14. COMMISSION DES ETALONS DE LONGUEUR D'ONDE ET DES TABLES DE SPECTRES

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THE PRIMARY STANDARD

The red radiation of cadmium (6438·4696 A.) which was internationally adopted in 1907 as the primary standard for spectroscopic measurements of wave-lengths and the definition of the international angstrom unit will probably always reign supreme as the best wave-length standard provided by nature.

A superior primary standard has been found in the radiation emitted by an even mass isotope of a heavy element such as mercury, and the availability, since 1947, of lamps containing artificial $^{198}_{80}$Hg has resulted in the following preliminary values of the wave-length of $^{198}_{80}$Hg green light in the same units as Cd red light:

5460·7532   (W. F. Meggers, *Compt. Rend. Neuvième Conf. Gen. Poids Mesures*, 75, 1948).

5460·7531   (H. Barrell and J. Puttock, *Compt. Rend. Neuvième Conf. Gen. Poids Mesures*, 77, 1948).

5460·7533   (A. Pérard and J. Terrien, *Compt. Rend.* **228**, 964, 1949).

5460·7531   (J. M. Blank, *J Optical Soc. Am.* **40**, 345, 1950).

5460·7532   (A. Pérard and J. Terrien, *J Phys. Rad.* **11**, 249, 1950).

The electrodeless lamps with which the above measurements were made each contained, in addition to $^{198}_{80}$Hg, pure argon gas at a pressure of about 3 mm. Hg to facilitate high frequency excitation of the mercury spectrum. By comparing the wave-lengths of such a lamp with those from one containing 0·1 mg. $^{198}_{80}$Hg, and argon at a pressure of 10 mm. Hg, Barrell has detected what is considered to be a pressure effect of the added argon gas. It appears that the mercury green wave-length increases about 0·0001 A./mm. pressure of argon. This pressure shift is being investigated with helium and argon gases. In any case the effect is small and probably reproducible; if it cannot be eliminated it can be accurately specified.

SECONDARY STANDARDS

(a) *Iron Standards*

The list of iron secondary standards adopted by the International Astronomical Union (*Trans. I.A.U.* **3**, 86, 1928; ibid. **4**, 234, 1932; ibid. **6**, 79, 1938) consists of 306 seven-figure values ranging from 2447·708 to 6677·933 A., thus covering about 1·3 octave. Preliminary values of long-wave iron lines (6750·158 to 10216·351 A.) have been suggested (*Trans. I.A.U.* **5**, 84, 1935; ibid. **7**, 147, 1950) but a third independent, concordant observation is required before standards are adopted in this wave-length range. Additional ultra-

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violet lines (2100·794–3383·980 A.) have also been suggested (*Trans. I.A.U* **6**, 80, 1938). To increase to 500 the present number of iron secondary standards, and to extend them over a range of 2·2 octaves, only one or two confirmatory observations are required for about 200 lines. It appears more likely, however, that additional standards will have to be based on two independent observers rather than three.

Although never mentioned heretofore, objection might have been raised against iron lines as wave-length standards on account of the isotopic complexity of natural iron. Iron consists of a mixture of four isotopes with integral mass numbers and relative abundances as follows: 54 (5·81), 56 (91·64), 57 (2·21), 58 (0·34). Nearly 92% of the intensity of iron lines thus arises from isotope 56, but it seemed possible that line displacements of isotope 54 and hyperfine structure from isotope 57 could cause asymmetries detectable as variations in relative wave-lengths when measured with different interferometers. The fact that no such variations have been detected in the past is explained by recent researches (Gurevitch and Teasdale, *Phys. Rev.* **76**, 151, 1949; Brossel, *Phys. Rev.* **76**, 858, 1949) in nuclear physics. A sample of iron with isotope 57 enriched to 68% was excited in a liquid-nitrogen-cooled hollow cathode and hundreds of lines were examined with interferometers capable of resolving components only 0·025 wave numbers apart. 'No structure, broadening or asymmetry was found.' This negative result gives assurance that iron spectra are indeed satisfactory sources of secondary standards; their past and present usefulness will continue throughout the future.

(b) Neon Standards

In 1935 eight-figure values of twenty neon wave-lengths were adopted (*Trans. I.A.U* **5**, 86, 1935) as secondary standards, with the reservation that they apply only to the conditions under which they were determined, viz. with interferometers of high resolving power but plate separations not exceeding 40 mm.

