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

PRÉSIDENT: M. B. Edlén.

MEMBRES: Mlle M. G. Adam, MM. Allen, H. D. Babcock, Barrell, Bates, Biermann, Bowen, Burns, Engelhard, Goldberg, Harrison, Kiess, A. S. King, R. B. King, Layzer, McMath, Meggers, Menzel, Migeotte, Minnaert, Mohler, Shajn †, Shortley, Mme Moore Sitterly, M. J. A. Smit.

14*a*. SOUS-COMMISSION DES TABLES D'INTENSITÉS

PRÉSIDENT: M. G. J. Minnaert.

MEMBRES: MM. Allen, Bates, Bowen, Goldberg, R. B. King, Layzer, Menzel, Shortley, J. A. Smit.

THE PRIMARY STANDARD

The International Committee on Weights and Measures appointed in 1952 an Advisory Committee on Redefining the Metre. At its first meeting, in 1953, the Advisory Committee formulated its recommendations in six propositions (*P.V. Com. int. Poids Mes.* 2e ser. **24**) of which the following are of immediate interest to this commission:

Proposition II. Le Comité consultatif considère que le mètre devrait être défini, lorsque le moment sera venu, par la longueur d'onde d'une radiation lumineuse se propageant dans le vide, le radiateur et l'observateur étant en repos relatif. Cette radiation serait spécifiée par deux termes spectraux d'un atome dont le spectre soit dépourvu de structure hyperfine, et qui ne soit soumis à aucune influence perturbatrice.

Proposition III. En vue d'assurer à l'unité de longueur une continuité aussi parfaite que possible lors du passage à la définition envisagée, il est recommandé d'établir cette dernière en se servant comme intermédiaire de la valeur $0{,}643\,846\,96 . 10^{-6}$ m. pour la longueur d'onde de la radiation rouge du cadmium, telle qu'elle a été spécifiée par la Septième Conférence Générale des Poids et Mesures. Pour ce passage, la réduction au vide des longueurs d'onde mesurées dans l'air devrait être effectuée par la formule de dispersion pour l'air normal adoptée à Rome en 1952 par la Commission Mixte de Spectroscopie.

Proposition IV. Pour ce qui concerne le choix de la radiation étalon qui présente les qualités métrologiques les meilleures (finesse, symétrie et autres), le Comité consultatif ne croit pas encore être suffisamment documenté pour émettre une proposition ferme. Il demande que les grands Laboratoires et le Bureau international poursuivent aussi activement que possible leurs travaux dans ce sens.

These recommendations were accepted by the International Committee in 1954 and communicated to the Tenth General Conference on Weights and Measures, which urged that the work required for arriving at a definite proposal should be vigorously pursued in order to enable the Eleventh General Conference, in 1960, to take final action. Thus, the question at issue has taken a step forward in so far as certain principles have been laid down which may serve as a guide and incitement in the further research that will be necessary. As regards these principles it seems appropriate to add some comments in this report.

The suggested new definition of the primary standard differs from the present one principally by replacing (*a*) the specified standard air by vacuum and (*b*) a specified light-source by an atom, radiating under conditions of perfect freedom of perturbing influences. By these changes it is intended to remove the arbitrariness and the main sources of uncertainty inherent in the present definition. The specification of a light source will have to reappear, of course, in the form of recommendations as to how the adopted wave-length value is to be realized, the advantage being, essentially, that improvements in the technique of producing the primary standard can be readily adopted without the complicated procedure of changing its definition. The recommendations would, presumably, take the form of numerical values for the corrections to be applied to the wave-length actually produced by certain light-sources under specified conditions.

The procedure outlined in proposition III will serve the purpose of conserving the numerical spectroscopic data at present accumulated. This, of course, is of paramount practical importance to spectroscopy. When the transition to the new primary standard has once been performed, the special significance of the wave-length value for the red cadmium line, as well as the international angstrom unit, will disappear. At the same time, it should be noted, the present wave-length values as defined in air will by virtue of proposition III remain essentially unchanged as long as the adopted dispersion formula remains valid. If future experiments should suggest a correction to that formula, and this correction—as is most likely—would be expressible as a constant factor, one could contemplate the possibility of redefining standard air in terms of the dispersion formula as a way of permanently conserving the air wave-lengths.

The choice of the line to be ultimately adopted as the new primary standard was left open by the Advisory Committee, and the problem was urgently recommended for further study. The requirement of a symmetrical line profile free of any fine structure precludes the use of anything but pure isotopes of even atomic number and even mass number. The condition that the line width, or rather $\Delta\lambda/\lambda$, shall be as small as possible, requires in the first place that Doppler broadening can be reduced by (*a*) high atomic mass, or (*b*) low temperature, or (*c*) collimation (atomic beam). If the Doppler width can be made sufficiently small, then the width depending on resonance and transition probability may come into play, in which case a compromise with intensity will have to be made. Finally, it is of importance that the wave-length should be as stable as possible against external influences (pressure, electric fields, etc.) in order that its practical reproduction should not necessitate too rigorous specifications.

For the time being it is recommended that the I.A.U. endorse the above propositions of the Advisory Committee.

THE DISPERSION OF STANDARD AIR

A critical analysis by Edlén (1) of the problem of the dispersion of air led to the proposal of the following formula for the refractivity of standard air:

$$(n-1)\ 10^7 = 643{\cdot}28 + \frac{294\ 981}{146-\sigma^2} + \frac{2554{\cdot}0}{41-\sigma^2},$$

where σ is the wave-number in vacuum expressed in reciprocal μ. A detailed discussion of its derivation and of the estimated accuracy is to be found in the reference cited. Tables of the vacuum correction, $\lambda_{\text{vac.}} - \lambda_{\text{air}}$, corresponding to this formula, are obtainable from the Physics Department, University of Lund, Lund (Sweden).

The formula was recommended for converting wave-lengths in standard air to wave-lengths in vacuum by the Joint Commission for Spectroscopy in 1952 and by the Advisory Committee on Redefining the Metre in 1953 (see preceding section). It is recommended that the I.A.U. adopt the same formula.

All conversions from air to vacuum or vice versa that appear in this report conform to the above formula.

