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

PRÉSIDENT: M. A. FOWLER, *Emeritus Professor of Astrophysics, Imperial College, London, S.W. 7, England.*

MEMBRES: MM. Babcock, Burns, C. Fabry, C. V. Jackson, Kayser, Meggers, Nagaoka, Pérard.

I. THE PRIMARY STANDARD

(*a*) SOURCE OF THE PRIMARY STANDARD

The 1932 report of this Commission, and the report of the ensuing discussion, revealed an unsatisfactory position with regard to sources of the red line of cadmium which could be relied upon to give the adopted standard value for the wave-length $6438{\cdot}4696 \times 10^{-10}$ metre.

Dr Meggers has summarised the position very clearly in a recent paper on "Interference Measurements in the Spectra of Noble Gases" (*B.S.J. Research*, **13**, 293, 1934) and has expressed a strong preference for the specification of the Michelson lamp adopted in 1927 by the International Conference of Weights and Measures (see *Trans I.A.U.* **4**, 58, 1932). He points out that the I.A.U. specification of 1925 is less restricted, inasmuch as it does not exclude high-frequency excitation and makes no mention of the volume or capillary bore of the tube, but requires that it must give interferences with differences of path of at least 200,000 waves. The last condition is considered objectionable on the ground that this is less than half of the theoretical or actual limit of the Michelson tube, and it is further considered that cadmium sources in which any such reduction in interference order occurs will certainly yield a different value for the primary standard.

A communication on this subject has been submitted by Mr Babcock, but this appears to the President to be more appropriate as a contribution to the discussion which may be expected at the Paris meeting than to the present report. One important detail which may be usefully mentioned here, however, is that referring to the volume of the Michelson cadmium lamp in the specification adopted in 1927 by the International Conference of Weights and Measures (quoted in *Trans. I.A.U.* **4**, 58). The volume of the tube is apparently required by the I.C.W.M. to be not greater than 25 $cm.^3$, but Mr Babcock states that this was never insisted upon by Michelson and much confusion has arisen over this point. As indicated in the 1932 report, it appears to have been the intention of the I.C.W.M. to follow the specification which had been adopted by the I.A.U. in 1925, but inadvertently the draft report was used instead of the final form that was actually adopted. However, in the draft report the volume 25 $cm.^3$ was named as a *lower* limit, while the I.C.W.M. stated this as an *upper* limit. In answer to a request from Mr Babcock for an authoritative copy of the resolution of the I.C.W.M., M. Guillaume forwarded a printed report of the proceedings, in which, however, he had deleted, with ink, in three places the two words "ne...pas", so as to restore the volume 25 $cm.^3$ as a *lower* limit. This may be taken as evidence that the I.C.W.M. introduced an error into the specification, but no further action appears to have been taken. If this interpretation be accepted, the I.C.W.M. specification for the Michelson lamp becomes:

La lumière doit être produite par un courant électrique de haute tension, continu ou alternatif, de fréquence industrielle (à l'exclusion de la haute fréquence), dans un tube à vide ayant des électrodes intérieures. La lampe doit avoir un volume dépassant 25 $cm.^3$

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

et un tube capillaire dont le diamètre ne soit pas inférieur à 2 mm.; elle doit être maintenue à une température voisine de 320°, et la valeur du courant qui la traverse ne doit pas excéder 0·02 ampère. A la température ambiante, le tube ne doit pas être lumineux lorsque le circuit à haute tension y est établi.

Mr Babcock states that for the present he is in favour of retaining the preliminary specification of the source of the primary standard which was approved by the I.A.U. in 1925; namely:

L'étalon primaire de longueur d'ondes, λ 6438·4696 du cadmium, sera produit par un courant électrique à haute tension dans un tube à vide portant des électrodes intérieures. La lampe sera maintenue à une température ne depassant 320° C., et devra donner des différences de marche d'au moins 200,000 longueurs d'ondes. La valeur efficace du courant d'excitation ne dépassera pas 0·05 ampère. A la temperature de la salle, le tube ne sera pas lumineux quand il sera connecté au circuit habituel à haute tension.

A valuable experimental contribution to the subject of the primary standard has been communicated by Dr C. V. Jackson, who first points out that although it does not seem possible to determine the wave-length of Cd_R in terms of the metre with an accuracy much greater than 1 part in 5 million—mainly on account of the nature of the metre standards—it appears possible to compare the wave-lengths of sharp lines with the primary standard to an accuracy of at least 1 part in 50 million. This is shown by the close agreement of the results for neon and krypton obtained by different observers, when the Michelson lamp as defined by the I.C.W.M. was used as the source of the primary standard.

Dr Jackson has compared various sources with the standard lamp and has reached the following conclusions:

(1) In the Michelson lamp, the bore of the capillary should not be less than 2 mm., the volume not much less than 20 $cm.^3$, the temperature should not exceed 320° C., and the current should not be greater than 0·02 ampere. If these conditions are fulfilled, the primary standard appears to be reproducible with an accuracy of about 1 part in 100 million.

(2) In agreement with Pérard, and with Sears and Barrell, it was found that with the Michelson lamp the visibility of the fringes at long paths was considerably improved by the addition of air equivalent to 1 mm. *Hg*. There was the additional advantage of a more intense light for the same current, and a longer life for the lamp. No measurable effect on the wave-length was observed, although it was estimated that a difference of 1 part in 100 million could have been detected.

