14. COMMISSION DES DONNÉES SPECTROSCOPIQUES FONDAMENTALES

Report of Meeting, 26 August 1964

PRESIDENT: Ch. Moore-Sitterly.

SECRETARY: J. G. Phillips.

Business Meeting

The Chairman opened the meeting with the request for corrections to the Draft Report in addition to those that had been submitted individually. No extensive changes were required, but at a later session Edlén suggested some notes regarding the wavelengths in Table 3 of the Draft Report (see below).

The Chairman submitted to the Commission the question of the designation for the primary standard, since the use of Paschen Notation, $2p_{10} - 5d_5$, has aroused considerable criticism.

In the discussion that followed it was pointed out that most *users* were familiar with the Paschen Notation and that a conversion to more modern notation would require revision of all previously published documents. It was agreed that the Commission go on record as having no objection to the inclusion of both the Paschen and the pair-coupling notation for the primary standard:

λ_{Vac}	λ_{Air}	cm^{-1}	Paschen	Pair-coupling
6057·80 210_5Å;	6056·12 525_3Å;	16 507·6373;	$2p_{10}-5d_5$;	$5p[0\frac{1}{2}]_1 - 6d[0\frac{1}{2}]_1^{\circ}$.

A note to this effect is being submitted to the Comité Consultatif pour la Définition du Mètre (CCDM).

In view of the persistent demand for Grotrian Diagrams, the Chairman then invited W. Lochte-Holtgreven to introduce this subject. He pointed out that the preparation of a new edition of Grotrian's book would be of great use to spectroscopists. Such a revision should include ionic states higher than two and a large range of elements.

As a starting point on such an extensive project three practical suggestions were made:

(1) Appendix A of the publication by P. W. Merrill on 'Lines of chemical elements in astronomical spectra' (*Publ. Carnegie Inst.* 610, 1956) contains a set of Partial Grotrian Diagrams of Astrophysical Interest, together with keys giving related lines in the spectra of the iso-electronic sequences represented by the diagrams. This Appendix might be published separately and distributed more widely.

(2) The literature references for the individual spectra in 'Atomic Energy Levels' are described by a series of letters including (GD), which denotes that the paper contains a Grotrian Diagram of the spectrum. A survey of these references should be made.

(3) In collecting diagrams for publication, stress should be laid on rare gases and on highly-ionized spectra, for example Cu IV.

The Chairman agreed to look into the question in more detail with the idea of assembling all currently available diagrams, possibly for the preparation of a single publication on Selected Grotrian Diagrams.

M. Minnaert urged the formation of two sub-committees under Committee 2—Transition Probabilities:

(2*a*) A sub-committee on *Broadening Parameters of Spectral Lines*. He stressed the fact that it is becoming increasingly necessary to include very strong lines in curves of growth, which requires information on broadening mechanisms. In addition, the study of the shapes of line profiles requires information on line broadening mechanisms in order to discuss line asymmetries, etc. Physical data are especially needed in four areas: (*a*) quadratic Stark effect, (*b*) interactions between atoms of the same species, (*c*) van der Waals effect, (*d*) hyperfine structure. With regard to hyperfine structure, he pointed out that one does not find in the literature information of value to astrophysicists, who wish to know the *total* effect, not separated into component phenomena. A group of specialists is needed, composed of physicists with astrophysical interests, to provide this information. The proposed sub-committee could consult with physicists.

(2*b*) A sub-committee on *Cross Sections*. He noted that in the past, f-values were the only quantities of importance, but cross-sections are playing an increasing role in the studies of processes involving non-thermal equilibrium, e.g. phenomena in the solar chromosphere, corona, etc. Data of high precision are becoming available, and these are being collected at JILA (See *Draft Report*, p. 144). Physicists must be urged to obtain information of interest to astrophysicists, e.g. by using electron beams of low velocity.

The question of re-forming a committee on molecular spectra was brought before the Commission. In the discussion the proposal received general support. Molecular spectra are becoming increasingly important, and it must be recognized that different groups of spectroscopists are interested in molecular and atomic spectra. It was proposed that the new committee be charged with the responsibility for both wavelength determinations and transition probabilities.

Further discussion followed about the advisability of issuing Newsletters giving references to work on atomic spectra, similar to those prepared at Berkeley for Molecular Spectra. The bibliographies published by the Triple Commission for Spectroscopy meet these needs to some extent. The various recent developments in the space sciences have demonstrated the urgent need for more investigations of laboratory atomic spectra. Opinion was divided about the advisability of publishing lists of *needs* for information. References to published lists of unidentified features in the spectra of celestial objects might prove to be more useful.

Father Salpeter presented excellent sample prints from the 'Atlas of the Schumann region from 1100 to 2250 Å', which is being prepared as a Vatican publication. The dispersion is 8 Å/mm. Spectra of C, Hg, Ge and Cu were included in the sample. B. Edlén noted that this effort was stimulated by earlier sponsorship by this Commission.

The Chairman called attention to the fact that the Triple Commission for Spectroscopy was convening on 4 September, and that the programme was of interest to Commission 14.

Scientific Meeting

M. J. Seaton presented in some detail a paper on 'Electron-atom collision cross sections'. A summary is contained in the Draft Report.