SECONDARY STANDARDS

The iron arc in air

Dr Meggers, the former President of this Commission, prepared and communicated for the present report a monumental compilation of data on the spectrum of the iron arc, including a wealth of as yet unpublished measurements. The new observations concern the regions above 6000 Å and below 3000 Å and provide the means to extend the existing system of iron standards very considerably.

The new observations in the long-wave region were made by Hayes (2), who measured 150 lines from 6065 to 8999 Å. At present there are sixteen standards available in this region, the longest wave-length being 6677 Å. Hayes's values may now be combined with the values of Burns (partly listed in the 1948 report of this Commission), Meggers (3), and Meggers and Kiess (4) to form new standards extending to 9000 Å.

The short-wave region has been covered by Healy (5) with measurements on 256 lines from 3000 to 2562 Å, including twenty-five previously adopted standards. Many of these lines were observed by Meggers and Humphreys (6), and practically all of them were measured in the vacuum arc by Burns and Walters (7). After applying the proper correction to the vacuum arc values (cf. 1938 report of this commission) it is possible to form means of three observations for a considerable number of lines, and many additional means of two observations.

Finally, the region below 2562 down to 2359 has been covered in a set of measurements by F. J. Sullivan (1953, unpublished) comprising 101 lines. Again, by combining these with the observations by Meggers and Humphreys, Burns and Walters, and Jackson (8) many new standards become available for this region where only one (2447·708 Å) was previously adopted.

After the additions described above, the work on the establishment of standard wave-lengths in the iron arc in air—initiated half a century ago by the International Union for Co-operation in Solar Research—may be considered as essentially completed. This ultimate success is due to the skill and perseverance of many contributors. It is appropriate to recall at this occasion some of the names: Heinrich Kayser was the first to suggest the iron arc for this purpose and as chairman of the Wave-length Committee in the Solar Union guided the project during its first decade; Fabry, Buisson and Perot created the interference technique that ever since has been the experimental basis of the work; H. D. Babcock especially contributed to clarifying the problem of wave-length variability; Keivin Burns has been very actively engaged in the project almost from its beginning and up to the present time; finally, W. F. Meggers—besides having provided, with co-workers at the Bureau of Standards, a large part of the measurements entering in the system—carried the burden of bringing the project to a successful conclusion during his long tenure of the presidency of this commission.

In order to make the best use of the great work that has been put into the measurements of the iron spectrum, one should obviously investigate the possibilities offered by the combination principle for checking the accuracy and smoothing accidental errors. These possibilities have been evident ever since regularities were first discovered. They were discussed by Meggers (9) and extensively used by Burns and Walters in their investigations of the vacuum arc. The combination principle is now being systematically applied to the accumulated data. From the observed wave-lengths are derived by a least square solution the best values for the levels involved and wave-lengths recalculated from these level values. By this procedure not only will accidental errors in the original wave-lengths be considerably reduced, but it will also be possible to calculate wave-lengths for a great number of additional lines to a precision equivalent to that of the adopted standards.

The result will be given in a comprehensive list, now being prepared, covering the entire spectral range of useful Fe I lines and including the basic observational data. As the list will exceed the space available in this draft report it will be communicated to members of the commission in typescript copies.

The iron hollow cathode

While it will be admitted that the iron arc in air was very probably the best choice for establishing wave-length standards that could be made at the time when the project was launched, and will no doubt continue to be very useful, its shortcomings have been gradually and sometimes painfully revealed as is witnessed in the records of this commission. The considerable width of the lines sets a definite limit to the attainable precision at about one part in five million, and instability of wave-length demands rigorous specifications of the arc and prevents the use of numerous lines, leaving inconvenient gaps in certain wave-length regions. Arguments for replacing the arc-in-air by a low-pressure source were forwarded at several occasions. However, in retrospect it appears fortunate that the vacuum arc was not adopted in view of the fact shown by recent experiments that a far superior source for the iron spectrum is now available in the hollow cathode.

Very interesting results which are in course of publication have been reported by R. W. Stanley and G. H. Dieke, and by J. Blackie and T. A. Littlefield. Dr Dieke writes:

> We have developed a simple sealed-off hollow cathode tube with iron electrodes and neon at 2–3 mm. It is operated at about 150 mÅ current. We believe this to be the best source for standard wave-lengths for all cases where the iron arc was used formerly. The lines are very sharp and there is every indication that the wave-lengths are constant for all operating conditions. The exposure times are somewhat longer than for the iron arc, but as the tube burns completely without attention, this is no serious drawback.
>
> We have made interferometric wave-lengths for 189 lines. The consistency between several sets of measurements is good, so that we had reason to believe that the wave-lengths should be accurate to within about 0·0005 Å. We find, however, discrepancies with the measurements of Williams and Middleton to 0·003 Å. This should be further investigated.

The tube used by Blackie and Littlefield is cooled with liquid air, as it was found that circulation of the carrier gas is then no longer necessary, and the spectra are easily excited by a current of about 100 mÅ. Littlefield reports the following wave-lengths (reduced to standard air) for twenty-seven iron lines measured with a reflecting echelon in vacuum:

2851·7973
2832·4357
2825·5559
2823·2763
2813·2867
2806·9845
2804·5207
2778·2205
2742·4060
2737·3099
2733·5810
2723·5776
2711·6555
2706·5829
2689·2131
2679·0622
2666·3982
2635·8096
2606·8270
2599·3966
2584·5364
2576·6907
2549·6140
2545·9789
2540·9719
2501·1326
2457·5975

Adopted standard values exist for eleven of these lines, and there is a satisfactory agreement, confirming that the pressure effect is quite small.

The suitability of the iron hollow cathode as a source of standard wave-lengths is placed beyond doubt by these experiments. It is strongly recommended that further measurements be made with this light-source with a view to establishing iron secondary standards of a superior quality.

Neon standards

The last report of this commission contained an extensive list of neon wave-lengths from 8919 to 3369 Å, compiled from publications by Burns, Adams and Longwell (10), Humphreys (11), and Meggers and Humphreys (12). No recommendations were made.

New measurements of twenty-one neon lines with wave-lengths from 3755 to 3376 Å have now been communicated by Blackie and Littlefield (13). They were made with a reflecting echelon in vacuum with reference to a vacuum value 6440·2491 for the red cadmium line emitted from an Osira cadmium lamp. The neon light-source was a Geissler tube, previously described (14), cooled in liquid air, neon being continuously circulated at a pressure of 0·5 mm. Hg.