In the last report (*Trans. I.A.U* **7**, 148, 1950) the values of twenty-three red and infra-red wave-lengths of neon were quoted from interference measurements by Meggers and Humphreys (*J. Res. Nat. Bur. Std.* **13**, 293, 1934) and by Burns (unpublished, 1947). The latter data have since been revised, extended and published by Burns, Adams and Longwell (*J Optical Soc. Am.* **40**, 339, 1950); they are assembled in Table 1 together with earlier results published by Meggers and Humphreys (loc. cit.) and by Humphreys (*J Res. Nat. Bur. Std.* **20**, 24, 1938). The M & H results are relative to the fundamental standard (Cd 6438·4696 A.) and to selected red lines of neon previously compared with the primary standard. The H results are relative to international secondary standards of wave-length in Kr I (*Trans. I.A.U* **5**, 87, 1935); those of B, A & L are relative to international secondary standards of wave-length in Ne I (loc. cit.). Numbers in parentheses represent the number of observations. Systematic differences between M & H and B, A & L were diminished when the latter doubled their number of observations. Regional systematic differences may be ascribed either to the use of different reference standards or to improper corrections for the dispersion of phase-change upon reflection in interferometers.

(c) Krypton Standards

The mean values of 20 Krypton wave-lengths were adopted in 1935 as secondary standards (*Trans. I.A.U* **5**, 87, 1935). These were measured with Fabry-Perot interferometers in air relative to Cd 6438·4696 A. In 1946 T A. Littlefield reported results for thirty-one krypton wave-lengths measured with a reflecting echelon in vacuum relative to Cd 6438·4696 × 1·00027638 = 6440·2491 A., using Barrell and Sears's value for the index of refraction. Littlefield (*Nature*, **165**, 187, 1950) converted his values to 'normal air' values with three different dispersion formulas, but unless a choice is made or new values of atmospheric refraction are adopted it is impossible to transform eight-figure wave-lengths in vacuum to exactly corresponding values in normal air. See section IV, p. 192.

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TABLE I

Wave-lengths of Neon

B, A & L (1950)		M & H (1934)		B, A & L (1950)		M & H (1934)	
8919·4987	(3)	—		6666·8967	(4)	—	
8865·7562	(12)	·759	(4)	6652·0925	(5)	—	
8865·3057	(3)	—		6444·7118	(7)	---	
8853·8669	(20)	·866	(7)	6421·7108	(5)	—	
8830·9078	(2)	—		6351·8618	(4)	—	
8783·7539	(30)	·755	(12)	6328·1646	(7)	—	
8780·6223	(34)	·6222	(12)	6313·6921	(4)	—	
8771·6592	(11)	—		6293·7447	(7)	—	
8704·1132	(6)	—		6246·7294	(6)	—	
8681·9216	(15)	·920	(4)	6213·8758	(6)	—	
8679·4898	(15)	·491	(2)	6205·7775	(6)	—	
8655·5206	(2)	—		6193·0663	(4)	—	
8654·3837	(46)	·3835	(13)	6189·0649	(5)	—	
8647·0400	(8)	—		6182·1460	(13)	·146	(3)
8634·6472	(44)	·6480	(14)	6174·8829	(5)	—	
8591·2583	(45)	·2584	(14)	6128·4498	(18)	·4510	(8)
8571·3535	(11)	—		6064·5359	(6)	—	
8544·6952	(8)	—		6046·1348	(5)	—	
8495·3591	(56)	·3601	(17)	6000·9275	(6)	—	
8484·4424	(3)	—		5991·6532	(7)	—	
8463·3569	(10)	—		5987·9074	(10)	·9069	(5)
8418·4265	(39)	·4274	(14)	5974·6273	(2)	·628	(4)
8377·6062	(57)	·6068	(19)	5965·4710	(13)	·474	(2)
8365·7464	(5)	—		5961·6228	(7)	—	
8300·3248	(48)	·3258	(16)	5918·9068	(8)	—	
8267·1166	(2)	—		5913·6327	(10)	·633	(4)
8266·0788	(21)	·076	(7)	5906·4294	(12)	·429	(3)
8259·3795	(11)	·380	(2)	5902·7835	(2)	---	
8248·6812	(4)	—		5902·4623	(20)	·4637	(6)
8136·4061	(38)	·4060	(14)	4872·8275	(12)	·828	(3)
8128·9077	(2)	—		5868·4183	(4)	—	
8118·5495	(14)	·5495	(6)	5820·1558	(44)	·1550	(10)
8082·4576	(19)	·4582	(8)	5811·4066	(5)	—	
7943·1805	(25)	·1802	(10)	5804·4496	(25)	·4488	(6)
7936·9946	(5)	—		5764·4188	(55)	·4181	(9)
7927·1172	(2)	—		5760·5885	(4)	—	
7839·0550	(2)	—		5748·2985	(30)	·299	(6)
7724·6281	(2)	—		5719·2248	(17)	·2254	(6)
7544·0439	(31)	·046	(4)	5689·8163	(24)	·8164	(6)
7535·7739	(46)	·7746	(13)	5662·5489	(9)	·547	(2)
7488·8712	(48)	·8720	(14)	5656·6588	(25)	·6585	(6)
7472·4383	(12)	---		5652·5664	(7)	—	
7438·8981	(57)	·8989	(17)	5562·7662	(21)	·769	(5)
7245·1665	(58)	1668	(19)	5533·6788	(2)	—	
7173·9380	(54)	·9389	(15)	5494·4158	(2)	—	
7059·1079	(26)	·109	(4)	5448·5091	(5)	·508	(2)
7051·2937	(8)	—		5433·6513	(9)	·649	(2)
7032·4128	(57)	·4131	(17)	5418·5584	(2)	—	
7024·0500	(44)	·0508	(6)	5400·5616	(46)	·5620	(5)
6929·4672	(54)	·4679	(6)	5374·9774	(2)	·975	(2)