W. L. Wiese submitted a report on 'Recent oscillator strength determinations' in the Plasma Spectroscopy Section at the National Bureau of Standards in Washington, D.C. It was presented by K. G. Kessler. For the lighter elements, extensive self-consistent field calculations are being made, specifically for the isoelectronic sequences of helium, lithium, beryllium, and some ions of carbon and neon. These should be generally reliable to within 20 per cent. In special cases, where interference in the transition integral, the effects of configuration interaction, and deviations from LS-coupling render the calculations less reliable, these calculations are supplemented by experimental work. Thus, a number of oxygen and carbon lines have been measured in wall-stabilized arcs and magnetically driven shock tubes, and lifetime

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

determinations of the important $3p$ states of Ne I are being determined by using the method of delayed coincidences. For heavier elements, experimental work with wall-stabilized arcs, which have been so successful for lighter elements, is in progress. A number of technical and diagnostical problems had to be solved first before this refined method for emission measurements could be applied. Determinations of S I, Ni I and Ni II oscillator strengths are in progress and the preliminary results are very encouraging. Some of the results are summarized in Tables 7 and 8.

Table 7

Values of mean lives of atomic levels in Ne I

Level	Transition	λ	Mean life in nanoseconds					
(Paschen notation)		Å	Ladenburg[a]	Doherty[b]	Osherovich[c]	Griffiths[d]	NBS exp.-theor.[e]	Present work[f]
$2p_1$	$2p_1 \rightarrow 1s_2$	5852	8	28·6	51	39	14·3	15·3 ± 0·4
$2p_2$	$2p_2 \rightarrow 1s_5$	5882	10	33·8	—	—	16·4	16·3 ± 0·6
$2p_5$	$2p_5 \rightarrow 1s_5$	5976	$>$10·4	$\lesssim$40	—	—	18·3	40·7 ± 1·8

(*a*) Ladenburg, R., Levy, S. *Z. Phys.*, **88,** 461, 1934.
(*b*) Doherty, L. R. Thesis, Univ. Michigan, 1961.
(*c*) Osherovich, A. L., Petelin, G. M. *Dokl. Akad. Nauk SSSR*, **129,** 544, 1959; [translation *Soviet Phys. Dok.*, **4,** 1289, 1960].
(*d*) Griffiths, J. H. E. *Proc. R. Soc.*, **A143,** 588, 1934.
(*e*) Best value from NBS data compilation.
(*f*) Klose, J. Z. *Astrophys. J.*, **141,** Feb. 1965.

Table 8

Preliminary S I transition probabilities (in 10^7 sec^{-1}) and comparison with the Coulomb approximation of Bates and Damgaard

Multiplet	λ (in Å)	Experiment[a]	Coulomb approx.[b]
$4s^5S^\circ - 4p^5P$	9212·9	2·1 ± 50%	2·68
	9228·1	2·3 ± 50%	2·68
	9237·5	2·4 ± 50%	2·68
$4s^5S^\circ - 5p^5P$	4695	0·085 ± 50%	Cancellation
$4s^3S^\circ - 4p^3P$	10456	2·1 ± 50%	2·18
$4s^3S^\circ - 5p^3P$	5279	0·041 ± 50%	Cancellation
$4p^5P - 4d^5D^\circ$	8685	1·2 ± 50%	1·22

(*a*) Bridges, J. M., Wiese, W. L. Unpublished, Oct. 1964.
(*b*) Bates, D. R., Damgaard, A. *Phil. Trans. R. Soc. London*, **A242,** 101, 1949.

The concluding paper was a brief comment by V. Prokofyev on 'Some empirical dependences in spectra of multiple ions of light atoms'. He presented plots of regularities similar to Moseley Diagrams, for isoelectronic sequences. For the H I sequence the quantity λ V 10^{-3} was used as the ordinate, where λ was the wavelength of the resonance lines in Å and V the ionization potential in eV. For sequences of He I and more complex atoms, effective quantum numbers were introduced for different series members to derive the ordinates for the diagrams.

Throughout the meeting there was an encouraging interest in the work of the Commission. More than 80 attended. The steady and increasing demand for spectroscopic data indicates a fundamental need for increasing the laboratory research programmes on the description and analyses of both atomic and molecular spectra.

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

The President wishes to record here her thanks to all who so willingly participated at the meeting, as well as to those who contributed to the Draft Report.

As requested, the Organizing Committee set up the two new sub-committees (*2a* and *2b*) and the new committee (3) described above.

COMMITTEE ON STANDARDS OF WAVELENGTH

Report of Meeting, 31 August 1964

CHAIRMAN: B. Edlén.

SECRETARY: J. G. Phillips.

The meeting opened with a plea by Dr Delbouille on behalf of Commission 12. A working group of Commission 12 is charged with the determination of the central intensities of solar lines. To calculate the instrumental profiles of lines one must know their true profiles. Dr Delbouille asked if some laboratory could measure profiles of selected isotopic lines (e.g. produced by a Hg lamp). Of greatest importance is the profile in wings. Dr Terrien commented that he has already a number of profiles, and cautioned that the source should be described in great detail since profiles are sensitive to source conditions. On behalf of Commission 12, Migeotte read the following proposal for consideration of Commission 14:

'Répondant à un voeu du "Working Group on Central Intensities of Solar Lines" de la Commission 12, la Commission 14 attire l'attention sur l'importance de la connaissance précise de profils de raies très fines, aisément reproductibles. Ces données sont importantes pour la détermination du profil instrumental des spectromètres solaires à haute résolution.'

Cook commented that profiles should not be limited to Hg. It was decided to include this request in the minutes, and Commission 14 will communicate with Pierce of the Working Group of Commission 12.

The Chairman called attention to corrections to be made in the Draft Report: In Table 2 the figure 4466·5914 should read 4466·5930, and in Table 3 a note should be inserted stating that the lines $\lambda\lambda$ 7589, 7603, 8115, 8192, 8265, 8300, 8779 are self-reversed and the measurements not reliable.