(3) In observations of various lamps which were constructed for comparative purposes, it was found that although giving definitely measurable fringes with paths exceeding 200,000 waves, some of them gave wave-lengths as much as 0·0004 A too high.

(4) The new type of cadmium vapour lamp introduced by the G.E.C. Osram Co. was found to give a wave-length for Cd_R which agreed with that given by the standard Michelson lamp within about $\pm$0·0001 A, provided that it was run with a current of 1·1 amp. When the current was increased to 2 amps, the fringes were appreciably broadened unsymmetrically, but the shift towards the red did not exceed 0·0002 A. (In a preliminary investigation Sears and Barrell had previously concluded that the wave-length of Cd_R given by this lamp, when carrying a current of 1 amp, agreed with that given by the Michelson lamp with a certainty of about 1 part in 16 million.)

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

(5) A comparison of the red line as emitted by a Schuler cadmium lamp with that given by a standard Michelson lamp revealed no difference of wave-length greater than 1 part in 50 million.

(6) The cadmium vacuum arc cannot be recommended as a useful source of the primary standard on account of excessive width of the line under these conditions.

Jackson's observations have convinced him that the "air-filled" Michelson lamp and the Osram cadmium lamp at 1·1 amp. are entirely satisfactory for the excitation of the primary standard, since they yield wave-lengths which are identical and reproducible to $\pm 0{\cdot}0001$ A.

It is greatly to be desired that similar investigations should be undertaken by other observers.

(*b*) Comparisons of the Metre with the Standard Cadmium Line

Reference was made in the Report for 1932 to the preliminary determination of the length of the metre in terms of the wave-length of the red cadmium line which had been made at the National Physical Laboratory, Teddington, England. A full account of the apparatus employed and of the results obtained has since been published by J. E. Sears and H. Barrell (*Phil. Trans. Roy. Soc.* **231** A, 75, 1932, and **233** A, 143, 1934). The final value for the wave-length of the red cadmium line, in "normal" air (dry air containing 0·03 per cent. carbon dioxide at 760 mm. pressure and at a temperature of 15° C.) is $6438{\cdot}4708 \times 10^{-10}$ m. The wave-length in vacuum is $6440{\cdot}2510 \times 10^{-10}$ m., and the refractive index of "normal" air 1·00027649.

During 1934 the result of a further determination was announced by Kösters and Lampe, of the Physikalisch-Technische Reichsanstalt, Charlottenburg, Berlin, the value given for the wave-length in "normal" air being $6438{\cdot}4672 \times 10^{-10}$ m. (*Phys. Zeit.* **35**, 223, 224, 1934).

The mean value of the wave-length in "normal" air derived from the five completely independent determinations which have now been made by different observers is closely the same as that originally given by Benoît, Fabry and Perot (6438·4696) which received international sanction in the definition of the Angstrom Unit. Sears and Barrell (*loc. cit.*), in outlining tentative suggestions for the future definition of the unit of length in terms of a wave-length in vacuum state that it should preferably be so chosen as to preserve the present accepted value of the wave-length of the cadmium red line in "normal" air. It is then pointed out that "since the present definition of the International Angstrom Unit is contained in the statement that the wave-length of the cadmium red line in 'normal' air is 6438·4696 A, and the suggested definition of the metre is based on the same value reduced to vacuum by the aid of a correction derived from a precise determination of the refractive index of air, the value of the Angstrom would be automatically preserved by re-defining it for the future simply as 10^{-10} metre". On this basis and assuming the accuracy of the above value for the refractive index of "normal" air,

$$1 \text{ metre} = 1{,}552{,}734{\cdot}81\ \lambda\ Cd_R\ (\text{vac.}).$$

II. IRON ARC STANDARDS

No further interferometer measurements of secondary iron standards in the region more refrangible than λ 7000 appear to have been made since the date of the previous report. Advantage has been taken, however, of the introduction of photographic plates which are sensitive to the near infra-red to extend interferometer

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

measurements to this region. In particular, Dr Meggers has published the results of his measurements of 91 iron lines ranging from λ 7164·469 to λ 10216·351 (*B.S.J. Research*, **14**, 33, 1935), which were made relatively to neon standards by the Fabry-Perot method. It was found that the usual form of the standard arc was impracticable for interference observations even in the near infra-red up to λ 8824, the reason probably being that most of the infra-red iron lines involve rather highly excited states and are accordingly strongly developed only near the electrodes. The apparatus was finally arranged in such a way that light from the entire arc, including that from the electrodes, was integrated in the interferometer. It then became possible to record interference patterns for all the stronger lines of iron up to λ 10216 with exposures of 1 to 2 hours on Eastman xeno-cyanine plates. Most of the measurements were made on plates resulting from the use of a 10 mm. étalon, as the character of the lines precluded orders of interference exceeding about 40,000.