The new data give reason to investigate the prospects for an extension of the list of neon standards adopted in 1935. The discussion will be confined to the groups of lines arising from the transitions 1*s*–2*p* and 1*s*–3*p* in the Paschen notation. The complete data are assembled in Tables 1 and 2. The figure in brackets following the decimal parts of a wave-length denotes the number of observations.

Table 1. *Neon, group* 1*s*–2*p*

Combination	Calculated wave-length in air	Burns, Adams and Longwell (1950)	Meggers and Humphreys (1934) 'Cd'	Meggers and Humphreys (1934) 'Ne'	Jackson (1933)	Burns, Meggers and Merrill (1918)
$1s_2$–$2p_{10}$	8082·4581	4576 (19)	4585 (2)	4580 (6)	—	—
$1s_3$–$2p_{10}$	7438·8984	8981 (57)	8988 (6)	8990 (11)	—	—
$1s_4$–$2p_{10}$	7245·1666	1665 (58)	1668 (6)	1668 (13)	—	—
$1s_2$–$2p_8$	7173·9381	9380 (54)	9390 (5)	9389 (10)	—	—
$1s_5$–$2p_{10}$	7032·4131	4128 (57)[a]	4125 (5)	4134 (12)	—	4130
$1s_2$–$2p_7$	7024·0504	0500 (44)	—	0508 (6)	—	—
$1s_2$–$2p_6$	6929·4673	4672 (54)	4679 (6)	—	—	4678
$1s_2$–$2p_5$	6717·0430	0428[b]	0430 (8)	—	0427 (2)	0427
$1s_2$–$2p_4$	6678·2762	2764[b]	2766 (8)	—	2766 (11)	2760
$1s_2$–$2p_3$	6652·0927	0925 (5)	—	—	—	—
$1s_2$–$2p_2$	6598·9529	9529[b]	9528 (8)	—	9530 (23)	9528
$1s_3$–$2p_7$	6532·8822	8824[b]	8824 (8)	—	8824 (23)	8826
$1s_4$–$2p_8$	6506·5281	5279[b]	5277 (7)	—	5280 (28)	5278
$1s_5$–$2p_9$	6402·2460	2460[c]	248 (4)	247 (4)	2461 (28)	2455
$1s_4$–$2p_7$	6382·9917	9914[b]	9914 (7)	—	9915 (28)	9913
$1s_5$–$2p_8$	6334·4278	4279[b]	4276 (8)	—	4280 (28)	4280
$1s_4$–$2p_6$	6304·7890	7892[b]	7893 (8)	—	7893 (23)	7890
$1s_3$–$2p_5$	6266·4950	4950[b]	4952 (8)	—	4949 (28)	4950
$1s_5$–$2p_7$	6217·2812	2813[b]	2812 (8)	—	2814 (28)	2811
$1s_3$–$2p_2$	6163·5939	5939[b]	5937 (8)	—	5941 (28)	5937
$1s_5$–$2p_6$	6143·0626	0623[b]	0627 (7)	—	0620 (28)	0624
$1s_4$–$2p_5$	6128·4499	4498 (18)	4502 (2)	4513 (6)	—	—
$1s_4$–$2p_4$	6096·1631	1630[b]	1630 (8)	—	1630 (28)	1630
$1s_4$–$2p_3$	6074·3377	3377[b]	3376 (8)	—	3377 (28)	3377
$1s_4$–$2p_2$	6029·9969	9971[b]	9968 (8)	—	9973 (21)	9970
$1s_5$–$2p_5$	5975·5340	5340[b]	5343 (8)	—	5340 (21)	5339
$1s_5$–$2p_4$	5944·8342	8342[b]	8340 (8)	—	8343 (28)	8343
$1s_5$–$2p_2$	5881·8952	8950[b]	8950 (8)	—	8948 (28)	8954
$1s_2$–$2p_1$	5852·4878	4878[b]	4878 (8)	—	4876 (28)	4880
$1s_4$–$2p_1$	5400·5617	5616 (46)	5620 (3)	5619 (2)	—	5620

[a] A value of 7032·4127 was adopted as standard in 1935. It was based on two measurements only.

[b] Standard values adopted in 1935.

[c] The value 6402·2460 is listed by Burns, Adams and Longwell as being a secondary standard. Actually, it was not included in the 1935 list of standards.

As shown by Table 2 the three sets of measurements of the group 1*s*–3*p* are in good mutual agreement as regards relative values. Blackie and Littlefield and Humphreys agree well also as regards absolute values, while Burns, Adams and Longwell are systematically lower by 0·0007–0·0008 Å. The sign and magnitude of the difference suggest an effect of isotopic structure.

In deriving the best mean values a significant smoothing of accidental errors is likely to be obtained by utilizing the relationships that exist between wave-lengths of different lines by virtue of the combination principle. From a set of weighted wave-lengths, derived from existing observations and including both 1*s*–2*p* and 1*s*–3*p* transitions, the levels involved have been computed by a least square solution and wave-lengths recalculated from these level values. The 1935 standards, except λ7032, entered unchanged in the calculation, and wave-numbers of the long-wave group were weighted on the average twice as high as those of the short-wave group. The wave-lengths finally obtained are given in the second column of Tables 1 and 2, respectively, and the levels are collected in Table 3.

The differences between calculated and adopted values for the 1935 standards (see Table 1) are of some interest. Though generally small, they reach in two cases 0·0003 Å.