The Chairman reported additional information on various items in the Draft Report:

Meggers has remeasured the interference spectrograms described in 1958 (114) and increased the number of thorium standards between 3269.6089 Å and 7020.5040 Å from 222 to 510, thus bringing the average interval between adjacent standards below 10 Å. The accuracy in relative wavelength values of 163 classified thorium lines was tested by the combination principle which indicates that the average error is less than one part in 20 to 40 million. These results have been published by Meggers and Stanley, (*J. Res. nat. Bur. Stand.*, **69**A2, 109, 1965). There should be mentioned, also, a paper by Giacchetti *et al.* (*J. opt. Soc. Am.*, **54**, 957, 1964) giving new measurements of 129 thorium lines from 2680 to 4600 Å.

H. M. Crosswhite at the Johns Hopkins University has compiled a preliminary list of more than 4000 lines from 2250 to 5775 Å appearing in the spectrum of the iron-neon hollow cathode. It contains lines of Fe I, Fe II, Ne I and Ne II and is partly based on extensive new measurements. Work on improving the wavelengths is being continued.

Vacuum-ultra-violet Ritz standards in Si I, including 90 lines from 1992 to 1580 Å, are given in a Purdue Ph. D. Thesis by L. J. Radziemski, (*J. opt. Soc. Am.* **55**, in press, 1965). An unpublished list of Mn II Ritz standards, comprising about 70 lines from 1100 to 2000 Å, has been received from Laura Iglesias of the Optical Institute in Madrid. To the

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

references given in the Draft Report on Ge II Ritz standards there should be added the paper by Shenstone (*Proc. R. Soc.*, **A276,** 293, 1963).

A. H. Cook drew attention to measurements in the Kr 86 spectrum by F. M. Phelps III (*J. opt. Soc. Am.*, **54,** 864, 1964) on 95 lines from 3425 to 6907 Å, and by V. Kaufman (Purdue Thesis, 1959) on 41 lines from 4185 to 7930 Å.

The Chairman raised the question of vacuum versus air wavelengths. While in earlier Reports the wavelengths had been given in standard air this was changed to vacuum wavelengths in the 1961 Report, and this lead was followed in the present Report. However, since most spectroscopic measurements are still made in air, the standard-air wavelengths are needed for most applications. Thus time and labour could be saved if air wavelengths were published. Herzberg, in reply, pointed out that the primary standard is defined in the vacuum, and that the new wavelengths to be included in the 1961 Report were available in the vacuum. Only the vacuum values were published in interests of economy. As a result of the discussion that followed it was agreed that air and vacuum values are both needed and both should be published as far as cost of publication would permit.

The following reports were presented.

J. Terrien: The Temperature Dependence of the Wavelength of the Green Line of Hg 198.

'Mr Terrien a mesuré au Bureau International des Poids et Mesures la longueur d'onde des quatre principales radiations visibles du mercure 198 émises par une lampe sans électrodes contenant de l'argon à la pression de 0·025 mm Hg.

Le tube était dans une circulation d'eau dont la température a été maintenue successivement à trois températures: 1°C, 10°C et 20°C.

La longueur d'onde des trois radiations 4359, 577,1 et 5792 Å est indépendante de cette température. Au contraire la longueur d'onde de la radiation verte 5462 augmente en fonction de la température d'une quantité qui est supérieure à ce qui a été obtenu au National Physical Laboratory.

La différence entre les résultats du NPL et du BIPM s'explique très probablement par la dissymétrie du profil spectral. On sait en effet que l'auto-absorption de la raie verte est déjà décelable à 5 ou 10°C et qu'elle altére le profil d'une façon dissymétrique.

L'interféromètre employé au NPL est un étalon Pérot-Fabry; au BIPM c'est un interféromètre de Michelson. Il n'est donc pas étonnant que la longueur d'onde mesurée sur un profil dissymétrique soit différente.

La variation de longueur d'onde observée à l'interféromètre de Michelson à la différence de marche de 250 mm est 0,000 25 Å entre 0 et 20°C. Elle est donc loin d'être négligeable.'

A. H. Cook: Current Work on Wavelength Standards at NPL.

'(1) Stabilization of the wavelength of a helium-neon gas laser.

Rowley and Wilson (1963) have published a preliminary account of their work on stabilizing the wavelength of a helium-neon laser. The laser is adjusted to give single mode operation and a servo-mechanism is arranged to control the separation of the plates of the Fabry-Pérot resonator so that the intensity of the output is a maximum; the laser is then operating at the peak of the gain curve which, it is hoped, is at a wavelength determined by the energy levels of neon. In fact, the wavelength of the peak depends on the power at which the laser is operated, because, when using the natural mixture of neon isotopes, the gain curve is asymmetrical. The wavelength varies by $1{\cdot}6 \times 10^{-7}$ over the range from cut-off to the onset of double mode operation. It is therefore necessary to control the power level as well as the length of the Fabry-Pérot cavity. There are no doubt also changes as the discharge tubes age and the gas pressures alter, but it seems that such changes are quite small. Present indications are that it should be possible to stabilize the wavelength to one part in 10^8 but its use as a primary standard is not contemplated at present.

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

(2) Measurements of line profiles with a stabilized laser.