TABLE I

Wave-lengths of Iron Lines, Integrated Arc, λ 7164–λ 10216 (Meggers)

λ	Intensity and temp. class	Probable error*	λ	Intensity and temp. class	Probable error*	λ	Intensity and temp. class	Probable error*
7164·469	250 V	A	8096·874	10 IV	A	8866·961	60 V	A
7187·341	800 V	B	8198·951	80 V	hA	8945·204	10 V	hA
7207·406	500 V	B	8207·767	40 V	hA	8975·408	10 IV	B
7389·425	80 V	B	8220·406	1500 V	B	8999·561	200 III	A
7401·689	4 IV	A	8232·347	50 V	hB	9012·098	10 V	hC
7411·178	100 V	B	8239·130	8 IV	B	9079·599	4 V	hC
7418·674	5 IV	A	8248·151	30 V	hC	9088·326	50 IV	A
7445·776	200 V	B	8293·527	20 V	B	9089·413	30 IV	B
7495·088	400 V	A	8327·063	1200 II	A	9118·888	25 IV	A
7511·045	800 V	C	8331·941	200 V	hB	9147·800	2 V	hB
7531·171	60 V	B	8339·431	80 V	hA	9210·030	6 IV	B
7568·925	30 V	C	8360·822	8 V	hA	9258·30	10 V	hC
7583·796	50 IV	B	8365·642	25 IV	A	9550·46	6 V	hC
7586·044	150 V	A	8387·781	1200 II	B	9359·420	3 IV	C
7620·538	25 V	hB	8439·603	20 V	hB	9362·370	4 IV	C
7661·223	30 V	A	8468·413	300 II	A	9372·900	6 IV	C
7664·302	80 IV	B	8514·075	150 II	B	9430·08	3 IV	C
7710·390	25 V	A	8526·685	8 V	hC	9513·24	8 V	hC
7748·281	125 IV	A	8582·267	15 IV	A	9569·960	15 V	hA
7780·586	300 V	hB	8611·807	40 III	A	9626·562	12 V	hC
7832·224	400 V	B	8621·612	10 IV	B	9653·143	15 V	hC
7912·866	6 II*a*	A	8661·908	600 II	A	9738·624	100 V	hC
7937·166	700 V	A	8674·751	60 III	A	9753·129	10 V	hA
7945·878	600 V	B	8688·633	1500 II	A	9763·450	10 V	hC
7994·473	20 IV	A	8757·192	25 IV	A	9763·913	12 V	hC
7998·972	700 V	C	8764·000	20 V	hB	9800·335	8 V	hC
8028·341	50 V	hB	8793·376	25 V	hB	9861·793	12 V	hC
8046·073	600 V	B	8804·624	—	A	9889·082	15 V	hC
8080·668	10 V	A	8824·227	250 II	A	10065·080	30 V	hC
8085·200	500 V	A	8838·433	30 IV	A	10145·601	40 V	hC
						10216·351	50 V	hC

* A indicates probable error less than 0·0007 A; B 0·0007 to 0·0012 A; and C a still larger probable error. When the probable error exceeds 0·004 A, the wave-length is limited to two decimal places. The letter h indicates that the interference patterns appear hazy or diffuse as compared with the remaining lines.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

Although the results obtained by Dr Meggers cannot yet be submitted for adoption as standards, it will probably be convenient to many workers to find them included in the present report. They are accordingly reproduced in Table I, with the omission of wave-numbers and other details.

An important conclusion arising from this work is that although the integrated arc light exhibits displacements due to pressure and to Stark effects, experience has shown that the degree of reproducibility in measuring wave-lengths in this source is of the same order as that obtainable either with the international arc or with the vacuum arc. From the standpoint of stability the integrated light is thus considered to be not inferior to other types of iron sources, and calls for careful consideration as a suitable and convenient source of iron standards in the near infra-red.

The integration of light from all parts of the arc was accomplished by placing the arc at the principal focus of a collecting lens which then illuminated the interferometer with essentially parallel light. After passing through the interferometer the light was collected by an achromatic lens which projected, on the slit of the spectrograph, interference patterns of the individual radiations and also an image of the arc slightly magnified. With an electrode gap of about 12 mm. the electrode images on the slit were separated by about 15 mm. so that 5 or 6 rings of the patterns appeared between the continuous spectra from the electrodes. The arc was operated with a current of 8 amperes, the applied potential being 240 volts. On account of differences of intensity in different parts of the arc, it was found necessary to alternate polarity during exposures in order to obtain symmetrical illumination of the interference patterns.

Note. A useful photographic map of the iron arc spectrum in the region λ 8800–λ 10250 has been published by H. Dingle (*M.N.R.A.S.* **94**, 866, 1934). The map is accompanied by a table of wave-lengths determined by the method of overlapping orders.

III. NEON STANDARDS

It would seem that the time has arrived when the neon standards adopted by the I.A.U. in 1922 can justifiably be revised and stated with considerable accuracy to eight figures. Three series of accordant measurements are now available for these 20 lines, all of which were made by direct comparisons with the red cadmium line as given by the Michelson lamp under standard conditions of excitation.

The first of these series, by Burns, Meggers and Merrill (*Bull. B.S.* **14**, 765, 1918 and *J.O.S.A.* **2**, 301, 1925), were made with étalons of separations ranging from 2 to 40 mm., the shorter gaps, however, being used only for finding phase corrections.

In the second series, by C. V. Jackson (*Proc. Roy. Soc.*, **143** A, 124, 1933), étalons of silver with 1 and 3 cm. separations, and of platinum with 2 and 3 cm. separations, were used; the systematic difference in wave-lengths in the four sets of observations was found to be not greater than 0·0001 A. With resolving powers over 250,000 and étalon gaps up to 3 cm. the wave-lengths of these neon lines were found to be accurately reproducible, and the isotope satellites had no measurable effect on the wave-lengths. With lower resolving powers, however, the apparent wave-lengths were systematically lower till 90,000, when they remained constant at about 0·002 A below the standard values.