Table 1 (continued)

B, A & L (1950)		M & H (1934)		B, A & L (1950)		M & H (1934)	
5372·3110	(6)	—		4710·0669	(3)	—	
5360·0121	(4)	·012	(2)	4708·8619	(5)	·854	(2)
5349·2038	(2)	—		4704·3949	(13)	·395	(5)
5343·2834	(16)	·284	(5)	4687·6724	(1)	·671	(4)
5341·0938	(22)	·092	(8)	4661·1054	(4)	·104	(5)
5330·7775	(28)	·777	(9)	4656·3936	(5)	·3923	(6)
5326·3968	(8)	·396	(2)	4645·4180	(4)	·416	(5)
5304·7580	(5)	·756	(2)	4628·3113	(1)	·309	(5)
5298·1891	(9)	·190	(5)	4582·4521	(4)	·450	(4)
5280·0853	(4)	—		4575·0620	(2)	·060	(4)
5234·0271	(5)	·028	(3)	4540·3801	(3)	·376	(4)
5222·3517	(10)	·351	(5)	4537·7545	(1)	·751	(4)
5210·5672	(2)	·573	(3)	4488·0926	(5)	·0928	(6)
5208·8648	(7)	·863	(3)	4466·8120	(1)	·807	(4)
5203·8962	(15)	·8950	(7)	4433·7239	(1)	·721	(3)
5193·2227	(2)	·224	(3)	4424·8096	(4)	·800	(5)
5193·1302	(2)	·130	(3)	4422·5205	(3)	·519	(5)
5188·6122	(14)	·612	(7)	4334·1267	(1)	·125	(2)
5158·9018	(2)	—		4275·5598	(5)	H (1938)	
5156·6672	(1)	·664	(2)	4270·2674	(4)		
5154·4271	(3)	·422	(3)	3754·2148	(13)	·2160	(22)
5151·9610	(8)	·963	(6)	3701·2247	(23)	·2250	(36)
5144·9384	(12)	·9376	(7)	3685·7351	(23)	·7359	(36)
5122·2565	(9)	·257	(4)	3682·2421	(20)	·2428	(32)
5116·5032	(20)	·503	(6)	3633·6643	(23)	·6646	(38)
5113·6724	(7)	·675	(5)	3609·1787	(9)	·1793	(19)
5104·7011	(3)	·705	(2)	3600·1694	(26)	·1693	(38)
5080·3852	(13)	·383	(6)	3593·639	(c)	·6398	(32)
5074·2007	(8)	·200	(6)	3593·5263	(21)	·5259	(32)
5037·7512	(19)	·7505	(7)	3562·9551	(6)	—	
5031·3504	(8)	·3484	(6)	3520·4714	(37)	·4717	(40)
5005·1587	(5)	·160	(5)	3515·1900	(31)	·1908	(38)
4957·0335	(5)	·0334	(6)	3510·7207	(24)	·7214	(33)
4944·9899	(1)	·987	(4)	3501·2154	(29)	·2165	(39)
4939·0457	(1)	·041	(4)	3498·0632	(28)	·0644	(39)
4892·1007	(1)	·090	(4)	3472·5706	(34)	·5711	(40)
4884·9170	(5)	·915	(5)	3466·5781	(28)	·5786	(40)
4865·5009	(1)	·505	(4)	3464·3385	(28)	·3389	(38)
4863·0800	(4)	·074	(5)	3460·5235	(31)	·5245	(38)
4852·6571	(2)	·655	(5)	3454·1942	(35)	·1952	(40)
4837·3139	(7)	·3118	(6)	3450·7641	(30)	·7653	(37)
4827·3444	(3)	·338	(6)	3447·7022	(38)	·7029	(40)
4821·9236	(2)	·924	(5)	3423·9120	(18)	·9127	(24)
4817·6386	(2)	·636	(6)	3418·		·0066	(25)
4810·0640	(7)	·0625	(6)	3417·9031	(31)	·9036	(40)
4788·9270	(3)	·9258	(6)	3375·6489	(10)	·6498	(6)
4752·7320	(7)	·7313	(6)	3369·9069	(25)	·9081	(38)
4749·5754	(3)	·572	(4)	3369·8076	(1)	·8086	(24)
4715·3466	(9)	·344	(5)				