W. R. C. Rowley and M. J. Hamon, working at the NPL, have studied the profile of the standard line 6058Å, in the spectrum of Kr 86 by using a Fabry-Pérot interferometer of which the instrumental profile was determined by means of the line 6328Å of a stabilized helium-neon laser. It is thought that the two wavelengths are sufficiently close that the same instrumental profile can be assumed, but it is certain that if other lines were to be studied with the same instrument, the variation of profile with wavelength would have to be considered. The best solution would be to have laser lines available throughout the visible spectrum, but Rowley proposes to see how far he is able to calculate the profile at another wavelength from that at which it was measured by using measurements of the reflectivity of the plates. The observed profile of the orange line is corrected for the instrumental profile by a method that depends on making a Fourier analysis of both profiles, using six Fourier components. The results are not quite complete but it seems that the profile of the orange line is slightly asymmetrical and can be represented by two components, the one of longer wavelength having an intensity of about one-twentieth of the main component. This result agrees with that previously obtained by Rowley and Hamon (1963), when working at the BIPM, and using a Michelson interferometer.

(3) Work between 1000 and 2000 Å.

We have only started work in this field since the last General Assembly and are still developing apparatus. Our object is to construct a Michelson interferometer with which to measure wavelengths and line profiles to wavelengths as short as we can manage; we hope, also, that some of our auxiliary apparatus may be useful for measuring lifetimes of excited states. At present we are trying to develop a Michelson interferometer by using photo-electric detection and digital recording of data with a mechanical scan of one of the mirrors. We have tried out the scanning and recording systems in the visible with good results, and hope soon to have an interferometer for wavelengths around 2000 Å. Our crucial problem is the production of a beam divider. For the shortest wavelengths we must use lithium fluoride, but we find that it is very difficult to work it flat without destroying its transmission at Lyman-α. A great deal of our effort so far has, therefore, been spent on auxiliary work such as the development of equipment for studying the optical properties of lithium fluoride and other optical materials, and the performance of mirrors and gratings. A high-dispersion échelle instrument is being designed which we intend to use to study the effects of source conditions on wavelengths of lines in the vacuum ultra-violet, a question that we think may be very important in setting up wavelength standards in this region. An interesting use of the helium-neon laser has been made in this connection in that it has been possible to obtain an interferogram of the whole wavefront diffracted from the échelle in the order in which it will be used.'

To a question by Dr Kessler whether laser oscillations were decoupled in studying the profile of the krypton line Dr Cook replied that a scattering plate was put in for uniform illumination.

C. J. Humphreys: Interferometric Determinations of Wavelengths in Ar, Kr 86 and Xe 136 in the Region between 1·2 and 3·5 μ. (Condensed version of a report to the Triple Commission for Spectroscopy).

'Three relatively short programs of interferometric measurements have been carried out at the U.S. Naval Ordnance Laboratory, Corona, California, during the past 5 months by continued use of the scanning method first reported in 1955. Essentially all of the experimental work in the recent series of observations has been performed by Edward Paul, Jr. Six innovations peculiarly applicable to the present series of measurements are: use of source tubes filled with Xe 136; use of CaF_2 interferometer plates coated with germanium; significant increase in interference path by use of an étalon of 105 mm length; employment of coolable lead sulfide detectors of improved characteristics; use of an X-Y recorder giving improved contrast in the patterns; development and use of a computer program for complete reduction of the patterns.

The same germanium-coated interferometer plates separated by a silica étalon of 105 mm length were used for all reported measurements. Shorter étalons were used to sort out order

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

ambiguities and to provide the basis for the correction for dispersion of optical path. Wavelength intercomparisons were made in most instances with the argon line λ (air) = 16 940·584 Å. Reasons for the selection of a standard at this wavelength and the justification for the adopted value will be discussed in connection with the program of measurements on argon lines. The experiments were carried out with the interferometer in air in an air-conditioned environment with the temperature at 15°C. It was decided to make the observations in air rather than with the usually preferable technique of placing the interferometer in a vacuum, because the energy advantage associated with fewer windows made it possible to include more lines in the program.

Xenon 136. The results for xenon represent an incursion into a new wavelength domain. The number of atomic emission lines located beyond 2 microns in the infra-red, that are intense enough for interferometric intercomparisons of wavelength by methods already proved successful, is extremely small. Of these, only the xenon lines can be excited in an easily manageable source. Three years ago at the Berkeley meeting a slide was introduced demonstrating the feasibility of scanning interference patterns in the 3-micron region of Xe I. At that time it was also learned from Dr Engelhard that Xe 136 was available from his laboratory (PTB), either as lamps of design similar to the Kr 86 lamp or as source tubes filled for the user according to his specifications. The U.S. Naval Ordnance Laboratory has obtained lamps of the Engelhard design, as well as electrodeless tubes featuring an inblown window for end-on use, and a pendant bulb to provide a reservoir of source material. The reported measurements were obtained by use of sources of the latter type. While the large number and the relative abundances of the isotopes make natural xenon unsuitable as a source of standards, it is obvious that the large atomic mass, together with ease of use in sources of simple design, make an isotope of the element of even mass number an ideal source for production of wavelength standards.

The measurements here reported cover ten lines of Xe 136 between 20 262 Å and 35 050 Å. The wavelengths are shown in Table 9 together with standard deviations, probable errors, vacuum values, wave numbers, and classifications. The final evaluation of the $3d$ levels of Xe 136 will have to await the determination of the $1s$ and $2p$ levels from photographic interferometric measurements. Also scheduled for observation by infra-red scanning are the relatively intense $2p - 2s$ combinations of the first ion-limit family of Xe 136 which occur between 12 623 Å and 16 727 Å.