Table 2. *Neon, group 1s–3p*

Combination	Calculated wave-length in air	Blackie and Littlefield (1955)	Burns, Adams and Longwell (1950)	Humphreys (1938)
$1s_2$–$3p_{10}$	3754·2156	2158 (12)	2148 (13)	2160 (22)
$1s_2$–$3p_8$	3701·2250	2251 (13)	2247 (23)	2250 (36)
$1s_2$–$3p_7$	3685·7357	7360 (13)	7351 (23)	7359 (36)
$1s_2$–$3p_6$	3682·2426	2426 (13)	2421 (20)	2428 (32)
$1s_2$–$3p_3$	3633·6646	6648 (13)	6643 (23)	6646 (38)
$1s_3$–$3p_{10}$	3609·1790	1793 (10)	1787 (9)	1793 (19)
$1s_2$–$3p_5$	3600·1691	1692 (13)	1694 (26)	1693 (38)
$1s_2$–$3p_2$	3593·6396	—	—	6398 (32)
$1s_2$–$3p_4$	3593·5262	—	5263 (21)	5259 (32)
$1s_4$–$3p_{10}$	3562·9541	—	9551 (6)	—
$1s_3$–$3p_7$	3545·8432	—	—	—
$1s_2$–$3p_1$	3520·4717	4719 (13)	4714 (37)	4717 (40)
$1s_4$–$3p_8$	3515·1907	1910 (13)	1900 (31)	1908 (38)
$1s_5$–$3p_{10}$	3510·7212	7216 (13)	7207 (24)	7214 (33)
$1s_4$–$3p_7$	3501·2163	2169 (13)	2154 (29)	2165 (39)
$1s_4$–$3p_6$	3498·0640	0646 (13)	0632 (28)	0644 (39)
$1s_5$–$3p_9$	3472·5711	5715 (13)	5706 (34)	5711 (40)
$1s_3$–$3p_5$	3466.5787	5787 (13)	5781 (28)	5786 (40)
$1s_5$–$3p_8$	3464·3387	3393 (13)	3385 (28)	3389 (38)
$1s_3$–$3p_2$	3460·5243	5248 (13)	5235 (31)	5245 (38)
$1s_4$–$3p_3$	3454·1949	1953 (13)	1942 (35)	1952 (40)
$1s_5$–$3p_7$	3450·7650	7657 (13)	7641 (30)	7653 (37)
$1s_5$–$3p_6$	3447·7028	7033 (13)	7022 (38)	7029 (40)
$1s_4$–$3p_5$	3423·9126	9128 (11)	9120 (17)	9127 (24)
$1s_4$–$3p_2$	3418·0062	—	—	0066 (25)
$1s_4$–$3p_4$	3417·9035	—	9031 (31)	9036 (40)
$1s_5$–$3p_5$	3375·6490	6494 (6)	6489 (10)	6498 (6)
$1s_5$–$3p_2$	3369·9078	—	9069 (25)	9081 (38)
$1s_5$–$3p_4$	3369·8080	—	8076 (1)	8086 (24)
$1s_4$–$3p_1$	3351·7492	—	—	—

Mean diff. obs. − calc.: +0003; −0005; +0002.

Table 3. *Relative values of the neon levels*

$1s_5$	0·0000	$2p_{10}$	14 215·9498	$3p_{10}$	28 476·0316
$1s_4$	417·4471	$2p_9$	15 615·2021[a]	$3p_9$	28 788·8632[a]
$1s_3$	776·8005	$2p_8$	15 782·3815	$3p_8$	28 857·2727
$1s_2$	1 846·8773	$2p_7$	16 079·7522	$3p_7$	28 970·7809
		$2p_6$	16 274·0212	$3p_6$	28 996·5111
		$2p_5$	16 730·2718	$3p_5$	29 615·4275
		$2p_4$	16 816·6679	$3p_4$	29 666·7589
		$2p_3$	16 875·5907[a]	$3p_3$	29 359·4614
		$2p_2$	16 996·6124	$3p_2$	29 665·8806
		$2p_1$	18 928·8928	$3p_1$	30 244·0420[a]

[a] Derived from one combination only.

Some correlation with the relative intensities of the lines is indicated. This is borne out more directly by the data displayed in Table 4, where the second column gives the wave-number corresponding to the adopted wave-length value, and the third column shows the interval $1s_4$–$1s_5$ obtained from five different pairs of lines, the deviation from the mean being shown in column 4. Column 5 contains the intensity estimate given by Burns, Meggers and Merrill (15), apparently on some logarithmic scale. A correlation between the size of the interval and the intensity ratio of the corresponding two lines is clearly revealed. The effect is indicated for other intervals as well, and on examining the three sets of observations which were averaged to form the 1935 standards it is found to be most pronounced in Jackson's (16) values.

Table 4. *The interval* $1s_4$–$1s_5$ *as appearing in the neon standards of* 1935

Combination	σ	$1s_4$–$1s_5$	Deviation from the mean	Intensity	ΔI
$1s_5$–$2p_2$	16 996·6130	417·4483	+0·0010	6	+2
$1s_4$–$2p_2$	16 579·1647			4	
$1s_5$–$2p_4$	16 816·6679	417·4468	−0·0005	8	0
$1s_4$–$2p_4$	16 399·2211			8	
$1s_5$–$2p_6$	16 274·0221	417·4486	+0·0013	9	+5
$1s_4$–$2p_6$	15 856·5735			4	
$1s_5$–$2p_7$	16 079·7520	417·4463	−0·0010	4	−4
$1s_4$–$2p_7$	15 662·3057			8	
$1s_5$–$2p_8$	15 782·3813	417·4464	−0·0009	8	−1
$1s_4$–$2p_8$	15 364·9349			9	

Mean: 417·4473

This intensity equation, which was also noticed by Burns (17), would imply that the measured wave-length of a strong line is too small or that of a faint line too large. This could be an effect of the isotopic structure of the neon lines. The main line, which is due to Ne20, is accompanied by a Ne22 satellite at an average distance of 0·055 cm.$^{-1}$ to the short-wave side, the intensity ratio being equal to the abundance ratio which is 10:1 for natural neon, and it would seem plausible that the influence of the satellite on the measured wave-length of the unresolved structure should increase with increasing density of the photographic image. Should this view be confirmed, it would raise some doubts as to the exact reproducibility of the neon wave-lengths even with the restrictions already imposed on their use (18).

While no difficulties seem to have been encountered in actual use of the neon standards the situation is not entirely satisfactory. To remove all objections it would be necessary to eliminate the Ne22 satellite either by using pure Ne20 or by arranging the experimental conditions so as to resolve the components. This would require, in addition to sufficient instrumental resolving power, that the discharge be cooled in liquid air.