Standards of wave-length in the solar spectrum have resulted mainly from two, or more, accordant interferometric results relative to neon or iron standards. Within the limits 3592·027 and 9889·050 A. seven-figure values of 582 such standards have been adopted (*Trans. I.A.U* **3**, 93, 1928; ibid. **6**, 90, 1938). Since then only M. G. Adam (*Monthly Notices*, **108**, 446, 1948) and F J. Treanor (*M.N.* **109**, 389, 1949) have reported interferometric measurements of solar wave-lengths but without contributing to the establishment of standards. The former measured relative to terrestrial oxygen lines the wave-lengths of fourteen solar lines (6013·5–6270·2 A.) when light was taken from successive parts of the polar diameter, and reported finding a shift over vacuum arc values of +0·005 A. at the centre, which increased to +0·013 A. near the limb. J. Evershed (*M.N.* **108**, 347, 1948; ibid. **109**, 594, 1949) has measured some solar wave-lengths relative to terrestrial oxygen and water-vapour lines; he reports that the wave-lengths appear to change with time. These reported spatial and temporal changes in solar spectrum standards should be independently checked relative to the primary standard; if confirmed these will cast doubt on the reproducibility and constancy of solar spectrum standards.

Modern investigation of the ultra photographic infra-red spectrum of the Sun is seriously handicapped by the lack of standard wave-lengths in that range. For a portion ($1·3–3·6\mu$) of that range, wave-lengths of iron lines calculated from transitions between well-established atomic energy levels have approximately fixed the scale of solar wave-lengths, but such lines are too infrequent or faint to standardize the longer waves. Overlapping spectral orders have also been employed but beyond $3·6\mu$ recourse must be had to the lines in the rotation structure of band spectra of molecules showing absorption in the terrestrial atmosphere. The calculated infra-red CO bands have been recommended as wave-number standards by K. N. Rao (*J. Chem. Phys.* **18**, 213, 1950), and thirteen lines of the CO band near $4·6\mu$ have indeed been detected in the Earth's atmosphere by M. Migeotte (*Phys. Rev.* **75**, 1108, 1949; *Physica*, **16**, 423, 1950). The relative accuracy of the predicted wave-lengths of CO rotation-vibration lines is probably near $\pm 0·01$ cm.$^{-1}$, and the absolute values are believed to be correct within $\pm 0·1$ cm.$^{-1}$

In addition to the CO lines at $4·6\mu$, and the H_2O lines throughout the infra-red, vibration-rotation lines of N_2O at 3·9, 4·0, 4·5 and $8·6\mu$, of CH_4 at 3·4 and $7·7\mu$, of CO_2 at 9·4 and $10·4\mu$ appear clearly on solar spectrograms recorded with high resolution. Among these lines those that are not blended with others may serve as secondary standards when they have been measured with sufficient accuracy.

THE DISPERSION OF AIR

The dispersion of normal air was discussed in an earlier report (*Trans. I.A.U* **6**, 87. 1939). Comparison of refractivities derived for wave-lengths 2000–10,000 A. from five different dispersion formulas showed large divergences in the ultra-violet, and it was suggested that the dispersion of air should be re-determined, preferably by two or more independent observers. Two independent observers have reported, one (D. Bender, *Phys. Rev.* **54**, 179, 1938) on the refractive index of air in the visible and photographic infra-red (5300–11,177 A.), and the other (H. Lowery, *Phil. Mag. J. Sci.* **33**, 622, 1942) on the ultra-violet dispersion of air (6563–1822 A.). Although these observations extend to greater and to smaller waves than any others, they do not agree with each other where they overlap nor with any previously reported.

Reliable values of atmospheric refraction are essential for specifying universal constants like the ultimate standard of length, Rydberg's constant, and atomic energy levels, and for calculating standard wave-lengths from the latter. In a discussion of the derivation of vacuum wave numbers and the reduction of measured wave-lengths to standard atmospheric conditions, H. D. Babcock (*Astrophys. J* **111**, 60, 1950) implied that the dispersion formula of Barrell and Sears (*Phil. Trans. Roy. Soc. London*, **238** A, 1,

1939) should be preferred over that of Meggers and Peters (*Bur. Stand. Sci. Pap.* **14**, 697, 1918).