Table 9

Interferometric measurements in Xe 136 (Xe I) by Humphreys and Paul

λ air (Å)	No. obs.	St. dev. × 10⁻⁴Å	Prob. error × 10⁻⁴Å	λ vac (Å)	σ(cm⁻¹)	Combination
20 262·2395	7	18·2	4·6	20 267·7705	4933·9418	$2p_7 - 3d_2$
23 193·3328	7	24·2	6·2	23 199.6619	4310·4076	$2p_9 - 3d'_1$
24 824·7157	7	23·6	6·0	24 831·4891	4027·1447	$2p_8 - 3d'_1$
26 269·0832	7	27·8	7·1	26 276·2499	3805·7181	$2p_9 - 3d''_1$
26 510·8645	7	18·3	4·7	26 518·0971	3771·0096	$2p_5 - 3d_2$
30 475·4527	9	36·8	8·3	30 483·7652	3280·4347	$2s_5 - 3p_8$
31 069·2302	9	51·3	11·5	31 077·7045	3217·7409	$2p_6 - 3d'_1$
32 739·2788	10	61·9	13·2	32 748·2080	3053·6022	$2p_{10} - 3d_3$
33 666·6991	9	42·8	9·6	33 675·8812	2969·4843	$2p_7 - 3d''_1$
35 070·2520	9	50·2	11·3	35 079·8164	2850·6420	$2p_9 - 3d_4$

Krypton 86. Interferometric observation of Kr 86 has covered 19 lines comprising $2p - 2s$ and $2p - 3d$ combinations between 11 819 Å and 21 902 Å and the strongest $2s - 3p$ combination at 28 655 Å. This work was undertaken primarily to supplement existing measurements, particularly those submitted by Littlefield and Sharp and included in the Draft Report. Interferometric measurements of essentially the same group of lines in the spectrum of natural krypton were reported in 1961. The techniques now employed were essentially the same as for Xe 136 including use of 16 940 Å of Ar I as the standard. It would probably be preferable to use a line of Kr 86 as a standard, but at the time the work was undertaken no line within the interval

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

was regarded as having a wavelength determined with a sufficient degree of accuracy. Microwave-excited electrodeless discharge tubes similar in design to the Xe 136 tubes were employed. These tubes were fabricated at NOL-Corona and filled with Kr 86 obtained from Oak Ridge. The filling was controlled for optimum brightness but the pressure was not measured owing to the desirability of minimizing the volume of the system that included the valuable supply of Kr 86. Indications based on previous experience pointed to a pressure of between 1 and 3 mm. No cooling system was used but the temperature of the environment was maintained at 15°C.

The results of the Kr 86 determinations are compiled in Table 10 including conversions to wavelengths in vacuum, wave numbers, and listing of classifications. The values represent averages of three to nine runs, each comprising 16 patterns for both experimental line and standard. A comparison of the present results with those obtained in 1961 for natural krypton is

Table 10

Interferometric measurements in Kr 86 (Kr I) by Paul and Humphreys

λ air (Å)	λ vac (Å)	σ(cm^{-1})	Combination	$10^4\,\Delta\sigma$[a]
11 819·3759	11 822·6109	8458·3685	$2p_{10} - 2s_5$	+ 19
13 177·4119	13 181·0157	7586·6687	$2p_8 - 2s_4$	− 5
13 622·4156	13 626·1403	7338·8353	$2p_8 - 3d_2$	+ 5
13 634·2209	13 637·9489	7332·4809	$2p_9 - 2s_5$	− 1
13 738·8500	13 742·6063	7276·6401	$1s_2 - 2p_6$	+ 30
14 426·7935	14 430·7368	6929·6531	$2p_7 - 2s_4$	− 3
14 734·4360	14 738·4630	6784·9680	$2p_9 - 3d'_1$	+ 26
15 239·6159	15 243·7803	6560·0526	$2p_8 - 3d''_1$	+ 28
15 334·9587	15 339·1490	6519·2665	$2p_{10} - 3d_3$	+ 37
16 785·1275	16 789·7122	5956·0282	$2p_6 - 3d'_1$	+ 20
16 853·4885	16 858·0918	5931·8695	$2p_9 - 3d_4$	+ 35
16 890·4409	16 895·0543	5918·8919	$2p_8 - 3d_4$	+ 46
16 896·7530	16 901·3681	5916·6808	$2p_{10} - 3d_5$	+ 42
16 935·8057	16 940·4314	5903·0374	$2p_7 - 3d''_1$	+ 28
17 098·7696	17 103·4397	5846·7771	$2p_4 - 3s''''_1$	+ 33
17 367·6050	17 372·3482	5756·2742	$2p_2 - 3s'''_1$	+ 30
17 842·7376	17 847·6101	5602·9911	$2p_{10} - 3d_6$	
18 002·2291	18 007·1450	5553·3512	$2p_5 - 3d_2$	+ 4
18 167·3153	18 172·2762	5502·8880	$2p_9 - 3d'_4$	+ 37
21 902·5111	21 908·4887	4564·4408	$2p_6 - 3d_3$	+ 44
28 655·7172	28 663·5340	3488·7533	$2s_5 - 3p_9$	

[a] $\Delta\sigma = \sigma$ Kr 86 − σ Kr, natural

shown in the last column. The differences are similar to those in Table 3 of the report of the 1958 meeting where wave numbers of certain lines of Kr 86 and Kr 84 are compared. Since the mass number of the naturally occurring mixture is near to 84 the wavelengths of natural krypton should be close to those of Kr 84.