The measurements by Blackie and Littlefield refer definitely to Ne20, over-exposed photographs showing the Ne22 satellite clearly resolved from the main line at an average distance of about 0·085 cm.$^{-1}$ in agreement with Ritschl and Schober (19). The systematic differences in the measurements in Table 2, if regarded as entirely an effect of isotopic structure, would imply that Humphreys actually measured only the main line while Burns, Adams and Longwell—with essentially the same experimental arrangements—measured the centre of gravity. The conclusion would be that there is an uncontrollable variability in measurements on the unresolved isotopic structure with a range of at least ±0·0004 Å for the short-wave (1*s*–3*p*) group of neon lines.

The wave-lengths in column 2 of Table 2 may, accordingly, be recommended as working standards for purposes where the precision requirements permit a tolerance of ±0·0004. To obtain the most probable values for pure Ne20 the same values should be increased by 0·0003 Å to bring them on level with Blackie and Littlefield's values. A set of unobjectionable standards, referring to Ne20, can be obtained as soon as the latter values have been confirmed by further measurements on pure Ne20. The pressure effect for the 1*s*–3*p* group should also be investigated.

As regards the 1*s*–2*p* group it may be recommended (*a*) to adopt as new secondary standards those wave-lengths in column 2 of Table 1 for which no adopted value is given in column 3, and (*b*) retain the adopted values in preference to the calculated ones, considering that in view of a possible intensity equation they will possibly represent the best approximation to what is usually observed. Measurements of the red neon lines using pure Ne20 would be informative.

Argon standards

Argon has long been recognized (20) as probably the best qualified of the rare gases for producing secondary standards on account of its almost perfect freedom of hyperfine and isotope structure. However, no argon standards have as yet been adopted because concordant measurements have been lacking. This deficiency has now been removed through the recent publications by Littlefield and Turnbull (21), and Burns and Adams (22). In Tables 5 and 6 are assembled the now existing data on the groups $1s$–$2p$ and $1s$–$3p$, respectively. Littlefield and Turnbull measured vacuum wave-lengths relative to an assumed value of 6440·2493 for the red cadmium line. The air wave-lengths given in column 4 of Table 6 were derived by first reducing the published vacuum values to the scale of 6440·2491 and then adding the proper vacuum correction.

Table 5. *Argon, group* $1s$–$2p$

Combination	Calculated wave-length in air	Burns and Adams (1953)	Meggers and Humphreys (1934)		Meggers (1921)	Meissner (1916)
			'Cd'	'Ne'		
$1s_2$–$2p_{10}$	11488·108[a]	—	—	—	—	—
$1s_3$–$2p_{10}$	10470·053[a]	—	—	051 (4)	—	—
$1s_2$–$2p_8$	9784·5020	—	—	5010 (10)	—	—
$1s_4$–$2p_{10}$	9657·7858[a]	785 (1)	—	7841 (10)	—	—
$1s_2$–$2p_7$	9354·2180	—	—	218 (8)	—	—
$1s_2$–$2p_6$	9224·4980	4955 (7)	498 (5)	498 (10)	—	—
$1s_5$–$2p_{10}$	9122·9667[a]	9660 (22)	9664 (6)	9660 (12)	—	—
$1s_3$–$2p_7$	8667·9430	9438 (31)	9435 (6)	9430 (13)	—	—
$1s_2$–$2p_5$	8578·0611	—	—	—	—	—
$1s_2$–$2p_4$	8521·4412	4428 (30)	4406 (6)	4407 (13)	442	—
$1s_4$–$2p_8$	8424·6474	6473 (40)	646 (2)	647 (12)	646	650
$1s_2$–$2p_3$	8408·2086	2094 (32)	207 (2)	208 (12)	210	216
$1s_2$–$2p_2$	8264·5215	5221 (46)	5210 (6)	5209 (13)	522	525
$1s_5$–$2p_9$	8115·3109	3108 (45)	3095 (3)	3115 (12)	307	310
$1s_4$–$2p_7$	8103·6921	6920 (37)	6922 (3)	6922 (12)	693	691
$1s_5$–$2p_8$	8014·7854	7853 (41)	785 (2)	7856 (12)	784	786
$1s_4$–$2p_6$	8006·1563	1566 (33)	155 (2)	1556 (12)	156	158
$1s_3$–$2p_4$	7948·1759	1755 (51)	1756 (6)	1754 (13)	175	177
$1s_3$–$2p_2$	7724·2067	2064 (42)	206 (2)	2064 (11)	210	210
$1s_5$–$2p_7$	7723·7600	7599 (18)	761 (2)	7597 (11)	758	760
$1s_5$–$2p_6$	7635·1054	1056 (55)	1055 (6)	1053 (13)	106	107
$1s_4$–$2p_5$	7514·6512	6514 (50)	653 (4)	6510 (12)	651	648
$1s_2$–$2p_1$	7503·8680	8685 (37)	8667 (4)	8676 (12)	867	868
$1s_4$–$2p_4$	7471·1636	1676 (4)	—	—	—	—
$1s_4$–$2p_3$	7383·9801	9796 (53)	9800 (6)	9800 (13)	979	978
$1s_4$–$2p_2$	7272·9354	9349 (31)	9356 (5)	9357 (9)	935	—
$1s_5$–$2p_4$	7147·0410	0408 (24)	0412 (5)	0406 (7)	042	—
$1s_5$–$2p_3$	7067·2175	2175 (63)	2177 (5)	2170 (12)	217	218
$1s_5$–$2p_2$	6965·4300	4304 (70)	4304 (5)	4302 (10)	429	432
$1s_4$–$2p_1$	6677·2811	2812 (27)	—	—	282	—

Mean diff. obs.-calc.: +0001; −0002; −0002; ±000; +001.

[a] Provisional values; cf. footnote to Table 7.

