328. Hazi, A.U., Rescigno, T.N.: 1977, Phys. Rev. A16, p. 2376.
329. Huebner, W.F., Argo, M.F., Ohlsen, L.D.: 1978, J. Quant. Spectr. Rad. Trans. 19, p. 93.
330. Barfield, W.D.: 1977, Los Alamos Sci. Lab. report LA - 6615.

A. BURGESS
Chairman of the Working Group

WORKING GROUP 4: STRUCTURE OF ATOMIC SPECTRA

A. *Compilation and Bibliographies on Energy Levels, Wavelengths, and Line Classifications*

The ongoing program of the Atomic Energy Levels Data Center (National Bureau of Standards) to produce new compilations of critically evaluated energy level data is at present focused on the first thirty elements. The most recently completed compilations in this series give energy levels for all the spectra of Mn (Mn I-XXV) (1), Cr (Cr I-XXIV) (2), V (V I-XXIII) (3), Ti (Ti I-XXII) (4),Ca (Ca I-XX) (5),and Al (Al I-XIII) (6), and work is underway on the spectra of K and Mg. C.E. Moore's "Selected Tables of Atomic Spectra" now include O I (7), O VI, O VII,and O VIII (8), work on the tables for the remaining oxygen spectra is in progress. A finding list for lines of the multiplets in Sections 1-7 of Moore's NSRDS-NBS 3 series has been compiled by Adelman et al. (9). A recent publication of the AEL Data Center, "Atomic Energy Levels - The Rare-Earth Elements" (10), gives energy-level data for 66 spectra of the 15 elements La through Lu (Z=57-71), including a number of astronomically important spectra. A review of rare-earth spectral data by Blaise et al. (11) gives partial tables of energy levels and wavelengths and includes data on hyperfine-structure and isotope shifts. The first version of a much needed new compilation of "Line Spectra of the Elements" has recently been published (12). These tables contain some 42,000 lines, including the stronger lines of the first and second spectra of 98 elements and lines of the third, fourth, and fifth spectra for about half the elements from the vacuum ultraviolet to the far infrared. Outred (13) has compiled 8885 selected lines of 57 elements in the infrared region 1-4 µm, with energy-level classifications being given where available. Energy-level and Grotrian diagrams for the atoms and positive ions of the elements H through P (Z=1-15) have been prepared by Bashkin and Stoner (14), and further publications for the heavier elements are planned. The AEL Data Center (NBS) expects to publish in 1979 a "Bibliography on Atomic Energy Levels and Spectra" for the period July 1975 through December 1978 (15). Edlên's 1976 review of term analysis of atomic spectra has references for spectra of the elements He through Ni (16), and Adelman et al. (17) have compiled an astronomically oriented bibliography on atomic autoionization. A bibliography on experimental isotope shifts in atomic spectra by Heilig (18) gives 666 references.

B. *Laboratory Research*

Reports on the research programs of a number of laboratories have been received. The present report is highly selective and incomplete regarding references to research on particular spectra, since the forthcoming bibliography (15) fully covers such references and will be widely available to astronomers.

I. Selected References, $Z \leq 28$

The references in Table 1 (in parentheses following the spectra) are a partial list of recent results for the elements through Ni. Several additional references for extensive isoelectronic-sequence results and a few references for spectra of heavier elements are given below.

II. *Isoelectronic Sequences*

Erickson (19) has calculated accurate energy levels for the one-electron species

https://doi.org/10.1017/S0251107X00010646 Published online by Cambridge University Press