Argon. In the programs on Xe 136 and Kr 86 a line in the argon spectrum provided the reference wavelength. Obviously it would have been desirable to use the primary standard of Kr 86. This, however, is impractical for observations beyond about 1·3 microns, first because of the limited response of the coolable detectors for the visible line and, secondly, because if one uses orders of the infra-red lines high enough to attain satisfactory precision, the pattern of a visible line will be washed out in the record where the scanning slit is wide enough to admit a working level of energy. A discussion of various possibilities left λ 16 940 as the most satisfactory choice on the basis of position, intensity, sharpness, and agreement of determinations by different observers. Table 6 of the 1961 Draft Report listed three vacuum values for this line as follows:

16 945·210 Å Humphreys and Paul
16 945·213 Å Littlefield and Rowley
16 945·209 Å Peck

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

On the basis of this information 16 945·211 Å, which translates to a standard air value 16 940·584 Å, was adopted. Further support for this value was obtained by direct intercomparison, by using the 105 mm étalon, with the line 13 718·576 Å, on the basis of what appears to be the best adopted value for the vacuum wavelength 13 722·327 Å. For additional confirmation the combination principle was used. The following pair is related by a common d-level:

$$12\,439{\cdot}321\,\text{Å}\ 2p_{10} - 3d_3$$
$$16\,940{\cdot}584\,\text{Å}\ 2p_6 - 3d_3$$

The line at 12 439 Å was remeasured by using the 105 mm étalon, and the wavelength found to agree with the previously reported value to within a few ten-thousandths Å. Recalculation of 16 940 Å making use of accepted values of the $2p_6$ and $2p_{10}$ levels again led to the adopted value.

Intercomparison of wavelength values of infra-red lines of argon in the 1·0 to 1·7-micron region, submitted by different observers in 1961, showed the satisfactory agreement except for the lines at λ(air) 12 802, 13 313 and 13 622. New measurements have been made of these and a few other lines, by using the 105 mm étalon, by comparison with both λ 13 718 and λ 16 940. The results, which show no significant deviations from those contributed in 1961, are: λ(air) 12 802·7376, 13 313·2090, 13 622·6584.'

In the discussion Dr Herzberg remarked that 3 years ago many infra-red Ritz standards were reported, and asked whether they were in agreement with the new measures. Dr Humphreys replied that some adjustments in these calculated wavelengths are needed. The Chairman concluded from detailed information kindly given to him by Dr Humphreys that many of the wavelengths in Table 14 (Ne I) and 15 (Ar I) of *Trans. IAU*, **11B** were provisional and needed revision. The word 'standards' could actually be applied to only about half of the entries. Dr Humphreys said that he was revising these tables for a Report to the Triple Commission for Spectroscopy and invited the IAU Commission to extract from that Report what it needs. (This has now been done with the result given at the end of this Report.)

T. A. Littlefield: Current Wavelength Work in Newcastle.

'The author's interest in precision wavelength measurements in the infra-red dates from Dr Humphreys's lecture at the Rydberg Centennial Conference held 10 years ago at Lund. In Newcastle an essentially different method was developed by using a reflecting échelon and a slowly rotating mirror to sweep the fringe pattern across a fixed slit. Behind the slit a lead sulphide cell was placed and the output was displayed upon a pen-recorder. Details of this have already been given by Littlefield and Rowley (*Proc. R. Soc.*, **A276**, 502, 1963).

Measurement of the pen-recorder traces for argon was found to be laborious and time-consuming. Later when Sharp came to measure the Kr 86 lines a digitizer was incorporated in the pen-recorder so that deflections were recorded in digital form. A computer could then be used for measuring the fringe positions as well as for calculating the final wavelengths. Comparison of the wavelengths given in the Draft Report with those of Humphreys shows an average difference of 0·003 Å which is about what one might expect, and a systematic error of only 0·0004 Å. However, four lines at 15 339, 17 103, 17 847, and 18 172 Å show a much larger discrepancy. A similar discrepancy was found in argon for the lines at 12 806, 13 316 and 13 626 Å, and the balance of evidence is in favour of the values submitted by Humphreys and Paul, two of which are supported by Peck's measurements. In view of the close agreement for the majority of the lines reported, it seems possible that the discrepancies might be associated with some perturbation in the source. Different sources were used, one being a Geissler tube excited by direct current and the other an electrodeless discharge excited at microwave frequency. It is hoped to support the work of Humphreys on Xe 136 and at the same time it should be possible to remeasure the above lines which show discrepancies.

In the visible and near ultra-violet the work on thorium has been completed and is ready for publication. Measurements were limited to three spectrograms so that a large number of wavelengths could be covered in the time available. The fact that there is no appreciable systematic error between the three sets of values available is especially gratifying in view of the widely different optical, source and standard equipment employed.

The work on iron is almost ready for publication, and the discrepancy between the wavelengths reported from Newcastle in 1961 and the accepted IAU values has been noted in the current Report and requires explanation. In this work a constant deviation spectrograph was used for lines above 4000 Å and a Littrow quartz spectrograph for lines below 4000 Å. Three lines which were measured through both spectrographs gave values which differed by 0·001 Å. At the time there seemed good reason to believe that the lines below 4000 Å had a systematic error amounting to 0·001 Å and a correction for this amount was applied. Further investigation suggests that this was a mistake and that the original raw values should be preferred. We now believe that the error arises from the telephoto objective used in the camera on the constant deviation spectrograph. If this is so the systematic error between our iron wavelengths and the IAU values would disappear.

In 1961 it was mentioned that an attempt was being made to measure germanium lines directly in the vacuum ultra-violet since it seemed likely that the precision of the earlier work by MacAdam in 1936 had been limited by the source he employed. We failed to record fringes, and this is attributed to the fact that we were unable to have the optics suitably coated in the time available. The project has been abandoned for the present.'

The Chairman thanked the speakers, and the meeting adjourned.

