of activity that directly concern molecular radio astronomy. The determination of the molecular origin of unidentified interstellar lines is an exceedingly difficult but important area of laboratory activity. Recent experiments leading to the assignment of an unidentified interstellar line at 84521 MHz to methanol (CH_3OH) were described. This example also served to illustrate the need for detailed spectral maps of all known interstellar molecules. The NBS laboratory has initiated a review series which is intended to provide a complete and critical review of the literature for all known interstellar molecules. Predicted transition frequencies complete with 95% confidence limits will be provided for the entire frequency range accessible to the telescope. Additional information on hyperfine splittings, line strengths and energy levels will also be included. Reviews of this type have been completed for formamide (NH_2 CHO), formaldehyde (H_2CO), thioformaldehyde (H_2CS), methylenimine (CH_2NH), methanol (CH_3OH), water (H_2O), hydrogen sulfide (H_2S), carbonyl sulfide (OCS), hydrogen cyanide (HCN) and sulfur monoxide (SO). Reviews are in progress for most of the other known interstellar molecules. Another equally important facet of the NBS laboratory is the generation, detection and spectral mapping of new molecules which potentially play an important role in interstellar chemistry. Thioformaldehyde (H_2CS) and methylenimine (CH_2NH) served as examples to illustrate how studies of new molecules proceed from ideas on a blackboard to telescope detection in the interstellar medium. Current laboratory experiments were discussed in which the possibility of generating and detecting short-lived tautomers of known interstellar molecules are being explored.

Dr R. H. Garstang described recent work by Oka who had used a method of double resonance spectroscopy to study collision cross-sections for various types of transition. He found that in pure gases, collisions taking place between similar molecules, the change of the rotational quantum number was greater than 1 in HCN, formaldehyde and ketene but in other cases followed dipole rules. In collisions of NH_3 with rare gases, especially helium, the dipole selection rules for rotational quantum number and parity are not followed closely, and in the collisions of NH_3 with H_2 there is a substantial number in which the change of rotational quantum number is 2. Finally Garstang argued that in the interstellar medium, radiative transitions are not important compared with collisions and that while collisions with electrons are very effective in changing the energy of a molecule, there are not enough electrons in the interstellar medium for them to be important.

All speakers, as well as contributors to the discussion, emphasised the need for more experimental and theoretical work to obtain the data needed to interpret the astronomical observations.

Joint Meeting of Commissions 4, 14, 31 and 40, 27 August 1973

CHAIRMAN: A. H. Cook.

THE RE-DEFINITION OF THE METRE AND THE VALUE OF THE SPEED OF LIGHT

The meeting was convened by *A. H. Cook*, the representative of the IAU on the Consultative Committee for the Definition of the Metre, to explain to members of the IAU the background to recommendations recently made by the Committee, to consider how the recommendations affected astronomical interests and to discuss the response that the IAU should make to the recommendations. He explained that the meeting of the Committee held in 1973 June was in response to a request from the IAU for guidance on the effect that recent developments in the measurements of frequencies of laser radiation would have in astronomy.

Shortly after the helium-neon laser was devised it was shown that the wavelength of the radiation could be controlled by varying the separation of the mirrors in a servo-system so that the wavelength was that at which the gain was a maximum and subsequently was that of the Lamb dip. Much higher stability results if the reference wavelength is that of the maximum absorption in gas in an external cell, for example, an absorption line of methane for the 3.39 μm line of the helium neon laser and one of a number of lines in the iodine molecule for the 633 nm line. By using saturated absorption the effective Doppler width is very greatly reduced and the stability of the resulting wavelength is very high. A second important development is that lasers giving radiations over a wide range of frequencies oscillating continuously at high power are now available, especially those using HCN, water, carbon dioxide and helium-neon; the frequencies range from 300 m to 633 nm. Lastly efficient mixers and harmonic generators operate over almost the whole of the range, making use of point contacts, the metal-insulator-metal diode, and the Josephson junction. The fact that laser radiations of high stability and high power can be mixed in such devices and their harmonics compared means that it is possible to lock the frequency of an HCN maser at 1000 GHz to the output of a klystron at 30 GHz and so to the caesium standard frequency (9 GHz) and on the other hand to compare frequencies up through a chain to those of the carbon dioxide laser at 10 μm (3×10^3 Hz) and of the helium-neon laser at 3.39 μm (10^4 Hz). Some eight standards laboratories are now engaged on this work and the related measurements of wavelengths of laser radiations in terms of the wavelength of the standard orange line of krypton-86.

At the meeting of the Consultative Committee, which is a committee of the International Committee of Weights and Measures, members reported on techniques of stabilising lasers, on comparisons of wavelengths of stabilised lasers with krypton-86 standard and on values of the speed of light derived from measurements of the frequency and wavelength of the same transition. The conclusions

https://doi.org/10.1017/S0251107X00031382 Published online by Cambridge University Press

of the Committee were embodied in the recommendations that are reproduced in the Appendix this Report.

Having explained the recommendations of the Committee, Cook said that in his view the IA was no longer concerned, as it had been in the past, with the definition of the Metre and with t primary standards of wavelength, for the accuracy that could now be achieved was far beyo anything required in astronomy, but that astronomers, who measure distances, as do geodesist in terms of the times of travel of electromagnetic radiation, may be concerned to use the new val of the speed of light proposed by the Consultative Committee.

The discussion was opened by *J. Terrien*, the Director of the Bureau International des Poids Mesures, who said that in his view it was possible and desirable for the metre to be redefined so th in effect the value of the speed of light recommended by the Consultative Committee is adopted a constant, the metre being derived as the distance travelled by light in a specified time. G. Winkl P L. Bender, D. J. Mulholland, G. A. Wilkins, J. Kovalevsky and others took part in the discussi and discussed the effect that the adoption of a new value of the speed of light would have upon t branches of astronomy with which they were concerned. It was agreed that it was desirable recommend that the new value should be used in future in preference to that in the System Astronomical Constants, and a resolution was passed by the meeting and subsequently by t General Assembly of the Union. (See Resolution No. 6.)