The third series of determinations was made by Meggers and Humphreys (*B.S.J. Research*, **13**, 293, 1934) with the aid of étalons coated with silver and having separations of 25 and 35 mm. These observers also noted that the faint isotope satellites had no appreciable effect on the reproducibility or precision of measure-

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

ment of the lines. Numerous lines in the range λ 4334 to λ 9665 were included in the measurements of these observers.

In Table II the first column indicates the wave-lengths adopted in 1922, while the second, third and fourth give the decimal parts of the wave-lengths arrived at in the three series of observations above mentioned. The numbers in brackets in the third and fourth columns indicate the number of observations on each line, those for Jackson including only the measurements made with high resolution. The last column states the wave-lengths recommended for adoption by the I.A.U.

TABLE II

Neon Secondary Standards (1935)

I.A. 1922	B.S.	Jackson	Meggers and Humphreys	Recommended I.A. 1935
5852·488	·4880	·4876 (28)	·4878 (8)	5852·4878
5881·896	·8954	·8948 (28)	·8950 (8)	5881·8950
5944·834	·8343	·8343 (28)	·8340 (8)	5944·8342
5975·534	·5339	·5340 (24)	·5343 (8)	5975·5340
6029·998	·9970	·9973 (24)	·9968 (8)	6029·9971
6074·338	·3377	·3377 (28)	·3376 (8)	6074·3377
6096·163	·1630	·1630 (28)	·1630 (8)	6096·1630
6143·062	·0624	·0620 (28)	·0627 (7)	6143·0623
6163·594	·5937	·5941 (28)	·5937 (8)	6163·5939
6217·280	·2811	·2814 (28)	·2812 (8)	6217·2813
6266·495	·4950	·4949 (28)	·4952 (8)	6266·4950
6304·789	·7890	·7893 (28)	·7893 (8)	6304·7892
6334·428	·4280	·4280 (28)	4276 (8)	6334·4279
6382·991	·9913	·9915 (28)	·9914 (7)	6382·9914
6506·528	·5278	·5280 (28)	·5277 (7)	6506·5279
6532·882	·8826	·8824 (23)	·8824 (8)	6532·8824
6598·953	·9528	·9530 (23)	·9528 (8)	6598·9529
6678·276	·2760	·2766 (11)	·2766 (8)	6678·2764
6717·042	·0427	·0427 (2)	·0430 (8)	6717·0428
7032·412	·4130	—	·4125 (5)	7032·4127

Although measured against the primary standard in each of the three series of observations, the line at λ 6402 has been omitted from the table on account of its tendency to reversal.

Burns and Jackson have also investigated the conditions of excitation necessary for accurate reproducibility, and their conclusions, which are in agreement, show that if an accuracy of 1 in 50,000,000 is required:

(1) The pressure of the neon should not exceed 15 mm. *Hg*.

(2) The bore of the capillary should be between 1 and 2½ mm.

(3) The current should not exceed 0·025 ampere and the discharge tube should be of the ordinary Geissler type, viewed transversely.

Jackson has also found that the wave-lengths given by the Hilger-G.E.C. neon lamp are in agreement with the standard wave-lengths to within 1 part in 15,000,000 (except the lines 6402 and 6143 which are reversed or broadened). This is in agreement with the conclusions of Babcock and Wallerath.

IV. KRYPTON STANDARDS

Further investigations of the wave-lengths of lines in the first spectrum of krypton suggest slight amendments to the eighth figure in the values for the ten bright violet lines adopted by the I.A.U. in 1932, and the addition of other lines to the recommended secondary standards.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

Meggers and Humphreys (*B.S.J. Research*, **13**, 306, 1934) have measured 55 lines extending from λ 4273 to λ 9751, all of which were compared with neon standards and 28 of them with the primary standard.

C. V. Jackson has communicated his recent unpublished measurements, which were made by comparisons with the primary standard over the range λ 4273 to λ 6456, with étalons ranging from 5 to 100 mm. separation.

Including previous observations by Meggers (*B.S. Sci. Pap.* **17**, 193, 1921), Humphreys (*B.S.J. Research*, **5**, 1047, 1930) and Jackson (*Trans. I.A.U.* **4**, 76, 1932), there are 20 lines for which 3 or more measurements are available. These are collected in Table III, which includes the values recommended in 1932 for the 10