Comments on infra-red Ritz standards in argon and neon

From the three sets of measurements of infra-red argon lines, quoted in *Trans. IAU*, **11A,** Table 6 (see also references **101a** and **140** in *Trans. IAU*, **12A**), supplemented by new measurements made at NOL-Corona, Humphreys has derived the three decimal values of the $2s$ and $3d$ levels shown in Table 11. By combining these values with the previously adopted

Table 11

Ar I levels, replacing those provisionally adopted in 1958 (*Trans. IAU*, 10, p. 229)

	cm^{-1}		cm^{-1}		cm^{-1}		cm^{-1}
$2s_5$	20 324·713	$3d_6$	18 524·006	$3d_4$	19 876·595	$3s_1''''$	21 497·232
$2s_4$	20 499·500	$3d_5$	18 674·268	$3d_1''$	20 282·204	$3s_1''$	21 661·375
$2s_3$	21 717·875	$3d_3$	18 995·164	$3d_1'$	20 572·795	$3s_1'''$	21 678·179
$2s_2$	21 831·259	$3d_4'$	19 606·393	$3d_2$	21 003·972	$3s_1'$	22 223·106

four-decimal values of the $2p$ levels one obtains the calculated wavelengths for $2p - 2s$ and $2p - 3d$ given in Table 12. Similarly, the $2s - 3p$ and $3d - 3p$ transitions can be calculated (Table 13). The average wavelength accuracy of this latter group is, however, much less than that of the former group because of the unfavourable effect of the relation $\Delta\lambda \sim \lambda^2 \Delta\sigma$.

Four-decimal values of the $2s$ levels in neon were given by Humphreys, Paul and Adams in 1961 (ref. **77** in *Trans. IAU*, **12A**). As the values have not yet been quoted in reports of this Commission we include them here in Table 14. The calculated wavelengths of the $2p - 2s$ transitions are shown in Table 15, and those of $2s - 3p$ in Table 16 to which applies the same remark concerning the accuracy as in the corresponding case of argon.

The transition array of $2p - 2s$ of neon given by Humphreys, Paul and Adams indicates a possible error in the adopted value for $2p_9$. From the observed wavenumber of $2p_9 - 2s_5$ and a level value of $2s_5$ determined from combinations with $2p_6$, $2p_8$ and $2p_{10}$ one obtains $2p_9$ = 15 615·1998 cm^{-1} as compared to 15 615·2021 adopted in 1955. The latter value was based on one line only, λ(air) = 6402·2460 Å. The wavelength calculated on the basis of the infra-red data would be 6402·2470 Å, and the difference could be due to an error in the measurement of this line which is difficult to measure because it is very liable to self-reversal. It is possible, therefore, tha

https://doi.org/10.1017/S0251107X00018897 Published online by Cambridge University Press

Table 12

Ar I wavelengths, in standard air, of transitions $2p - 3d$ and $2p - 2s$, calculated by means of the $2p$ levels from *Trans. IAU*, 9, p. 209, and the $3d$ and $2s$ levels as revised 1964 (see Table 11)

Å	Å	Å	Å	Å
8 874·800	11 467·545	12 933·196	13 992·808	16 860·088
9 194·638	11 645·867	12 956·658	14 093·640	16 940·584
9 291·532	11 668·709	13 008·264	14 249·193	17 444·903
9 340·581	11 687·604	13 028·425	14 577·458	17 445·248
9 486·060	11 719·487	13 213·991	14 739·139	17 914·629
9 951·846	11 896·632	13 228·104	14 974·568	17 914·726
10 254·025	12 026·648	13 230·897	15 030·513	18 427·765
10 478·034	12 112·324	13 272·635	15 046·503	19 965·730
10 673·566	12 139·737	13 302·312	15 172·691	20 317·011
10 681·771	12 343·392	13 313·209	15 329·345	20 616·229
10 683·404	12 377·194	13 367·110	15 353·128	20 986·111
10 700·984	12 402·828	13 367·827	15 555·460	21 332·885
10 722·229	12 439·321	13 499·406	15 734·909	21 534·207
10 773·368	12 456·114	13 504·190	15 776·614	22 039·561
10 861·077	12 487·663	13 544·205	15 883·163	22 077·181
10 880·941	12 554·324	13 573·618	15 989·491	23 133·204
10 892·361	12 621·619	13 599·333	16 122·656	23 966·518
10 950·726	12 638·480	13 622·659	16 180·023	32 297·104
11 078·868	12 702·280	13 678·549	16 264·070	
11 248·350	12 733·418	13 718·577*	16 292·110	
11 393·703	12 746·232	13 825·717	16 519·867	
11 441·832	12 802·737	13 907·476	16 740·078	

* The observed value 13 718.576, should be preferred since the upper level, $3d_4'$, depends on this line alone. The difference is due to the rounding-off error in the level value of $3d_4'$.