Table 6. *Argon, group* 1*s*–3*p*

Combination	Calculated wave-length in air	Burns and Adams (1953)	Littlefield and Turnbull (1953)	Humphreys (1938)	Meggers and Humphreys (1934)	Megger (1921)
$1s_2$–$3p_{10}$	4702·3163	3155 (14)	3160 (10)	3164 (11)	3151	317
$1s_2$–$3p_8$	4628·4409	4409 (11)	4406 (5)	4410 (10)	4398	445
$1s_2$–$3p_7$	4596·0966	0964 (13)	0962 (10)	0970 (11)	0964	096
$1s_2$–$3p_6$	4589·2893	288 (1)	—	—	2884	—
$1s_3$–$3p_{10}$	4522·3233	3238 (15)	3230 (13)	3238 (11)	3216	325
$1s_2$–$3p_5$	4510·7334	7335 (20)	7332 (19)	7333 (13)	7323	733
$1s_3$–$3p_7$	4423·9944	996 (2)	—	—	9936	—
$1s_4$–$3p_{10}$	4363·7949	7957 (5)	7943 (3)	—	7936	—
$1s_2$–$3p_4$	4345·1678	1697 (8)	1678 (14)	1682 (13)	1666	168
$1s_2$–$3p_2$	4335·3378	3381 (9)	3375 (20)	3380 (13)	3366	—
$1s_2$–$3p_3$	4333·5612	5612 (19)	5611 (20)	5612 (13)	5598	561
$1s_4$–$3p_8$	4300·1009	1011 (24)	1006 (20)	1011 (13)	0997	101
$1s_4$–$3p_7$	4272·1689	1690 (19)	1688 (21)	1690 (13)	1679	169
$1s_4$–$3p_6$	4266·2866	2868 (26)	2865 (19)	2867 (13)	2854	286
$1s_2$–$3p_1$	4259·3617	3617 (26)	3616 (18)	3618 (13)	3605	362
$1s_5$–$3p_{10}$	4251·1849	1850 (17)	1849 (12)	1852 (13)	1842	184
$1s_5$–$3p_9$	4200·6747	6746 (20)	6745 (15)	6751 (13)	6738	676
$1s_4$–$3p_5$	4198·3173	3176 (22)	3173 (15)	3170 (13)	3160	316
$1s_3$–$3p_4$	4191·0293	0288 (8)	0292 (20)	0296 (7)	0270	027
$1s_5$–$3p_8$	4190·7129	7138 (8)	7126 (20)	7127 (7)	7098	714
$1s_3$–$3p_2$	4181·8835	8837 (23)	8834 (18)	8838 (13)	8825	884
$1s_5$–$3p_7$	4164·1795	1795 (20)	1794 (15)	1800 (13)	1789	180
$1s_5$–$3p_6$	4158·5907	5906 (30)	5906 (19)	5906 (13)	5895	591
$1s_4$–$3p_4$	4054·5257	5279 (5)	5259 (3)	5254 (7)	5250	—
$1s_4$–$3p_2$	4045·9654	9658 (8)	9645 (10)	9658 (7)	—	—
$1s_4$–$3p_3$	4044·4180	4185 (20)	4176 (19)	4182 (13)	4173	419
$1s_4$–$3p_1$	3979·7154	7149 (1)	—	—	—	—
$1s_5$–$3p_4$	3957·1332	—	—	—	—	—
$1s_5$–$3p_2$	3948·9788	9785 (26)	9785 (17)	9788 (13)	977	980
$1s_5$–$3p_3$	3947·5047	5048 (13)	5047 (12)	5043 (9)	—	—

Mean diff. obs.-calc.: +0001; −0002; +0001; −0011; ±000.

Table 7. *Relative values of the argon levels*

$1s_5$	0·0000	$2p_{10}$	10 958·3390[a]	$3p_{10}$	23 516·2334
$1s_4$	606·8378	$2p_9$	12 318·9996[b]	$3p_9$	23 798·9942[b]
$1s_3$	1 409·9052	$2p_8$	12 473·5100	$3p_8$	23 855·5659
$1s_2$	2 256·0676	$2p_7$	12 943·4998	$3p_7$	24 007·5664
		$2p_6$	13 093·7918	$3p_6$	24 039·8301
		$2p_5$	13 910·5120[b]	$3p_5$	24 419·1953
		$2p_4$	13 987·9486	$3p_4$	25 263·6703
		$2p_3$	14 145·9401	$3p_3$	25 325·2908
		$2p_2$	14 352·6566	$3p_2$	25 315·8375
		$2p_1$	15 578·8594	$3p_1$	25 727·1570[b]

[a] From λ 9122 is obtained $2p_{10} = 10\ 958{\cdot}3397$ while several combinations $2p$–nd, ns, as observed by Littlefield and Turnbull, consistently indicate a lower value, about 10 958·3380. A weighted mean has been adopted. New measurements in the region above 9000 Å are desirable.

[b] Determined from one combination only.

In Table 6 the values given by Meggers and Humphreys in 1934 deviate systematically from the other sets by several times the estimated errors. This deviation was remarked on by Humphreys (23) who was unable to explain it. In view of the concordance of the three later measurements it seems inevitable to assume that the error is in the series of

1934, which has accordingly been disregarded. To attempt an explanation it might be suggested that a change in the phase dispersion by ageing of the silver films may have occurred, in which case the short wave-lengths would have been falsified while the longer ones, contained in Table 5, may well have been unaffected.

The data have been treated in the same way as is described above for neon. The levels are collected in Table 7 and the final wave-lengths are given in the second column of Tables 5 and 6. Wave-numbers are implicitly contained in the level table. Wave-lengths were calculated for all transitions allowed by the selection rule for *J*, numbering thirty for each transition group. All these wave-lengths can be recommended as secondary standards with the exception of the four infra-red lines marked with an "*a*" in Table 5 (cf. footnote to Table 7). It should be remarked, however, that further comparisons of the 1*s*–2*p* group with the primary standard, or an adequate substitute, would be desirable. Also, the dependence of the wave-lengths on discharge conditions should be investigated, especially in the 1*s*–3*p* group.

Krypton standards

Wave-lengths for twenty lines of natural krypton were adopted as secondary standards in 1935. Two of the values were given to seven figures only. The eighteen 8-figure values, ranging from 5993 to 4273 Å, correspond to transitions 1*s*–2*p* or 1*s*–3*p*. By the same procedure as was applied above to neon and argon the system of krypton standards could be smoothed and extended to cover the range from 3495 to beyond 10,000 Å, but before this can be profitably done at least one more set of concordant measurements in the regions above 7000 and below 4000 Å will be required.