TABLE III

The Krypton Secondary Standards

Recommended 1932	Meggers 1921	Humphreys 1930	Jackson 1932	Meggers and Humphreys 1934	Jackson 1935	Pérard† 1935	Recommended 1935
4273·9702	·9696	·9705	·9702 (26)	·9699 (10)*	·9700 (97)		4273·9700
4282·9688	·967	·9686	·9689 (14)	·9680 (4)	·9683 (82)		4282·9683
4286	—	·4875	—	·487 (1)	·4873 (25)		4286·4873
4300	—	·4877	—	·487 (1)	·4877 (16)		4300·4877
4318·5522	·552	·5523	·5522 (7)	·5524 (5)*	·5525 (24)		4318·5525
4319·5800	·580	·5798	·5801 (21)	·5798 (12)*	·5796 (54)		4319·5797
4351	—	·3605	—	·3602 (2)	·3609 (28)		4351·3607
4362·6425	·6422	·6429	·6425 (24)	·6421 (9)*	·6423 (103)		4362·6423
4376·1220	·122	·1217	·1221 (28)	·1219 (11)*	·1220 (103)		4376·1220
4399·9674	·969	·9675	·9673 (16)	·9667 (2)	·9669 (76)		4399·9670
4453·9179	·9174	·9183	·9179 (28)	·9177 (9)*	·9179 (100)		4453·9179
4463·6903	·690	·6897	·6906 (29)	·6901 (8)*	·6902 (107)		4463·6902
4502·3546	·354	·3546	·3548 (27)	·3547 (8)*	·3547 (103)		4502·3547
5562	·224	·2251	·2266	·2254 (7)*	·2257 (55)	·2257	5562·2257
5570	·2872	·2890	·2900	·2893 (10)*	·2895 (62)	·2894	5570·2895
5649	—	·5627	—	·5625 (2)	·5628 (17)	·5627	5649·5628
5870	·9137	·9153	·9167	·9154 (7)*	·9158 (56)	·9159	5870·9158
5993	—	·8500	—	·8506 (2)	·8503 (17)	·8504	5993·8503
6421	—	·028	—	·0283 (2)	·0300 (13)		6421·029
6456	·290	·293	—	·2894 (2)	·2910 (21)	·2904	6456·291

Pérard's earlier values were:

5562·22576	5570·2894	5649·5628	5870·9161	(1932)
5562·2257	5570·2892	5649·5627	5870·9154	(1923)

* These were measured against *Cd* as well as *Ne*; the tabulated wave-lengths are the means of the two values.

† Added in proof.

strong violet lines, and in the last column the wave-lengths recommended for consideration with a view to their adoption by the I.A.U. In this table, numbers in brackets indicate numbers of observations.

Jackson remarks that gas pressure as high as 10 mm. *Hg* may be used for the 1s–2p lines, and 4 mm. for the 1s–3p lines without introducing any appreciable pressure shifts. For the 1s–4p lines, however, the pressure of krypton should not exceed 1 mm.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

V. OTHER MEASUREMENTS

HELIUM, ARGON AND XENON

Besides the measurements to which reference has already been made, several additional investigations have been reported since the date of the 1932 report. Although not yet presented for adoption as standards, it is thought that some reference to them will be of value.

In their paper on the spectra of the noble gases, Meggers and Humphreys have included extensive measurements for helium, argon and xenon, in addition to neon and krypton. For the infra-red lines of helium they give the wave-lengths (in air) 10829·081, 10830·250, 10830·341, with the corresponding vacuum wave-numbers 9231·866, 9230·870, 9230·792.

The table for argon covers the range λ 3948 to λ 10470, and that for xenon λ 3948 to λ 9923. It is remarked that "on account of the relatively high sharpness of argon lines, absence of hyperfine structure due to nuclear spin, and almost ideal freedom from isotopic displacements, it seems probable that among all of the noble gas spectra *A* I lines will be found best qualified to serve as wave-length standards or standards of length". With regard to xenon, it is remarked that "In view of the relatively large abundance of odd isotopes and intensity of hyperfine structure components, the *Xe* I lines appear to be least suited among noble gas spectra as standards. However, if measurements are restricted to the main component, the reproducibility is of the same order as for the best lines in other spectra."

SILICON

C. V. Jackson has made interferometer measures of the wave-lengths of ten lines of silicon by comparison with the secondary standards of krypton (*M.N.R.A.S.* **94**, 723, 1934). Etalons of ¼ cm. and ½ cm. thickness, with films of platinum and of silver on the interferometer plates were used in this investigation. The results are given in Table IV.

TABLE IV

Wave-lengths of Silicon Lines (Jackson)

	λ	No. of observations	Probable error
Si IV	4088·862	6	A
Si IV	4116·103	6	B
Si II	4128·051	16	A
Si II	4130·876	16	B
Si III	4552·622	16	A
Si III	4567·841	17	A
Si III	4574·758	17	A
Si III	4716·654	8	B
Si II	5041·035	9	A
Si II	5056·001	11	B
Si II	5056·34	1	—

The calculated probable error of all the wave-lengths is under 0·001 A, but the actual accuracy is probably of the order of ± 0·001 A for the lines marked A in Table IV and ± 0·002 for those marked B.

These new values of the wave-lengths are of considerable importance on account of the prominence of the lines in the spectra of stars of spectral classes O and B. The

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

lines are very suitable for radial velocity determinations and these new values are doubtless to be preferred to those adopted by the I.A.U. Commission on Radial Velocities in 1932 (*Trans. I.A.U.* **4**, 187, 1932).

CALCIUM, STRONTIUM AND BARIUM

The wave-lengths of the H and K lines of calcium have been measured by C. V. Jackson, with the vacuum arc as source, by interferometric comparisons with the krypton standards adopted by the I.A.U. in 1932 (*M.N.R.A.S.* **93**, 98, 1932). The values obtained were 3968·470 ± 0·0006 A and 3933·664 ± 0·0006 A.

Mr Babcock has communicated the unpublished measurements of the vacuum arc spectra of barium and strontium which are shown in Table V. It is noted that the wave-lengths obtained for a few *Ca* lines which appeared as impurities in the arc were in satisfactory agreement with those given in Table XIII of the 1932 Report.