Table 13

Ar I wavelengths, in standard air, of transitions $3d-3p$ and $2s-3d$, calculated by means of the $3p$ levels from *Trans. IAU*, 9, p. 209, and the $3d$ and $2s$ levels as revised 1964

Å	Å	Å	Å	Å
14 174·712	20 030·097	26 180·428	29 126·092	43 433·131
14 719·546	20 068·932	26 543·041	29 272·677	43 662·102
14 833·480	20 241·663	26 605·288	29 788·667	45 265·801
15 031·174	20 568·816	26 835·705	30 453·764	45 523·076
15 052·568	20 647·135	26 909·711	30 912·746	45 562·462
15 171·737	20 716·338	27 145·454	30 987·774	45 914·091
15 793·157	20 756·999	27 285·760	31 324·485	45 936·865
15 816·777	20 811·042	27 356·342	32 226·556	46 768·265
15 948·407	20 984·286	27 411·479	32 325·060	47 138·827
17 401·908	21 035·834	27 752·508	32 879·664	49 386·158
18 231·349	21 166·377	27 785·928	32 930·634	49 515·934
18 348·006	22 112·626	27 977·219	33 139·400	53 897·78
18 632·289	23 134·770	28 194·726	33 284·366	55 029·13
18 745·005	23 185·491	28 238·250	35 058·546	55 591·11
19 123·807	23 469·437	28 314·045	38 630·293	56 024·07
19 294·916	23 845·035	28 427·265	39 319·127	59 331·91
19 817·508	24 013·230	28 497·958	39 793·924	61 240·55
19 823·714	25 125·271	28 530·615	39 824·470	77 310·82
19 860·943	25 487·646	28 612·427	42 032·637	
19 945·068	25 505·228	28 690·049	42 331·714	
19 992·232	25 661·022	28 775·083	42 391·257	
20 025·672	26 115·776	28 835·223	42 610·649	

$2p_9$ in neon should be revised. This would call for some changes in the calculated wavelengths of the $2p - 3d$ group (*Trans. IAU*, **10**, Table 6), especially of the λλ(air) 7833, 7839, 7840, 8300, 8302, 8366 and 8376. Slight adjustments of one or two of the $3d$ levels would also be required. An independent check on the wavelength of the line at 6402 Å would be very desirable.

Table 14

The $2s$-levels of Ne I according to Humphreys, Paul and Adams (Navweps Report 7190 (1961))

	cm⁻¹		cm⁻¹
$2s_5$	24 559·2752	$2s_3$	25 338·1535
$2s_4$	24 754·1524	$2s_2$	25 492·7796

Table 15

Calculated wavelengths, in standard air, of the $2p-2s$ transitions in Ne I, replacing the corresponding values in *Trans. IAU*, 10, p. 229

Å	Å	Å	Å	Å
8 865·3063	10 798·043	11 522·746	11 789·889	12 769·525
8 988·5564	10 844·477	11 525·019	11 984·912	12 887·159
9 486·6819	11 143·020	11 601·537	12 066·334	12 912·014
9 665·4198	11 177·528*	11 614·081	12 459·389	13 219·241
10 295·417	11 390·434	11 766·792	12 595·004	15 230·714
10 620·665	11 409·134	11 789·044	12 689·201	17 161·930

*The observed value, 11 177·525 Å, is to be preferred for this $2p_9$ combination in view of the uncertainty in $2p_9$.

Table 16

Calculated wavelengths, in standard air, of the $2s - 3p$ transitions in Ne I

Å	Å	Å	Å	Å
18 210·330	20 565·121	23 260·302	23 956·459	27 520·777
19 573·769	21 041·295	23 372·999	24 249·639	28 533.216
19 577·136	21 708·145	23 565·362	24 365·048	28 744·305
19 772·488	22 530·404	23 636·515	25 524·366	29 714·054
20 350·238	22 661·813	23 709·160	25 854·914	31 859·980
20 353·877	23 100·514	23 951·417	26 860·820	33 511·327

COMMITTEE ON TRANSITION PROBABILITIES

Report of Meeting, 28 August 1964

CHAIRMAN: M. Minnaert.

SECRETARY: J. G. Phillips.

C. W. Allen reported on the use of 'confined arcs for the determination of f-values'. In order to reach high temperatures, the arc was enclosed within a rapidly spinning hollow cylinder. In the case of Mn, for example, this cylinder was made of compressed MnO_2 powder. A high-intensity flash was observed through the hollow pole pieces and the arc vapour; the absorption spectrum was photographed.

Several members present emphasized the difficulty of getting sources in which thermal equilibrium is reliably established for lines of high excitation. *Warner* reported his experiences with the gliding spark. *Van Bueren* suggested inductive heating of the arc, as it is done at Eindhoven: this increases the temperature of the outer layers of the arc and improves the temperature homogeneity.

R. Tousey, speaking on 'the need for f-Values in the far solar UV' projected a number of beautiful rocket spectra and reported that only about half of their spectral lines have been identified. The uncertainties about the calibration and the continuous background make the spectrophotometry and the quantitative analysis very difficult. The identifications in the region 30–340Å are especially uncertain. The f-values can be roughly calculated, but laboratory data are still insufficient. Many of the lines are present in the Zeta discharge; however, the elements and the ions are unknown. A plot of the elements observed shows gaps in the fluorine and neon sequences.

From the reactions of the audience it became clear that very few laboratories at the moment are measuring f-values in the far UV: München, Ohio State, Meudon (within a short time), National Physical Laboratory. Because of quantum-mechanical considerations it does not seem possible to establish isoelectronic sequences of f-values.

The paper of *J. G. Phillips* was concerned with the study of molecules on 'the Berkeley Program'. The Red System of CN, the Swan System of C_2 and the TiO bands have been analysed. Relative f-values have been published for the Swan bands and for TiO; for ZrO they are being studied by E. J. Eastmond. A measurement of lifetimes and absolute f-values for some bands will be started.

Finally *R. Wilson* discussed the 'spectra of high temperature plasmas of astrophysical interest'. In the far UV Zeta discharge many lines are found which also appear in the region 170–210Å of the solar spectrum; these are probably iron lines of high-ionization spectra, from the walls. This was checked by studying the thetatron discharge, to which traces of iron could be added : the same lines appeared but the intensities were abnormal.