TABLE 1

Selected references on energy levels and line classifications, Z≤28

B I (33)	Ca V-VIII (46)	Mn XIX (69)
	Ca X (49-51)	Mn XXII (58)
F I (34)	Ca XIV (52)	Mn XXIII (64)
	Ca XV (44,52)	
Na IV (35)	Ca XVI, XVII (53)	Fe I (70,71)
		Fe II (72-75)
Mg XI (36)	Sc I (54)	Fe IV (76)
	Sc VI-IX (46)	Fe V (77)
Al V (37)	Sc XI (50)	Fe IX (78,79)
Al XII (36)	Sc XVI (44)	Fe X (46,78,80,81)
		Fe XI (46,81)
Si V (38,39)	Ti III (55)	Fe XVI (82)
Si VI (40)	Ti V (56)	Fe XVII (83)
	Ti VII-X (46)	Fe XVIII (83,84)
P III (41)	Ti XII (57,50)	Fe XIX (82-86)
P IV (42)	Ti XVII (44)	Fe XX (69,83,86-88)
P VI (43)	Ti XIX (58)	Fe XXI (44,83,86,87)
P X (44)		Fe XXII (61,87)
P XIV (36)	V II (59)	Fe XXIII (58,61)
	V VI (60)	Fe XXIV (64)
S I (45)	V VII-XI (46)	
S IV (46)	V XIII (50)	Co VI (89)
S VII (47)	V XVIII (44)	Co X (79)
S XI (44)	V XX (58,61)	Co XX, XXI (69)
S XIV (48)		Co XXIV (58)
S XV (36)	Cr III (62)	
	Cr VII (63)	Ni IV (90)
Cl XII (44)	Cr VIII-XI (46)	Ni V (91,92)
Cl XVI (36)	Cr XIV (50)	Ni VII (93)
	Cr XXI (58)	Ni X (79)
Ar XIII (44)	Cr XXII (64)	Ni XI (78,79)
		Ni XII (78)
K IV-VII (46)	Mn III (65)	Ni XVIII (82)
K IX (49,50)	Mn V (66,67)	Ni XXI (82,86)
K XIV (44)	Mn VI (68)	Ni XXV (58)
	Mn IX-XI (46)	Ni XXVI (64)
	Mn XV (50)	

of all atoms (H I sequence, Z =1-105), and Vainshtein and Safronova (20,21) tabulate calculated wavelengths and transition probabilities for the He I and Li I sequences up to Z=34. Experimental wavelengths and energy-level classifications have been given by Boiko et al. (22) for about 1000 lines belonging to ion spectra of the H I (Z=12-16), He I (11-26), Li I (19-26), Be I (22-34), and Ne I (26-42) sequences. A semi-empirical treatment of the Li I sequence by Edlên (23) gives energy-level and wavelength data for line identifications (Z=3-28). Edlên has also obtained expressions for the Na I sequence predicting the 3s-3p and 3s-3d transitions and the ionization energies (Z=16-42) (24). Edlên's predictions of the ground-term ^2P intervals for the F I and B I sequences (Z=24-42) (25) can be used for the identification of the corresponding forbidden lines.

III. Brief Report on Laboratory Programs

The following notes on current research of astrophysical interest are mostly excerpted from information supplied by the persons whose names appear in parentheses. At the University of Lund, work is almost complete on the spectra O II, P I, II, S II, Sc II, Ti II, and Ga II, and work in progress includes B II, F II, III, S IV-VI, Cl IV-VII, Sc V-Fe X (sequence), Ti I, Cr IV, V, Fe II, III, VII, VIII, and Ni I (U. Litzén). Spectra under investigation at the Lund Institute of Technology include O III, Ne III, Ar III, IV, and K II (L. Minnhagen). Extensive research on highly ionized atoms from laser-produced plasmas is continuing at both the Lebedev Physical Institute and the Institute for Spectroscopy, U.S.S.R. Academy of Sciences, and predicted wavelengths of forbidden lines (1800-10,000 Å) are being obtained (S.L. Mandelstam, M.A. Mazing). Laboratory spectroscopy in the Astrophysical Research Division, Culham, is concentrated on highly ionized iron-group atoms, especially V, Fe, Co, and Ni (B.C. Fawcett). Spectra of ions of Al and Si are under investigation at the Paris-Meudon Observatory, with work on Al VI nearing completion, and a compilation of forbidden transitions of astrophysical interest is in progress (M.-C. Artru, M. Eidelsberg). Autoionization and photoionization spectra are among the areas emphasized at the Harvard-Smithsonian Center for Astrophysics, with a new ion-beam facility being used for investigations of multiply charged ions (J.L. Kohl, W.H. Parkinson). Work on Co II and Ni III is almost complete at the Institute of Optics, Madrid, and V II and Cr II, III are among the other spectra now being analyzed (L. Iglesias). Papers on Co IV, V, VI, Cu VI, and Er I, II have been submitted or are being prepared at the Zeeman Laboratory, Amsterdam, and spectra under investigation include Mn IV, Ni VI, Cu VII, and Tb I, II, III (E. Meinders, T.A.M. van Kleef). A number of complex spectra are being analyzed at the Aimé-Cotton Laboratory, Orsay, including Pr I, II, and Yb I; an extension of the Lu I analysis has been published (26) (J. Blaise, J.-F. Wyart). Accurate ionization potentials for most of the neutral rare-earth atoms have recently been determined at the Lawrence Livermore Laboratory, University of California, by use of laser techniques (27), and regularities across the f-shell rows yielded predicted energies in higher ions (28). Work in the Theoretical Chemistry Dept., Oxford, is centered on accurate relativistic calculations of low-energy states of heavy atoms (29); a number of related computer programs have been made available (30) (I.P. Grant). From the Dept. of Theoretical Physics, Oxford: A recent review of the atomic physics of astrophysical plasmas has a useful section on energy levels and line identifications (31) (C. Jordan). Energies in H^- and He I (32) have been calculated at the Centre for Research in Experimental Space Science, York University (H.O. Pritchard).