Recently the wave-lengths in air of twenty-six visible and ultra-violet radiations from $^{198}_{80}$Hg were measured by Meggers and Kessler (*J Optical Soc. Amer.* **40**, 737, 1950) relative to 5460·7532 A., provisionally adopted for the green line. Conversion of these measurements to vacuum wave numbers and application of the combination principle revealed systematic deviations from constancy of atomic energy differences as functions of wave-length. These deviations result from errors in relative values of refractive indices for various radiations. In particular, the deviations resulting from the use of the dispersion formula of Barrell and Sears are equal but opposite to those given by the dispersion formula of Meggers and Peters, and it is concluded that none of the available dispersion formulas for standard air appears to be correct within the errors of measuring relative wave-lengths. It is planned to undertake re-determinations of $^{198}_{80}$Hg wave-lengths relative to Cd 6438·4696 A., both in standard air and in vacuum, and thus derive for standard air a new dispersion formula that will satisfy the observations.

TABLES OF SPECTRA

At the Zürich meeting of the I.A.U., Commission 14 was made responsible for reviews and recommendations regarding all Tables of Spectra, including Tables of Solar Spectra with which it has been concerned since 1922.

(a) Second Revision of Rowland's Table of the Solar Spectrum

The programme on the revision of the 'Revised Rowland Table' (*Carnegie Publ.* No. 396, 1928) is being carried forward with steady progress. It is planned at present to include in one publication the solar spectrum as observed over the photographic range, i.e. from 2950 to 13,495 A.

Minnaert and his collaborators have completed the measurements of equivalent widths based on the Minnaert Atlas, from 6000 to 8700 A. (the red limit of the Atlas), and expect to start soon on the region of wave-length shorter than 6000 A.

Revised identifications of lines in the solar spectrum are also in progress. The final revised solar table will include the following data.

1. The wave-lengths from the 1928 publication corrected from the 1922 scale to the 1928 scale recommended by the I.A.U. The correction factors are those listed in the last report (*Trans. I.A.U* **7**, 151, 1950).

2. The equivalent width as determined from the Minnaert Atlas, expressed in mA. ($\Delta\lambda$).

3. The equivalent width, expressed in Fraunhofer units ($\Delta\lambda/\lambda$), which is the mean of the Utrecht measures and those of other observatories, corrected for the influence of blends.

4. A letter indicating the behaviour of the *atomic* lines in the sunspot spectrum. These letters are assigned on the basis of the estimated spot intensities of atomic lines published in 1933, for the region from 3894 to 6600 A.; and of those in *Carnegie Publ.* No. 579, 1947 for atomic lines of wave-length greater than 6600 A.

5. The revised identification with underlines indicating the chief contributors to blends. These identifications, as regards atomic lines, are based on the material being compiled for 'Atomic Energy Levels' discussed below. To date about 69% of the lines in the solar spectrum are wholly, or at least partially, identified. Russell has suggested that most of the faint lines still unexplained are probably of molecular origin. This illustrates the urgent need of further laboratory study of molecular spectra of the elements abundant in the Sun.

6. The low excitation potential of atomic lines of spectra that have been analysed in the laboratory. For molecular lines band data will be included in this column.

7. A column for notes.

(b) Tables of Atomic Energy Levels

The programme on the compilation of 'Atomic Energy Levels', as derived from the analyses of optical spectra, is being continued. Vol. 1, containing the spectra of 1H through 23V, was issued in June 1949 (*Circ. Nat. Bur. Std.* 467, Vol. 1). Vol. 2 will contain the spectra of the elements 24Cr through 41Nb, 152 in all. Unpublished data on analyses are included in Vol. 2 for thirty-three spectra.

The analyses of atomic spectra used for this compilation serve also for the revised identifications of solar lines and for the calculation of excitation potentials for the revised solar table discussed above. This programme also provides the material for the Ultra-violet Multiplet Table now in progress. Section 1 of this Multiplet Table, published in April 1950, contains the ultra-violet multiplets of selected spectra (seventy-nine in all) of the elements 1H through 23V (*Circ. Nat. Bur. Std.* 488, sect. 1). Section 2 is being prepared along with Vol. 2 of 'Atomic Energy Levels', both are now in press.

(c) Tables of Atomic Spectra

Since 1932 when the late Prof. H. Kayser discontinued revision and publication of his monumental *Handbuch der Spectroscopie* there has been no comprehensive compilation of spectroscopic data, and to find such material in the world's scientific literature recourse must be had to abridged bibliographies such as those published by Meggers (*J Opt. Soc. Amer.* 36, 431, 1946) and by Mack (*Rev. Mod. Phys.* 22, 64, 1950). Eventually the principal publications on atomic spectra will be found listed in the volumes of 'Atomic Energy Levels' described above; and details of wave-lengths and intensities of selected lines will be found in the Multiplet Tables mentioned.