TABLE V

Vacuum Arc Wave-lengths, *Ba* and *Sr* (Babcock)

Barium	Strontium	Barium	Strontium
5535·481	5504·182	6141·712	6878·308
5777·617	6380·730	6341·678	7070·067
5800·227	6386·453	6450·849	
5805·681	6388·198	6482·905	
5826·272	6408·457	6496·896	
5853·672	6503·986	6498·757	
5971·695	6546·781	6527·309	
5997·084	6550·241	6595·323	
6019·467	6617·257	6675·267	
6063·112	6643·531	6693·839	
6110·780	6791·014	7059·940	

VI. WAVE-LENGTHS IN THE EXTREME ULTRA-VIOLET

Although there may be some doubt as to the extent to which Commission 14 should accept responsibility for the establishment of wave-length standards in the extreme ultra-violet, mention should be made of a valuable contribution which has been made by J. C. Boyce and C. A. Rieke (*Phys. Rev.* **47**, 653, 1935). This paper discusses the criteria for suitable standards in this region and presents provisional values for a number of lines of *C*, *N*, *O* and *A* falling in the region λ 1850–λ 800, as obtained with a two-metre normal incidence vacuum spectrograph. These are compared with the previous results of Edlén and of Bowen, and of Bowen and Ingram. It is recognized that the values tabulated may be subject to small systematic errors arising from the method of overlapping orders, which must be eliminated before permanent standards can be established. It is hoped that such errors may be eliminated by the use of some form of vacuum interferometer and, especially in the case of copper, by the adoption of wave-lengths which can be predicted with great accuracy from terms calculated by visible and near ultra-violet combinations.

As an indication of the degree of agreement between different observers, it will suffice to quote Boyce and Rieke's table for lines of oxygen, namely:

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

Table VI

Oxygen Lines, λ 1306–λ 580

Boyce and Rieke	Bowen	Edlén	Int.	Spectrum	Wt.
1306·038	—	—	9	I	3
1304·864	—	—	12	I	3
1302·192	—	—	12	I	2
1217·645	—	—	10	I	10
999·494	—	—	6	I	9
990·797	—	—	4	I	6
990·213	—	—	8	I	4
990·121	—	—	3	I	4
988·775	—	—	8	I	9
(988·64)	—	—	3	I	—
935·183	—	—	4	I	3
898·956	—	—	2	III	3
835·293	·288	·292	7	III	18
(835·10)	·094	·096	5	III	—
834·467	·462	·462	20	II	30
833·749	·741	·742	11	III	18
833·332	·326	·326	12	II	30
(832·93)	·926	·927	5	III	—
832·762	·756	·754	8	II	30
796·667	·665	·661	9	II	9
617·060	·064	—	7	II	8
616·304	·309	—	9	II	8
600·585	·583	—	5	II	8
599·594	·600	·598	10	III	16
580·974	·975	—	7	II	8

VII. SOLAR STANDARDS

Mr Babcock has forwarded a revised list of infra-red solar lines which are considered suitable as standards, extending from λ7050 to λ12425. The measurements were made in air at temperatures near 20° C. and pressures of about 74·5 cm. of mercury, but the corrections required to reduce them to 15° C. and 76·0 cm. are so small that they have not been applied. Corrections for motion of the apparatus with respect to the sun have been applied for all lines believed to originate in the sun. Beyond λ 11000, however, the present criteria for distinguishing solar and atmospheric lines are insufficient, and as water-vapour lines are very numerous in this region, all the lines except λ 11157·31 have been provisionally regarded as of atmospheric origin. The measured wave-lengths are for integrated sunlight.

From λ 7050 to λ 9000 the revised list includes numerous lines which appeared in the report for 1932 (*Trans. I.A.U.* **4**, 83), and since the amendments are small only the additional lines in this region are given here (Table VII). Beyond λ 9000, however, the revised list is given in full.

Between λ 9900 and λ 10604 the third decimal place, when included, has been rounded off to the nearest 0 or 5. Beyond λ 11423 the results depend on a single spectrogram and the second decimal place has little significance; the lines selected have been chosen with regard to spacing, sharpness, freedom from close companions, and intensity. The identifications are due to Dr Charlotte E. Moore, but these have not yet been completed beyond λ 11000. The intensities assigned are only tentative, but they will be of assistance in finding the lines.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