REFERENCES

1. Corliss, C., Sugar, J.: 1977, J. Phys. Chem. Ref. Data 6, p. 1253.
2. Sugar, J., Corliss, C.: 1977, J. Phys. Chem. Ref. Data 6, p. 317.
3. Sugar, J., Corliss, C.: 1978, J. Phys. Chem. Ref. Data 7, p. 1191.
4. Corliss, C., Sugar, J.: 1979, J. Phys. Chem. Ref. Data 8, No. 1.
5. Sugar, J., Corliss, C.: 1979, J. Phys. Chem. Ref. Data, submitted 1978.
6. Martin, W.C., Zalubas, R.: 1979, J. Phys. Chem. Ref. Data, submitted 1978.
7. Moore, C.E.: 1976, Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.) 3, Sec. 7.
8. Moore, C.E.: 1978, Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.) 3, Sec. 8.
9. Adelman, C.J., Adelman, S.J., Fischel, D.: 1977, Document X-685-77-287, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. 20771.
10. Martin, W.C., Zalubas, R., Hagan, L.: 1978, Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.) 60.
11. Blaise, J., Camus, P., Wyart, J.F.: 1976, Gmelin Handbuch der Anorganischen Chemie 39, Part B4, Springer-Verlag, Berlin.
12. Reader, J., Corliss, C.H., Eds.: 1978, in "Handbook of Chemistry and Physics", Ed. Weast, R.C., 59th edition, CRC Press, Cleveland, Ohio. These tables were compiled by a number of contributors under the auspices of the Committee on Line Spectra of the Elements, U.S. National Academy of Sciences -- National Research Council.
13. Outred, M.: 1978, J. Phys. Chem. Ref. Data 7, p. 1.
14. Bashkin, S., Stoner Jr., J.O.: 1975, Atomic Energy Levels and Grotrian

https://doi.org/10.1017/S0251107X00010646 Published online by Cambridge University Press