Vacuum wave-lengths for thirty-one lines in the visible spectrum of krypton, including all the adopted standards, have been given by Littlefield (24). The corresponding values in standard air are as follows:

4273·9703
4282·9681
4286·4869
4300·4861
4318·5529
4319·5805
4351·3623
4362·6422
4376·1227
4399·9674
4425·1905
4453·9184
4463·6907
4502·3550
5562·2279
5570·2903
5580·3890
5649·5628
5672·4514
5707·5128
5832·8600
5866·7514
5870·9169
5879·9004
5993·8513
6012·1570
6056·1274
6082·8630
6236·3520
6421·0285
6456·2910

The agreement with the adopted standards is good for well-observed lines.

Natural krypton consists of six isotopes with the following mass numbers and relative abundances: 78 (0·34%), 80 (2·22%), 82 (11·50%), 83 (11·48%), 84 (57·02%), 86 (17·43%). In spite of this complication the krypton lines have been found suitable for precision measurements due to the fact that the isotope shift is very small and the h.f.s. pattern of the odd isotope is faint and symmetrical to the main line. The isotope shift was recently measured by E. Rasmussen (25) for twenty-four lines of the groups 1*s*–2*p* and 1*s*–3*p*. He found the separations for 82–84 and 84–86 to be identical, ranging from 0·002 to 0·005 $\mathrm{cm.}^{-1}$ in rough proportion to the wave-number of the line. The shift is in the direction of shorter wave-lengths for increasing mass.

As is well known, Kösters and co-workers at the former P.T.R. have demonstrated the excellent metrological properties of the radiations from pure Kr84 and Kr86. This study is being continued at the P.T.B. by Engelhard, who has communicated a detailed report on the work carried out at the P.T.B. in the field of this commission. An improved design of the krypton lamp was recently described by Engelhard (26). By cooling the discharge tube to the triple-point of nitrogen (63° K.), at which the vapour pressure of the solid krypton amounts to a few hundredths mm. Hg, the Doppler broadening as well as pressure effects are reduced to a minimum. The relative intensities in the spectrum are markedly different from those of ordinary Geissler tubes. The line 6056 Å is found to be specially favourable for metrological purposes on account of both sharpness and intensity. Other laboratories are invited to make measurements on pure isotope krypton lines for which purpose the P.T.B. offers to provide the lamps.

Experiments on Xe 136 have also been made. The vapour pressure at 80° K. is 0·04 mm. Hg and is still sufficient for maintaining the discharge. The sharpness of the lines is then equal to that of the krypton lamp, but intensity relations in the xenon spectrum are less favourable than for krypton.

Dr Engelhard further points to the possibilities offered by cooled hollow cathodes for producing high precision standards.

Mercury 198

The electrodeless lamp containing a pure even isotope of mercury with a few mm. of argon as carrier gas (the Meggers lamp) has been described in the last two reports of this commission, and its eminent suitability as a source of wave-length standards was demonstrated. Regardless of the choice of primary standard, this lamp is bound to become a most powerful tool in spectroscopy and metrology on account of the excellent quality of its radiations as regards both sharpness, intensity and distribution, and because of its simplicity and convenience in use.

The last report gave five highly concordant wave-length determinations for the green line of Hg 198, centered around 5460·7532. It was also mentioned that Barrell's (27) observations indicated a pressure shift, amounting for the strong visible lines to about +0·0001 Å/mm. Hg of argon. The argon pressure will therefore have to be specified in order to secure complete reproducibility.

Dr Meggers has communicated the following preliminary values for the vacuum wave-lengths of seven visible radiations from Hg 198 which were determined relative to the vacuum value 6440·24907 for the red cadmium line and correspond to zero pressure of argon:

5792·2679	5462·2703	4359·5621	4078·9891
5771·1980	—	4348·7175	4047·7143

Burns and Adams (28) have published extensive wave-length lists for several pure isotopes of mercury. For Hg 198 they give observed 8-figure values for sixty-three lines from 6907 to 2262 Å. For the purpose of establishing secondary standards it is recommended that further independent observations be made of these lines and the stability of the various wave-lengths be investigated.

Other elements

Burns and Adams report measurements in the spectra of cadmium and copper. Dr Adams writes:

> We have fairly extensive measurements of the cadmium spectrum from 2144 Å to 8200 Å in a 'Beese' type lamp with natural cadmium; this is a low-pressure quartz lamp with coated electrodes run at approximately 200 V. a.c. and 2·5 amps. Also, many measurements of cadmium 114 in a quartz Michelson lamp with 2 mm. Hg pressure of pure argon at various temperatures up to 310° C. One low-pressure electrodeless discharge tube that was excited by 500 mc. waves containing cadmium 114 and mercury 198 with approximately 3 mm. Hg pressure of argon was run at 300° K. We have almost all of these various sources of the cadmium spectra reduced and hope to have a paper ready for the Dublin meeting. Incidentally, we hope to get a few of the longer wave-lengths of cadmium out to 10,394 Å before stopping.
>
> We have arrived at the conclusion that cadmium 114 is no better than natural cadmium for good wave-lengths except in the green region where the isotopic structure shows up in the natural. On the average we only find a difference between natural and the isotope of 0·001 cm.$^{-1}$.
>
> We have copper worked over in pretty good shape down to 2200 Å. We plan to use a permanently evacuated hollow cathode to go shorter. We have tried the above type of hollow cathode on silver and find it works well.

For the past two years we have made all of our measurements with the interferometer in vacuum. This we feel is the ideal way to do this job. It makes the reduction of the measured plates much simpler and gives our wave-numbers directly in vacuum.

Reference should also be made here to the recent measurements of very high accuracy on some lines in the germanium spectrum by Deverall, Meissner and Zissis (29), made by using an atomic beam light-source.

TABLES OF SPECTRA

The solar spectrum

Mrs Sitterly reports:

The programme on the revision of the 'Revised Rowland Tables' (*Carnegie Publ.* no. 396, 1928) is continuing with steady progress. The data to be included are as outlined in the preceding report of this Commission. Minnaert and his staff have published their measurements of equivalent widths based on the Minnaert Solar Atlas, in the interval 6000 to 8700 Å (the long-wave limit of the Atlas) (*Recherches Astron. Obs. Utrecht*, **12**, part 2, 38 pp., 1951). Their work has since been completed in the range 4500 to 6000 Å, and is in progress for the region 4000 to 4500 Å.