Here it suffices to call attention to a new description and analysis of the first spectrum of arsenic (Meggers, Shenstone and Moore, *J Research Nat. Bur. Std.* 45, 346, 1950), and of tantalum (Klinkenberg *et al.* *Physica*, 16, 861, 1950). Extensive analyses of the first two spectra of gadolinium have been published (Russell, *J Opt. Soc. Amer.* 40, 550, 1950), and the final analyses have been completed for the first two spectra of chromium (Kiess, in preparation) and for the first and third spectra of manganese (Catalán, in preparation).

Preliminary descriptions of the atomic spectra of artificial elements have been released as follows. technetium (Meggers and Scribner, *J Research Nat. Bur. Std.* 45, 476, 1950), promethium (Meggers, Scribner and Bozman, ibid. 46, 85, 1951), plutonium (Dodgen, Chrisney and Rollefson, *The Transuranium Elements*, part II, 1327, 1949, McGraw Hill Book Co., Inc.) and abbreviated data for protactinium, neptunium, plutonium, americium (Tomkins and Fred, *J Opt. Soc. Amer.* 39, 357, 1949).

(d) Tables of Molecular Spectra

For up-to-date compilations of molecular spectra we are indebted to R. W B. Pearse and A. G. Gaydon (*The Identification of Molecular Spectra* (2nd edit.): John Wiley and Sons, New York, 1950), and to G. Herzberg (*Molecular Spectra and Molecular Structure*, I. Spectra of Diatomic Molecules, II. Infra-red and Raman Spectra of Polyatomic Molecules: D. van Nostrand Co., Inc.).

INTENSITY TABLES

Considerable progress has been made since 1948 in the determination of true line intensities, f-values, or strengths of lines in atomic spectra of astrophysical importance. Not only have significant quantities of new data appeared, but what is probably more important, promising new methods of attack, both theoretical and experimental, have been developed which, if vigorously applied, should lead to production of very important new data in the near future. The following report attempts to indicate the trends in investigations in this field and to point out some recent investigations and compilations of special significance to astrophysics.

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(a) Intensity Tables

A very important contribution has been made by L. Biermann of Göttingen who has compiled tables of existing f-values which have been recently published in the Landolt-Börnstein, *Zahlenwerte und Funktionen*, 6th edit., Vol. 1, part 1 (Springer-Verlag, 1950). These include the following tables of particular interest to astrophysicists: (1) Absolute f-values; (2) Relative f-values for Fe I and Ti II; (3) Transition probabilities for forbidden lines; (4) List of literature on molecular oscillator strengths. All tables contain complete references to the sources of the data. These tables are by far the most comprehensive tabulation of data on line strengths yet made.

At least two other major lists of line strength data are in the process of preparation. A compilation of 'Astrophysical Quantities' is being prepared for publication by C. W Allen of the Commonwealth Observatory, Canberra, Australia. This will include oscillator strengths for over 300 lines (in addition to H lines) judged by Allen to be of most significance in astrophysics. A table of line strengths is also being prepared by D. H. Menzel of Harvard for the Smithsonian Physical Tables.

(b) Theoretical Intensities

Transition probabilities of some Na I, K I, Al I, Mg II, Si II and C II lines have been calculated by Biermann and Lübeck (*Z. Astr.* **25**, 325, 1948), and of some transitions in the Mg I spectrum by Biermann and Krefftz (*Z. Astr* **26**, 213, 240, 1949; ibid. **28**, 67, 1950).

Bates and Damgaard (*Phil. Trans. Roy. Soc.* A, **242**, 101, 1949) have attempted to calculate by quantal methods the absolute strength of very many spectral lines. They have shown that it is permissible to neglect the departure of the potential of an atom or ion from its asymptotic coulomb form. Because of this it is possible to derive a general analytical expression for the transition integrals involved. Tables are given which enable the absolute line strengths of large numbers of atoms and ions to be obtained if the energies of the upper and lower levels are known. Comparison with experiment suggests that the method is remarkably accurate at least for the simpler atomic and ionic systems; indeed, that it is more accurate than the more usual and elaborate technique of computation.

Another general attack on atomic line intensities is being made by David Layzer at the University of Michigan. He is attempting to obtain analytical wave functions for atoms in the first row of the periodic table with the aim of calculating line strengths. The variational wave functions are of the form given by Morse, Young, and Haurwitz, except that they are analytical in Z, the atomic number. Thus all members of an iso-electronic sequence can be treated simultaneously. This method may very well be applicable to more complex spectra.