Diagrams, Vol. 1, North-Holland, Amsterdam.
15. Zalubas, R., Albright, A.: Nat. Bur. Stand. (U.S.), Spec. Publ. 363, Suppl. 2 (publication expected during latter part of 1979). For references earlier than July 1975, see Hagan, L: 1977, ibid., Suppl. 1, and previous bibliographies referenced therein.
16. Edlén, B.: 1976, in "Beam-Foil Spectroscopy", Eds. Sellin, I.A. and Pegg, D.J., Vol. 1, p. 1, Plenum, New York.
17. Adelman, S.J., Shore, S.N., Nasson, M.A.: 1977, Publ. Astron. Soc. Pac. 89, p. 780.
18. Heilig, K.: 1977, Spectrochim. Acta, Part B 32B, p. 1.
19. Erickson, G.W.: 1977, J. Phys. Chem. Ref. Data 6, p. 831.
20. Vainshein, L.A., Safronova, U.I.: 1978, At. Data Nucl. Data Tables 21, p. 49.
21. Vainshtein, L.A., Safronova, U.I.: 1977, The Spectroscopic Atomic Constants, Science Council for Spectroscopy of the Academy of Sciences, USSR.
22. Boiko, V.A., Faenov, A. Ya., Pikuz, S.A.: 1978, J. Quant. Spectr. Rad. Trans. 19, p. 11.
23. Edlén, B.: 1978, Phys. Scr., in press.
24. Edlén, B.: 1978, Phys. Scr. 17, p. 565.
25. Edlén, B.: 1978, Opt. Pura Apl., in press.
26. Vergés, J., Wyart, J.-F.: 1978, Phys. Scr. 17, p. 495.
27. Worden, E.F., Solarz, R.W., Paisner, J.A., Conway, J.G.: 1978, J. Opt. Soc. Am. 68, p. 52.
28. Rajnak, K., Shore, B.W.: 1978, J. Opt. Soc. Am. 68, p. 360.
29. Grant, I.P., Mayers, D.F., Pyper, M.C.: 1976, J. Phys. B: At. Mol. Phys. 9, p. 2777; Pyper, N.C., Grant, I.P.: 1978, J. Chem. Soc. Faraday Trans. II, in press, and references therein.
30. Pyper, N.C., Grant, I.P., Beatham, N.: 1978, Computer Phys. Commun., in press, and references therein. Several programs are available from the CPC Program Library, Dept. of Applied Mathematics and Theoretical Physics, Queen's University of Belfast, Northern Ireland.
31. Jordan, C.: 1978, in "Progress in Atomic Spectroscopy", Part B, Eds. Hanle, W. and Kleinpoppen, H., p. 1453, Plenum Press, New York, in press.
32. Ma, W.-T., Kuriyan, M., Pritchard, H.O.: 1978, Can. J. Chem. 56, p. 884.
33. Roig, R.A., Tondello, G.: 1976, J. Phys. B: At. Mol. Phys. 9, p. 2373.
34. Palenius, H.P., Huffman, R.E., Larrabee, J.C., Tanaka, J.: 1978, J. Opt. Soc. Am., in press.
35. Minnhagen, L.: 1976, J. Opt. Soc. Am. 66, p. 659.
36. Boiko, V.A., Faenov, A. Ya., Pikuz, S.A., Skobelev, I. Yu., Vinogradov, A.V. Yukov, E.A.: 1977, J. Phys. B: At. Mol. Phys. 10, p. 3387.
37. Brillet, W.L., Artru, M.C.: 1975, J. Opt. Soc. Am. 65, p. 1399.
38. Brillet, W.L.: 1976, Phys. Scr. 13, p. 289.
39. Brillet, W.L., Artru, M.C.: 1976, Phys. Scr. 14, p. 285.
40. Artru, M.C., Brillet, W.L.: 1977, Phys. Scr. 16, p. 93.
41. Magnusson, C.E., Zetterberg, P.O.: 1977, Phys. Scr. 15, p. 237.
42. Zetterberg, P.O., Magnusson, C.E.: 1977, Phys. Scr. 15, p. 189.
43. Eidelsberg, M., Artru, M.C.: 1977, Phys. Scr. 16, p. 109.
44. Bromage, G.E., Fawcett, B.C.: 1977, Mon. Not. Roy. Astron. Soc. 178, p. 605.
45. Ericksson, K.B.S.: 1978, Astrophys. J. 222, p. 398.
46. Smitt, R., Svensson, L.A., Outred, M.: 1976, Phys. Scr. 13, p. 293.
47. Garnir, H.P., Baudinet-Robinet, Y., Dumont, P.D.: 1978, Phys. Scr. 17, p. 463.
48. Pegg. D.J., Forester, J.P., Elston, S.B., Griffin, P.M., Groeneveld, K.O., Peterson, R.S., Thoe, R.S., Vane, C.R., Sellin, I.A.: 1977, Astrophys. J. 214, p. 331.
49. Edlén, B., Bodén, E.: 1976, Phys. Scr. 14, p. 31.
50. Cohen, L., Behring, W.E.: 1976, J. Opt. Soc. Am. 66, p. 899.
51. Fawcett, B.C.: 1976, J. Opt. Soc. Am. 66, p. 632.
52. Kononov, E. Ya., Koshelev, K.N., Podobedova, L.I., Churilov, S.S.: 1976, Opt. Spectrosc. 40, p. 121.
53. Kononov, E. Ya., Koshelev, K.N., Podobedova, L.I., Churilov, S.S.: 1975, Opt.