Table VII*

A Scale of Wave-lengths in the Infra-Red Solar Spectrum

λ	Element	Int.
7050·853	Atm.	0
7068·423	Fe	2
7090·390	Fe	2
7122·206	Ni	4
7130·925	Fe	3
7148·150	Ca	3
7178·423	Atm.	
7202·208	Ca	1
7227·493	Atm.	3
7236·136	Atm.	1
7260·730	Atm.	0
7275·398	Atm.	2
7287·378	Atm.	2
7303·197	Atm.	2
7315·516	Atm.	0
7619·212	Ni	1
7657·605	Mg	2
7665·944	Atm.O	6
7670·600	Atm.O	5
7671·670	Atm.O	5
7676·563	Atm.O	4
7677·618	Atm.O	4
7680·267	Si?	1
7683·800	Atm.O	3
7689·177	Atm.O	2
7690·217	Atm.O	2
7893·511	Atm.	2
7920·664	Atm.	1
8387·782	Fe	9
8397·152	Atm.	2
8736·040	Mg	1
8963·492	Atm.	8
8986·600	Atm.	2
8993·042	Atm.	3
9018·090	Atm.	3
9031·395	Atm.	10
9047·411	Atm.	4
9052·972	Atm.	10
9074·308	Atm.	10
9085·453	⊙	3
9092·482	Atm.	1
9105·401	Atm.	3
9115·644	Atm.	0
9132·442	Atm.	1
9160·904	Atm.	1
9178·535	Atm., Fe	1
9192·568	Atm.	2
9205·586	Atm.	0
9225·007	Atm.	2
9251·100	Atm.	2
9275·072	Atm.	0
9289·855	Atm.	0
9301·910	Atm.	2
9311·735	Atm.	2
9330·456	Atm.	1
9348·382	Atm.	1
9363·332	Atm.	1
9374·278	Atm.	0
9406·903	Atm.	3
9444·410	Atm.	2
9463·993	Atm.	0
9476·753	Atm.	2
9491·526	Atm.	1
9504·435	Atm.	1
9512·630	Atm.	1
9533·411	Atm.	1
9575·680	Atm.	1
9587·125	Atm.	3
9598·871	Atm.	2
9614·048	Atm.	1
9624·496	Atm.	2
9643·105	Atm.	1
9659·729	Atm.	2
9686·386	Atm.	2
9700·140	Atm.	0
9708·922	Atm.	1
9724·576	Atm.	2
9730·636	Atm.	1
9749·322	Atm.	3
9765·497	Atm.	2
9779·408	Atm.	2
9799·475	Atm.	2
9813·461	Atm.	0
9821·754	Atm.	−1
9831·961	Atm.?	0
9861·746	Fe	1
9889·052	Fe	−1
9898·972	Ni, Atm.	−1
9944·220	Fe	1
9986·490	⊙	3

* This table has been revised in accordance with a communication from Mr Babcock received after the draft report had been printed and circulated.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

TABLE VII (*continued*)

λ	Element	Int.	λ	Element	Int.
9997·665	⊙	2	11074·61	Atm.	7
10036·670	Sr^+	5	11078·65	Atm.	6
10065·070	Fe	8	11094·68	Atm.	6
10077·665	⊙	3	11123·30	Atm.	5
10087·140	⊙	3	11143·34	Atm.	6
10092·745	⊙	3	11157·30	Cr	10
10118·995	⊙	3	11227·53	Atm.	9
10123·895	⊙	8	11268·16	Atm.	
10145·580	Fe	10	11316·75	Atm.	3
10172·095	⊙	2	11371·96	Atm.	3
10193·245	Ni	4	11394·77		2
10216·335	Fe	9	11423·27		8
10218·415	Fe	3	11427·90		6
10272·950	⊙	1	11460·17		3
10288·950	Si	6	11501·72		1
10327·360	Sr^+	7	11530·62		0
10340·900	Fe	3	11569·14		2
10343·840	Ca	8	11581·81		2
10371·285	Si	9	11609·53		1
10395·795	Fe	3	11620·27		2
10455·450	S	6	11635·12		2
10459·430	S	6	11664·40		2
10469·680	Fe	5	11691·90		2
10585·165	Si	10	11720·47		0
10603·440	Si	9	11774·40		2
10627·63	Si	7	11780·87		3
10660·98	Si	9	11849·97		1
10683·11	C	7	11873·32		2
10685·35	⊙	6	11899·54		2
10689·73	Si	6	11915·37		1
10707·32	C	5	11933·61		1
10743·47	⊙	1	11973·26		1
10772·86	⊙	−1	12005·29		4
10784·58	⊙	1	12051·92		2
10799·58	⊙	5	12084·39		2
10834·01	⊙	3	12103·47		4
10857·31	⊙	5	12112·11		2
10863·50	Fe, Ca	3	12150·00		2
10874·92	⊙	2	12172·40		3
10892·24	⊙	5	12214·49		1
10903·70	⊙	5	12232·80		2
10935·17	⊙	6	12252·54		3
10946·32	⊙	10	12304·06		3
10965·45	⊙	5	12339·11		4
10985·84	⊙	7	12351·50		3
10996·46	⊙	10	12364·49		1
11007·68	Atm.	10	12387·79		3
11032·42	Atm.	8	12409·46		2
11054·74	Atm.	4	12425·41		−1
11061·67	Atm.	4			

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

VIII. WORK REPORTED IN PROGRESS

Mount Wilson Observatory. The following account of work in progress at the Mount Wilson Observatory has been submitted by Mr Babcock:

Due to unforeseen interruptions and delays the results of Babcock, Miss Moore, and Hoge's work on the infra-red solar spectrum at Mount Wilson and Princeton have not yet been published. Much progress has been made toward its completion, however, and some advantages accrue from deferring its publication. Since recent work has shown that valuable additions can be made to the Revision of Rowland's Solar Table for wave-lengths greater than λ 6600, the new table will begin at that point. It will extend as far as photographic observations seem feasible, a limit that may at any time be somewhat extended beyond that which now terminates our work, λ 13300. In this region begins a heavy absorption band due to water vapour that obliterates most of the solar spectrum for several hundred angstroms. Unless some of the valuable new photographic sensitizers permit observations near λ 14000, beyond the farther edge of the water band, astrophysical photography must cease near the limit now reached.

The new table will contain about 6000 lines, for which will be given the wave-lengths on the neon scale, the intensities, and a large amount of information concerning the identifications. From λ 6600 to about λ 7150 the wave-lengths, now reduced to the neon scale, are taken from Rowland. Beyond λ 7150 our own measurements of position and estimates of intensity are given. The wave-lengths have been found by interpolation between solar and atmospheric standards accurately determined with the interferometer as far as λ 10603. Beyond that point solar standards from overlapping higher orders of spectra have been used to establish a system of temporary standards and the details have been filled in by interpolation between these.