Revised identifications of atomic lines are being made to parallel the work on equivalent widths. These are fairly definitive from the long-wave region to 4000 Å, and are being investigated in the section 4000 Å and 2950 Å (the short-wave limit of the Table).

The 1928 identifications of molecular lines need extensive revision, and this problem is receiving serious consideration. A start has been made by H. P. Broida and the writer with the bands of CH. A preliminary study based on Broida's observed intensities of the $^2\Sigma-{}^2\Pi$ (0, 0) band, and accurate laboratory wave-lengths, indicates that approximately 98% of the lines are present or accounted for in the solar spectrum. Work is in progress on other CH bands and on OH, and it is hoped to extend it much further in an attempt to account for the many observed solar lines whose origin is completely unknown or only partially explained.

Dr Mohler reports:

The McMath-Hulbert Observatory now has in final form the table of solar wave-lengths for the range from 12,000 to 25,000 Å. This table includes water vapour identifications by Dr William S. Benedict. We think the wave-lengths in the table are sufficiently accurate to make possible rapid application of interferometric methods to this wave-length region.

Dr Goldberg draws attention to the fact that nearly 600 lines remain unidentified between 1·2 and 2·5μ and hopes that the laboratory spectroscopists will proceed to fill this gap by observing the infra-red spectra of at least the most abundant elements.

In a recent paper by Righini and Rigutti (30) eighty-five lines of solar origin have been identified as belonging to the (2, 0) band of CN.

Miss Adam reports that she is now extending to other regions of the spectrum the interferometric measurements of solar and vacuum-arc wave-lengths, a first account of which has been published (31).

(The solar spectrum is treated also by Commission 12.)

Atomic energy levels

Mrs Sitterly reports:

The programme on the compilation of 'Atomic Energy Levels' as derived from the analyses of optical spectra (*Circ. Nat. Bur. Std*, 467) is being continued according to schedule. Two volumes are in print: Vol. **1**, 1949, contains the energy levels of 206 spectra of the elements H through V (Z = 1 through 23); Vol. **2**, 1952, contains similar data for 152 spectra of the elements Cr through Nb (Z = 24 through 41). Vol. **3** is in progress and should be completed in 1955. It will include the elements Mo through La (Z = 42 through 57), and Ta through Ac (Z = 73 through 89). Structure has been recognized in 125 spectra in these groups. Analyses are in progress for 32 of these spectra and manuscript has been completed for 76.

Atomic spectra

Mrs Sitterly reports on the Ultra-violet Multiplet Table:

Two Sections of this Table have been published (*Circ. Nat. Bur. Std.* 488). Section 1, published in 1950, contains ultra-violet multiplets of 79 spectra of the elements H through V (Z = 1 through 23). Section 2, published in 1952, contains the leading ultra-violet multiplets of 46 spectra of the elements Cr through Nb (Z = 24 through 41). Section 3, similarly, will parallel Vol. **3** of *Atomic Energy Levels*, and is now in course of preparation.

A number of more or less comprehensive descriptions of individual atomic spectra of special interest to astrophysicists have recently been completed:

C II, S. Glad (32); C III, K. Bockasten (33); Mg I, R. A. Fisher and F. E. Eshbach (34); Mg II, P. Risberg (35); Ca II, B. Edlén and P. Risberg (36); Cr I, C. C. Kiess (37); Cr II, C. C. Kiess (38); Fe III, S. Glad (39); Ni III, A. G. Shenstone (40); Zr II, C. C. Kiess (41).

At the National Bureau of Standards new descriptions of the following spectra have been completed and may be published during 1955 and 1956: Mo I, Mo II, Tc I, Tc II, Ru I, Ru II, Ta I and Ta II.

Molecular spectra

Attention is directed to the comprehensive compilations by R. F. Barrow, A. D. Caunt, A. R. Downie, R. Herman, E. Huldt, A. McKellar, E. Miescher, B. Rosen, K. Wieland—Editor B. Rosen: *Données Spectroscopiques concernant les molécules diatomiques* (1951) and *Atlas des longueurs d'onde caractéristiques des bandes d'émission et d'absorption des molécules diatomiques* (1952), being Vols. **4** and **5** of the *Tables de constantes et données numeriques*.

NOMENCLATURE

In the 1938 report of this commission a list of symbols for use in the description of spectra were recommended, including the symbol A. for the wave-length unit. It now appears from the resolution made by the Joint Commission for Spectroscopy in 1954 that a change to the symbol Å should be recommended.

BENGT EDLÉN
President of the Commission

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14*a*. SUB-COMMISSION ON INTENSITY TABLES: REPORT ON TABLES OF *f* VALUES

The necessity of collecting all available oscillator strengths, either determined by experiments or calculated by quantum mechanics, has been repeatedly emphasized in these *Transactions*. A first survey of the literature was published in the report of Commission 36 for the 1948 meeting. Since then, several such tables have been prepared, which apparently will soon provide for this generally felt need.

(*a*) In 1950 appeared the sixth edition of Landolt-Börnstein's *Zahlenwerte und Funktionen*, of which Vol. **1** contains tables of *f* values by Biermann. The tables of absolute values are fairly complete; relative values are quoted for Fe and Ti; for other elements the necessary references are given. Special lists refer to forbidden lines and to molecular bands. Dr Biermann writes that he is still keeping his catalogue up to date in view of further editions.

(*b*) In the book by Allen, *Astrophysical Quantities* (in the Press) about 350 oscillator strengths of astrophysical importance will be collected, 100 of these being components of hydrogen lines.

(*c*) Another list is being prepared by Menzel for the *Smithsonian Physical Tables*.

(*d*) In the new edition of Unsöld's book, now in the Press, a very complete list of references will be communicated, ordered according to the periodic system and mentioning whether the determinations were absolute or relative, experimental or theoretical.

(*e*) Finally, a list is expected to be found in Condon, *Handbook of Physics*, part 7, chap. 3 (in the Press; McGraw Hill).

Although these compilations will be of the greatest use for the astrophysicist, it must be recognized that they do not yet give the whole of the data, critically combined and ready for use. No spectroscopist would be satisfied if instead of tables of spectral lines he had only a list of references or the wave-lengths of 350 selected lines. There is therefore ample opportunity for future work, which should make available all theoretical and