Spectrosc. 39, p. 458.
54. Ben Ahmed, Z., Vergês, J.: 1977, Physica 92C, p. 113.
55. Edlên, B., Swensson, J.W.: 1975, Phys. Scr. 12, p. 21.
56. Svensson, L.A.: 1976, Phys. Scr. 13, p. 235.
57. Ekberg, J.O., Svensson, L.A.: 1975, Phys. Scr. 12, p. 116.
58. Boiko, V.A., Pikuz, S.A., Safronova, U.I., Faenov, A.Ya.: 1977, J. Phys. B: At. Mol. Phys. 10, p. 1253.
59. Iglesias, L.: 1977, Opt. Pura Apl. 10, p. 267.
60. Ekberg, J.O.: 1976, Phys. Scr. 13, p. 111.
61. Bromage, G.E., Cowan, R.D., Fawcett, B.C., Ridgeley, A.: 1978, J. Opt. Soc. Am. 68, p. 48.
62. Ekberg, J.O.: 1976, Phys. Scr. 14, p. 109.
63. Ekberg, J.C.: 1976, Phys. Scr. 13, p. 245.
64. Widing, K.G., Purcell, J.D.: 1976, Astrophys. J. Letts. 204, p. L151.
65. Garcia-Riquelme, O.: 1977, Opt. Pura Apl. 10, p. 275.
66. Kovalev, V.I., Ramonas, A.A., Ryabtsev, A.N.: 1977, Opt. Spectrosc. 43, p. 4.
67. Ryabtsev, A.N.: 1977, Sov. Astron. 21, p. 519.
68. King, W.H.: 1977, J. Phys. B: At. Mol. Phys. 10, p. 3381.
69. Doschek, G.A., Feldman, U., Davis, J., Cowan, R.D.: 1975, Phys. Rev. A 12, p. 980.
70. Litzên, U., Vergês, J.: 1976, Phys. Scr. 13, p. 240.
71. Litzên, U.: 1976, Phys. Scr. 14, p. 165.
72. Johansson, S.: 1977, Astrophys. J. 212, p. 923.
73. Johansson, S.: 1977, Phys. Scr. 15, p. 183.
74. Johansson, S.: 1978, Mon. Not. Roy. Astron. Soc., in press.
75. Johansson, S.: 1978, Phys. Scr., in press.
76. Ekberg, J.O., Edlên, B.: 1978, Phys. Scr. 18, p. 107.
77. Ekberg, J.O.: 1975, Phys. Scr. 12, p. 42.
78. Edlên, B., Smitt, R.: 1978, Sol. Phys., in press.
79. Swartz, M., Kastner, S.O., Goldsmith, L., Neupert, W.M.: 1976, J. Opt. Soc. Am. 66, p. 240.
80. Smitt, R.: 1977, Sol. Phys. 51, p. 113.
81. Bromage, G.E., Cowan, R.D., Fawcett, B.C.: 1977, Phys. Scr. 15, p. 177.
82. Kononov, E. Ya., Kovalev, V.I., Ryabtsev, A.N., Churilov, S.S.: 1977, Sov. J. Quantum Electron. 7, p. 111.
83. Bromage, G.E., Cowan, R.D., Fawcett, B.C., Gordon, H., Hobby, M.G., Peacock, M.J., Ridgeley, A.: 1977, Culham Laboratory Report CLM-R 170; U.K.A.E.A., Culham Laboratory, Abingdon, Oxon. OX14 3DB, England.
84. Bromage, G.E., Fawcett, B.C., Cowan, R.D.: 1977, Mon. Not. Roy. Astron. Soc. 178, p. 599.
85. Bromage, G.E., Fawcett, B.C.: 1977, Mon. Not. Roy. Astron. Soc. 178, p. 591.
86. Widing, K.G.: 1978, Astrophys. J. 222, p. 735.
87. Kononov, E. Ya., Koshelev, K.N., Podobedova, L.I., Chekalin, S.V., Churilov, S.S.: 1976, J. Phys. B: At. Mol. Phys. 9, p. 565.
88. Suckewer, S., Hinnov, E.: 1978, Phys. Rev. Lett. 41, p. 756.
89. Henrichs, H.F., Fawcett, B.C.: 1976, Astron. Astrophys. Suppl. 23, p. 139.
90. Poppe, R.: 1976, Physica 81C, p. 351.
91. Raassen, A.J.J., van Kleef, T.A.M., Metsch, B.C.: 1976, Physica 84C, p. 133.
92. Raassen, A.J.J., van Kleef, T.A.M.: 1977, Physica 85C, p. 180.
93. Henrichs, H.F.: 1975, Astron. Astrophys. 44, p. 41.

W.C. MARTIN
Chairman of the Working Group