Reference should be made to the Report of Commission No. 12, for a discussion of those phases of this work dealing with the intensities and the identifications of the lines. The generous co-operation of investigators of laboratory spectra who have supplied unpublished data has considerably advanced the interpretation of the solar data.

In a Mount Wilson contribution now being prepared our latest and most accurate wave-lengths will be given for a selected list of lines that seem best suited to serve as standards in this part of the solar spectrum. Most of the lines are included in Table XV in the 1932 Report of this Commission, and, as the changes from the wave-lengths stated there are small, it is perhaps unnecessary to repeat them here. The interferometer has been used for this work as far as λ 10604; beyond that point the overlapping second order solar spectrum supplied standards of reference.

A concluding remark on the technique of infra-red spectroscopy seems called for because of the publication from different laboratories of a considerable number of lines, not only in arc spectra but also in absorption spectra, that are not real but are merely Lyman ghosts. There is apparently insufficient recognition of the fact that a grating may exhibit the highest excellence in some respects and still be contaminated with that type of periodic error in the ruling that gives rise to Lyman ghosts. Better colour filters would be a great help in this part of the spectrum, but permanent glass filters having steep gradients and high efficiency are too rare. A so-called heat transmitting glass made by the Corning glass works and numbered 254 is one of the most useful filters which has been introduced. A brief summary of the properties of filters now in use for the infra-red would be valuable.

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

Fortunately the need for efficient filters is mitigated to some extent by the production of new sensitizers with maxima more remote from the visible, for which all spectroscopists are deeply indebted to men like Dr C. E. K. Mees.

Allegheny Observatory. Dr Keivin Burns has informed the President that the results of work on several elements at the Allegheny Observatory are almost ready for publication. These include the vacuum arc spectra of: zinc λ 2100–λ 7800, strong lines only; calcium λ 3600–λ 8600, nearly all known lines; cobalt λ 2100–λ 10000, some 1800 lines; 100 lines of nickel and a few each of tin, lead, the alkalis and beryllium. These have all been measured by interference, using neon standards. Dr Burns remarks that the cobalt spectrum emphasises the great importance of obtaining accurate wave-lengths of lines of solar intensity 0 and less; as the "Revised Rowland" wave-lengths are not of sufficient accuracy for the identification of weak lines.

Bureau of Standards, Washington. Dr Meggers reports that in addition to the results to which reference has already been made, use has been made of new types of sensitized photographic plates to extend observations of the iron spectrum somewhat beyond 12000 A and noble gas spectra beyond 13000 A.

Massachusetts Institute of Technology. Prof. G. R. Harrison has kindly communicated the following statement of that portion of the work in progress at the Massachusetts Institute of Technology which deals with wave-length measurements designed to have sufficiently high precision for possible consideration as standards:

(1) In connection with our programme of analysis of rare earth spectra, we are making measurements in the first, second and third order of a 30,000 line per inch 6-inch concave grating of 10 m. radius, and are working intensively now on the arc spectra of cerium, neodymium and samarium. These measurements are being made with reference to the International Secondary Iron Standards, and at the same time we are measuring up all of the tertiary iron standards. In this way we are gradually accumulating a large number of measurements on the lines of the Pfund iron arc, which should be accurate to one or two thousandths of an angstrom. We believe that we can greatly improve the present tertiary standards, because whereas our measurements give a very smooth correction curve through the secondary standards, the tertiary values jump around considerably and consistently on the various plates. Our automatic wave-length machine is practically complete now, and when this is finished it should greatly expedite the task of making measurements. From these plates we shall also, of course, have a number of wave-length values for impurity lines that may occur in the iron and in the rare earth salts that we use.

(2) In the Schumann and extreme ultra-violet regions, we are operating a 2-m. normal incidence vacuum spectrograph, a 2-m. grazing incidence vacuum spectrograph, and a 21 ft. normal incidence vacuum spectrograph, all containing gratings of 30,000 lines to the inch. Dr Boyce has communicated to the *Physical Review* a paper on wave-lengths of carbon, nitrogen, oxygen and neon wave-lengths obtained with the 2-m. spectrograph, and a large number of plates with the 21 ft. instrument, showing the same lines, are expected to be reduced within the next few months. With the large instrument we are comparing higher orders of the extreme ultra-violet lines directly with the first order iron standards. Since the accuracy is comparable with that ordinarily obtained with a 21 ft. grating in the visible region, it is thought that some very good standards should be obtained in this way, provided that no errors arise from the method of overlapping orders. In order to test this, it is proposed to make measurements of ultra-violet standards directly with a Hilger

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press

reflection echelon in vacuum. In this way it is hoped to check the values obtained with the gratings. At the same time, Dr Humphreys is using quartz étalons in comparisons of some of the lines used with the reflection echelon directly with the cadmium primary standard.

Imperial College. Dr C. V. Jackson proposes to make measurements of lines in the spectrum of argon, and to remeasure the ultra-violet lines of iron, λ 2000–λ 3500, with improved interferometer plates. In view of the discrepancies between the two existing sets of determinations, measurements of infra-red krypton lines will also be undertaken.

A. FOWLER
President of the Commission

IMPERIAL COLLEGE
LONDON

https://doi.org/10.1017/S0251107X00017181 Published online by Cambridge University Press