The quantum-mechanical calculations of line strengths for a complex spectrum of intermediate coupling and great astrophysical importance have been accomplished with considerable success by W M. Gottschalk (*Ap. J* **108**, 326, 1948). He has calculated strengths for the $3d^7$ (^{4}P) $4s - 3d^7$ (^{4}P) $4p$ and $3d^7$ (^{4}F) $4s - 3d^7$ (^{4}F) $4p$ transitions in the Fe I spectrum, taking into account spin-orbit interaction, but neglecting configuration interaction, and assuming that the L and S of the core are 'good quantum numbers' The validity of the method is confirmed by the reasonable agreement of the results with experimental results from electric furnace spectra and by the fact that Landé g-factors, calculated with the transformation matrices derived in the intensity calculations, are in accord with experimental values. The matrices calculated may be of use in computing line strengths in other transition arrays in Fe I and also in Ti II.

Calculations of oscillator strengths for Ca I and Ca II are being made by L. C. Green of Haverford College (*Ap. J* **111**, 582, 587, 1950). He has derived wave functions by numerical integration of the Schrödinger equation, with suitable fields introduced. Actual integrations were performed by relay calculating machines. This is one of the

first attempts to apply rigorous quantum mechanical methods to the calculation of line strengths in a complex spectrum on an extensive scale. The results will be of significance, not only in themselves, but in indicating the practicability of these methods in attacks on still more complex spectra, using modern calculating machines.

(c) Laboratory Intensities

Extension of laboratory data on strengths for lines of Fe I from electric furnace spectra has been made by W W Carter (*Phys. Rev.* **76**, 962, 1949). Previous data obtained from absorption spectra have covered only lines arising from the three lowest terms a^5D, a^5F, and a^3F. Using furnace emission spectra and measuring intensities directly with a photo multiplier tube, Carter was able to measure strengths of lines from terms as high as 3·5 volts low E.P. This method offers an important supplement to the furnace absorption spectra technique whose usefulness is generally limited to lines of low E.P. On the other hand lines of E.P. less than 1·0 volt are strongly affected by self-reversal in furnace emission spectra, so that the two methods should be combined.

Using electric furnace absorption spectra and photographic photometry, A. J. Hill and R. B. King (*J Opt. Soc. Amer.* **41**, 315, 1951) have measured strengths for 410 lines in the Cr I spectrum. In addition, strengths of 134 lines from the lowest terms in Ni II have been measured by R. B. King (*Ap. J* **108**, 87, 1948). These bring the number of spectra of astrophysical interest for which substantial numbers of relative line strengths have been measured in furnace spectra to six, namely: V I, Ti I, Ti II, Cr I, Fe I, and Ni I.

If strengths of highly excited lines in atomic and ionic spectra are to be determined in the laboratory it is first necessary to study thoroughly the physical conditions in the sources in which these lines can be excited if true relative line strengths are to be deduced from observations of relative intensities. Very important work in this direction has been carried on at the Utrecht Physical Laboratory over a period of many years, particularly in the study of excitation conditions in the electric arc. Recently, J. A. Smit has completed an investigation of the method of temperature determination in the electric arc by means of the CN bands (in Press). Other work on thermal dissociation and ionization in flames, and arc temperature as a function of gas pressure and velocity, is in progress.

An important advance in the technique of measurement of *absolute* line strengths has been made by G. Wessel (*Z. Phys.* **126**, 440, 1949). Using an atomic beam in which the number of atoms can be precisely and directly determined he has measured the oscillator strengths of the Ba I resonance line. This method has the great advantage that vapour pressure data from other investigators are not needed to determine the numbers of atoms involved. The lack of reliable vapour pressure data has been the main obstacle in other methods. The atomic beam method offers promise in the attack on the important elements of the iron group. A method similar in principle is being developed at the California Institute of Technology.

(d) Intensities from Astrophysical Sources

An intensity catalogue containing equivalent widths of solar lines is being prepared by M. Minnaert of the Utrecht Observatory. The section 6600–8700 A. is in the Press. That for 6000–6600 A. is practically finished. While this is not a table of oscillator strengths themselves, the data will be of fundamental importance in deriving 'solar line strengths'

During the past few years the work of Goldberg and Pierce, W W Carter, K. O. Wright, and others has emphasized the important fact that no single curve of growth for solar lines will suffice for lines of all elements or even for all lines of a single atom or ion. Hence the use of 'solar line strengths' derived from a single solar curve of growth may contain large systematic errors. Recognizing this, Miss Barbara Bell of Harvard College

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Observatory in compiling tables of 'solar line strength' (unpublished) from data in the Utrecht Atlas has found it necessary to construct individual curves of growth. She has been able to construct satisfactory curves for low E.P. Fe I, Ti I, and high E.P. odd-parity Fe I lines from which line strengths can be derived.

(e) Recommendations

The following general and specific recommendations for future atomic line intensity investigations have been made by members of the Sub-Commission:

(1) To check the method of Bates and Damgaard for calculating strengths for heavier atoms, laboratory measurements on higher series members of K and Ca, and heavier elements are needed; also for some of the lighter elements, particularly Be and Mg. Laboratory data for Ca I and Ca II are also required to compare with the results of Green's theoretical work on these spectra.

(2) For aid in the analysis of the infra-red solar spectrum in the region of $1·6\mu$ intensity data are badly needed, particularly for neutral lines of Fe, C, Na, Al, Mg, and Si. For further detailed analysis of curves of growth for lines in the visible portion of the solar spectrum, data for Si I, Fe II and extensions to fainter lines and higher E.P. of existing data for Fe I and Ti II are urgently needed. Data for lines appearing in the far ultra-violet (below 2900 A.) solar spectrum, especially Fe II, are also desired.

(3) Accurate values of collision parameters, while not strictly intensity data, are urgently needed to aid in the interpretation of observed line intensities in astrophysical sources.

(4) Laboratory absolute oscillator strengths are still urgently required both to check theoretical calculations and to aid in quantitative analyses of abundances of elements in astrophysical sources.

THE JOINT COMMISSION FOR SPECTROSCOPY

Under auspices of the International Council of Scientific Unions the Joint Commission for Spectroscopy was created by the International Union for Pure and Applied Physics and by the International Astronomical Union. All six I.A.U. representatives (Edlén, Gatterer, Herzberg, Meggers, Moore-Sitterly, Swings) participated in the organization of that Joint Commission at meetings held in Cambridge, England, September 25–29, 1950.

W. F. MEGGERS
President of the Commission

Report of meeting. 8 September 1952

PRESIDENT· Dr W. F. MEGGERS.

SECRÉTARY: G. R. HARRISON.

PRESENT: MM. Edlén and Harrison, and Mme Moore-Sitterly, and from Sub-commission 14a, MM. Allen and Shortley.

VISITORS: MM. Barcelo, Biermann, Catalán, Cialdea, Dingle, Harrington, Jenkins, Pearce, Richardson, Sitterly, Swings, Treanor, and Mlles Adam and Strobel.

The President discussed item by item the Report of the Commission as printed in draft form. He raised the question of possibly relaxing requirements for secondary wave-length standards from three independent determinations to two, in view of the very great difficulty of obtaining such wave-length measurements. Harrison suggested that two independent values might be considered adequate if they agreed, but not otherwise. Swings suggested that this matter be referred to the Joint Commission.

During the discussion on solar wave-lengths, Miss Adam mentioned work by Dr Treanor and herself on the measurement of solar wave-lengths interferometrically, directly in terms of the cadmium red line. Variations in phase retardation were being determined in terms of known Hg 198 wave-lengths.

The President suggested four alternative methods of meeting the problem of accounting for the dispersion of air. These were:

(1) to continue to use Kayser's tables;
(2) to use Barrell's compromise formula;
(3) to follow Edlén's new formula;
(4) to make new determinations of the required conversion factors.

At Edlén's suggestion this matter was referred to the Joint Commission.

Under item V of the Draft Report, Mrs Sitterly stated that Prof. Minnaert had now published values of solar intensities in the range 6000–8700 A.

The President reported that vol. II of *Atomic Energy Levels* has now been published, covering elements 24 to 41. He raised the question of the proper order for publication of the remaining elements, stating his belief that the order of atomic numbers might be departed from and the spectra of rare earth type be reserved for vol. IV, since these are least complete. There was general agreement with this view.

The President reported that he has re-described the spectrum of rhenium from new measures and that Catalán and his students are now working on the analysis. Meggers is also preparing new descriptions of the spectra of technetium and actinium. The Secretary reported that Zeeman studies of erbium, holmium and terbium are under way at M.I.T., and that Dr Blank is engaged in the analysis of Dy II.

Pearce stated that many new data on molecular spectra are becoming available, but that better intensity values are needed for band systems. He plans a third edition of his tables. Swings noted that there is much information on molecular spectra in the new *Tables Annuelles de Données Numériques*, and in Landolt-Börnstein, vol. III. Allen gave a brief report on his intensity tables.

The President discussed the measurements made at the N.B.S. under his direction on the intensities of 30,000 principal lines of 70 elements under standard conditions of excitation. He stated that internal evidence indicated that gf-values of astrophysical interest can be obtained from this mass of data which was originally determined for purposes of spectrochemical analysis, and was urged to arrange for its reduction and publication.

Edlén informed the group that the new wave-length tables in Landolt-Börnstein contain many awkward errors, regarding which he had written the publishers.

No changes were suggested in the Draft Report of the Commission.